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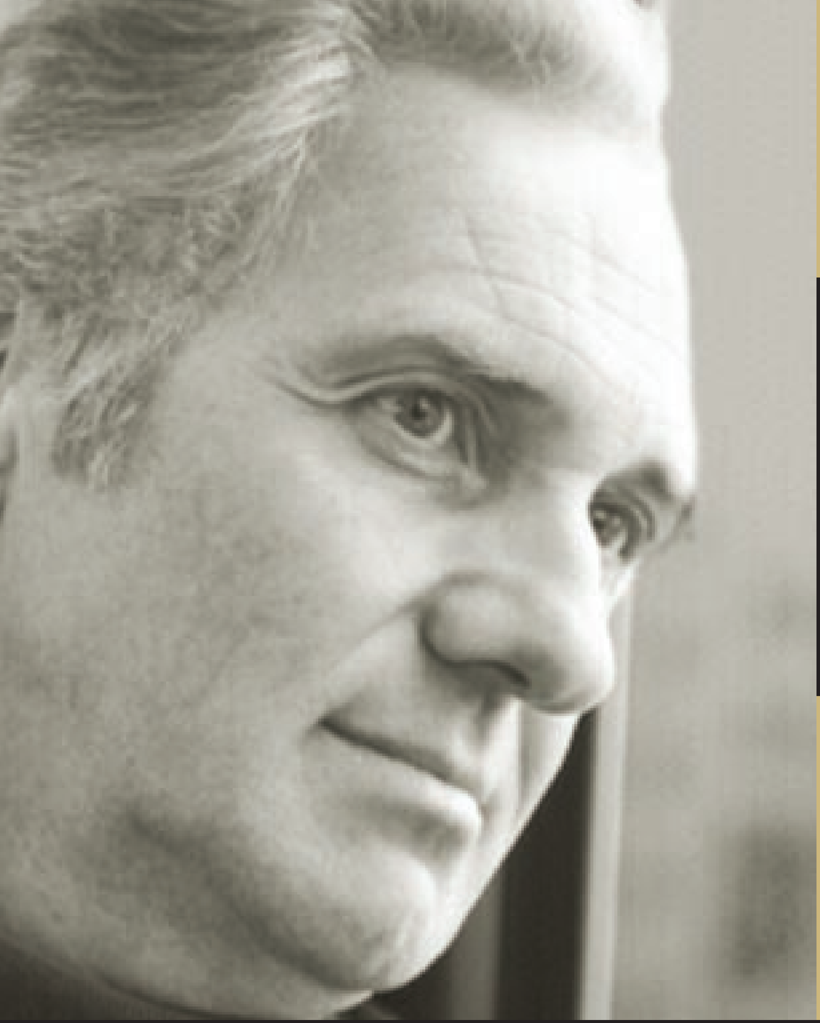

9th National Light Rail Transit Conference

**EXPERIENCE, ECONOMICS & EVOLUTION—
FROM STARTER LINES TO GROWING SYSTEMS**

November 16-18, 2003

Hilton Portland Hotel
Portland, Oregon

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Experience, Economics, and Evolution
From Starter Lines to Growing Systems

9th National Light Rail Transit Conference

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Sponsors
American Public Transportation Association
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Foreword

Experience, Economics and Evolution—From Starter Lines to Growing Systems" is this year's joint national conference on light rail transit (LRT), the ninth such meeting. At the first conference, held in Philadelphia in June 1975, the technical sessions focused on introducing—or reintroducing—the concept of LRT in North America.

Now, 28 years later, 16 new systems have joined the 8 original systems (in operation prior to 1975)—a total of 24 North American LRT systems are now in operation. In addition, there are 36 projects in planning or conceptual design, 15 in final design, and 22 in construction.

The focus and related topics of the previous eight national conferences have paralleled the development and reintroduction of LRT in North America:

- Introduction to LRT—first national conference, Philadelphia, Pennsylvania, 1975;
- Light Rail Transit: Planning and Technology—second national conference, Boston, Massachusetts, 1978;
- Light Rail Transit: Planning, Design, and Implementation—third national conference, San Diego, California, 1982;
- Light Rail Transit: System Design for Cost-Effectiveness—fourth national conference, Pittsburgh, Pennsylvania, 1985;
- Light Rail Transit: New System Successes at Affordable Prices—fifth national conference, San Jose, California, 1988;
- Light Rail Transit: Planning, Design, and Operating Experience—sixth national conference, Calgary, Canada, 1992;
- Building on Success, Learning from Experience—seventh national conference, Baltimore, Maryland, 1995; and
- Light Rail: Investment for the Future—eighth national conference, Dallas, Texas, 2000.

The technical information contained in the proceedings of these conferences *(1–8)* provides planners, designers, decision makers, and operators with a valuable collection of experiences and ingredients necessary for a successful transit development project.

The ninth national conference focuses on the planning, design, construction, operation, maintenance, and administration of LRT systems. Thus, the Conference Steering Committee decided that the conference title should be "Experience, Economics and Evolution – From Starter Lines to Growing Systems." A wealth of technical material is offered at the conference. There are 16 sessions; several technical tours of Portland area transit construction, operations, and related development; and 52 papers presented at the conference and published in this compendium. The papers were peer-reviewed by members of the Light Rail Transit Committee in an anonymous online process.

The Transportation Research Board (TRB) and the American Public Transportation Association (APTA) are conference cosponsors. This partnership, started in 1994 in preparation for the 1995 conference, is a formal recognition of the mutual and supportive respect for joint aims and purposes in a cooperative conference venture. TriMet—Tri-County Metropolitan Transit District of Oregon—provided invaluable assistance as the host organization for the ninth joint conference.

The objective of each of these conferences is to add to the growing body of knowledge and real-world experiences with modern LRT applications in order to improve continually new systems being planned, as well as those already in operation.

Success can be fleeting, and we need to learn from past and current experience in order to do the best possible job of providing cost-effective public transportation services. The information, data, and research contained in this proceeding are meant to serve this need.

—John Schumann
LTK Engineering Services
Chair, Conference Planning Committee
Chair, TRB Committee on Light Rail Transit
Secretary, APTA Light Rail Transit Technical Forum

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OPENING GENERAL SESSION

Status of North American Light Rail Transit Systems
Year 2003 Update

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Metropolitan Council

This paper reports on changes and additions to light rail transit (LRT) and streetcar systems in the United States and Canada that have occurred since the last National Light Rail Conference was held in 2000.

Although there were no completely new LRT start-ups during this period, there were—somewhat amazingly—the light diesel multiple unit (DMU) line in southern New Jersey, and four new "streetcar" lines: two (San Pedro, California, and Tampa, Florida) using actual or replica "vintage" trolleys, and two (Portland, Oregon, and Tacoma, Washington) using modern streetcars. In addition, several cities extended existing lines: Jersey City and Newark, New Jersey; St. Louis, Missouri; Dallas, Texas (both Dallas Area Rapid Transit LRT and McKinney Avenue streetcar); Denver, Colorado; Salt Lake City, Utah; Los Angeles, San Jose, and Sacramento, California; Portland. Oregon; and Calgary, Canada.

These developments are discussed in the text and reflected in the accompanying data tables. The paper also provides an overview of ongoing work to further extend existing LRT systems in North America, and progress on still more new starts. In the latter category, Houston, Texas, and Minneapolis, Minnesota, are under construction; LRT projects in Seattle, Washington, and Charlotte, North Carolina, are advancing through design; and a light DMU line in southern California has received its full funding grant agreement.

In summary, interest in and implementation of LRT projects continues apace, now joined by new streetcar and light DMU services.

INTRODUCTION

In 1917, nearly 45,000 mi (72,400 km) of streetcar and interurban lines were laced across the United States. By 1977, when the first edition of this paper was prepared, that figure had declined to eight cities operating little more than 300 mi (480 km) of lines, of which perhaps 125 mi (200 km) could be called light rail transit (LRT). Since then, there has been a rebirth of interest and activity, with 571 mi (918 km) of such services operating now in 21 U.S. cities plus 3 each in Canada and Mexico. More are under construction, being designed, or planned. This paper reports on the progress of North American LRT projects since the last TRB/APTA Conference on Light Rail transit was held in 2000.

New Starts and Extensions Since 2000

Although there were no completely new LRT start-ups during this period, there were—somewhat amazingly—the light diesel multiple unit (DMU) line in southern New Jersey, and four new "streetcar" lines: two (San Pedro, California, and Tampa, Florida) using actual or replica "vintage" trolleys, and two (Portland, Oregon, and Tacoma, Washington) using modern streetcars. In addition, several cities extended existing lines: Jersey City and Newark, New Jersey; St. Louis, Missouri; Dallas, Texas [both Dallas Area Rapid Transit (DART) LRT and McKinney Avenue streetcar); Denver, Colorado; Salt Lake City, Utah; Los Angeles, San Jose, and Sacramento, California; Portland, Oregon; and Calgary, Canada.

PORTLAND

In 2000, Portland's Tri-County Metropolitan Transportation District (Tri-Met) was operating a continuous east–west LRT line centered on Downtown Portland. The original Eastside MAX, opened in 1984, extends 15 mi to the suburban community of Gresham. In 1998, the Westside line was completed extending 18 mi to Beaverton and Hillsboro. The two lines, now through-routed and called the Blue Line, meet in downtown Portland where MAX operates on reserved lanes on downtown Portland's street system. In FY 2001, MAX was the sixth most used LRT system in the United States, with over 77,000 weekday boardings.

New Lines and Extensions

Portland opened two new lines in 2001, both of which are remarkable:

- The 2.5-mi Portland Streetcar, operating in downtown Portland, is the first new "mixed traffic" city streetcar line built in perhaps 50 years. The line's seven Skoda streetcars link downtown with immediately adjacent neighborhoods, including the River District, a "new town in town" on an old rail yard site. As of mid-2003, the streetcar is carrying 5,000-6,000 people per day. It intersects the original Portland MAX at the Galleria/Library stations.
- The 5.5-mi Airport MAX extension opened, fatefully, on September 10. The Airport line proceeds north from a connection to the original Eastside line at the Gateway Transit Center, 5 mi east of downtown Portland. Now light rail vehicles (LRVs) deliver passengers directly to the southeast corner of the main terminal building's ticket hall and baggage claim areas. The line is proving popular with travelers and airport employees.

Under Construction

In addition, construction is far advanced on the 5.6-mi Interstate MAX line to North Portland, which will open in 2004. Interstate MAX connects to the Eastside line near the Convention Center, across the Willamette River from downtown, and follows Interstate Avenue to the north. The 17 Siemens LRVs being purchased as part of this project will bring TriMet's fleet to 95 cars.

Several future projects are planned. Design is already complete for a streetcar extension to River Place; and preferred alternatives have been selected for MAX extensions to the southeast.

SEATTLE/TACOMA

In 2000, Sound Transit was still working towards the area's first LRT line. Years of effort are starting to bear fruit as the region's first line has opened and a second is on the way.

New Lines

Perhaps the heading shown above should read Tacoma/Seattle because Sound Transit's first LRT project to be completed is the 1.6-mi Tacoma Link. Somewhat similar to Portland's Streetcar, the Tacoma Link opened in August 2003 to link the Tacoma Dome and commuter rail station with business, education, and cultural attractions in Downtown Tacoma. The line uses three Skoda LRVs purchased as an add-on to Portland's streetcar order.

Current Construction

Meanwhile, final design continues on the 14.5-mi Central Link, which is to run south from downtown Seattle to the SeaTac airport. Central Link construction is just starting; a 2009 opening is anticipated. (*1*)

Planning for a northerly downtown to Seattle's University District extension continues.

SACRAMENTO

Sacramento's Regional Transit District (RT) opened its first LRT line in March 1987.(*2*) Two lines radiated from downtown Sacramento, one to the East and a second to the Northeast, and were operated as a single through route of 20.6 mi. RT LRT continued to operate in this configuration in 2000. Popular and successful, RT Light Rail carries 29,400 weekday unlinked trips, nearly a third of all RT's boarding rides.

New Lines and Extensions

September 2003 saw the opening of RT's third LRT line, a 6.3-mi route through South Sacramento. The new South Line connects to the original East Line at 16th Street in downtown Sacramento. As with the starter line, addition of LRT has been accompanied by construction of several large park–and–rides at stations, and reconfiguration of the sub-area's bus lines to work with LRT as an integrated multimodal transit system.

Current Construction

Construction also has started on a 10.5-mi extension of the eastern line to the city of Folsom. This extension is scheduled to be completed in 2005.(*3*) This project includes a 0.7-mi extension to the Amtrak station in downtown Sacramento.

To serve this enlarged system, Sacramento is taking delivery of 40 new LRVs from CAF. Planning is in progress for a north line to the Natomas neighborhoods and Sacramento’s airport.

SAN FRANCISCO

California’s sole “survivor” street railway, the second-busiest LRT system in the United States with over 164,000 weekday boardings, continues to grow. The extensive San Francisco LRT system includes 77.6 mi of mainline track, organized into six routes. Five of these routes primarily serve the neighborhoods west and southwest of downtown San Francisco. These lines operate on city streets but then converge onto downtown San Francisco and join to operate in a subway that it shares with the Bay Area Rapid Transit system one level below. (*4*) A sixth route, the F-Line, connects Market Street to Fisherman’s Wharf by way of the Embarcadero.

Current Construction

- In 2001, construction began on the Bayshore Line, a new 5.4-mi surface LRT route extending south, primarily along a new median in Third Street, from the Caltrain Depot through residential neighborhoods. Phase 1 is scheduled to open in 2005.(*5*)
- A second phase is planned to extend 1.7 mi from the Caltrain station north into a new subway, perpendicular to the existing Market Street Tunnel to Chinatown.

The fleet now includes 136 Breda and Boeing LRVs, and 39 heritage streetcars of President’s Conference Committee (PCC; 17 cars) and pre-PCC designs (10 Milan Peter Witts and 12 historic Muni cars). The latter are used on the F-Line to Fisherman’s Wharf, which has become an attraction in its own right, even as it relieves overloaded cable car lines.

SAN JOSE

Santa Clara Valley Transportation Authority (VTA) currently operates the 28.6-mi VTA light rail line system, which extends from south San Jose through downtown to the northern areas of San Jose, Santa Clara, Mountain View, and Sunnyvale. The three lines that comprise this region’s LRT system carry 22,485 riders on an average weekday—16% of VTA’s total boardings in FY 2001.

At Baypointe, the 7.6-mi Tasman West line connects Downtown Mountain View on the west to Milpitas on the East line. The Tasman Light Rail Project was initially planned as a 12.4-mi expansion of the existing line. However, funding constraints resulted in a phased construction. The Baypointe Transfer Station, which connects to the earlier Guadalupe line, opened with the Tasman West Project in December 1999. Service to the Interstate 880/Milpitas Station opened May 18, 2001. (*6*)

Current Construction

- The 8.3-mi Tasman East/Capitol LRT project, which includes part of the original Tasman LRT project, extends the east–west Tasman line to Hostetter on the east. It is slated to open in summer 2004.
- Major construction began in March 2001 on the 6.8-mi Vasona extension, which will ultimately connect downtown San Jose to Vasona Junction in Los Gatos. Service on the first 5.3 mi between downtown San Jose and downtown Campbell is anticipated to begin in January 2006.(*7*) The 1.5-mi second phase is dependent on available funding.(*8*)

To serve this expanded system and provide improved accessibility all its LRT lines, VTA is receiving 70 Kinki Sharyo low-floor LRVs (LFLRVs), and has offered its original 50 Urban Transportation Development Corporation LRVs for sale to other properties.

Planning studies continue for an East San Carlos extension, but VTA's currently constricted budget seems likely to prevent its early implementation.

LOS ANGELES

Los Angeles County Metropolitan Transportation Authority's (LACMTA) Blue and Green Lines, totaling 41.2 mi, constituted the United State's third busiest LRT system in FY 2001, with over 105,000 weekday trips. The Blue Line, the first LRT line constructed in Los Angeles, opened for service in 1990, followed by the Green Line in 1995. The Blue Line connects downtown Los Angeles to Long Beach, 22 mi to the south. In downtown Los Angeles, the Blue Line connects to the Red Line heavy rail system at the Metro Center Station. The Green Line, which connects to the Blue Line at the Imperial/Wilmington Station, runs east–west from Norwalk to Redondo Beach, a distance of 20 mi. (*9*)

New Lines and Extensions

- The Los Angeles to Pasadena Construction Authority (LAPCA) completed the 13.7-mi Pasadena Gold Line and turned it over to LACMTA. The Gold Line, which connects to the Red Line at Union Station, began revenue service in July 2003, using some of the LA2000 LRVs supplied earlier by Siemens.
- Separately, a 1.5-mi heritage trolley line opened in San Pedro in late 2002, operating one restored and two replica Pacific Electric interurban cars on an old port railroad line.

Current Construction

LAPCA has turned its attention to the 6-mi Gold Line extension from Union Station into East Los Angeles.

Elsewhere in greater Los Angeles, preliminary engineering has begun on two more LRT projects: LACMTA's Expo Line to the southwestern part of the city, and Orange County Transit Authority's CenterLine in Santa Ana, Costa Mesa, and Irvine.

SAN DIEGO

The Metropolitan Development Transit Board (MDTB) operates 45.4 mi of LRT on two routes (four corridors). The original “South Line” opened in 1980 from downtown San Diego to the international border at Tijuana, Mexico. The current system is the result of six extensions over the last 20 years. The 25.2-mi “South Line”, renamed the Blue Line, now extends to Mission Valley, northeast of downtown San Diego. The 21.6-mi Orange Line starts in downtown San Diego (where some trackage is shared with the Blue Line) and extends east and then northeast to El Cajon and Santee.

Current Construction

- During 2003, construction continued on San Diego Trolley, Inc.’s (SDTI’s) 5.8-mi Mission Valley East extension, a line that will close the gap between the Mission Valley West terminus of the Blue Line and roughly the mid-point of the Orange Line. This new track, to be finished in 2004, includes San Diego’s first subway station, in a half-mile tunnel beneath San Diego State University.
- In North San Diego County, the North County Transit District (NCTD) has begun construction on the 22-mi cross-suburban Oceanside–Escondido light DMU line, called the Sprinter, now scheduled to open in 2005. (*10*)

To serve these lines, MDTB/SDTI have ordered 11 LFLRVs from Siemens. NCTD is ordering low-floor light DMUs.

SALT LAKE CITY

The Utah Transit Authority’s (UTA’s)LRT system, called TRAX, opened its initial operating segment in December 1999, 15 mi from downtown Salt Lake City south to Sandy. LRT has been favorably received in Salt Lake City. Ridership has quickly exceeded projections and additional lines are planned.

New Lines and Extensions

In December 2001, UTA opened its 2.3-mi university extension connecting Main Street with Rice-Eccles Stadium at the University of Utah, and just in time to help carry the rush of Winter Olympics passengers. For this event, 29 LRVs also were borrowed from Dallas Area Rapid Transit (DART) in Dallas, Texas, to supplement UTA’s own fleet.

Current Construction

The Medical Center LRT Project is a 1.5-mi light rail line extending from Rice-Eccles Stadium to the University of Utah Health Sciences Complex. An additional seven LRVs will be purchased for this line. Service is expected to open on the extension in 2004. (*11*)

UTA has also undertaken a series of smaller projects to improve the system's efficiency and is conducting planning studies for several possible extensions.

DENVER

In October 1994, Denver's Regional Transit District (RTD) began operation of its first 5.5-mi LRT line from downtown Denver, extended 8.5 mi southwest to Littleton in 2000. Ridership quickly grew to about 30,000 per weekday. Currently, RTD has a fleet of 49 Siemens LRVs.

New Lines and Extensions

In April 2002, RTD opened its 1.6-mi Central Platte Valley extension, which reaches Union Station and the north end of the 16th Street Mall Shuttle in Lower Downtown by way of several sports and other leisure venues. This line provides direct LRT service for fans attending major league football, baseball, basketball, and hockey games, as well as rock concerts and other shows at these facilities.

Current Construction

One of the largest LRT projects currently under way is the joint Colorado Department of Transportation/RTD "T-REX" work that is modernizing I-25 and adding 19 mi of LRT within the freeway right-of-way. Another 34 Siemens LRVs have been ordered as well. Scheduled to open in late 2006, the Southeast extension—including its 4-mi branch in I-225—will more than double the size of RTD's LRT system.

Meanwhile, planning and design studies continue for future LRT lines to the west, north, and east, the latter including service to Denver's airport.

DALLAS

DART opened its first 20-mi starter line in June 1996 and quickly began exceeding ridership expectations, overloading the initial fleet of 40 LRVs. The system's two lines connect the northern communities of Plano and Garland to downtown Dallas and the southern part of the city.

New Lines and Extensions

The second half of 2002 witnessed the staged opening of DART's north and northeast extensions, a total of 24 mi that more than doubles the 1996 starter system.

Kinki Sharyo supplied 55 more of DART's unique LRVs to operate the expanded lines. Now, DART is exploring the possibility of adding a low-floor center section to improve accessibility and further increase fleet capacity.

Also in Dallas, the McKinney Avenue Transit Authority has seen its service integrated with DART's system, and extended to City Place Station, with a further extension into the central business district (CBD) anticipated. Planning also continues on additional LRT lines, to the southeast, northwest, and Dallas/Fort Worth International Airport.

NEW ORLEANS

Dating back to 1836, New Orleans' St. Charles Streetcar Line, which began electric operations in 1893, is one of the world's oldest continuously operated rail lines. As with other cities, streetcar service gradually declined and with the closing of the Canal Street Line in 1964, the St. Charles Line became New Orleans sole surviving streetcar. The line starts in downtown New Orleans at Canal Street and extends approximately 7 mi, the majority of which is in a center median on St. Charles Avenue. (*12*)

In August 1988, New Orleans opened a new streetcar line. The initial 1.5-mi Riverfront Line connected the commercial developments in the Warehouse District, along the Riverfront, and in the French Quarter. In 1990, the Riverfront Line was extended another half mile and a second track was added. On December 6, 1999, the St. Charles and Riverfront Lines were connected when streetcar service began on a six-block section of Canal Street

New Lines and Extensions

Streetcars will return to the "neutral ground" (median) of Canal Street in 2004, with completion of a 5.1-mi project begun in the mid-1990s.

New Orleans Regional Transit Authority (RTA) has built 24 replica Perley Thomas cars in its own shops, air-conditioned, and outfitted with modern trucks and propulsion systems from Brookville Manufacturing in Pennsylvania. This program sets a pattern RTA intends to follow with restoration of streetcar service through the French Quarter, the Desire Line.

TAMPA

New Lines and Extensions

In October 2002, celebrations marked the opening of the 2.3-mi Tampa Electric Company Streetcar System linking Ybor City with other Tampa tourist attractions and the edge of downtown. Much of the line uses a new side-of-street reservation, single track, and passing sidings spaced to support headways of 15 to 20 min.

Current Construction

A 0.6-mi link will extend farther into downtown Tampa.

Eight replica—but air-conditioned—double truck Birney cars were built by Gomaco Trolley Company. Future plans envision LRT and/or light DMU lines in the region.

MEMPHIS

Memphis Area Transit Authority opened a historic trolley system in 1993 that currently transports more than 800,000 passengers a year over two downtown lines. The initial 2.5-mi system on Main Street linked the South Main and Pinch historic districts with numerous downtown attractions. It was expanded in 1997 with a 2-mi Riverfront Trolley Loop. (*13*)

Current Construction

The 2-mi Madison Avenue extension of the Main Street Trolley to the Medical Center is scheduled to open in 2004. It will be operated with the system's vintage streetcars, but fixed facilities have been built to LRT standards in anticipation of further extensions that will eventually take the line south to the Memphis Airport.

Two other LRT lines also are envisioned. Thus, Memphis exemplifies a pattern of incremental system development, a modest downtown streetcar circulator gradually growing into a regional LRT service.

ST. LOUIS

The initial 17-mi MetroLink alignment from Lambert–St. Louis International Airport to the 5th and Missouri Station in East St. Louis opened in July 1993.

New Lines and Extensions

- Bi-State's east extension opened on schedule in 2001, doubling the length of the east–west LRT line to 34 mi, and bringing LRT service to Belleville and intermediate Illinois suburbs. The initial fleet of 31 Siemens LRVs has been increased, to 65 cars currently.
- Construction began in Spring 2001 on an additional 3.5-mi extension from Southwestern Illinois College to Shiloh–Scott station, located east of Illinois 158 and adjacent to Scott Air Force Base. This extension opened in June 2003. (*14*)

Current Construction

Construction began in spring 2003 on the Cross County MetroLink Extension. The 11.5-mi extension on the Missouri side, from Forest Park through Clayton to Shrewsbury, involves a further increase in the LRV fleet to 87 cars. This link is expected to open in 2006. (*15*)

After this project, the region will turn its attention to further extensions and new lines in additional corridors.

CLEVELAND AND BUFFALO

Changing economies and residential patterns in these two lake cities have resulted in strained budgets and static riding patterns, which have stymied expansion of both systems. Cleveland's Waterfront extension continues to draw leisure venue riders, and LRT extensions to outer suburbs are planned, but construction does not seem imminent. In Buffalo, Niagara Frontier Transportation Authority works hard to maintain the existing system, which generates weekday passengers and annual passenger mile per mile of line comparable to several larger systems.

PITTSBURGH

The Port Authority of Alleghany County (PAAC) operates a 25-mi light rail system that represents one of the nation's surviving trolley systems. The LRT line operates in a tunnel in downtown Pittsburgh, crosses the Monongahela River and climbs the bluff to the South Hills neighborhoods through the Mount Washington Tunnel, which is shared by LRVs and buses.

During the 1980s, the Stage I LRT project resulted in the reconstruction of 13 mi of the system to light rail standards.

Reconstruction

The Stage II reconstruction program of the Sawmill Run and Library branches is nearing completion, bringing all of the South Hills lines up to modern LRT standards. As part of this program, CAF (Construcciones y Auxiliar de Ferrocarriles)is providing 28 new LRVs, and renovating PAAC's 55 Siemens cars, including installation of new AC inverter propulsion systems.

Plans for a North Shore Connector have been completed to link downtown with the PNC Park pro-sports stadium by 2007, and to set the stage for possible future north side LRT lines.

BALTIMORE

Baltimore's initial route of 22.5 mi opened in 1992. The current 29-mi system extends from Hunt Valley on the north through downtown Baltimore to Baltimore–Washington International Airport on the south, including a stop at Camden Yards, the Baltimore Orioles stadium.

Existing System Upgrades

Long sections of single track have burdened the Baltimore system since it opened. But now a $150 million program is in progress to double track almost all of the existing central LRT line. This will allow service to be improved using "clock" headways in place of the 17-min intervals presently necessary due to the extensive single track originally built.

In early 2003, Maryland Mass Transit unveiled an ambitious rail transit expansion program that would add new LRT, heavy rail, and commuter rail links to Baltimore's multimodal system.

PHILADELPHIA

In West Philadelphia and Delaware County, the Subway–Surface and Media–Sharon Hill LRT lines continue to run as reported in past years.

Reconstruction

In the city, construction is proceeding to renew tracks and electrification, and 15 PCC cars are being rebuilt by Brookville Manufacturing, all in anticipation of restoring streetcar service on Route 15–Girard Avenue. When reborn, this traditional middle-of-street alignment will be enhanced with a number of "transit first" traffic management measures intended to expedite transit service and improve its schedule reliability.

NEW JERSEY TRANSIT

LRT developments are occurring on three fronts in the Garden State.

New Lines and Extensions

- In 2002, Newark's "Survivor" City Subway line was extended 1 mi to serve two new stations and to reach a new shop and yard in Bloomfield, where its new Kinki Sharyo LFLRVs are serviced.
- The new Hudson–Bergen line was extended through Jersey City to connect with several commuter rail lines at New Jersey Transit's Hoboken Terminal.
- The 34-mi Southern New Jersey Light Rail Line, which connects Camden to Trenton along the Delaware River and is served by 20 Stadler–Bombardier light DMUs, opened in mid-2003.

Current Construction

- Construction is in progress on the first mile of a planned Newark–Elizabeth LRT line.
- A further extension of the Hudson–Bergen Line to the north is now in progress.
- Planning for additional South Jersey lines is ongoing.

BOSTON

Boston's Green Line (the "T") is the remaining vestige of the city's once-vast surface rail (streetcar) network. The Green Line has four branches which run underground in the Boston CBD, through America's oldest subway tunnel opened in 1897, and at street level, mostly in median reservations, with numerous grade crossings at intersections. The system consists of about 25.4 mi of route, of which 5.0 mi are underground, and 1.3 mi are elevated. There are some 70 stations/stops along all the routes of the Green Line system, and well over 200 LRVs are operated. With over 230,000 weekday boardings, the T's four-route Green Line retains its title as the busiest LRT system in the United States. (*16*)

After careful studies and modifications to LRVs and tracks, 23 Breda #8 LFLRVs have returned to Commonwealth Avenue, and Massachusetts Bay Transportation Authority (MBTA) expected to decide during 2003 what to do about the remainder of this procurement. In 2002, MBTA was directed by state environmental authorities to restore LRV service from Heath Street through Jamaica Plain to the Arborway; studies and community consultations on this project began in early 2003.

TORONTO

Torontonians love their streetcars, all 248 of them, which still ply nine routes totaling 49 mi and carry over 300,000 weekday rides—the most heavily patronized light rail system in North America. But Canada's largest streetcar network may be at a crossroads. Public budgets are tight, and politicians are looking for ways to cut costs. Thus, there are periodic proposals for bus substitutions, which advocates so far have been able to beat back. For the foreseeable future, however, there appears to be little scope for growth.

EDMONTON

On April 22, 2003, Edmonton celebrated the 25th anniversary of the opening of LRT service. Since 1978, North America's first "new age" LRT system has grown from 4.3 mi to a nearly 8-mi line carrying 36,000 weekday rides. LRT now travels from the northeast part of the city southwest to downtown Edmonton, follows a tunnel under Jasper Avenue downtown and then crosses the North Saskatchewan River to the University of Alberta campus.

Current Construction

In 2000, the city decided to extend the line from the University of Alberta campus into south-end neighborhoods. Construction began in February 2003 on the first phase of this extension, which involves the boring of two 6-m diameter tunnels to connect the underground University Station to the new at-grade Health Sciences Station, a total length of 640 m. This first segment is scheduled to open in 2006. (*17*)

Plans are now advanced for the rest of the South Line extension and the project is ready for design.

CALGARY

From a single line opened in 1981, Calgary's LRT system has grown to two lines serving three travel corridors totaling 19.9 mi, carrying over 185,000 weekday rides.

Current Construction

Short extensions of all three lines are programmed:

- Northwest (one station) in 2003,
- South (two stations) in 2004, and
- Northeast (one station) in 2006.

To carry increasing passenger loads, Calgary Transit has taken delivery of 14 new Siemens LRVs.

MORE NEW STARTS ON THE WAY

Two LRT and one streetcar new starts are under construction, and two more LRT projects are in an advanced design status, nearly ready for construction:

- LRT:
  - Houston: 7.5-mi Main Street LRT line with LFLRVS, 2004 completion
  - Minneapolis: 12-mi Hiawatha LRT with LFLRVS, 2004 completion
  - Phoenix: 20-mi Central LRT line with LFLRVs, 2006 partial completion
  - Charlotte: 11.5-mi South LRT line, Uptown Charlotte to Pineville, for 2006 opening
- Streetcars (SC):
  - Little Rock**:** 1.5-mi River Rail for 2004 completion with 3 replica double truck Birneys
- Behind this group are numerous cities in various stages of system planning or preliminary design. Projects in this group are emerging in
  - Albuquerque: LR,
  - Atlanta: LR (suburbs),
  - Austin: LR,
  - Birmingham: LR/SC,
  - Cincinnati: LR,
  - Columbus: LR (preliminary),
  - Dubuque: SC,
  - El Paso: SC,
  - Ft. Worth: SC,
  - Grand Rapids: LR,
  - Norfolk (preliminary)/Hampton Roads: LR,
  - Honolulu: LR/SC,

- Indianapolis: LR,
- Jacksonville: LR,
- Kansas City: LR,
- Louisville: LR (preliminary),
- Miami: LR,
- Milwaukee: LR/SC,
- Oakland/Berkeley/East Bay: LR/SC,
- Oklahoma City: LR,
- Omaha: SC,
- Orlando: LR,
- Richmond: SC,
- Rochester: LR,
- San Antonio: LR/SC,
- Sioux City: SC,
- Spokane: LR,
- Tucson: LR/SC, and
- Washington, D.C.: LR/SC.

Several of these are very early in the development process; others have been unable to fund specific proposals, but seem likely to try again at some future time as their populations continue to grow and dissatisfaction with worsening traffic congestion drives a search for alternatives.

CONCLUSIONS

In the 25 years since Edmonton opened North America's first "new age" LRT line, the rebirth of LRT has blossomed into a full renaissance. Far from being yesterday's technology, modern LRT systems—and their streetcar and light DMU cousins—are proving themselves to be important elements in multimodal transit systems that can attract more riders while helping use limited resources efficiently. With more new starts a-building, extensions already built, under construction, or planned in every "new start" city, and more of America's growing urban regions turning to transit alternatives, the new century will see continued interest in light rail, and further growth of the light rail mode in North America.

RESOURCES

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TABLE 1 Line Lengths, Car Fleets, and Productivity Indicators

		One-Way Line		Fleet	Cars per		Weekday	Service Productivity, Psgrs per		
City/System		km	miles	Cars	km	mi	Rides	Line km	Line Mile	Car
							(000s)			
Baltimore, Central Corridor	d	47.0	29.0	53	1.1	1.8	24.7	525	852	466
Boston, Green Line & Mattapan	b	41.5	25.6	215	5.2	8.4	230.8	5560	9016	1073
Buffalo, MetroRail	a	10.4	6.4	27	2.6	4.2	22.6	2178	3531	837
Cleveland, Blue/Green	b	25.0	15.4	48	1.9	3.1	15.1	605	981	315
Dallas, DART LRT	d	71.3	44.0	95	1.3	2.2	55.1	772	1252	580
Denver, RTD LRT	d	25.6	15.8	31	1.2	2.0	31.4	1226	1987	1013
Jersey City & Newark, NJ Transit	e	24.0	14.8	45	1.9	3.0	25.5	1063	1723	567
Los Angeles, Blue/Green/Gold	d	90.3	55.7	121	1.3	2.2	105.6	1169	1896	873
New Orleans, Streetcars	b	14.1	8.7	41	2.9	4.7	14.1	1000	1621	344
Philadelphia, City & Suburban	b	55.6	34.3	141	2.5	4.1	84.1	1512	2452	596
Pittsburgh, South Hills	b	30.2	18.6	55	1.8	3.0	27.0	895	1452	491
Portland, MAX	a	61.9	38.2	78	1.3	2.0	80.0	1292	2094	1026
Portland, Streetcar	d	4.1	2.5	7	1.7	2.8	4.5	1110	1800	643
Sacramento, RT LRT	a	43.6	26.9	56	1.3	2.1	29.4	674	1093	525
St Louis, MetroLink	d	61.5	37.9	65	1.1	1.7	44.0	716	1161	677
Salt Lake City, UTA LRT	d	28.2	17.4	33	1.2	1.9	21.0	744	1207	636
San Diego Trolley	a	73.6	45.4	123	1.7	2.7	84.5	1148	1861	687
San Francisco, Muni	c	41.5	25.6	175	4.2	6.8	164.2	3956	6414	938
San Jose, VTA LRT	a	49.5	30.5	50	1.0	1.6	25.0	506	820	500
Seattle/Tacoma	d	2.6	1.6	3	1.2	1.9	tbd	tbd	tbd	tbd
Total US		801.5	494.3	1462	1.8	3.0	1088.6	1358	2202	745
Calgary, C-Train	a	32.3	19.9	99	3.1	5.0	137.0	4246	6884	1384
Edmonton, LRT	a	12.3	7.6	37	3.0	4.9	36.0	2921	4737	973
Toronto, Streetcars	b	79.6	49.1	248	3.1	5.1	307.1	3858	6255	1238
Total Canada		124.2	76.6	384	3.1	5.0	480.1	3866	6268	1250

a - New start since 1977. b - Major reconstruction/rehabilitation since 1977. c - Upgraded from streetcar to LRT standards since 1977. d - New start since 1990. e - Jersey City-d, Newark-b.

TABLE 2 Key Descriptive Statistics

City/System	Reserved R/W	Av Stop Spacing km	Av Stop Spacing mi	Double Track %	Through Service Routes	Number of Cars 4-Axle	Number of Cars 6-Axle	Approx. System Average Speed km/h	Approx. System Average Speed mph
Baltimore, Central Corridor	100%	1.6	1.0	61%	2	0	53	35	22
Boston, Green Line & Mattapan	97%	0.5	0.3	100%	5	11	204	22	14
Buffalo, MetroRail	100%	0.8	0.5	100%	1	27	0	20	12
Cleveland, Blue/Green	100%	0.8	0.5	100%	2	0	48	30	19
Dallas, DART LRT-a	100%	2.1	1.3	100%	2	0	95	34	21
Denver, RTD LRT	100%	1.3	0.8	98%	2	0	31	23	14
Jersey City & Newark, NJ Transit	>99%	1.0	0.6	100%	3	0	45	28	17
Los Angeles, Blue/Green/Gold	100%	1.8	1.1	100%	3	0	121	34	21
New Orleans, Streetcars	91%	0.3	0.2	100%	2	41	0	15	9
Philadelphia, City & Suburban	41%	0.3	0.2	91%	7	141	0	18/26	11/16
Pittsburgh, South Hills	81%	0.5	0.3	91%	4	0	55	26	16
Portland, MAX	>99%	1.1	0.7	99%	2	0	78	30	19
Portland, Streetcar	0%	0.3	0.2	100%	1	7	0	16	10
Sacramento, RT LRT	89%	1.1	0.7	77%	2	0	56	34	21
St Louis, MetroLink	100%	1.4	0.9	97%	1	0	65	43	27
Salt Lake City, UTA LRT	100%	1.4	0.9	99%	2	0	33	40	25
San Diego Trolley	100%	1.4	0.9	99%	2	0	123	30	19
San Francisco, Muni	50%	0.2	0.1	100%	6	39	136	18	11
San Jose, VTA LRT	100%	1.1	0.7	96%	3	0	50	32	20
Seattle/Tacoma	100.0	0.6	0.4	~50%	1	3	0	20	12
Total US	--				53	269	1193		
Calgary, C-Train	100%	1.0	0.6	100%	2	0	99	29	18
Edmonton, LRT	100%	1.3	0.8	100%	1	0	37	30	19
Toronto, Streetcars	11%	0.2	0.1	100%	10	196	52	15	9
Total Canada	--				13	196	188		
Total U.S. & Canada					66	465	1381		

a-one LRV expanded in 2003 to 8-axle double articulated w/low floor middle car.

TABLE 3 Right of Way Locations

City/System	km of line							miles of line						
	Subway/ Tunnel	Exclusive R/W	Private R/W	St/Hwy Median	Reserved Lanes*	Mixed Traffic	Total	Subway/ Tunnel	Exclusive R/W	Private R/W	St/Hwy Median	Reserved Lanes	Mixed Traffic	Total
Baltimore, Central Corridor	--	0.5	40.6	--	5.6	--	46.7	--	0.3	25.2	--	3.5	--	29.0
Boston, Green Line & Mattapan	7.2	21.4	--	11.4	--	1.1	41.1	4.5	13.3	--	7.1	--	0.7	25.6
Buffalo, MetroRail	8.4	--	--	--	1.9	--	10.3	5.2	--	--	--	1.2	--	6.4
Cleveland, Blue/Green	--	11.3	3.7	9.8	--	--	24.8	--	7.0	2.3	6.1	--	--	15.4
Dallas, DART LRT	5.6	41.5	17.1	4.7	1.9	--	70.8	3.5	25.8	10.6	2.9	1.2	--	44.0
Denver, RTD LRT	--	14.0	8.5	--	2.9	--	25.4	--	8.7	5.3	--	1.8	--	15.8
Jersey City & Newark, NJ Transit	2.1	4.8	14.8	--	2.1	--	23.8	1.3	3.0	9.2	--	1.3	--	14.8
Los Angeles, Blue/Green/Gold	0.8	35.9	48.1	3.2	1.6	--	89.6	0.5	22.3	29.9	2.0	1.0	--	55.7
New Orleans, Streetcars	--	--	3.5	9.0	0.2	1.3	14.0	--	--	2.2	5.6	0.1	0.8	8.7
Philadelphia, City & Suburban	4.0	--	16.3	1.9	0.3	32.6	55.1	2.5	--	10.1	1.2	0.2	20.3	34.3
Pittsburgh, South Hills	3.4	--	20.9	--	--	5.6	29.9	2.1	--	13.0	--	--	3.5	18.6
Portland, MAX	4.7	18.2	23.6	10.8	4.0	0.1	61.4	2.9	11.3	14.7	6.7	2.5	0.1	38.2
Portland, Streetcar	--	--	--	--	--	4.0	4.0	--	--	--	--	--	2.5	2.5
Sacramento, RT LRT	--	9.5	26.2	1.0	1.8	4.8	43.3	--	5.9	16.3	0.6	1.1	3.0	26.9
St Louis, MetroLink	1.3	14.3	45.3	--	--	--	60.9	0.8	8.9	28.2	--	--	--	37.9
Salt Lake City, UTA LRT	--	--	19.6	8.3	--	--	27.9	--	--	12.2	5.2	--	--	17.4
San Diego Trolley	--	7.7	59.5	3.1	2.7	--	73.0	--	4.8	37.0	1.9	1.7	--	45.4
San Francisco, Muni	10.8	--	3.2	6.8	--	20.4	41.2	6.7	--	2.0	4.2	--	12.7	25.6
San Jose, VTA LRT	--	15.8	4.2	28.0	1.1	--	49.1	--	9.8	2.6	17.4	0.7	--	30.5
Seattle/Tacoma	--	--	--	2.6	--	--	2.6	--	--	--	1.6	--	--	1.6
Total US	48.3	194.9	355.1	100.6	26.1	69.9	794.9	30.0	121.1	220.8	62.5	16.3	43.6	494.3
Calgary, C-Train	1.9	2.6	14.6	10.5	2.4	--	32.0	1.2	1.6	9.1	6.5	1.5	--	19.9
Edmonton, LRT	4.7	--	7.6	--	--	--	12.3	2.9	--	4.7	--	--	--	7.6
Toronto, Streetcars	1.3	--	--	7.2	--	70.5	79.0	0.8	--	--	4.5	--	43.8	49.1
Total Canada	7.9	2.6	22.2	17.7	2.4	70.5	123.3	4.9	1.6	13.8	11.0	1.5	43.8	76.6
Total U.S. & Canada	56.2	197.5	377.3	118.3	28.5	140.4	918.2	34.9	122.7	234.6	73.5	17.8	87.4	570.9
% Total	6.1%	21.5%	41.1%	12.9%	3.1%	15.3%	100.0%	6.1%	21.5%	41.1%	12.9%	3.1%	15.3%	100.0%

* In streets, including pedestrian malls.

TABLE 4 Stations, Double Tracking, Electrification & Signaling

City/System	Passenger Stations & Car Stops	Double Track km	Double Track mi	Traction Power (vDC)	Substations No.	Substations Rating (mW)	Type of Overhead	Signals Block	Signals Traffic
Baltimore, Central Corridor	28	28.6	17.8	750	14+	1	Catenary	91%	9%
Boston, Green Line & Mattapan	~83	44.4	27.6	600	12	3-6	Trolley	62%	38%
Buffalo, MetroRail	14	10.3	6.4	650	5	2	Catenary	81%	19%
Cleveland, Blue/Green	33	21.1	13.1	600	6+	?	Catenary	84%	46%
Dallas, DART LRT	34	32.2	20.0	750	?	?	Catenary	~80%	~20%
Denver, RTD LRT	17	22.0	13.7	750	7	1	Both	60%	40%
Jersey City & Newark, NJ Transit	29	23.8	14.8	750	4+	?	Both	?	?
Los Angeles, Blue/Green/Gold	36	66.3	41.2	750	21	1.5-3.0	Both	86%	14%
New Orleans, Streetcars	55	14.0	8.7	600	?	?	Trolley	0%	100%
Philadelphia, City & Suburban	217	49.6	30.8	600/635	4+	?	Trolley	25%	75%
Pittsburgh, South Hills	59	27.4	17.0	640	6	6	Both	90%	10%
Portland, MAX	46	52.5	32.6	750	34	0.75	Both	52%	48%
Portland, Streetcar	24	8.1	5.0	750	5	0.30	Trolley	0%	100%
Sacramento, RT LRT	30	25.4	15.8	750	15	1	Both	77%	23%
St Louis, MetroLink	18	26.5	16.5	750	12	1.5	Catenary	100%	0%
Salt Lake City, UTA LRT	16	24.4	15.2	750	?	?	Both	77%	13%
San Diego Trolley	48	72.0	44.7	600	33	1	Both	92%	8%
San Francisco, Muni	~215	35.6	22.1	600	12	2-8	Trolley	19%	81%
San Jose, VTA LRT	41	43.1	26.8	750	15+	1.5	Both	58%	42%
Seattle/Tacoma	5	0.8	0.5	750	2	?	Catenary	?	100%
Total US	1020	628.1	390.3	--	--	--	--	--	--
Calgary, C-Train	31	29.3	18.2	600	17	2	Both	92%	8%
Edmonton, LRT	10	12.3	7.6	600	8	2	Catenary	100%	0%
Toronto, Streetcars	~625	75.5	46.9	600	?	?	Trolley	0%	100%
Total Canada	666	117.1	72.8	--	--	--	--	--	--
Totals - US & Canada	1686	745.2	463.1	--	--	--	--	--	--

TABLE 5 Revenue Service Vehicles

City/System	Car Types[1]	Builders	Fleet No.	Accel m/s/s	Accel mphps	Vmax km/h	Vmax mph	Length m	Length ft	Weight tonnes	Weight tons	Train # cars	Capacity	ATS
				Characteristics of Most Common Vehicle										
Baltimore, Central Corridor	LRV-6-ADac	ABB/Adtranz	53	1.3	3.0	88	55	29	95	50	55	3	84/174	No
Boston, Green Line & Mattapan	LRV-6-ADac	Boeing, Kinki, Breda[2]	215	1.3	3.0	80	50	22	72	38	42	3	50/130	No
Buffalo, MetroRail	LRV-4-RDac	Tokyu	27	1.3	3.0	80	50	20	67	17	19	3	51/121	Yes
Cleveland, Blue/Green	LRV-6-ADac	Breda	48	1.3	3.0	88	55	24	80	40	45	2	80/144	Part
Dallas, DART LRT	LRV-6-ADac	Kinki	95	1.3	3.0	105	65	28	93	50	55	3	76/160	?
Denver, RTD LRT	LRV-6-ADac	Siemens	31	1.3	3.0	88	55	24	80	37	41	3	64/144	No
Jersey City & Newark, NJ Transit	LRV-6-ADac	Kinki	45	1.3	3.0	80	50	27	90	45	49	2	68/160	?
Los Angeles, Blue/Green/Gold	LRV-6-ADac	Siemens & Nippon	121	1.3	3.0	88	55	27	89	43	47	3	76/160	Yes
New Orleans, Streetcars	VTL-4-RD	Perley Thomas	41	0.8	1.7	43	27	14	48	19	21	1	52/68	No
Philadelphia, City & Suburban	LRV-4-RS/Dac	Kawasaki	141	1.3	3.0	80	50	15/16	50/53	27	30	1	50/95	No
Pittsburgh, South Hills	LRV-6-ADac	Siemens	55	1.3	3.0	80	50	26	84	36	40	2	62/150	Yes
Portland, MAX	LRV-6-ADac	Siemens & Bombardier	78	1.3	3.0	88	55	27/28	89/92	42/50	46/55	2	64-76/170	Yes
Portland, Streetcar	LRV-4-ADac	Inekon-Skoda	7	1.5	3.4	70	43	20	66	29	32	1	30/90	No
Sacramento, RT LRT	LRV-6-ADac	Siemens	56	1.1	2.5	80	50	24	80	36	40	4	60/144	No
St Louis, MetroLink	LRV-6-ADac	Siemens	65	1.3	3.0	88	55	26	86	41	45	2	72/155	Yes-Cab
Salt Lake City, UTA LRT	LRV-6-ADac	Siemens	33	1.3	3.0	88	55	24	80	37	41	4	64/144	No
San Diego Trolley	LRV-6-ADac	Siemens	123	1.3	3.0	88	55	24	80	37	41	4	64/144	No
San Francisco, Muni	LRV-6-ADac	Breda	175	1.3	3.0	84	52	23	75	30	33	3	60/130	Part-Cab
San Jose, VTA LRT	LRV-6-ADac	Kinki & UTDC	50	1.3	3.0	88	55	27/28	89/92	45	49	2	75/160	No
Seattle/Tacoma	LRV-4-Adac	Inekon-Skoda	3	1.5	3.4	70	43	20	66	29	32	1	30/90	?
Total US			1462											
Calgary, C-Train	LRV-6-AD	Siemens	99	1.0	2.2	80	50	24	80	32	35	3	64/162	Yes
Edmonton, LRT	LRV-6-AD	Siemens	37	1.0	2.2	80	50	24	80	40	45	5	64/162	Yes
Toronto, Streetcars	LRV-4/6-R/AS	UTDC	248	1.3	3.0	85	53	16/23	53/75	23/37	26/40	1	46/95	No
Total Canada			384											
Totals - US & Canada			1846											

1-LRV=light rail vehicle, VTL=vintag trolley, #=no. of axles, A/R=articulated or rigid, D/S=double or single ended & sided, ac=air conditioned. 2-Boston total includes 11 PCC-4-RS.

TABLE 6 Changes in North American LRT & Streetcar Systems, 2001-2003

City/System	Code*	Changes
UNITED STATES:		
Baltimore, Central Corridor	R	Double tracking in progress - 9.4 mi
Boston, Green Line & Mattapan	RV	Introducing Type 8 LFLRVs; planning Heath St-Arborway rail service restoration
Buffalo, MetroRail	--	--
Cleveland, Blue/Green	--	--
Dallas, DART LRT	XV	Opened 24 mi North & Northeast extensions, late 2002; planning 40+ mi NW, West & SE extensions; adding 20 LRVs
Denver, RTD LRT	XV	Opened 1.6 mi Central Platte Valley extension, spring 2001; 19 mi TREX (southeast) under construction; added ?? LRVs
Jersey City & Newark, NJ Transit	X	Opened Hoboken extension 2002; under construction: 6.1 Mi Tonelle Av extension (HBLRT) & 1.1 mi NERL (Newark)
Los Angeles, Blue/Green/Gold	XV	Opened 13.7 mi Pasadena Gold Line mid-2003 w/26 Siemens LRVs; building 6 mi East Los Angeles Gold Line; adding 50 LRVs.
New Orleans, Streetcars	XV	4.1 mi Canal line under construction; building 24 replica streetcars in house
Philadelphia, City & Suburban	R	Restoring 8.2 mi Girard Ave line & 15 remanufactured PCC cars
Pittsburgh, South Hills	RV	Completing 5.5 mi Stage 2 reconstruction in 2004; purchasing 28 New CAF LRVs; start North Shore Connector design for 2007 oper
Portland, MAX	XV	Opened 5.5 mi Airport MAX 2001; completing 5.8 mi Interstate MAX for 2004 opening; purchasing 27 Siemens LFLRVs
Portland, Streetcar	NX	Opened 2.5 mi streetcar line 2001 w/7 Skoda cars; building 0.5 mi Waterfront extension
Sacramento, RT LRT	XV	Opened 6.3 mi South line fall 2003; building 10.9 mi Folsom extension for 2004/5 opening; purchasing 40 new CAF LRVs
St Louis, MetroLink	XV	Opened 20.5 mi East extension in two phases 2001 and 2003; added 9 Siemens LRVs; building 8 mi Cross County
Salt Lake City, UTA LRT	XV	Opened 2.5 mi University line in 2001 and adding another 1.5 mi to open 2004; adding 3 new Siemens LRVs + 29 used UTDC LRVs
San Diego Trolley	XV	Building 5.8 mi Mission Valley East extension for 2004 opening; purchasing 11 Siemens LFLRVs
San Francisco, Muni	XV	Building 5.4 mi Bayshore Line (3rd St) for 2005 opening; completed deliveries of 159 Breda LRVs
San Jose, VTA LRT	XV	Building 6.4 mi Tasman East/ Capitol & 5.3 mi Vasona extensions; purchasing 70 Kinki Sharyo LFLRVs to replace 50 UTDC cars an
Seattle/Tacoma	N	Opened 1.6 mi Tacoma LRT line with 3 Skoda LFLRVs Sep 2003; building 14 mi Seattle Central Link LRT for 2009 opening
CANADA:		
Calgary, C-Train	XV	Extending all lines: NW 1.9 mi (2003), South 1.9 mi (2004), 1.3 mi NE (2005-6); purchased 17 Siemens LRVs
Edmonton, LRT	X	5 mi South extension to Heritage Mall in design for 2005 opening
Toronto, Streetcars	--	--
NEW STARTS UNDER CONSTRUCTION: Houston (Jan 2004); Minneapolis (spring 2004)		
* N = New Start; R = Renovation/Reconstruction; V = Vehicle Procurement; X = Extension.		

Defining an Alternative Future
Birth of the Light Rail Movement in North America

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Covering three subjects, this paper sets forth conditions that led to the beginning of the light rail movement in North America. The first subject is a history of ideas and conditions that led to the National Conference on Light Rail held in Philadelphia, Pennsylvania, in June 1975. The second and third subjects are summaries of the ideas and conditions that led to the adoption of light rail transit in Edmonton, Alberta, and San Diego, California, the first regions to adopt light rail in Canada and the United States, respectively. The information presented relies primarily on written documents and interviews with people who participated in events described herein. It is argued that light rail transit was a product of social movements of the late 1960s and 1970s when, for the first time in American history, large numbers of people looked to the future with a sense of foreboding but at the same time felt empowered to control the future. Many thought that they could reverse the fortunes of transit, thereby improving urban conditions, by embracing light rail transit. This was a northern European concept that strove to achieve the level of service of rapid transit at a fraction of the cost. Although the American transit industry was ambivalent to the idea activists championed it, which the National Conference on Light Rail disseminated to the planning and transportation engineering community throughout the United States and Canada. At the same time the same forces led to light rail adoption in Edmonton and San Diego.

INTRODUCTION

In the two decades preceding 1970, U.S. transit patronage fell by 58%, and the percentage of that ridership using streetcars declined from 23% in 1950 to just 3% in 1970 (*1*). During this period automobile use grew much more than transit use declined, so transit's relative decline was much more than even these figures suggest. In 1970 there appeared to be little future for the U.S. transit industry and its suppliers.

What actually transpired was quite different. Not only was there a renaissance in U.S. and Canadian transit investment, in some metropolitan areas there was even a small increase in transit's importance. The renaissance partly is the result of visionaries and reformers who, because of globalization, were able to look past the domestic transit industry and its suppliers to more promising offerings from the transit industry in northern Europe. One of the promising prospects from northern Europe was light rail transit, that evolved from traditional streetcar systems in many northern European cities during the 1950s and 1960s. Light rail jumped the Atlantic in the late 1960s and early 1970s.

This discussion will trace how European experience with light rail captured the imagination of transit reformers in the United States, and it will look at how the idea actually took root in the first application of light rail in Canada (Edmonton, 1978) and the United States (San Diego, 1981).

In general, the light rail movement arose in North America during the 1960s and 1970s amidst growing disillusionment with technological progress. Prior to this time the public was fatalistic about its ability to alter the course of technological progress but optimistic that the results ultimately would turn out for the better. In the 1960s, pessimism began to replace optimism about the long-term consequences of market-led technological progress (*2*). At the same time, however, there was increasing optimism that individuals could act collectively to alter the course of technological (and also social) progress for the greater good. Fatalism about the inevitability of progress gave way to activism.

This paper argues that the coming of light rail to North America was an expression of this new North American spirit of political activism. The light rail movement attempted to steer technological progress away from what the established transit institutions in North America promised. In that respect it had a revolutionary aspect to it, earning the appellation of a "movement." I also argue, however, that the early light rail movement had a strong pragmatic streak, resulting in a complex and not obvious relationship between the light rail movement and both the established transit industry and the anti-highway movement of the same period.

APPEARANCE OF THE LIGHT RAIL VISION IN NORTH AMERICA

Dean Quinby's Contribution

The term "light rail transit" did not appear in North America until 1972, but the concept to which it referred had been talked about for at least a decade before then. In 1962, *Traffic Quarterly* published an article by H. Dean Quinby describing the concept (*3*). Quinby was an engineer employed by Parsons, Brinkerhoff, Quade and Douglas, and he was a part of the team assembled in California's San Francisco Bay Area to design and build the nation's first regional rapid transit system, the Bay Area Rapid Transit (BART). What Quinby talked about in "Major Urban Corridor Facilities: A New Concept" was not BART, however. It was a description of a new form of transit that was evolving in several West German, Swiss, Belgian, Netherlands, and Swedish cities from their efforts to upgrade their historic streetcar systems during the post World War II period as automobile use was surging upward.

Rebuilding took different forms in the various northern European cities, but Quinby discerned two attributes common to most of the rebuilding efforts that together constituted to him the emergence of a new transit concept. One was capacity enhancement with emphasis on larger cars, operation of cars in trains, and much greater door capacity with new fare systems to make use of that capacity. The result was that for the first time surface transit could engorge and disgorge large volumes of passengers at intermediate stops quickly. The other was speed enhancement, achieved through traffic engineering and light infrastructure investments, with short applications of heavy infrastructure investment in critical areas. What particularly impressed Quinby was the effort to achieve both attributes at low cost. Rapid transit lines, of course, already had both attributes, but they were prohibitively costly. As Quinby saw it, the goal of the streetcar rebuilding was to bring the qualities that long had been the sole province of rapid transit to surface-running transit, thus making the attributes much more widely available to the public.

These ideas appealed to some who wished to reverse the long decline of transit, summarized in Figure 1. From 1930 on, transit managers replaced streetcars with buses to cut costs. Buses were not popular, however. By 1970, the public's use of them was plummeting. Had traditional streetcars been retained, they probably would not have done much better. Interestingly, though, rapid transit patronage was comparatively resilient to the auto onslaught. For those who wanted to preserve public transit use, rapid transit seemed like an obvious choice. Unfortunately, it was too costly to be adopted widely. What, however, if one could obtain many of the characteristics of rapid transit at a fraction of the cost? The goal of what became known as light rail transit after 1972 was to do just that: it was to be every city's rapid transit.

The appeal of such ideas spread through the 1960s even as streetcar lines and the last of the interurbans continued to be abandoned in cities such as St. Louis, Los Angeles, Chicago, Baltimore, Pittsburgh, Philadelphia, and Washington, D.C., and U.S. transit use continued to plummet. An English publication, *Modern Tramways*, kept North American readers up to date with the latest northern European developments, and increasing numbers of North Americans were traveling to northern Europe, including some who were interested in transit revival. The difference between what they were experiencing at home and what they saw in northern Europe was stunning and galvanizing.

Bill Adams' Contribution

In 1965, *Traffic Quarterly* published another article on the concept, but this was rooted in rationalization of American transit practices (*4*). As an employee of the Boston Redevelopment Authority and the Metropolitan Boston Transit Authority, the article's author, William Adams,

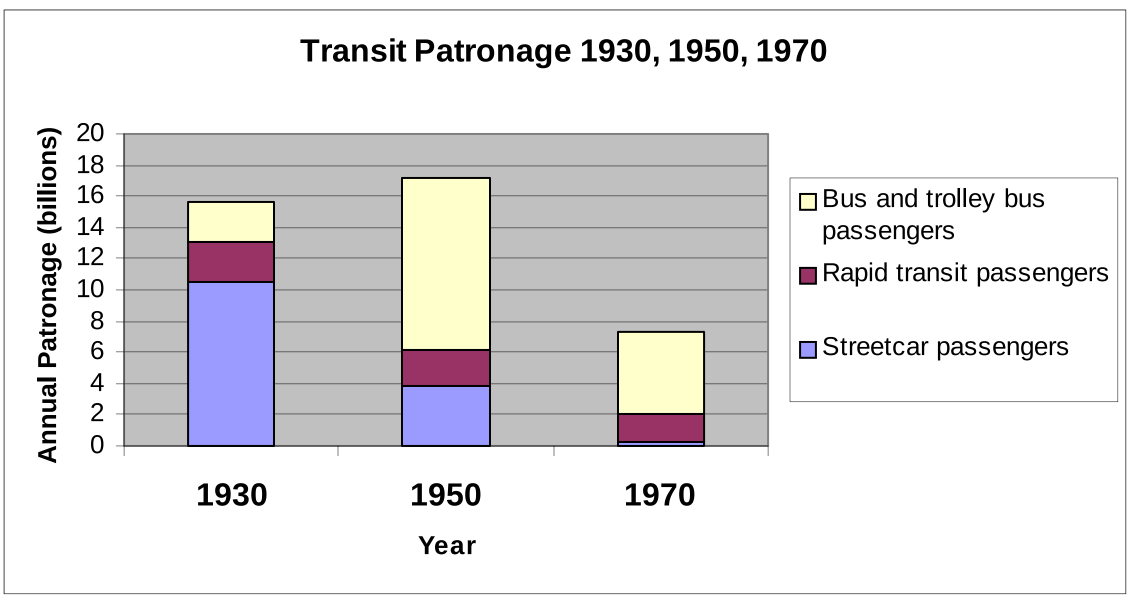

FIGURE 1 U.S. transit patronage by mode; 1930, 1950, and 1970.

studied operations of Boston's remaining subway-surface streetcar lines and came to conclusions for reorganizing their operations that paralleled transformations in northern Europe. Adams claims that he was at the time unaware of northern European developments, but when he traveled to Germany shortly thereafter his convictions were reinforced. Not long thereafter Adams was hired by the newly established Urban Mass Transit Administration (UMTA) (interview with William Adams, June 11, 2002; interview with Jeff Mora, June 10, 2002).

Stewart Taylor's Contribution

In the late 1960s, a U.S. transit consultant who had been traveling to Europe since before World War II and who regularly read *Modern Tramways* came to the conclusion that many of the nation's urban ills—urban highway expansion, suburban sprawl, and transit decline—were interrelated issues. The consultant, Stewart Taylor, was from an influential Washington family and had grown up comfortable in the presence of power. He also was a gifted writer. He believed that northern European streetcar transformations held considerable promise for U.S. urban regions, and he resolved to popularize the concept with those in power. After contacting the editors of *Traffic Quarterly*, which he considered the most widely read and erudite journal in the transportation field, of their potential interest in a story on the topic, he traveled at his own expense to tour several of the systems undergoing transformation and meet with their managements. He then drafted an article intended to appeal to decision makers, and *Traffic Quarterly* published it in 1970 as "The Rapid Tramway: A Feasible Solution to the Urban Transportation Problem" (*5*).

Taylor characterized his article as "the shot heard around the world," for the light rail movement (interview with Stewart Taylor, June 14, 2002), and for years thereafter he used the article and variants of it to lobby influential people and as support in appearances on radio and TV programs. News magazines also summarized Taylor's theme. The article outlined problems of congestion, inner city troubles, and suburban sprawl as consequences of federal policy promoting massive urban freeways, while it stated that rapid transit was an infeasible alternative because of its cost. Buses were an unacceptable form of transportation to those with choice. The rapid tramway, on the other hand, could be afforded in most U.S. urban regions and would be used by those with choice. Taylor's concept of light rail was as a higher capacity but lower cost and more environmentally friendly transport mode serving the downtowns of major cities.

Federal Transportation Legislation

By the early 1970s, such efforts began to affect public policy, which was in a period of rapid flux. The Highway Act of 1962 established the beginnings of the metropolitan planning organization (MPO) planning process, which was strengthened with the Highway Act of 1973. In the early 1970s, newly established regional planning bodies around the U.S. were undertaking studies of regional rapid transit systems alongside regional freeway systems. Municipal and regional transit authorities took control of most U.S. private transit systems during this period. The Urban Mass Transit Act of 1964 established the UMTA and provided funds for the public takeover of private bus systems, the purchase of new buses, and the construction of new garages. The Urban Mass Transportation Assistance Act of 1970 provided $3.1 billion to mass transit systems over a 5-year period, some of it intended for the renewal of existing rapid transit systems, but much of it intended for new-start rapid transit systems. It was apparent from the beginning, however, that claims for such funds would outstrip supply by several fold (*6–8*, interview with Ken Orski, June 14, 2002).

The Role of Vukan Vuchic

In 1972 the UMTA commissioned Vukan Vuchic, Professor of Civil Engineering and Planning at the University of Pennsylvania, to write a report that summarized modern tramway development in Europe along with the status of subway-surface streetcar operation in the United States. Vuchic had been collaborating with Dr. Friedrich Lehner, the most influential of Germany's transit engineers and the developer of many of the ideas associated with light rail. Vuchic also was a confidant of Dean Quinby (interview with Vukan Vuchic, June 13, 2002). At the time, Boston and Philadelphia had old streetcar subways in their downtowns. Outside of the downtowns, streetcars in those cities ran in the streets or in the medians of streets. The BART project in the San Francisco Bay Area also was nearing completion, and in addition to regional rapid transit, it created a downtown subway in San Francisco which might be used by a new local rapid transit line or, alternatively, by the few remaining local streetcars. A heated political fight in the late 1960s in which both Quinby and Vuchic figured (Quinby clandestinely; Vuchic openly), resulted in a decision to put the streetcars in the subway. The streetcars still would operate on the surface in the inner suburbs. By this time, there was considerable interest in reconfiguring the U.S. subway-surface streetcar systems to resemble northern European practice, and there was increasing recognition that modern tramways might be appropriate for urban regions that long since had given up streetcar operation. The Vuchic report provided a state-of-the art benchmark for future progress (interview with J. Mora; interview with V. Vuchic).

It also was in 1972 that the term light rail was coined to describe the concept of the streetcar transformations. By this time the Germans used the term *Stadtbahn* to describe the concept, and Vuchic was in favor of using the English translation, which is "city rail," but UMTA decided upon light rail. Vuchic ultimately issued his report using the term light rail (interviews with V. Vuchic, J. Mora; interview with Robert Abrams, June 10, 2002).

UMTA and the Standard Light Rail Vehicle

During this time, UMTA decided to prepare a performance specification for what became known as the Standard Light Rail Vehicle (SLRV) to replace President's Conference Committee streetcars in San Francisco and Boston. According to Robert Abrams, who administered UMTA's capital grants program at the time, UMTA wanted to reduce the costs of light rail vehicles by creating an off-the-shelf model that all applicants for federal funds to build or refurbish light rail lines would be required to use. After the San Francisco Municipal Railway rejected high bids on its own specifications for a new light rail vehicle, UMTA retained Parsons-Brinkerhof to rewrite the specifications for the SLRV. The resulting performance specificiation was the size of a phone book, and in 1972 bid solicitations went out for the construction of 100 SLRVs for San Francisco and 150 SLRVs for Boston. There was only one bidder—not an established U.S. car company, but Boeing Vertol, which previously made helicopters for Viet Nam. The part of the Boeing Vertol order that went to Boston in 1976 was plagued with problems. The cars that went to San Francisco fared somewhat better but still required an inordinate maintenance effort to keep them running. To Abrams, the SLRV program turned into a fiasco, but it advanced awareness of light rail technology and its possible applicability to U.S.

transit systems (interview with R. Abrams).

Ken Orski and the National Conference on Light Rail

Between 1974 and 1976, a new UMTA Associate Administrator for Policy and Programs, Ken Orski, advanced the light rail movement considerably by changing its focus from re-equipping old streetcar systems to building entirely new systems. Orski, a lawyer trained at Harvard, joined General Dynamics in 1956, and during his 12 years there he examined peacetime markets that the company might pursue. Despite the declining fortunes of mass transit, Orski foresaw a sizeable market in rapid transit rolling stock that would be necessary to restore U.S. urban areas. Between 1968 and 1974 Orski worked for the Organization for Economic Cooperation and Development (OECD) in Brussels, where he focused on multilateral cooperation on transportation and urban development. That experience exposed Orski to the concept of light rail, which appealed to him. Shortly after assuming his UMTA role in early 1974, Orski circulated an internal memo calling for UMTA to require a planning process, ultimately known as alternatives analysis, for regions applying for federal funds to build new rail systems. One alternative that was to be given serious consideration was light rail transit, which was oriented to many of the same objectives as rapid transit but at lower cost. Orski issued a second internal memo in early 1974 suggesting that UMTA sponsor a national light rail conference to get the word out to planning bodies throughout the United States about the possibilities of light rail, which henceforth had to be considered in alternatives analysis (interview with K. Orski).

Orski approached Stewart Taylor, whom he already knew, to begin planning for the conference, which became known as the National Conference on Light Rail. Taylor brought in Vukan Vuchic, whom Taylor had known since Vuchic had invited Taylor to address one of Vuchic's classes on the modern tramway concept. Joseph Silien and Bill Morris, both associated with an effort to start a new light rail line in Rochester, New York, also joined the planning committee. Orski wanted the committee to carve out a prominent role in the conference for Senator James R. Mills, president pro tempore of the California State Senate who was actively promoting the development of light rail in San Diego (interviews with K. Orski, S. Taylor, V. Vuchic, J. Mora).

Orski also approached TRB to cosponsor the light rail conference. In 1972 the then Highway Research Board (HRB) held a retreat in New Hampshire to discuss the growing federal role in transit and whether the HRB committee system should reflect that role. Following the conference HRB changed its name and established a new public transportation section with four committees and assigned Wm. Campbell Graeub to staff the new transit committees. Graeub (pronounced "Groib") was originally from Bern, Switzerland, but he was trained as a civil engineer in the U.S., and he had worked in highway planning for the District of Columbia before joining HRB in 1968. Graeub retained an interest in trams from his youth in Bern; however, and he was very interested in the light concept when he first heard of it. When TRB responded enthusiastically to Orski's request, Graeub was the logical person to handle the logistics of the conference (interview with Campbell Graeub, June 11, 2002).

The other logical body to cosponsor the conference was the American Public Transit Association (APTA), but Graeub said there was serious internal division within APTA over whether the organization should be associated with light rail. There was very strong opposition from APTA members associated with rapid transit systems. Graeub did not know why the rail transit people were opposed, but he speculated that they did not want potential government money for rail rapid transit diverted to new light rail systems. [Neither Graeub nor Vuchic mentioned it, and I did not bring it up in the interviews because I did not know it at the time, but by 1977 the president of APTA was Thomas O. Prior, General Manager of the San Diego Transit Corporation and a bitter foe of Senator Mills and of light rail in San Diego (Interview with Senator James R. Mills, July 17, 2003). Whether Prior was president of APTA in 1975 I do not know, but if not he likely would have been an important member of APTA.] Ultimately, APTA decided to allow its name to be used as a cosponsor, but only reluctantly, according to both Graeub and Vuchic (interviews with C. Graeub, V. Vuchic).

The National Conference on Light Rail took place in Philadelphia in June 1975, with approximately 300 people registered, about double the number that Graeub and other organizers anticipated (interview with C. Graeub). Attendance exceeded that of earlier TRB specialty conferences. Trolley enthusiasts, which Graeub did not target in publicity for the conference, accounted for a significant part of the attendance. They came from all over the country and slept in dorms at the University of Pennsylvania. Graeub said that the trolley buffs were disappointed; they were not interested in light rail but in restoring old streetcar service, and there was little in the conference that interested them. The program focused largely on European light rail development and its potential applicability to North American urban regions. Much of the U.S. content focused on UMTA's efforts to develop the SLRV, and the conference featured a tour of the Boeing Vertol plant near Philadelphia to view SLRVs under construction. While these topics did not interest trolley buffs, they did interest community activists as well as city planners, MPO planners, state highway officials, transit operators, and other transportation professionals from around the country, who also were in attendance. Many of these people became enthusiastic carriers of the light rail message, which was that high performance regional rail transit could be achieved at costs low enough to be practical in mid-sized U.S. and Canadian cities. The conference met Orski's expectations, and subsequent to it, he commissioned DeLeuw Cather to write a state-of-the art review of light rail in Europe and the U.S. (*9*; interviews with S. Taylor, C. Graeub, V. Vuchic, K. Orski).

ADOPTION

The first region to adopt light rail in North America was Edmonton, whose first line opened in 1978. Calgary and San Diego opened their first lines in 1981. Decision making leading to the first three light rail starts was not influenced much by the light rail conference of 1975, but it was influenced by many of the same forces that led to the first national light rail conference. On the other hand, decision making leading to the second wave of light rail openings, in Portland, San Jose and Sacramento, California, was heavily swayed by the first national light rail conference. I am in the process of researching light rail adoption and its consequences in these cities, with research most advanced for Edmonton and San Diego. At this point I will briefly summarize factors influencing light rail adoption in Edmonton and San Diego and their relationship to the North American light rail movement. I will conclude with preliminary observations about how factors leading to the light rail conference and light rail adoption in Edmonton, Calgary, and San Diego influenced subsequent light rail adoption.

Edmonton

Edmonton had a municipally owned transit system dating from about 1912, which was managed by a cadre of professionally schooled engineers throughout its history. The general manager from 1949 to 1973 was an electrical engineer, Donald L. MacDonald, whose first major task was to replace the antiquated streetcar system with trolley buses circa 1949–51. Because of the discovery of oil in nearby Leduc in 1947, the city's population grew from about 150,000 in 1950 to about 500,000 in 1970, and MacDonald strove to expand the transit system to match the growth of the city. John J. Bakker, a civil engineering professor at the University of Alberta who gained experience in the planning and operation of timed transfer bus systems in German-occupied Netherlands during World War II, aided MacDonald with this effort. During the 1960s MacDonald and Bakker developed a long-range strategy of serving the downtown with rapid transit that was integrated with a region-wide timed transfer bus system, and although they persuaded city council to approve the construction of a small rapid transit system in 1968, the realization that fares could not support its construction caused city council to withdraw its support in 1970. The city engineering department then asked the council to approve the construction of a freeway ring encircling the downtown from which radials would extend to the suburbs. The proposal led to a revolt by community groups, which researched freeway revolts in Toronto and the United States and documented urban destruction that would ensue from the Edmonton freeway proposal, known as the Metropolitan Edmonton Transportation Study, or METS plan. The group published its findings in a little red book called *The Immorality of the Motor Car* and successfully lobbied city council to scrap the freeway plan in 1971. The group, called the Practicum on Community Analysis, then turned its attention to light rail, having been persuaded of its efficacy by articles in *Modern Tramways*, Dean Quinby's and Stewart Taylor's articles in *Traffic Quarterly*, and visits to German, Dutch, Swedish, and Swiss light rail systems. In 1972 the group published *Light Rapid Transit, the (Immediate) Answer for Edmonton*, explaining the light rail concept in Europe and showing how it could be applied to Edmonton. MacDonald's and Bakker's earlier integrated rapid transit and regional bus plans were adapted for this purpose. Nothing further happened until the 1973 energy crisis bloated Alberta provincial coffers with royalties. Both MacDonald and his counterpart in Calgary, William Kuyt, were known and respected by the new premier of Alberta, Peter Lougheed, who created funds for both Edmonton and Calgary to support the construction of light rapid transit for those cities. This led Edmonton City Council to approve light rail construction, using German U-2 cars identical to those that were placed into operation in Frankfurt am Main in Germany in 1968. Calgary City Council followed a couple of years later, using the same type of car. Both cities had looked widely for cars and could find no interest on the part of U.S., Canadian, Dutch, or English manufacturers in supplying small orders. (Edmonton's was for 14 cars; Calgary's was for 25 cars.) That was until DuWag, the manufacturer of the U2 car, was found. Bakker recalls DuWag asking, "How many cars do you want? Two, three, six?" (interview with John Bakker, Aug. 14, 2002; interview with Jaswant Kooner, July 22, 2002; interview with William Kuyt, Aug. 13, 2002; interview with Peter Boothroyd, Aug. 16 2002; interview with John Schnablegger, Aug. 20, 2002).

San Diego

San Diego was the first U.S. region to adopt a new light rail line. Planning for rail transit in San Diego originated in the region's MPO, then called the Comprehensive Planning Organization (CPO). CPO's executive director, Dick Huff and his assistant, Ken Sulzer had been recruited in the mid-1960s from the National Capital Planning Commission in Washington, D.C., and CPO's first regional plan reflected their vision for the region. Similar to the adopted plan for the nation's capital, the San Diego plan featured 59 mi of radial regional rail transit lines focused on the central business district. The rapid transit system was to be supported by dense land use development as well as approximately 2000 feeder buses. At the time the San Diego Transit Corporation (SDTC) operated about 250 buses. Low density development would separate the radial transit fingers. Prepared pursuant to national transit legislation of the early 1970s that allocated several billion dollars for the construction of new rail rapid transit systems, the CPO plan was released in 1974 (interview with Ken Sulzer, July 16, 2003; interview with J. Kooner).

The president pro tem of the California State Senate, Senator James R. Mills, represented San Diego and favored transit development, having carried two important transit funding bills that enable expansion of the state's transit industry. He believed that the CPO plan was far too rich for the San Diego taxpayer, however, and having been reading *Modern Tramways* for a couple of years and having been in touch with Ken Orski, Mills advocated light rail development for San Diego. Rebuffed by both CPO and earlier by the SDTC's Tom Prior, Mills turned to the San Diego County Board of Supervisors for assistance. The board authorized its assistant county engineer and highway designer, Rudy Massman, to investigate the feasibility of light rail in CPO's highest priority corridor. Massman put together a small staff of road designers, costers, and a transit engineer (Jas Kooner) who had worked under MacDonald and Bakker. Massman concluded that a high performance light rail line could be built at low cost from downtown San Diego to the south. In the second part of the study, which included another protege of MacDonald and Bakker, Greg Thompson, Massman concluded that a regional light rail system was feasible and would serve the region effectively if it were the central part of a reconfigured bus system that allowed multidestinational bus service in the region. On the basis of the study, Mills introduced and carried state legislation that created the San Diego Metropolitan Transit Development Board (MTDB) with power and funding to carry out the vision put forward by Massman. Much of the power of MTDB was gained at the expense of both SDTC and CPO, and UMTA staffers attempted unsuccessfully to decertify the San Diego region as a consequence of its passage (Interview with Sen.Mills; interview with Arthur Bauer, Aug. 6, 2002; interview with Rudy Massman, Aug. 15, 2002; interview with J. Kooner; interview with K. Sulzer).

Under the direction of Bob Nelson, who previously had been deputy general manager in charge of finance for BART and who held a similar position later at MARTA in Atlanta, Georgia, MTDB crafted a plan for constructing light rail within the constraints of existing state and local funding sources. The San Diego proposal called for the use of DuWag U2 cars almost identical to those about to go into operation in Edmonton. MTDB's task was made easier in August 1976 when Tropical Storm Kathleen washed out part of the San Diego & Arizona Eastern Railway, which coincidently traversed the desired corridor, making its owner, the Southern Pacific Company amenable to talking about selling the railroad to MTDB. In 1978 SDTC threatened to reduce bus service if MTDB went ahead with its plans, because it said that there was not enough money in the region to operate both the bus and rail service. For the previous 3 years SDTC's unit costs escalated at about 15% per year, more than double the rate of inflation. Nelson countered that if SDTC's unit costs could be frozen for 2 years and then allowed to grow at 5.5% per year, the region not only could afford both the existing bus service and light rail, but the amount of transit service operated in the region could be doubled over the next 15 years. Nelson then demonstrated how the region could control the growth in unit bus costs. His argument was credible with Mayor Pete Wilson, who already was impressed by MTDB's ability to get an agreement from the Southern Pacific Company to buy the San Diego & Arizona Eastern Railroad for $18.1 million. Wilson then added his considerable weight to the light rail cause, and the project went forward. Nelson was replaced by MTDB's director of planning Tom Larwin, who spread oil over the stormy bureaucratic waters, and under Larwin's leadership, MTDB largely kept Nelson's promise. The magnitude of transit service roughly did double in the MTDB service territory over the ensuing 15 years with no significant increase in taxes supporting transit operations, while transit patronage also doubled, and light rail became politically popular (*10–12*; interview with Ben Dillingham III, July 17 and 19, 2003; interview with Tom Larwin, July 22, 2003; interview with Judith Bauer, July 18, 2003).

CONCLUSIONS AND DISCUSSION

Light rail arose from the social ferment of the mid-1960s through 1970s as activists and politicians sought more benign and affordable solutions to transportation problems facing North American urban regions. The goal was to approach the level of service provided by rapid transit and gain many of its benefits at a small part of the cost. This made it possible to introduce rail transit into previously all-bus cities and by doing so achieve overall transit improvement. Cities in northern Europe provided the model. Dean Quinby, Bill Adams, Stewart Taylor, Vukan Vuchic, and others promoted and refined the idea for over a decade before Ken Orski wove the various threads into the National Conference on Light Rail held in Philadelphia in June 1975.

The decision to build light rail in Edmonton came before the National Conference on Light Rail, but the forces that led to the National Conference led also to the Edmonton decision. From the 1950s into the 1970s the city grew rapidly, straining the city's transportation system. Looking to the future, Don MacDonald and John Bakker sought to add capacity to the transit system's central business district trunk lines with rapid transit while reorienting buses to suburban destinations, but were thwarted by the cost of rapid transit. At the same time, citizen activists resisted the imposition of a freeway network over the city fabric and sought a more socially benign solution that also was less costly. Light rail was seized by both the transit system and the citizens.

In San Diego the major issue was how to improve the region's transit system at an affordable cost. The CPO plan, while laudable, was not achievable fiscally. On the other hand, SDTC used money given to it by Senator Mills to inflate its unit costs, reduce fares, and add unproductive service. By the mid-1970s the system was out of money and threatening service cutbacks. The European model of light rail promised a different and potentially achievable approach toward improving and expanding transit in the region, and the approach used in Edmonton of restructuring the bus system around light rail into a regional, multidestinational system appealed to Mills. Excellent results have been achieved following this approach in San Diego.

It is impossible to say whether or not light rail would have happened in other U.S. regions in the absence of Edmonton's and San Diego's decisions to go ahead. The forces that led to the National Conference on Light Rail and the decisions to move ahead in Edmonton, Calgary, and San Diego, affected other U.S. urban regions, as well, and other regions might have adopted light rail even without the examples of Edmonton, Calgary, and San Diego. Strong anti-freeway movements in Sacramento and Portland (Oregon), for example, would have occurred in any event. Activists from those movements attended the National Conference on Light Rail and were energized by the experience. They would have been energized whether or not light rail decisions happened in Edmonton, Calgary, and San Diego. The Interstate Transfer Provision of the Highway Act of 1973 ultimately provided most of the funding for the initial Sacramento and Portland projects. One is tempted to think that those projects would have gone ahead, even without the examples of Edmonton, Calgary, and San Diego. Other projects may have gone ahead, as well.

I will end on still another speculative note. Before the opening of light rail service in San Diego, the U.S. transit industry was ambivalent toward light rail. After San Diego opened, however, the political popularity of the light rail idea became evident, at least to some in the industry. If a light rail movement started in a particular community, the transit agency that stood in its way might not prosper, whether or not the decision was made to go ahead. Some argue that if light rail is rejected in a region, there is more money with which to expand bus service, but I am not aware of major bus service expansions coming on the heels of light rail proposals being placed on the back burner. Rochester, New York, Dayton, Ohio, Kansas City, Kansas, Tampa, Florida, and Columbus, Ohio, come to mind. Bus transit in those regions has stagnated after it was decided not to proceed with light rail. On the other hand, there are examples of transit agencies that seized upon the light rail idea and ran with it and saw political animus toward transit turn into support, not only for light rail, but for expanding bus service, as well. We have seen this not only in San Diego, but in Portland, Dallas, Texas, Denver, Colorado, and St. Louis, Missouri. Based on the evidence that I have seen so far, I venture to say that where light rail has been conceived not of a technology unto its own but as the central and cost effective backbone of a regional restructuring of bus services, light rail has generated political support that previously was nonexistent for transit improvement. Whether it will continue to do so depends to a large degree on how cost effective future light rail proposals are and what role they are scripted to play in the evolution of regional transit networks.

ACKNOWLEDGMENTS

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Joint Agency Planning for MetroLink Expansion in St. Louis, Missouri

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Since 1996, the St. Louis region has been conducting all multimodal transportation corridor planning through an interagency planning unit housed at the East-West Gateway Coordinating Council (MPO). We believe this to be a unique approach to transportation planning in the United States. The joint planning group, known as the Transportation Corridor Improvement Group (TCIG), includes staff members from each of three agencies—the transit authority (Metro), the state transportation department and the MPO. To date, approximately 10 planning studies or major investment studies have been completed by this group, including 4 studies that included consideration of major MetroLink light rail extensions.

This paper will summarize the St. Louis experience in carrying out these joint planning studies, particularly those involving corridors in which light rail expansion is an alternative, and will discuss the benefits and issues that have resulted from using this collaborative process over the past 6 years.

Many significant benefits have resulted from the joint planning of the MetroLink extensions including better public understanding and acceptance of the process, a more coordinated cooperative planning process, more effective community engagement due to consistency of people and messages, and more efficient use of limited planning staff, consultants, and other resources with minimal duplication of effort. However, there are some pitfalls that we are working to resolve in current and future studies. The most notable of these involves the need to ensure the complete buy-in of staff outside the TCIG within the three agencies during the planning process so as to facilitate the smooth transfer of the resulting projects to the implementing agency.

PURPOSE

The purpose of this paper is to summarize the benefits of collaborative joint agency planning for light rail transit extensions by examining the experience in St. Louis, Missouri, over the past 6 years.

BACKGROUND

St. Louis Region

The St. Louis region includes four counties and the city of St. Louis in Missouri, plus three counties across the Mississippi River in Illinois. The regional population is approximately 2.5 million of which approximately 1 million reside in St. Louis County.

MetroLink System

The initial 18-mi line in the St. Louis region's MetroLink light rail system opened for service in 1993. This line linked Illinois with downtown St. Louis, major destinations in the city of St. Louis and St. Louis County and Lambert–St. Louis International Airport. In May 2001, an 18-mi extension opened in St. Clair County, Illinois, to which 3 mi more of track were added in 2003. To a varying extent, these existing lines were all federally funded. A locally-funded 9-mi extension in the city of St. Louis and St. Louis County is currently under construction and scheduled to open for service in 2006. Five other potential extensions in Missouri have been identified as a result of major investment studies (MISs) completed since 1997, one of which is now being carried forward in an alternatives analysis and draft environmental impact studies (DEIS). At this point, no funding has been identified for any of these five proposed routes. See Figure 1 depicting existing and potential alignments for the MetroLink system.

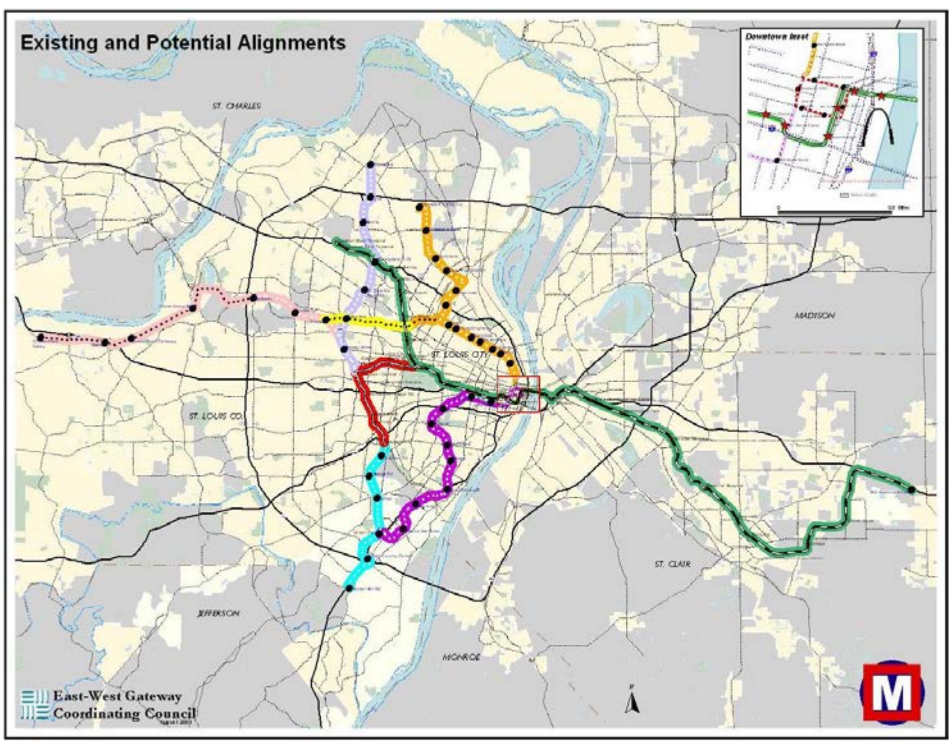

FIGURE 1 Existing and potential alignments for the MetroLink system.

Pre-1996 Transportation Planning Approach

Up until the fall of 1996, major planning studies for proposed transportation improvement projects were carried out by either the metropolitan planning organization (MPO), the East–West Gateway Coordinating Council (EWGCC), the transit authority (Metro), Missouri Department of Transportation (MoDOT), or Illinois Department of Transportation (IDOT).

Planning of the light rail system in St. Louis has been an evolutionary process. Early planning efforts were characterized by minimal or no interagency collaboration. All of the planning, environmental documentation, and preliminary engineering for the initial MetroLink line in the 1980s was carried out by the MPO. During that time, there was real uncertainty in the region as to what organization would build and operate the light rail system, since there was a lack of technical capability and interest at the transit authority. The final decision to hand off the project to the transit authority was a political decision made by the MPO board of directors. The transit authority had not been involved in the project up until this point. Only minimal design changes were made before or during construction.

The MPO also carried out the planning work for the first extension into St. Clair County, Illinois, in the early 1990s, this time with very limited involvement of the transit authority whose technical staff were focused on building the initial line. When the St. Clair project was handed over for preliminary design, the transit authority made some significant design changes. This situation created confusion on the part of the public and local governments.

Based on this early experience, the agencies recognized that there was a need for a more collaborative planning process, with the transit authority being more fully engaged in light rail studies.

The federal regulations were also evolving. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) changed the federal transportation planning process significantly. The requirement for integrated project development from transportation corridor planning through project implementation confirmed the need for serious involvement of the implementing agencies throughout the planning process. However, the St. Louis regional MIS experience for planning light rail and highways which followed ISTEA in 1993 to 1996 was still characterized by studies done by one agency somewhat in isolation from the others, a lack of attention to overall financial capacity for the region to carry out the improvements, and some dispute over the validity of calculations of travel demand, project operational characteristics and impacts, and costs.

The regional agencies tried to coordinate their work as much as they could, but recognized the limitations of not having formal, integrated agreements between the MPO, responsible for planning and authorizing the region’s long-range transportation plan, and the implementing agencies, responsible for the development, operation and maintenance of major improvement projects.

This experience finally led to a frank confrontation on the issues among the agencies and a proposal to implement a unique solution to regional transportation planning.

COLLABORATIVE PLANNING

Planning Approach since 1996

In 1996, the EWGCC, Metro (at that time known as the Bi-State Development Agency), and MoDOT entered into formal agreements to cooperate in carrying out transportation planning activities within the Missouri portion of the region. As part of these agreements, the three agencies created a planning group—Transportation Corridor Improvement Group (TCIG)—staffed by employees of each agency and physically housed together in the council's offices. This group has maintained its unique identity as a joint planning group and has been responsible for the day-to-day management of all major corridor planning studies (mass transit and roadway) carried out since that time in the Missouri portion of the region.

IDOT has continued to carry out planning studies on its own, with representation from the MPO and transit authority on study management groups formed to provide guidance and oversight on individual corridor study projects.

The two formal memoranda of understanding (MOUs) between the MPO and the transit authority and the MPO and MoDOT created a joint interagency planning and programming process for developing the Transportation Improvement Program (TIP) and the updates to the long-range transportation plan. As stated, this cooperative process must be used for the planning of all major transportation programs and projects in Missouri, regardless of mode, in order for the projects to be considered for programming. The MOUs spell out general planning principles to guide the cooperative planning process and set up administrative guidelines for the contribution of personnel and resources to implement the process. The MOUs were signed by the officers of the agencies' boards of directors in 1996. The MPO and the transit authority also sign cost-sharing agreements to cover specific planning studies for MetroLink extension corridors.

Transportation Corridor Improvement Group

TCIG is a concept central to the success of the collaborative endeavor. The commitment of permanent staff from each of the agencies—the MPO, transit authority, and DOTs—to work together as a joint planning group elevates the work done by the group above any individual agency effort.

The TCIG is made up of six individuals, two from each of the signatory agencies. The manager of the planning group is a TCIG member from the MPO. The members of the group from the DOTs and transit authority may have secondary responsibilities at their agencies (depending on their individual TCIG workload or assignments), but their primary work is the TCIG. No agency work takes precedence over TCIG responsibilities.

The TCIG members from the transit authority are from the planning or operations units. The transit authority also designates an internal liaison to the TCIG to facilitate dissemination and internal discussion of information generated by the TCIG within the authority. Individual transit authority TCIG members often serve as "leader" for planning studies primarily focusing on light rail extension corridors, or in areas where transit impact is significant. The transit TCIG members are well versed in the regional transit network. They facilitate on-board survey work and are knowledgeable about rail and bus operations as well as the TRAPEZE system the transit authority uses for bus routing and bus and rail scheduling. The transit TCIG staff members also attend public meetings held by the transit authority and are able to promote understanding and acceptance on the part of the general public of the region's long-range transportation plan and planning processes.

TCIG members from MoDOT are from the planning or traffic operations units. They most often serve as "leader" for studies primarily focusing on corridors where major road and bridge improvements are being considered. The MoDOT TCIG members are well versed in the characteristics of the road network, traffic planning, design, management and operations, and traffic data collection and analysis.

The regional travel demand model used in planning studies is housed at the MPO. TCIG members make use of the model for study purposes and are involved in model updating and verification.

The members of the TCIG also assist MPO staff with work on the long-range transportation plan. This approach is designed to ensure that there is consistency and comparability between the studies and the plan.

The three agencies attempt to maintain a balance of skills within the TCIG by appointments made to the group. The level of experience of TCIG members is such that any member could serve as "leader" of a particular corridor study. The individual agencies pay the salaries of their appointees to the group. The group is physically housed at the MPO. TCIG members' computers are linked with each other and with their own agency's networks to facilitate their work.

Project Planning/Programming

The TCIG plans its work program within the framework of studies needed to advance Missouri elements of the region's long-range transportation plan. The very existence of the TCIG means no single agency moves a major planning study forward without the agreement, understanding, and participation of the others (albeit, at varying levels of particular staff involvement depending on the nature of the individual study). This collaboration results in a prioritization of effort that is accomplished across modes, taking into account the total regional need for advancing particular Missouri projects on the metropolitan area's long-range agenda.

ANALYSIS OF COLLABORATIVE PLANNING EXPERIENCE

Planning Studies

The TCIG has carried out and completed a total of 10 major planning studies or MISs since 1996. Although almost all of these were multimodal in nature, four of them specifically considered major MetroLink extensions. These four studies were the Cross-County Corridor Conceptual Design and Environmental Analysis, completed in June of 1999, and the Northside, Southside, and Daniel Boone Major Transportation Investment Analyses, completed in May 2000. Although the EWGCC was the main sponsor for each of these studies, the day-to-day team leaders were from the transit agency (Southside, Northside), the state DOT (Daniel Boone), and the council (Cross-County). Each study resulted in the selection of a specific MetroLink alignment as the locally preferred alternative (LPA) by the EWGCC Board of Directors.

At the conclusion of the conceptual design planning study, responsibility for the Cross-County project was handed over to Metro for engineering, design and construction. This extension is locally funded and currently under construction. The line will open for revenue service in 2006.

The TCIG is currently engaged in carrying out an alternatives analysis and DEIS to move forward a MetroLink extension for the Metro South study area in South St. Louis County (Figure 1.). This planning study is scheduled for completion in early 2005.

Summary of Collaborative Planning Experience

Public Understanding and Acceptance of the Planning Process

Prior to the existence of the interagency TCIG, individual agencies sponsored MISs or planning studies, some of which were carried out in a near vacuum. This resulted in confusion on the part of the public as to "who is responsible for what" and "how things got planned and implemented." In such an environment, the role of the MPO as the authorizing agency for the long-range transportation plan, the purpose of the plan, and its relationship to the TIP and the programming process was often obscured. The role of implementing agencies (i.e., the transit authority and the DOTs) and their need to be connected to MPO planning and programming processes, was sometimes misunderstood.

In one example, in 1995, the transit authority undertook studies in two corridors that looked at commuter rail as a major investment alternative. Members of the board of directors of the MPO, the elected officials who would have funded the implementation of commuter rail had it been selected as a locally preferred alternative in the corridors, chose not to vote on moving forward. The confusion on the part of the public as to the authority of the MPO or the transit agency to make a final determination on the implementation of such projects led to a general lack of trust in the study process by the public and finger pointing on the part of the MPO and transit authority.

It was out of this experience that the need for greater cooperation among agencies was recognized and the formalization of the joint planning process was born. Now, with the collaborative process in place, the TCIG responsible for all MISs, and 10 completed studies, the public has a much better understanding of the roles of the MPO, transit authority, and state DOT and respect for the form and predictability of the study process.

Corridor Study Effectiveness

Many significant benefits have resulted from the collaborative, joint planning of the MetroLink extensions in particular. The planning process for the corridor studies is smoother, more coordinated and cooperative and better understood by the public. The community engagement process is more effective due to consistency of people and messages being presented. At all public meetings, conducted during the study process, the public is reminded of the MIS process, the roles of the planning and implementing agencies, the overall funding environment for major investments, and the milestones to be encountered along the road to implementation.

In general, the planning studies now progress smoothly from the planning stage, to selection of a locally preferred alternative, to implementation quicker with the joint agency cooperation of the MPO and implementing agencies.

The collaborative major investment study process itself is also more cost-effective now compared to pre-TCIG work since more efficient use is made of limited planning staff, consultants, and other resources with minimal duplication of effort.

Comparability Across Studies and Prioritization in an Environment of Fiscal Constraint

The collaborative process ensures comparability of the planning study results across studies. Travel demand forecasting, cost estimating, financial analysis, and other critical study elements conducted in similar fashion for different corridor studies allow for an easy comparison of project benefits among studies. This is particularly useful and relevant in an environment of fiscal constraint.

The collaborative approach helps assure a consistent, regional, multimodal perspective for making funding decisions. It assists in development of a financially-constrained regional long-range plan and TIP.

Due to the involvement of all the agencies during the planning process, the multimodal approach, and comparability of study results, the task of prioritizing for further project development and implementation is enhanced.

Trade-offs between road and transit improvements are made easier by the process. For example, in 1997, the Cross-County MIS resulted in a decision to forego the building of a new Interstate extension in favor of implementation of an extension of MetroLink in the south corridor. The public had weighed-in in favor of the transit element in spite of some local elected officials favoring the road extension. The elected officials on the MPO Board of Directors respected the planning process and voted for MetroLink expansion in the corridor as the locally preferred alternative.

Planning to Implementation

The TCIG was developed, in part, to make the transition from corridor planning to project implementation as seamless as possible. However, we have had varying degrees of success in achieving this goal. In most cases, the transition has gone smoothly, while in some others it has proven to be a more difficult task. In order to assure efficient and effective project development, the results of the joint planning studies including the selection of the locally preferred alternative must be accepted by the implementing agencies, even if the planning decisions were made by the MPO Board of Directors. In the case of one MetroLink extension, the transit authority chose to reopen the conceptual design decision that had been made during the planning study and to reengage the community. This action led to considerable confusion on the part of the public, slowed the project implementation and lessened the credibility of the TCIG and the collaborative planning process. This experience highlighted the need to ensure the complete buy-in of all relevant staff within the three agencies during the planning process so as to facilitate the smooth transfer of the resulting projects to the implementing agency.

CONCLUSION

We believe that our collaborative planning approach including the existence of a joint agency team working together everyday at the MPO is unique in this country. It has led to many positive results over the past 6 years. However, there are some possible pitfalls which we have identified. We are committed to this collaborative process and will continue to refine the concept to make it function even better.

Actual Versus Forecast Ridership on MetroLink in St. Clair County, Illinois

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MARC WARNER
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The St. Louis metropolitan area has been seeking to expand its successful light rail transit system known as MetroLink. The initial segment of MetroLink was opened in 1993 and ridership on this segment exceeded the forecasts. The first extension of MetroLink, which opened in May 2001, extends 17.4 mi east from East St. Louis to Southwestern Illinois College (SWIC). Multisystems prepared ridership forecasts for this extension during preliminary engineering in 1996. The existing St. Louis regional demand forecasting model, maintained by the metropolitan planning organization, was employed. Multisystems performed validation and re-calibration of the model to 1995-1996 conditions. Using the validated model, ridership forecasting was conducted for the project for the horizon year (2010) and the opening year (2001). In Fall 2001, Multisystems was asked to prepare forecasts for a second phase MetroLink extension to the east of SWIC. Since the extension to SWIC had already been open for several months and it was reported that MetroLink ridership was growing unexpectedly rapidly, a revalidation to 2001 conditions was incorporated in the new analysis. It was found that actual ridership in 2001 was very similar to the ridership forecast for the 2001 opening year prepared in 1996. The actual ridership on the new segment was merely 6% greater than the forecast. This paper compares the model's ridership projections with the actual ridership and attempts to identify the reasons behind any significant discrepancies. It will also identify how the revalidation improved the model's performance.

INTRODUCTION

Predicting future transit ridership has traditionally been an extremely tough task for transportation planners. Many different models and methods are used to gauge the impact on ridership of future transit projects, enhancements, and improvements. Since the prediction of human behavior is by no means an exact science, considerable deviation can be observed when forecasts are compared and contrasted with actual ridership once the project is implemented. However, a recent comparison has shown that ridership predictions made by Multisystems for a light rail extension in the St. Louis metropolitan area were rather accurate.

PROJECT DESCRIPTION

The initial segment of St. Louis's light rail system, MetroLink, was opened in 1993 and ridership on this segment exceeded the forecasts. An extension of the existing light rail line from its easternmost terminus in East St. Louis further eastward into Illinois was proposed in two phases. The proposed alignment for the expansion can be seen in Figure 1. The first extension, shown in red in Figure 1, was planned to run from the 5th and Missouri MetroLink light rail station to Southwestern Illinois College (SWIC), formerly known as Belleville Area College. Eight new light rail stations were proposed to lie along this 17.4-mi alignment. The second phase of the extension, shown in purple in Figure 1, would run 8.92 mi northeast from SWIC to Mid-America Airport and have three new light rail stations. In 1996, Multisystems, and its subconsultant Warner Transportation Consulting, prepared ridership forecasts for each phase during this project's Preliminary Engineering and Environment Impact Study.

The existing St. Louis regional demand forecasting model, maintained by East-West Gateway Coordinating Council (EWGCC), the region's metropolitan planning organization, was employed for the study. This model uses the MINUTP demand modeling software package. EWGCC had divided the metropolitan area into 1,170 Transportation Analysis Zones (TAZs). In order to best represent current conditions, much of the model needed to be updated. One specific request that was made was to refine the zone system near the alignment of the proposed extension. Multisystems performed validation and recalibration of the model to 1995-1996 conditions, with a special emphasis on St. Clair County. Using the newly validated model, ridership forecasting was conducted for the project for the horizon year (2010) and the opening year (2001).

COMPARISON TO ACTUAL CONDITIONS

The FTA approved only Phase 1 for construction. FTA also requested the Phase 2 be treated as a separate New Starts project. FTA further requested that the final station at Mid-America Airport be dropped from the New Start project since Mid-America Airport had not achieved commercial aviation status. Thus the New Start extension was shortened from 8.92 mi to 2.5 mi, with the terminus being located at Scott Air Force Base.

In Spring 2001, the St. Clair MetroLink Extension to SWIC opened. Initial reports indicated that ridership upon this new segment was growing rapidly. In fact, ridership at the MetroLink stations in Illinois had been growing at a faster rate than at the Missouri stations even before the opening of the extension. In Fall 2001, Multisystems was asked to prepare new ridership forecasts for the new Phase 2 MetroLink extension. The analysis included revalidating a different and more recently calibrated EWGCC model to 2001 conditions. It was decided that it would be wise to wait until ridership on the St. Clair Extension was available and stable. Hence, collection of ridership data on MetroLink, including on the new segment in St. Clair County, was conducted to aid this effort. Upon examination, it was discovered that actual ridership in 2001 on the new segment was very similar to Multisystems' ridership forecast for the 2001 opening year, which was prepared in 1996. The overall ridership on the new segment was merely 5.5% greater than Multisystems' forecast.

Looking at Figure 2, one can see that ridership exceeded predictions at all of the stations except two, Emerson Park and Memorial Hospital. Although the total observed ridership was

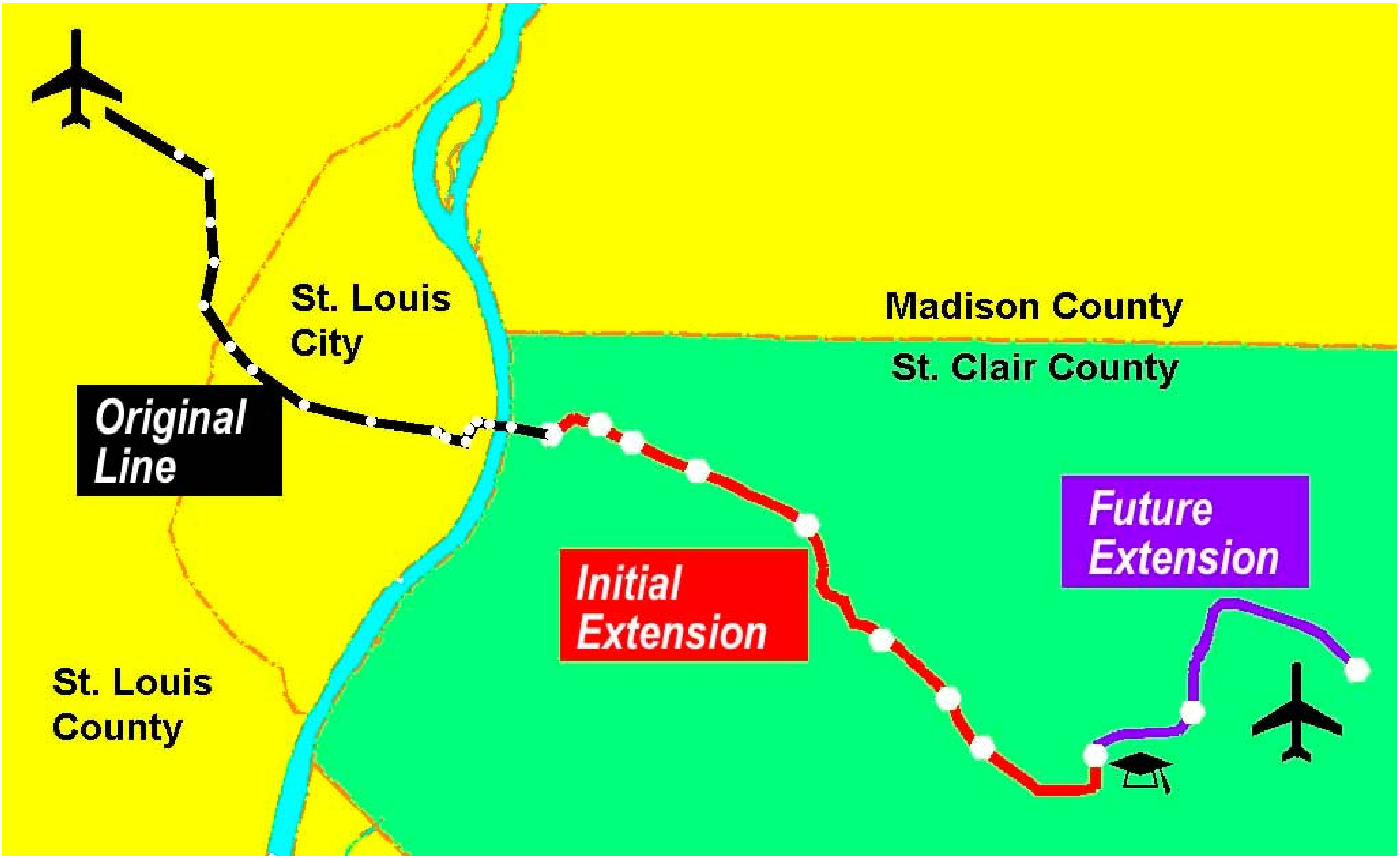

FIGURE 1 Proposed St. Clair MetroLink Extension

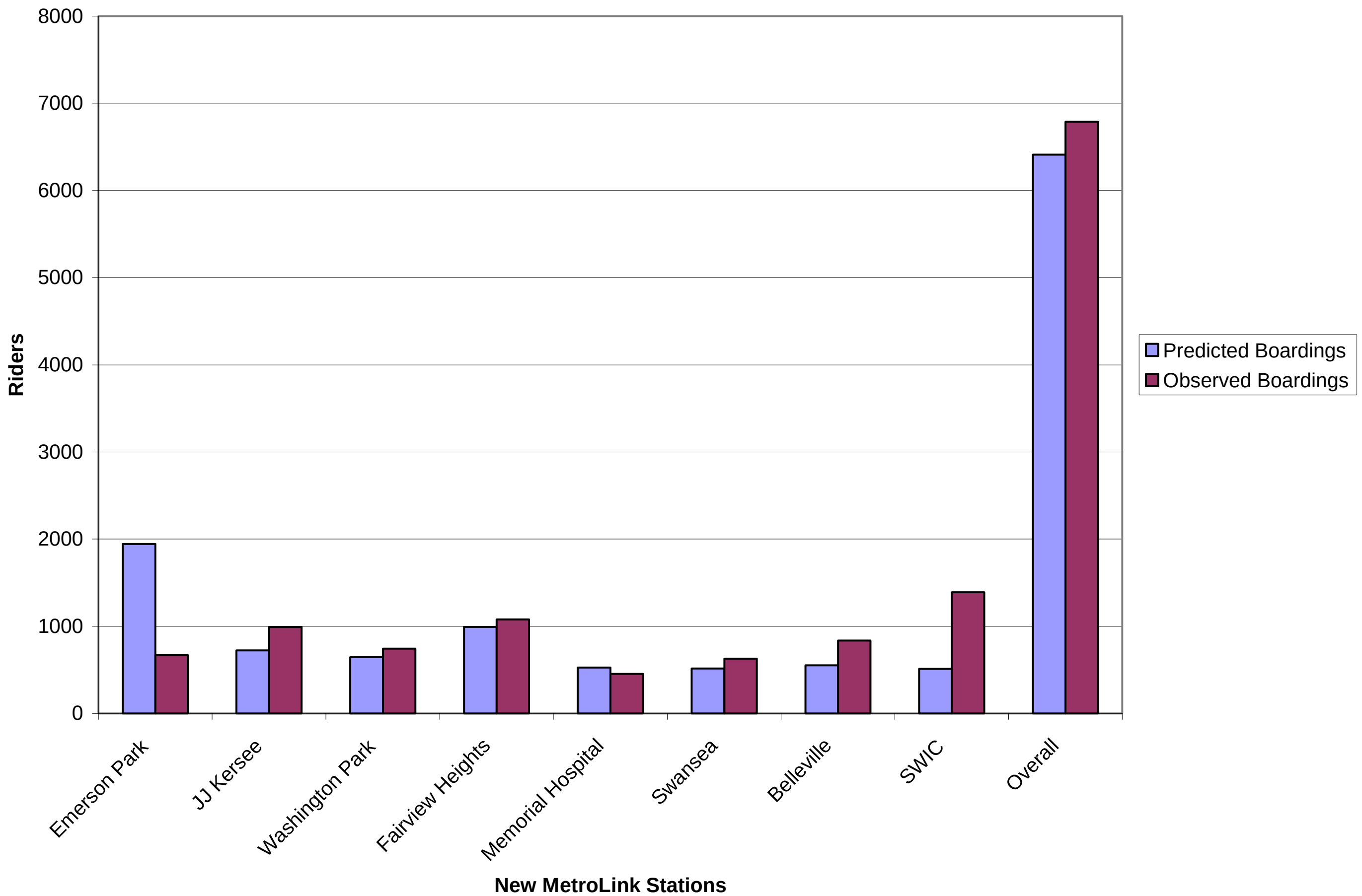

FIGURE 2 St. Clair County Extension MetroLink Ridership.

close to the total predicted ridership, the accuracy varied from station to station. As seen in Table 1, The most significant deviations were at the Emerson Park and SWIC Stations. However, it seems that the large overprediction at the Emerson Park Station was offset by aggregate underprediction at the stations in the eastern part of the county. Nearly two-thirds of the overall overprediction was offset by the underprediction at SWIC alone.

MODELING APPROACH

Multisystems introduced several key innovations during the 1996 modeling process. All of these had the effect of better representing the study area.

Better Representation of St. Clair County TAZ Structure

The TAZ structure for the model was revised to better represent St. Clair County, the focus of the study. Previously, St. Clair County was divided into 132 TAZs of varying size and population. A more detailed zonal system was developed and used in order to improve forecasting accuracy. This was accomplished by the subdivision of large TAZs into smaller compact TAZs. A total of 47 new zones were created in this manner; they can be viewed in Figure 3. The new zone system improves the representation of transit demand and transit access characteristics in St. Clair County.

Several criteria were used to decide which TAZs should be subdivided. Among these factors were zone size, proximity to MetroLink stations, proximity to bus transit, intra-zone variations in household income levels, population density, and land use patterns. The most important factor was proximity to the MetroLink stations followed by proximity to St. Clair County Transit District (SCCTD) bus routes. These factors were considered in reflecting walk access to transit.

TABLE 1 St. Clair County Extension MetroLink Ridership

New MetroLink Stations	Predicted Boardings	Observed Boardings	Difference Between Predicted and Observed	Percentage Difference from Observed
Emerson Park	1945	671	1274	189.9%
JJ Kersee	724	991	-267	-26.9%
Washington Park	644	742	-98	-13.2%
Fairview Heights	993	1078	-85	-7.9%
Memorial Hospital	526	452	74	16.4%
Swansea	515	627	-112	-17.9%
Belleville	552	835	-283	-33.9%
SWIC	511	1390	-879	-63.2%
Overall	6410	6786	-376	-5.5%

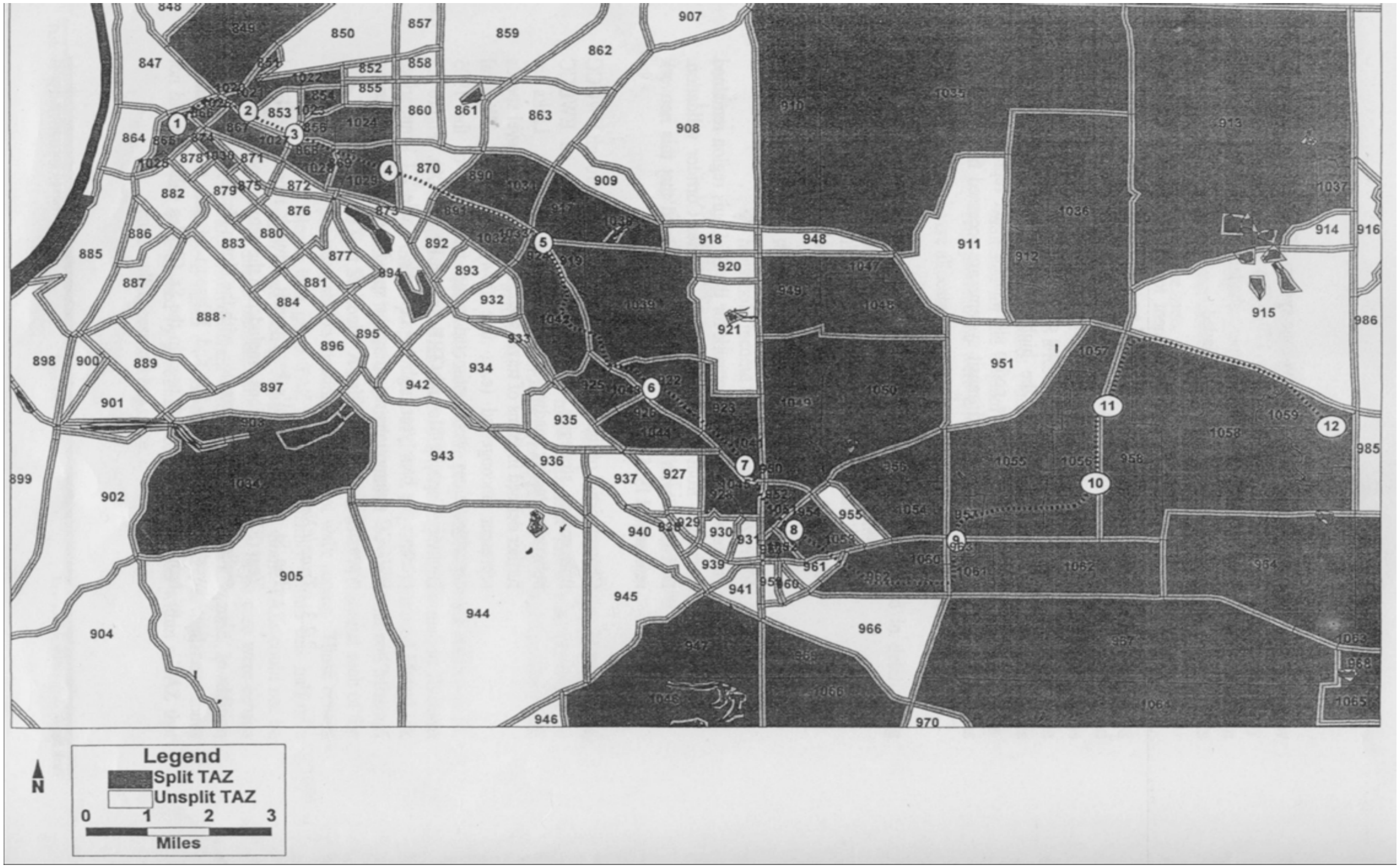

FIGURE 3 TAZ splits in St. Clair County.

The approach to subdividing TAZs worked as follows. New walk only access zones were created around MetroLink station locations as well as along bus routes. A half-mile radius was drawn around each station location to represent walk access to the station. Census blocks in a given TAZ falling within this half-mile radius were grouped together to form a new zone. This new TAZ was therefore carved out of the old zone. A similar process was performed to create new TAZs having walk only access to SCCTD bus routes.

Unfortunately, full trip generation routines were not able to be run for these new zones. The trip ends we received from EWGCC were created using procedures that utilized broad data sets, such as population by income level and employment by type. These data sets were not available at the census block level. To compensate for this, trip ends estimated for the original TAZ were allocated to the new subdivided zones. Trip productions were allocated by population while trip attractions were allocated by a combination of population and area.

Improved Representation of Travel Behavior by Low-Income Residents

Improvements were made in the trip distribution routine to better represent low-income residents' travel behavior than it had been in previous EWGCC travel demand models. Traditionally, low-income persons have been a significant component of transit riders. This becomes even more critical when one considers the relatively low income level of residents in some parts of St. Clair County, specifically in and around the city of East St. Louis.

Earlier models had distributed trips based solely on automobile travel times during trip distribution even though many transit-dependent residents would choose their travel destinations based on transit accessibility. In an effort to be inclusive of this transit-dependent population, the new model considered transit travel times as well as automobile travel times in its trip distribution. Paths built only on highway times were replaced by a weighted sum of paths built over the transit and highway networks. Transit path times were computed by summing the time for the transit walk, in-vehicle travel time, transfer time, and boarding time. For zone pairs without a transit connection, the transit path time was assigned to be 150 min, the maximum impedance used in the trip distribution routines. Transit travel times were then weighted according to the percent of households in each TAZ that were assumed to lack vehicular access, while highway travel times were weighted according to the percent of households in each TAZ that were assumed to have vehicular access. These two weighted travel times were then summed. This percentage of transit-dependent riders was calculated from 1990 census data in the following fashion. The percentage of households without vehicles at the census tract level was compared to the percentage of low income households at the census tract and TAZ levels to determine the comparable percentages of zero vehicle households at the TAZ level. This behaviorally sound adjustment channeled more trips from low income, transit-dependent areas to destinations served by transit.

Improved Distribution of Journey to Work Trips

Census data on the income distribution of workers by zone of employment was incorporated in the distribution step of the model to obtain a more realistic distribution of workers to jobs of appropriate wage levels. The reliance of earlier models on the gravity model for HBW distribution caused previous misrepresentation. For example, higher wage central business district (CBD) jobs are usually filled by members of high income suburban households making long commutes. However, previous models tended to assign the lion's share of these jobs to residents of East St. Louis due to its close proximity to the St. Louis CBD. This situation was rectified by consulting Table 2 and 3 of the Census Transportation Planning Package of the 1990 Census data and identifying the income distribution of workers by their zone of employment. Incorporating this information by income tertile into the model added precision and greater credibility to the model's HBW distribution.

Downtown Fare Free Zone

The downtown fare free zone, which operates on MetroLink between Union Station and Laclede's Landing during midday hours, was included in the regional model for the first time. This was handled by creating transit paths and calculating impedances based on free fares for trips originating and ending in the St. Louis downtown area (a subset of zones within a reasonable walk distance of MetroLink stations in the free zone).

TABLE 2 Automobile Access Boardings and Vehicle Counts on the St. Clair County MetroLink Extension

New MetroLink Stations	Predicted Boardings	Observed Vehicle Counts	Difference Between Predicted and Observed	Percentage Difference	Ratio of Modeled Drive Access to Observed
Emerson Park	665	328	337	102.7%	2.03
JJ Kersee	0	0	0	0.0%	0.00
Washington Park	438	181	257	142.0%	2.42
Fairview Heights	534	514	20	3.9%	1.04
Memorial Hospital	116	204	-88	-43.1%	0.57
Swansea	190	387	-197	-50.9%	0.49
Belleville	97	199	-102	-51.3%	0.49
SWIC	197	383	-186	-48.6%	0.51
Overall	2237	2196	41	1.9%	1.02

Note: Park-and-Ride/Kiss-and-Ride may exceed vehicle counts as a result of vehicle occupancy or turnover.

TABLE 3 Access Mode Percentages

New MetroLink Stations	From 2001 Survey			From Model		
	Drive	Walk/Bike	Bus	Drive	Walk/Bike	Bus
Emerson Park	72%	7%	21%	34%	26%	40%
JJ Kersee	10%	11%	77%	0%	28%	72%
Washington Park	61%	4%	35%	68%	29%	3%
Fairview Heights	76%	1%	23%	54%	12%	34%
Memorial Hospital	91%	2%	7%	22%	9%	69%
Swansea	87%	11%	3%	37%	34%	30%
Belleville	42%	22%	35%	18%	53%	30%
SWIC	83%	13%	5%	39%	46%	15%

Note: The percentages from the 2001 Survey are only for access between homes and MetroLink stations. The Drive Percentage from the 2001 Survey includes drive alone, carpool, taxi, and kiss-and-ride modes

Post-Model Adjustments

Two important post-model adjustments were added to correct for the model's underestimation of off-peak non-work discretionary trips. Previous models focused on population and employment to forecast traditional home-to-work peak trip making as well as other trips. Little attention was paid to credibly forecasting non-HBW trips. However, in reality, a significant portion of MetroLink's ridership is comprised of people, both tourists and residents, making non-work or non-home based trips. Not surprisingly, the model had been underpredicting the attractiveness of this mode (MetroLink) for these trip purposes. Steps were taken to correct this problem and to more accurately represent total MetroLink ridership for all purposes and time periods.

Seasonal Adjustment

A seasonal adjustment, designed to reflect additional trips, either generated by tourists or made for other non-work activities, was introduced. This factor is based on the ratio of the 1996 validation year observed actual off-peak non-event weekday MetroLink boardings to the unadjusted off-peak MetroLink boardings generated by the model. The resultant ratio was then applied to the 1996 modeled non-event weekday MetroLink boardings. In this fashion, the "low" off-peak MetroLink counts were factored up to their actual counts. This same seasonal adjustment factor, developed during the calibration and validation of the model to existing 1996 conditions, was then applied to modeled non-event weekday MetroLink boardings in the future forecasts.

Adjustment for Special Events

Special events, such as concerts, entertainment, and sporting events, were known to have a large impact on MetroLink ridership. Special events occur on approximately 59% of the weekdays during the year. Hence, it was decided to create two distinct types of daily ridership profiles—one for event days and one for non-event days. The event day profile was created by applying an adjustment to increase boardings at MetroLink stations in a manner consistent with an "average" observed event day during the year. Using special event count data collected by METRO from 1996, it was estimated that the average weekday event-day event ridership is 4,200. Note that this figure takes into account the larger impact of baseball games than other events. This average event day may understate the impact of either an afternoon or evening event on a single day because it is assumed to be the average of event days with afternoon and evening events. A composite average weekday MetroLink ridership profile was then created by averaging the two (event and non-event) forecasts and weighting it by the number of weekdays with and without special events.

Special event ridership on the yet unbuilt St. Clair MetroLink extension was assumed to behave much like the existing pattern on the existing MetroLink segment in Missouri. The extension was assumed to offer enhanced access to MetroLink from most of St. Clair County; this enhanced Illinois MetroLink access would be comparable to the good access to MetroLink on the Missouri side. Therefore, it was assumed that the ratio of special event day ridership to weekend ridership in Illinois would equal the ratio in Missouri. Additionally, special event ridership was assumed to be distributed among the Illinois MetroLink stations in a pattern similar to its distribution at Missouri stations. Special event ridership in Illinois was primarily allocated to MetroLink stations having large park-and-ride facilities; some walk and bus access special event MetroLink trips were distributed over nearly all the stations.

DISCREPANCIES

Although the overall number of actual boardings on the St. Clair County MetroLink Extension is relatively close to the number of modeled boardings, the same cannot be said when boardings at individual stations are compared. Other discrepancies were discovered as the collected data and the modeled data were scrutinized at a finer level of detail. Upon closer examination, differences were seen between the observed rider behavior and modeled behavior in the realms of MetroLink access mode shares, specifically automobile access, and in park-and-ride station choice.

Access Mode

Comparison of Vehicle Counts to Modeled Automobile Access

One clear discrepancy between the 2001 forecast (from 1996) and the observed 2001 data concerns access mode, specifically automobile access. Vehicle counts were performed at Illinois MetroLink stations on several weekdays in November 2001. These observations are compared to the modeled data in Table 2 and illustrate the wide distribution of accuracy.

As seen in Figure 4, the model overpredicted boardings resulting from auto access in the western portion of St. Clair County, while underpredicting boardings of the same type in the eastern portion of St. Clair County. Every station in eastern St. Clair County, with the exception of Fairview Heights, was underpredicted by at least 75% while the new East St. Louis stations (Emerson Park and Washington Heights) were overpredicted by more than 50%. Once again, the overall overprediction and underprediction at the stations seem to balance each other out. As seen in Table 2, the overall observed automobile total is 1.9% less than the predicted total. It would appear that a shift in park-and-ride patterns is to blame for the great discrepancies in the overall predicted ridership. The automobile access pattern comes close to mimicking the overall ridership pattern.

However, this parking analysis is imperfect. The vehicle counts may underestimate the actual number of passengers boarding by automobile access in two ways. First, counts of parked cars may have missed some turnover of vehicles parked at the stations. Second, some automobile access riders carpool or kiss-and-ride. Hence, the differences between the observed parked cars and the modeled automobile access boardings may actually be less than shown in Figure 4. Overall, the ratio is 1.02, which is reasonable considering the aforementioned factors.

Comparison to On-Board Survey Results

An on-board survey was included as part of the MetroLink data collection effort in 2001. MetroLink riders traveling to, from, and within Illinois in the St. Louis metropolitan area were surveyed on October 4, 2001. Among the questions asked of riders were several concerning access mode. Riders were asked how they accessed their home MetroLink station. Looking at the home end allows us to contrast use of park-and-ride, bus, and walk. Table 3 displays these percentages along with the access mode percentages associated with the modeled boardings.

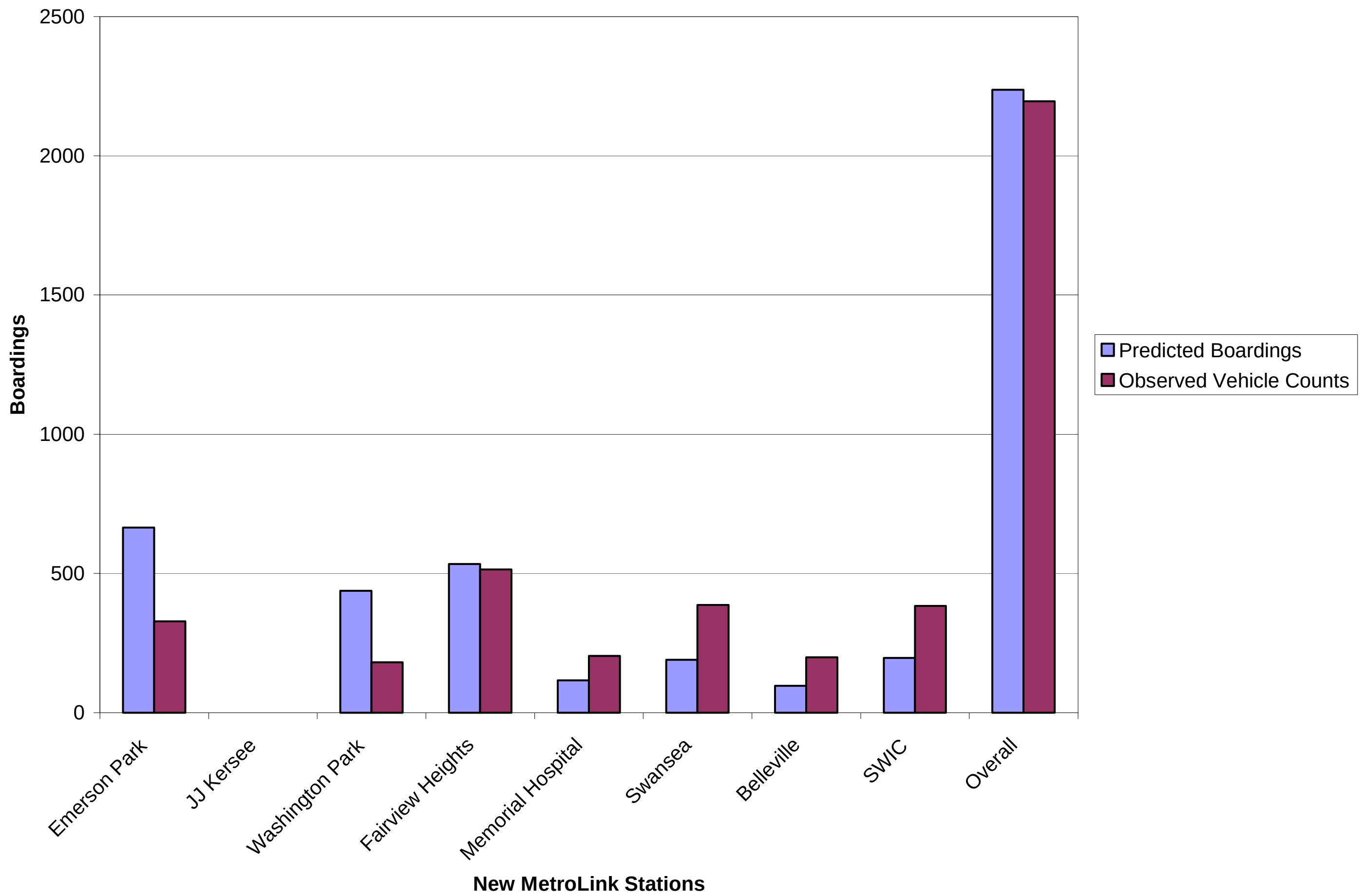

FIGURE 4 Automobile access on the St. Clair County MetroLink extension.

Note that the drive percentage from the 2001 survey includes drive alone, carpool, taxi, and kiss-and-ride modes. Significant and substantial differences exist between the survey percentages and the modeled results. Surveyed drive access is considerably higher than predicted at every station except Washington Park. Across the board, surveyed walk percentages were a lot lower than predicted in the model. With three notable station exceptions—Jackie Joyner Kersee, Washington Park, and Belleville—surveyed bus access at the Illinois stations was lower than predicted in the model; however, bus access at the Jackie Joyner Kersee and Belleville Stations were only 5% higher, which is not a huge difference.

Some of the differences in the percentages of bus access at stations may be attributed to the fact that the actual 2001 SCCTD service differs considerably from the service modeled (in 1996) for the 2001 forecast. The current SCCTD bus system is a pure feeder bus system; all bus routes terminate at MetroLink stations. On the other hand, the modeled SCCTD service contained some non-feeder bus routes. Also, most Illinois MetroLink stations are not served by the same number of SCCTD feeder routes as they were in the 2001 forecast. MetroLink stations in the western portion of the county have less bus service than was modeled. The Belleville and Swansea Stations each have more service than when modeled. The only stations served by the same number of SCCTD routes in 2001 as when modeled are Fairview Heights and SWIC. Moreover, almost every SCCTD bus route has undergone revisions. That is to say, nearly every route travels a different alignment than was modeled in 1996, not to mention schedule changes. Population centers, as well as attraction areas, are not necessarily currently connected to the same MetroLink stations as they were in the modeled 2001 forecast.

So, as in the vehicle count analysis, comparing the specific modal access percentages gleaned from the survey against the modeled modal access percentages is imperfect. However, it does provide us with the knowledge that a considerably higher percentage of riders access MetroLink by automobile than was predicted.

Reasons for Disparity in Park-and-Ride Lot Choice

Clearly, the model did not accurately predict the behavior of park-and-riders at the station level. The aforementioned Figure 4 illustrates the disparity between observed vehicle counts at MetroLink stations and the modeled automobile access boardings. Moreover, the on-board survey of riders also demonstrated that some MetroLink riders chose park-and-ride lots other than those the model had originally predicted. The residential locations of the park-and-riders at each Illinois station were mapped using zip codes and specific addresses where available (and geocodable). These did not always fall into the park-and-ride catchments area that had been designated for each specific station in the model. One noticeable element was that in reality, park-and-riders from the same home location often chose to travel to different stations. A review of the model assumptions, in combination with survey responses, suggested the following reasons for this difference: (1) parking availability, (2) perceived versus actual travel time, and (3) safety, convenience, and familiarity.

One of the primary determining factors used by the model for park-and-ride station choice is parking constraint. However, this does not concur with the responses to a question posed on the on-board survey. Park-and-riders at each Illinois MetroLink station were asked why they chose to park at that particular MetroLink station. As seen in Table 4, availability of parking was the deciding factor for less than 10% of the respondents at all but two Illinois MetroLink stations; in no case did more than 15% of respondents cite this as an answer.

TABLE 4 Reasons for Station Choice

	It takes the least time to drive there	It feels like a safer location	It is the most likely to have parking available when I arrive	I am most familiar with that station and how to get there	I try to park as close to St. Louis as I can	Other
College	83%	8%	1%	1%	6%	1%
Belleville	74%	4%	15%	4%		3%
Swansea	84%	5%	4%	4%	1%	3%
Memorial Hospital	96%	1%	1%	1%		
Fairview Heights	75%	8%	9%	2%	2%	2%
Washington Park	80%		4%	4%	4%	8%
Emerson Park	74%	9%	9%			9%
5th and Missouri	65%	10%	15%	10%		
East Riverfront	15%	41%		30%	14%	

The principal component of park-and-ride station choice for the model is travel time. Consistent with the model, the vast majority of survey respondents cited least travel time as the primary reason for station choice. However, a distinction needs to be made between modeled travel time and perceived travel time.

For example, the model assigned park-and-riders living along the Interstate 64 corridor to the large park-and-ride lots at Emerson Park and Washington Park. These stations have good Interstate access and hence, short travel times. However, vehicle counts and boardings at these stations were considerably lower than predicted. One possible explanation is that the incidence of road congestion en route to the stations, not uncommon on interstates, may have discouraged people from parking at these stations and instead caused them to park at MetroLink stations geographically closer to their homes. For some, travel to stations via local roads with lower speed limits may be preferable to traveling on a crowded highway. Another likely explanation is that in-vehicle travel time on MetroLink may be even a greater factor in decision-making than the model anticipated. People from eastern St. Clair County who are predisposed to take transit may be willing to travel to the geographically closest MetroLink station irrespective of overall travel time. For example, people may prefer to spend more time aboard MetroLink instead of driving to a further “downstream” park-and-ride location if a long trip is being made. Some riders may choose to minimize their access times even if it means a longer overall travel time.

Although the majority of park-and-riders used travel time as their chief decision making tool, many did not. Park-and-riders at 5th and Missouri and East Riverfront Stations are the least likely of any of the Illinois park-and-riders to report that time to drive there is the most important factor. These park-and-riders were also the only ones to cite familiarity and safety concerns as significant reasons for their station choice. These two stations are the only Illinois MetroLink stations to predate the St. Clair Extension.

Combining the higher numbers for safety and familiarity, as well as the relative unimportance of travel time, suggests the possibility that some 5th and Missouri and East Riverfront riders have not experimented with the parking at the new MetroLink stations closer to their homes. Instead of parking at the large new park-and-ride lots at nearby Emerson Park and Washington Park, they continue to park at the other East St. Louis MetroLink stations out of habit. This assertion is supported by the fact that more than three times as many vehicles were observed at the 5th and Missouri station park-and-ride facility as were expected from the model.

CONCLUSION

Underprediction and overprediction of boardings at individual MetroLink stations seem to have balanced out so that the total ridership on the new extension closely matches the observed total. Unanticipated changes in the study area, such as the loss of commercial air service at MidAmerica St. Louis Airport and the reconfiguration of the feeder bus system, likely contributed to the deviations at specific stations. The fact that the total boardings on the St. Clair Extension were as close as they were is probably due to a number of improvements made to the model including: better representation of the TAZ system in St. Clair County, improved representation of travel behavior by low-income residents, inclusion of the fare-free zone, improved distribution of journey to work trips, adjustments for seasonality, and adjustments for special events. Given the deviations at individual stations, it is expected that further refinements could be made. Opportunities for such refinements may include revisions to park-and-ride catchments areas for Illinois MetroLink stations and adjustments for special generators in Illinois, such as Scott Air Force Base, SWIC, and riverboat casinos. These enhancements, among others, were in fact included in the most recent St. Clair modeling efforts by Multisystems.

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Community and Systems Planning for Muni's Third Street Light Rail Project

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San Francisco's Municipal Railway (Muni) is one of the seven "first generation" light rail operations in the United States to survive until the streetcar's rebirth as light rail transit (LRT) in the 1970s. Currently under construction is its two-phase Third Street Light Rail Project, projected to open in fall 2005, the most significant expansion of any of these systems since 1959. The planning history of this project is traced, with particular emphasis on how the project was developed as an integral component of Muni's network, not as a line onto itself. The twists and turns of community planning and politics are described to show how such issues can be resolved and lead to a strengthened project which furthers various objectives. The paper describes how a simple surface LRT proposal evolved into a two-phase project, including a 5.4-mi Phase 1 Initial Operating Segment (IOS) and a Phase 2 New Central Subway (NCS) extending 1.7 mi into San Francisco's Chinatown. With 92,000 daily projected riders, a project which could have dissolved in bickering and divisiveness is instead on track to become one of the most densely ridden LRT projects in the nation.

OVERVIEW: MUNI IN THE REGION

San Francisco's Municipal Railway (Muni) is the largest transit operator in the San Francisco Bay Area, and the seventh largest in the nation, with approximately 750,000 boardings per weekday. Muni operates a multimodal urban core transit system, characterized by a dense network of lines, frequent services, high ridership, and high load factors. Muni's operation is diverse, with service provided by five modes—light rail (both subway and surface operations), historic streetcars, electric trolley coaches, motor coaches, and cable cars. San Francisco is a city with a strong urban tradition, and Muni is used by San Franciscans, Bay Area residents, and visitors for all types of trips.

The San Francisco Bay Area is a region of approximately 7 million residents, composed of nine counties, with three central cities (San Francisco, Oakland, and San Jose). The region is served by four regional rail systems [Bay Area Rapid Transit (BART), Caltrain, Altamont Commuter Express, and Amtrak's Capitol Corridor], and a multitude of operators that provide service from San Francisco to outlying counties, as well as services within the other counties. Though San Francisco's population is only slightly more than 1/10th of the region's population, Muni carries almost half of the transit riders in the region.

Muni began operation in 1912 as one of the first publicly owned transit systems in the United States. Muni constructed a network of rail lines prior to World War II in competition with privately owned operators; it then absorbed the larger privately owned system in 1944. Since then, Muni has experienced many of the same forces as other transit systems in the nation, including retrenchment of much of the rail network in the 1940s and 1950s, and replacement of much of that network by diesel buses and electric trolley coaches. Muni managed to retain a core five-line streetcar system into the 1970s, largely due to significant tunnel and reserved right-of-way running, and Muni maintained the largest electric trolley coach network in the nation. Muni's streetcar system was modernized with a downtown subway and new light rail vehicles (LRVs) in the late 1970s, and was extended several times in the 1980s and 1990s.

In contrast to most other large city transit systems, Muni remains a department of the city and county of San Francisco. Some governance changes resulting from the passage of Proposition E in 1999 have given Muni some measure of independence in administrative matters, and the proposition established performance measures for Muni to meet in a variety of areas.

SYSTEM AND NETWORK

Properly, one does not set out to plan for light rail; one designs a transit network and the needs of the network will identify the need for higher capacity services, which might appropriately be served by light rail. Carried further, it is as important to consider the design of the bus portions of the network as the rail line itself; success or failure will be determined by the functioning of the transit system as a whole, not by a light rail line in isolation.

In the case of San Francisco, transit service was restructured in the 1980s along multidestinational principals to form a modified radial grid system of routes. The nature of San Francisco's geography, with a downtown skewed to the northeast corner of a peninsula, and the absence of a single rectilinear grid precluded consideration of a pure grid system of routes. Instead, the restructured system of the 1980s consists of a reduced number of radial trunk lines, and an expanded system of circumferential (usually L-shaped) and, usually further from downtown, north–south and east–west cross-town lines. Figure 1 gives a schematic representation of San Francisco's radial grid transit network.

A number of rail lines served the middle southwest-to-northeast "slice" of the network: in counterclockwise order, (1) the N-Judah Sunset District light rail line, (2) the K, L, and M Twin Peaks corridor light rail lines, and (3) the BART Mission Street corridor rapid transit line. Two additional principal corridors existed which served concentrated volumes of demand, reinforced by the nature of the radial grid, but served entirely by buses: (1) the east–west Richmond corridor in the city's northern area centered on Geary Street, and (2) the north–south Bayshore-Third Street corridor along the eastern portion of the city, naturally intersecting Market Street and connecting to the also heavily traveled Chinatown–North Beach corridor north of the central business district (CBD).

PROPOSITION B AND SYSTEMS PLANNING

In the 1980s, state law in California encouraged several metropolitan areas to turn to a county-wide sales tax as a way to finance transit system improvements. In San Francisco, such a sales tax measure appeared on the ballot as Proposition B in 1989. The package of projects to be funded from Proposition B was assembled by a citizens' task force, and stressed systems planning and what was then about $900 million in capital funding for major corridor projects,

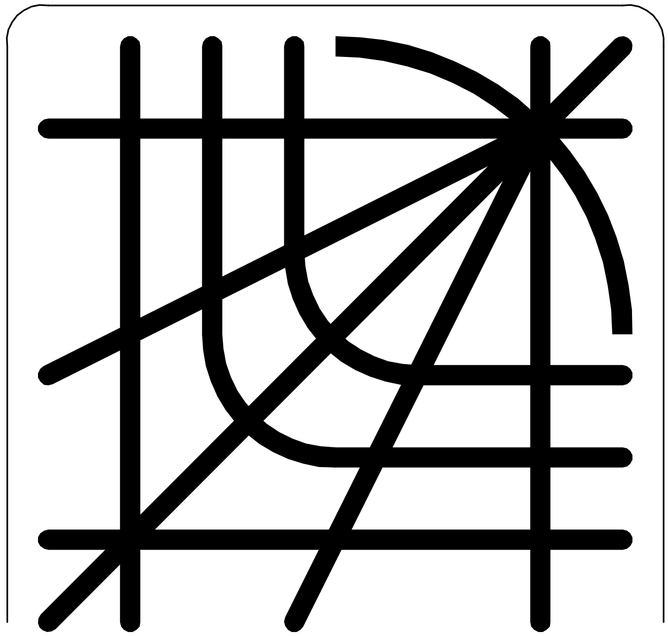

FIGURE 1 Conceptual framework for San Francisco's multidestinational modified radial grid route network.

specifically for the Geary and Bayshore corridors, with Chinatown–North Beach a secondary priority.

Systems planning studies in the early 1990s confirmed the appropriateness of light rail to either corridor, but community support was far stronger in the city's southeastern communities, and ensured that first priority be given to a Bayshore–Third Street corridor project.

Systems planning was intended to first confirm the viability of each corridor for further project development, and to identify what alternatives should be carried forth. The Bayshore Systems Study examined three classes of project for this corridor (*1*):

- Bus-only alignments,
- Light rail surface projects on a Third Street alignment, and
- Light rail rapid transit projects on a shared Caltrain alignment.

Bus rapid transit (BRT) had not yet been invented, at least not in the United States, so there was no full BRT alternative studied. The bus alternatives included both diesel and trolley bus variants, and were retained as a TSM (Transportation Systems Management) alternative to be carried through the final environmental impact study (EIS) and environmental impact review (EIR). However, there was no enthusiasm in the very involved Bayshore neighborhoods for a long-term, bus solution.

Third Street is, however, paralleled by the Caltrain commuter rail service between San Francisco and San Jose (now extended to Gilroy), and the fact that this was a four-track alignment in the city with only two tracks in use made it a very attractive alignment for a high speed light rail or true rapid transit type alignment. However, there are four tunnels in the city, only one of which was ever bored through for more than two tracks.

Various factors led to the eventual dropping of the Caltrain alternatives in favor of a Third Street surface line, one with relatively close station spacing at that:

- Shared use of Caltrain tunnels proved hopelessly complex to the point of infeasibility, primarily because of FRA and California Public Utilities Commission issues concerning train compatibility from a safety perspective.
- Constructing new bores for Muni was fiscally infeasible using available funds, which was necessary for near-term implementation (as explained below).
- Access to stations would neutralize any benefits of rapid transit speeds and result in longer travel times for residents than current bus service and the surface light rail transit (LRT) options.
- San Francisco is a physically small, compact area. Frequent stops—or a residual bus service—were necessary to retain transit service viability in this dense corridor relatively close to downtown San Francisco.
- Community pride wanted a service which would be close and accessible to all (and still, of course, unobtrusive).

At the end of systems planning, alternatives to be carried forward were the no-build alternative, a TSM bus alternative, and variations of a Third Street surface alignment, with a median right-of-way throughout the corridor.

GEARY STREET AND FOUR CORRIDORS PLAN

Systems planning for the Bayshore–Third Street corridor in mid-1993 was immediately followed by systems planning for Geary Street, the other first priority corridor included in Proposition B. While a full description of this process is beyond the scope of this paper, it is significant that two alternatives identified were (1) a surface alignment feeding onto Muni's surface Market Street tracks downtown, those intended for the F-Market Street and Wharves vintage line, and (2) a subway–surface line that would run in a subway east of Laguna Street and serve downtown in a subway that would thread it's way down Geary, cross over the two-level Market Street subway in a shallow tunnel at Third and Kearny Streets, and continue south of Market (*2*).

But Proposition B contained only enough local funds to build one corridor, so both Geary and Third Street could not proceed. On Geary, community opinion had never coalesced sufficiently around any alternative to generate political momentum to move a project forward. Though there was strong support for the light rail alternative among transit advocates, neither the residential nor the business community in the neighborhoods had gotten together strongly behind the project.

In the Third Street corridor, community support was building for light rail, partially due the transportation improvements that would be realized, and partially as a community development strategy for a neighborhood that had traditionally felt bypassed by much of the city's development boom and rising incomes. Political and community support for Third Street ultimately caused the Third Street project to be moved forward as the corridor that would be built first.

In this same period, the San Francisco County Transportation Authority initiated a "Four Corridors" planning effort to tie together the Bayshore, Geary, and eventual Chinatown and possible Van Ness corridors in spring 1994, paralleling the Geary study. The eventual recommendation endorsed a concept put forth by Muni that the Geary subway–surface concept could connect to a north–south trunk at Geary and Stockton Streets, which would eventually serve Chinatown, and after crossing Market could surface and connect to the proposed Third Street line (*3*).

COMMUNITY ISSUES

Project planning in any American city in the last decades of the 20th century or the start of the 21st is a partnership between the agencies of government, including the transit agencies, and the communities served. Local community activism is probably more highly developed in San Francisco neighborhoods than in many jurisdictions, and planning for the Third Street project inevitably took place in this turbulent fishbowl environment. Transportation goals were perhaps most obvious, but hardly the only expectation placed on the project.

Jobs, Jobs, Jobs

The central community served by the Third Street Light Rail Project is Bay View–Hunter's Point, a politically astute community, yet one plagued by high unemployment, gang activity, and physical deterioration. If there was an economic boom underway, it had bypassed Bay View. While Third Street forms the axis of the community, numerous storefronts are vacant or marginal, community services such as groceries and supermarkets are few, and general retail is almost nonexistent. Activists saw the light rail project as a catalyst for the community, and one that would not only bring a brief influx of jobs during construction, but one that could provide job training to make residents more competitive in the open job market long after the line was built, as well as bring economic revitalization—and jobs—to the community as a whole. Transportation improvements were not enough; the goal was transit-oriented development along Third Street (but without residential displacement)—and jobs.

Make Bay View Part of the City

Through the 1970s, the economic, social, and racial isolation of Bay View–Hunter's Point (after the city's other major African American community was obliterated by the bulldozer of 1950s style "redevelopment") was mirrored by the structure of transit service. The 15-Third served the corridor, but most "cross-town" services were only interrupted feeders and failed to connect the eastern portion of the city with other areas. Restructuring in the early 1980s remedied much of this isolation, but travel times remained long and the perception of isolation remained. A strong community goal was for a Third Street LRT to physically interconnect the community's trunkline with the rail fabric which interwove San Francisco's other neighborhoods, with the strong belief that this would bring customers and pedestrians to a revitalized Bay View core.

The Push of Politics

The hope, or rather the expectation, that the light rail project could precipitate an economic transformation naturally found its champions on the local political scene. Given that the San

Francisco County Transportation Authority, as administrator of San Francisco's half-cent sales tax, was the principal local funding source, it was only natural that the city and county Board of Supervisors, sitting as the Authority's board, would respond. This took the form of substantial pressure, both internally on the Authority board and externally on Muni as the implementing agency, to use the local sales tax money as 100% financing for a quickly implemented, locally funded project. Skip the EIS, no cumbersome federal process—let's build the thing!

The Municipal Railway, as well as Authority staff, found this alarming and foolish in the long term, as planners naturally wanted to leverage local funds against federal and state monies to stretch the Authority's $900 million resource into as much as a $4.5 billion dollar program, under the 80-20 match program still available in theory.

Visitacion Valley and Chinatown

Lest this sound like a project with universal support and the only dialogue being whether to build it quickly or deliberately, dissent started to emerge from the Visitacion Valley community just south of Bay View–Hunter's Point. Bay View, as noted, was home to a large African American community, largely born of the jobs of World War II's Naval Shipyard and reinforced by the redevelopment of the Western Addition cited above. Visitacion Valley harbors another strong ethnic community, this one of several Asian communities in San Francisco that evolved as satellites of crowded Chinatown. With shops and family ties to Chinatown itself, community leaders in Visitacion Valley started to note that the proposed Third Street LRT line running south along Bayshore Boulevard would both fail to serve the heart of Visitacion Valley to the west, but would also sever the 24-h, 7-day-a-week connection between the two parts of the Asian community afforded by the 15-line bus. As systems-level planning evolved toward preliminary design, these voices became increasingly shrill. Third Street Light Rail was not yet a done deal.

What About Geary?

A last lingering concern, if only for the planners, concerned the Geary corridor. As mentioned, enthusiasm for the Bayshore Third Street project eclipsed interest in a Geary project as systems planning wound down, but from a planner's perspective, the 80,000 riders of a Geary project ensured the desirability of an eventual Geary project's still being achieved. Was there any way to advance a Geary agenda from within the parameters of a Third Street project?

NEW CENTRAL SUBWAY STRATEGY

The largest public meeting held until that point was the meeting at which over 200 residents of the Visitacion Valley community had been gathered in opposition to the project, but out of this Muni developed the strategy that has led to implementation of the project.

As described, Visitacion Valley residents protested that while Third Street would receive a shiny new light rail line, they would be deprived of their direct access via Muni's 15-line between their community and Chinatown. The solution was in the refinement of the Bayshore Light Rail Project into a two-phase project, as shown in Figure 2.

Phase 1 would consist of the project as it had been defined to date: a "Third Street Light Rail Project Initial Operating Segment" between the Bayshore Caltrain Station and King Street,

FIGURE 2 The Third Street light rail project.
(Solid line indicates Phase 1IOS; dashed line indicates Phase 2 NCS.)

where it would connect to Muni's existing light rail Muni Metro System. During this phase, another bus route, the 9X San Bruno Express, which shared the 15-line's Visitacion Valley routing, would be expanded from part-time (weekday-daytime) to daily, 20-h service, to address the immediate concerns of Visitacion Valley's Asian community. Extensions at each end would further maintain coverage to San Francisco City College at the south end, and Fisherman's Wharf at the north.

But the project would be proposed to include a Phase 2 which would extend from King Street northwest into a "New Central Subway" under Third Street, passing the Moscone Convention Center, crossing Market Street, serving the Union Square retail and hotel district, and continuing into Chinatown.

In fact, this would be the downtown portion of the Four Corridors plan. It would construct the keystone portion of an eventual Geary corridor project, and as much of the Chinatown subway as funds and politics would permit. (Since "Chinatown" was a lower priority than "Bayshore" and "Geary" under Proposition B, the Transportation Authority insisted only a one-station link as far as Clay Street could be considered as part of an initial "Bayshore" project.). This would not only mesh with the city's grid route system, but would offer the Visitacion Valley community the restoration in the mid-term of their Chinatown connections as an extension of the nearby rail service.

It would furthermore bring a new community, Chinatown itself, into the constellation of support for the emerging Third Street project. So rather than trying to advance a project primarily supported by one established community (Bay View–Hunters Point) and the developer of Mission Bay, that initial Third Street surface line had the potential to be supported by a series of constituencies lined up along the entire eastern half of the city: Visitacion Valley, Little Hollywood, Bay View–Hunters Point, Mission Bay, various downtown interests (convention, retail, and hotel businesses), Chinatown, and even supporters of the Geary subway-surface proposal.

It would further allow Muni to pursue a funding strategy under which the Third Street Initial Operating Segment (IOS) would be built as quickly as possible using 100% local Proposition B funds, but a federal "Letter of No Prejudice" would be sought under which federal funds could subsequently be awarded to construct the more costly New Central Subway (NCS) project, leveraged by the full $584 million cost of the IOS.

Muni began a process to move the Third Street line into implementation. An major investment study, EIS, and EIR process was undertaken, which resulted in a draft EIS/EIR in 1998. A Locally-Preferred Alternative was selected in June 1998. In March 1999, FTA issued a Record of Decision (ROD) for Phase 1 of the Third Street project, the IOS. FTA did not issue a ROD for Phase 2 of the Third Street project at that time.

While the two phases of the Third Street project had been intended to follow in rapid succession, funding issues within the region about the use of FTA Section 5309 New Starts funds pushed the phases further apart. Muni originally planned to build the entire Third Street corridor project using a mix of local and New Starts funds. At this time, however, BART had a commitment from FTA for New Starts funds through 2007, and FTA would not approve two New Starts projects for funding at the same time within the region. Therefore, a regional agreement was reached which split Muni's Third Street project more formally into two elements, and allowed the first component, the Phase 1 IOS, to proceed with local funds. The Phase 2 NCS would proceed later with New Starts funds after BART's extension to San Francisco International Airport was completed. This decision has continued to have ramifications for

Muni's project to this day. The main issue is that FTA has not allowed local funds spent on Phase 1 to be credited as match to the New Starts funds in Phase 2 as originally intended. This has become more of an issue as FTA has increased the match requirement incrementally. Muni is currently seeking legislation that would instruct FTA to credit the local funds in Phase 1 to match the New Starts funds in Phase 2, in much the same way that Las Vegas has done.

REFINING THE PROJECT

Jobs, Jobs, Jobs

From the beginning of the project, a focus of the community in the Third Street corridor has always been on the creation of jobs for local and minority businesses and individuals. Muni took this concern seriously, and has worked throughout the project to develop appropriate methods for ensuring that project work is done, as much as possible within federal regulations, by local and minority business enterprises, and that project contractors consider hiring local workers to fill vacancies. Muni initiated three programs to assist local businesses and individuals:

1. Community Employment, Recruitment, and Training program to identify Third Street construction-related job opportunities. The program, administered by the San Francisco Private Industry Council with the assistance of local community-based organizations, helps local residents prepare and become placed in these positions.
2. Small Enterprise, Recruiting, and Subcontracting program to assist local businesses in obtaining surety bonding, and to support subcontractor lines of credit.
3. Community Outreach Program to provide information and outreach throughout the community about the project, as well as maintain a Plan Room, to allow local contractors to obtain assistance in preparing bid documents.

In addition, Muni decided to use an alternative method of contracting for the construction of the Metro East Maintenance Facility, which would increase local subcontractor opportunities. Muni is using a construction manager/general contractor process for Metro East facility construction, which will increase the number of opportunities for smaller contractors to competitively bid on smaller packaged project components throughout the term of the contract.

Mission Bay

Mission Bay is a project of the Catellus Development Corporation (formerly Santa Fe Southern Pacific Real Estate Company) primarily on the site of the Southern Pacific Railroad's former San Francisco terminal rail yards. The development spans approximately 300 acres, about 1 mi south of the San Francisco CBD. Plans include mixed use development with about 1.5 million gross square feet of retail, 6000 residential units, a 43-acre University of California at San Francisco medical campus, and 5.65 million gross square feet of research and development, light industrial and office space (*4*).

Initial planning for the Third Street corridor envisioned a line which continued along alignment of King Street, swinging east adjacent to Owens Street parallel to the Caltrain, formerly Southern Pacific, commuter-rail tracks. One advantage was averting crossing bridges over Mission Creek channel, which remained a navigable waterway with just enough traffic to require lifting bridges and raise concern about the resultant schedule interruptions. Secondly, this alignment facilitated connection to the Caltrain right-of-way to provide the Bayshore rapid transit service described earlier.

But as development plans for the Mission Bay project progressed, it became apparent that this alignment would miss the relatively high density development along this portion of Third Street, in favor of low-density research and perhaps even industrial facilities along the King-Owens alignment. And when the Caltrain right-of-way alignments were discarded in favor of Third Street itself, this benefit too became moot. When finally Catellus began to covet the rail yard site adjacent to the King–Owens alignment, the shorter route along Third Street had too many obvious benefits despite the bridge interruptions, and even the frequency of those occasions had abated over the intervening years. The switch to a Third Street alignment through Mission Bay was a win-win situation. (A jog at the north end over the Fourth Street bridge, not the bridge over Third Street itself, would serve the Caltrain terminal and better avoid traffic congestion at the San Francisco Giants' Pac Bell Park.)

Ridership and Travel Times

San Francisco is a largely developed city with high transit ridership and a congested core. The Third Street Light Rail Project will serve an existing market drawn largely from 25,000 present riders of line 15–Third, plus increasing volumes of trips generated largely by Mission Bay. By the time of the IOS line's opening, Mission Bay is expected to generate approximately 20,000 additional daily transit trips, which will largely be served by the Third Street rail line (*4*).

As was stressed earlier, the Third Street line does not stand in isolation, but will function and attract the ridership expected in part because it is still but one line in Muni's network, connected to a rich fabric of cross-town services at almost every stop. This connecting network for the most part is already in place as part of the current bus system, and will only require minor modifications to integrate with light rail. Figure 3 illustrates the bus network, which is an inseparable component of the project.

Including connecting trips, corridor ridership of 66,000 in 1996 was projected to increase to 136,000 on the IOS by 2015, or 143,000 with the NCS, though the economic downturn has slowed the Mission Bay project and suggests 2015 volumes may fall about 10,000 short of those figures. Light rail ridership on IOS was projected as reaching 71,000 by 2015 and 92,000 with the NCS, though again a slowed pace of Mission Bay development will defer the attainment of those projections. Ridership is summarized in Table 1 (*5*).

Table 2 summarizes transit trip times and shows significant reductions over future no project conditions, as well as over current travel times. Future conditions project deterioration of surface traffic conditions. Thus current comparisons show time savings in the 10% to 20% range, while future time savings are in the 20% to 30% range. (These are for total trip times, not just in-vehicle times.)

Trip time reductions have been estimated at various stages of the planning process, but unfortunately do not exist as one fully consistent set at this juncture. Initial work for environmental documentation estimated average trip time savings of 4.0 min for the IOS and 6.9 min for the NCS phase. Subsequent refinements for FTA reporting derived the following net user time savings for the IOS relative to the TSM alternative, and for the NCS relative to the

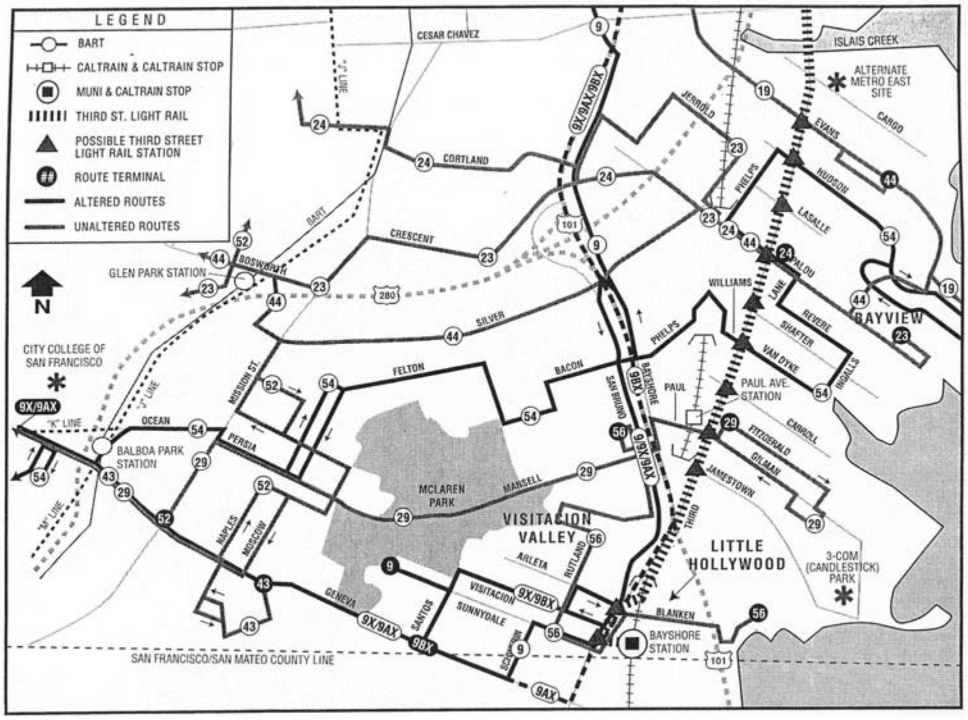

FIGURE 3 IOS bus service plan.

TABLE 1 Estimated Weekday Transit Ridership

LRT/BUS LINE	**EXISTING (1996)**	**2007 IOS**	**2020 IOS**	**2020 NCS**
Light Rail Lines in Corridor:				
Embarcadero Ext. (1998)	n/a	7,238	9,050	2,020
Third Street LRT	n/a	39,834	71,010	92,110
Subtotal	**n/a**	**47,072**	**80,060**	**94,130**
Bus Lines in Corridor:				
Line 15-Third	25,050	n/a	n/a	n/a
Lines 9X, 9AX, 9BX	14,330	14,330	21,780	18,200
Lines 30, 45	26,640	26,640	31,770	25,880
Shifts from 15 to other lines	n/a	1,500	4,480	4,480
Subtotal	**66,020**	**42,470**	**58,030**	**48,560**
TOTAL IN CORRIDOR	**66,020**	**89,542**	**138,090**	**142,690**
Increase over existing:	n/a	23,522	72,070	76,670

Notes: "2007" figures were initially projected as 2003; this adjustment represents a 2002 estimate of delayed Mission Bay development. Similarly, "2020" figures were presented in the EIS as 2015. Table adapted from *Third Street Light Rail Project FEIS/FEIR*. Data are drawn from *Third Street Light Rail Project FEIS/FEIR*; *Travel Demand Forecasting Results Working Paper*, and *Mission Bay Muni Service Extension Strategies* reports. Projections for "2007" for bus lines other than line 15 were not prepared; estimates in table are inferences drawn from other entries.

TABLE 2 In-Vehicle and Total Transit Travel Times for Selected Third Street Corridor Transit Trips (Times in Minutes)

ORIGIN–DESTINATION	EXISTING (1996)	2020 NO BUILD/TSM ALTERNATIVE	2020 Phase 1 (IOS)	2020 Phase 2 (NCS)
Arleta/Bayshore–Third/Market	36/45	42/51	31/44	27/40
Third/Palou–Montgomery/Market (IOS) Third/Market (NCS)	30/44	30/44	24/38	19/33
Arleta/Bayshore–Stockton/Clay	49/61	49/61	n/a	30/44
Third/Palou–Stockton/Clay	36/50	36/50	n/a	22/37
Arleta/Bayshore–Montgomery/Market (IOS) Main/Market (NCS)	42/54	42/54	29/42	n/a
Third/Palou–Main/Market	30/47	30/47	22/36	n/a

Notes: First number represents in-vehicle travel times; second number represents total point-to-point travel times. "2020" figures were initially projected as 2015 in EIS; this adjustment represents a 2002 estimate of delayed Mission Bay development. Table adapted from *Third Street Light Rail Project FEIS/FEIR*. Data are drawn from *Third Street Light Rail Project FEIS/FEIR*; *Travel Demand Forecasting Results Working Paper*, and *Mission Bay Muni Service Extension Strategies* reports.

IOS. (Again, the reader is warned that the numerical bases of these two estimates are unfortunately not entirely consistent with one another, the NCS estimate incorporating later refinements.)

IOS	4,293 daily hours	1,343,709 annual hours (over TSM)
NCS	13,320 daily hours	4,169,160 annual hours (over IOS)

Costed at a user travel time value of $11.70, as recommended by FTA when environmental documentation was prepared, the annualized value of these savings to users is estimated as:

IOS	1,343,709 annual hours	$15.7 million per year (over TSM)
NCS	4,169,160 annual hours	$48.8 million per year (over IOS)

Signal Priority and Semi-Exclusive Right-of-Way

Visitors to San Francisco since the 1970s have puzzled over the one 10-block stretch of semi-exclusive median treatment (i.e., a transit-only exclusive median, but one still interrupted by cross streets) on a portion of the N-Judah line, not repeated elsewhere in the system. At the time, community opposition, primarily concerned with driveway access and on-street parking, prevented expansion of this approach. Community support for transit-priority applications has since become far more (but, no, not universally) acceptable, and hence transit rights-of-way have become generally accepted for rail expansion programs on city streets, and are likely to characterize future bus rapid transit projects on city streets, too.

Thus the community accepted the concept of a transit median for the Third Street project (illustrated in Figure 4), even recognizing the traffic impacts this would have by reducing three traffic lanes to two on a busy truck corridor. Many residents even viewed this as positive in that it might force reduction of traffic volumes.

The only exception came in the Bay View commercial core, a nine-block stretch in which the community sought widened sidewalks with pedestrian amenities. The compromise was to accept shared traffic operation in these nine blocks, light rail operating in one of the two traffic lanes, with the remaining street width given to the widened sidewalks (see Figure 5).

Similarly, all signals along Third Street will be signalized (many are now two-way arterial stop signs for cross-traffic) specifically so that transit can be given pre-emptive control over the length of the project. Muni's LRVs are outfitted with Vetag controllers and the Vetag technology is being utilized for signal pre-emption.

Stops and Stations

It is undeniable that Muni remains in many ways a "streetcar" system, and this will remain true of the Third Street line. Muni's service standards for its bus system call for stops every 800 to 1000 feet. This stop spacing was expanded somewhat for light rail, but the project's 19 surface stations remain a pedestrian-friendly four blocks and 1,000-1,200 ft apart on average. All are

FIGURE 4 Third Street trackway design, with side platform station.

FIGURE 5 Bay View commercial core treatment at Palou–Oakdale Station.

high-level, with ramp entry at one or both ends wherever feasible. Most stations are center island platforms, but a number of stops in the Bay View district are paired side platforms. While this obviously results in slower operation, less frequent stops would require retention of a local bus service, a financial and physical impossibility. Being a pedestrian-scaled city has its price.

Proof of Payment Fare Collection

Muni initiated Proof-of-Payment (POP) fare collection incrementally in the 1990s on the existing LRT system. Muni has developed a hybrid approach to POP that incorporates Paid Areas within subway stations with barrier fare collection, and POP surface operation in which passengers can still pay fares onboard the first car of each train of LRVs at surface stops, or board any door if they already have POP. Roving inspectors enforce the regulations. The Third Street line was designed from the start to incorporate Muni's hybrid features, which means that high-volume stations will have ticket vending machines (TVMs) available for fare prepayment, but at low-volume stations, passengers needing to pay a fare will be able to pay onboard the cars. Surface station platforms are not considered Paid Areas, and passengers are not subject to inspection on these platforms.

High-Floor Versus Low-Floor

When Muni's initial Market Street subway was designed in the late 1960s and early 1970s, it was laid out as a high-floor platform facility, to facilitate boarding from a level floor. Similarly, the vehicles eventually designed to serve it used a surprisingly successful and reliable high-low step design to serve either the high-level subway platforms or street level surface stops. At the time, today's low-floor light rail car had not yet been invented.

But when planning commenced for the Third Street project, low-floor cars now existed and offered some very attractive features. Community members along Third Street were very concerned that massive, high-platform stations could form a barrier between the two sides of the future revitalized neighborhood commercial street they foresaw. Less intrusive low-level platforms, served by low-level cars were a very attractive alternative. From a planning perspective, low-level cars and platforms also simplified wheelchair accessibility from platforms in blocks too short to accommodate ramps at each end.

A concept was developed to through-route Third Street service with the N-Judah line. Lowering a portion of the platform at the downtown subway stations was shown by an engineering feasibility study to be less problematic that it might seem, and providing accessibility at all N-line stops offered an obvious attraction to disabled transit users over the occasional high-block mini-platforms provided only at major stops.

While this low-floor concept was given serious consideration, a decision was eventually made, however, to stick with a uniform fleet of high-floor LRVs. Principal concerns were to simplify maintenance requirements, as well as to retain a fleet of vehicles which could serve all lines, and certainly simplify the capital construction program for the IOS.

Metro East Light Rail Maintenance Facility

Muni's current LRV maintenance facility, Green Division, is overcrowded and sorely in need of relief in order to function effectively. Muni could not even consider building a new light rail line without increasing maintenance and storage capability, and given that Green Division is hemmed in on all sides by development, Muni had to find a location for a new maintenance facility. After several alternative locations had been considered and rejected, Muni settled on a site for the new Metro East Light Rail Vehicle Maintenance and Operations Facility along the Third Street project corridor, in the vicinity of Illinois and 25th Streets. This new facility is currently under construction, and will be able to store, maintain, and operate up to 100 LRVs.

CONSTRUCTION STATUS AND OPENING DAY: FALL 2005

After years of planning, it is always exciting to move into actual project construction and implementation. All segments of the Surface Rail Alignment for Third Street are under construction as of this writing (July 2003), and the 15 LRVs needed to operate the IOS have been purchased and delivered. The Metro East facility is scheduled to begin construction in Fall 2003, and opening day for revenue operation on the line is scheduled for Fall 2005.

LESSONS LEARNED

The lessons learned by Muni in planning and building the Third Street line are fairly universal transit lessons that are applicable to other situations.

1. Build the network, not the line. The truth is that not all rail projects (and not all light rail projects) that get built are successes. The probability of success will be greatly enhanced when your project makes sense as part of your overall transit network. Your network should be telling you where to consider light rail.
2. Community planning can be a win-win. If you establish credibility with your constituencies—yes, your community comes first, your agency comes second—working with neighborhood activists and other stakeholders does not require you to abandon your transportation principles to reach consensus. Know what's important to you, and know what's important to community members. A win for all (or at least most) is not always, but usually, achievable.
3. Consider the longer-term implications of phasing and funding early. With FTA's new practices regarding phasing of projects, and the reduced ability to match New Starts funds across phases, you should seriously consider the implications of how your project funding is assigned between the phases. It has become much more difficult to build a Minimum Operable Segment or IOS with your local funds, and then use those local funds to match New Starts funds on extensions and future phases. The politics may dictate that you proceed with a locally funded project anyway, but be mindful of the potential future consequences of that.

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How the Introduction of the HBLRT Changed the Demand for the Liberty State Park Park-and-Ride Facility

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NJ Transit was faced with the problem of how to increase demand for an underutilized park-and-ride facility that was about to see the introduction of light rail transit (LRT) service.

A study was conducted in 1999 to determine why the Liberty State Park Park-and-Ride (LSPPR) facility was underused, how the introduction of the Hudson–Bergen LRT (HBLRT) would impact LSPPR usage, and what other factors might increase usage of the LSPPR facility. The paper describes how the study was conducted using the "convened groups" method to understand and identify the needs and preferences of travelers in the study area, its recommendations, and the measures that were implemented to attempt to increase the LSPPR facility's utilization.

The study results indicated LSPPR could be made more attractive and therefore more successful by increasing awareness of the park-and-ride lot and the upcoming LRT service. As seen from the model developed by the study, with competitive pricing and travel times, the LSPPR facility was expected to attract a number of new users.

Since the study was conducted, the HBLRT has been introduced; parking was made free for a period of 8 months to increase awareness of the lot; a pricing scheme was devised, based in large part on the study recommendations; and demand for the LSPPR has risen substantially.

The paper concludes with the lessons learned to make the LSPPR facility a highly utilized and viable park-and-ride facility, and how these lessons might apply to other park and ride facilities serving LRT facilities.

INTRODUCTION

In November 1998, the Liberty State Park Park-and-Ride (LSPPR) lot was opened as part of the yet-to-be-built Hudson–Bergen Light Rail Transit (HBLRT) system. LSPPR was initially served by an express bus that took customers to Exchange Place in Jersey City. The 1,250-space lot was only 2% utilized when express bus service was started and this eventually grew to about 6% utilization over roughly 12 months. However, at only 6% utilization with express bus as the ride mode, the lot was still significantly underutilized during the year prior to the introduction of the light rail transit (LRT) service. Due to the lack of use, and with the opening of the HBLRT system to occur in April 2000, NJ Transit commissioned a study in June 1999 to answer the question, "How can we increase the lot's utilization, especially with the coming of the HBLRT?"

BACKGROUND OF LSPPR

For the LSPPR facility, there were many things in its favor to make the facility successful—the facility's location was well planned, with good access to and from the New Jersey (NJ) Turnpike (Figure 1). The LSPPR was also located near the growing Jersey City Waterfront area (JCW), which had strong parking needs. However, the facility was underachieving, so the need for obtaining customer preferences and viewpoints was critical in understanding how to increase demand for the facility.

As mentioned above, the LSPPR facility was opened in November 1998 with express buses running from the lot to Exchange Place. In April 2000, the HBLRT was introduced, providing LRT service from the lot to Exchange Place. The HBLRT then expanded northward with partial service to Newport in November 2000 (full service to Newport opened April 2001) and finally to Hoboken in September 2002, giving a greater reach for those parking at the LSPPR facility. Overall ridership on the HBLRT started well below projections. However, HBLRT ridership did increase steadily and has held these gains. The second "operating stage" of the HBLRT project will ultimately take the system north of Hoboken into Bergen County and is currently under construction.

Another benefit of the LSPPR location is that it is located on the "trunk" part of the HBLRT line. This means its service is twice as frequent as stations on the "branch" lines to West Side Avenue and 34th Street (Figure 2).

FIGURE 1 Immediate area around LSPPR.

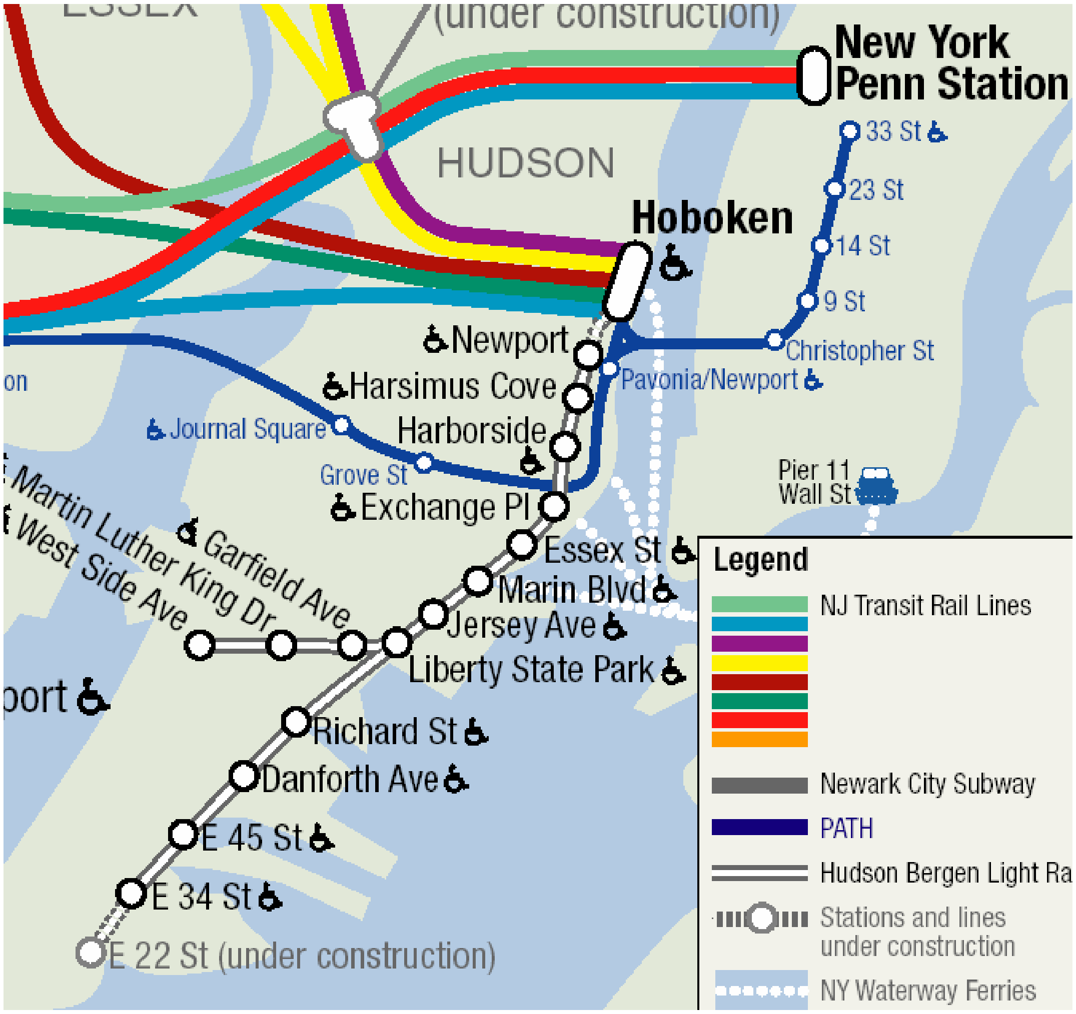


FIGURE 2 HBLRT system map (White Line) with Liberty State Park station at end of trunk line.

Based on a survey of HBLRT riders conducted by NJ Transit in January 2001, it is known that LSPPR draws riders from the larger region, with 72% of its riders coming from outside of the local Hudson County area. Of these riders, the majority are from suburban NJ locations which are at least 10 mi from LSPPR. The impact of these long-distance park-and-riders is that 83% of all LSPPR riders actually use the parking facility. Of the total riders on HBLRT, 31% were former auto-only users to their destination that subsequently diverted to HBLRT; and over half of these riders use the LSPPR facility.

Average household income at LSPPR, from the 2001 survey, was $97,000 while at all other stations combined on the HBLRT household income was only $60,000. The high-income LSPPR riders could therefore support the pricing measures that were put into place based on the 1999 study described below in this paper.

The LSPPR functions primarily as a remote shuttle parking lot to the JCW, which is the final destination of 60% of LSPPR patrons. The remaining 40% of LSPPR riders continue on to Manhattan. This split is not surprising, as there are various one-seat rides to Manhattan on the regional commuter rail system from park-and-ride facilities, while easy one-seat access from a park-and-ride lot to the JCW is found only on the HBLRT and primarily at the LSPPR.

1999 LSPPR STUDY

To answer NJ Transit's question of how to increase the LSPPR facility's utilization, a study was undertaken to better understand the factors which determine demand for the LSPPR facility, from both qualitative and quantitative perspectives. This study's goals were to determine why the LSPPR facility was underused, how the introduction of the HBLRT would impact LSPPR usage, and what other factors might increase use of the LSPPR facility.

To achieve the study goals, research was conducted using the "convened groups" method to understand and identify the needs and preferences of travelers in the study area. Convened groups are somewhat larger than typical focus groups (about 15 people in a convened group as opposed to 10 in a focus group) and engage participants in two primary activities: (1) focus-group-style discussions of the research topics; and (2) a comprehensive survey covering participants' travel needs and preferences, the results of which are used as the basis for quantitative analysis.

For the LSPPR study, three convened groups were held during the evenings of June 14–15, 1999, in the executive board room of the Liberty Science Center, which is adjacent to the LSPPR facility. In total, 44 respondents participated in the three convened groups.

Respondents were recruited by handing out flyers at and around Exchange Place, at toll plaza 14C on the NJ Turnpike, and at the LSPPR facility. Those living in South Jersey City and North Bayonne were recruited using a database of past NJ Transit research study participants. Table 1 summarizes the methods used for recruiting and the yield from each. The study's purpose was to obtain a general impression of the LSPPR facility from a random sample of potential users, which worked nicely with the convened groups method, as this study did not have the budget to conduct a large study with many respondents.

Eligible respondents included those living parallel to or south of the LSPPR facility who commute to the JCW or New York City (NYC). This recruitment included commuters living in Brooklyn who work at Exchange Place, as the route passing by LSPPR is the most efficient one for some of these commuters. The map below indicates the general study area (Figure 3). The black line is an approximate study-area border, and respondents were recruited from west of this line.

TABLE 1 Recruitment Techniques and Results

Recruitment Technique	Location	Flyers Distributed	Recruits	Remarks
Flyer Distribution	NJ Turnpike toll plaza 14C	1000	3	The turnpike's extremely low response rate leads one to presume that, in reality, very few flyers were handed out. The Turnpike did not allow on-site oversight by the study team in order to ensure that flyers were properly distributed.
Flyer Distribution	Exchange Place	800	26	
Flyer Distribution	LSPPR	20	6	
Telephone using database	N/A	N/A	10	

Four primary respondent categories were recruited for the study: (1) drivers to JCW, including those who continue via PATH/FERRY to NYC; (2) park-and-ride customers currently using the LSPPR facility; (3) transit-only users traveling to JCW/NYC destinations; and (4) drivers commuting to NYC.

The first three respondent categories are well represented in the study based on respondent mode, home location, and final destination (Table 2).

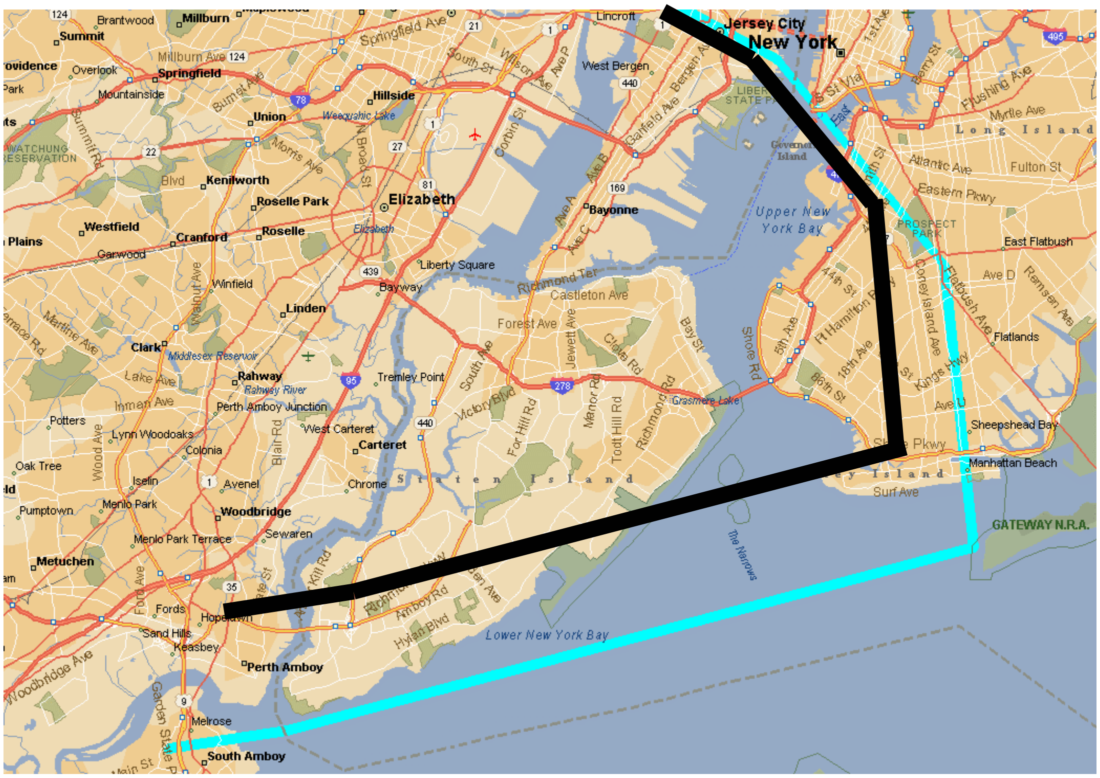


FIGURE 3 General area of LSPPR study participant recruitment.

TABLE 2 Number of Respondents in Each Recruit Category

Destination	**Survey Segment**						**Total**
	Drive to JCW		**Park-and-Ride at Liberty State Park**		**Transit**		
	Non-local resident	**Local Resident**	**Non-local resident**	**Local Resident**	**Non-local resident**	**Local Resident**	
Exchange Place/JCW	10	2	3	2	10	5	32
NYC via PATH	5	3		1	2	1	12
Total	15	5	3	3	12	6	44

QUALITATIVE OBSERVATIONS

Participants in all convened groups generally agreed that parking in the JCW area is expensive, as much as $200 per month. The price had been increasing and the availability of empty spaces decreasing. Most also felt that continuing development would continue to push parking prices up. All three respondent categories (Drive to JCW, LSPPR users, Transit to JCW/NYC) observed that congestion in the JCW area was the worst of their entire commute and was continuing to increase.

Awareness of the LSPPR was not widespread, with only 40% of respondents aware of the facility. A billboard on the NJ Turnpike advertising the LSPPR was suggested. Most respondents did not know that the lot was open or that there was a bus to transport commuters from LSPPR to JCW. Some commented that the bus service, facing the same congestion as autos, did not provide any incentive for commuters to use LSPPR. Current LSPPR users also mentioned lack of air conditioning on shuttle buses and faulty ticket vending machines making the use of LSPPR less attractive.

Many study participants were aware of the plans for the new LRT line and favored using it because of the benefits it offers: exclusive right of way, faster travel time than auto or bus, and greater frequency than bus. However, there were concerns that the LRT might stop too frequently, like a bus rather than like a train, and that the line might not operate reliably in bad weather. Some participants were also concerned that the parking prices at LSPPR would begin to escalate just as they have in the JCW area.

Current users of LSPPR were generally satisfied with the facility and looked forward to the new LRT for its greater service frequencies and faster travel times due to its exclusive right of way. Participants expressed the desire for full parking/ticketing options: monthly, multitrip tickets, and “combos.”

Some participants thought a parking fee of $1 per day should be maintained to keep in line with other HBLRT lots while others thought up to $2 per day would be acceptable, as the LSPPR lot was so close to their Exchange Place destination. A total fee of $5 per day was considered fair for both parking and a round-trip LRT fare. There was a suggestion that parking be made free to carpools. There was minimal concern about transferring or alighting at Exchange Place, Newport, or the ferry. Several participants expressed the need for excellent security in the lot for personal protection and to protect against stolen or vandalized cars. Current LSPPR users were concerned that there was no active telephone line connected to the security booth or any public telephone available nearby.

QUANTITATIVE RESULTS

Sample Representation

The study sample represented the targeted LSPPR market well. Respondents were overwhelmingly 5-days-per-week commuters (93%). Eighty percent of respondents were aware of the HBLRT, but less than 50% had been aware of LSPPR prior to the session. Eighty-nine percent of respondents were employed full time, spread across a variety of occupations. The average number of vehicles per household was 1.5, while average household size was 2.5. Race was not asked in the survey, but from general observation of the focus groups, a reasonably diverse sample was achieved. All income levels were reasonably represented in the sample (Figure 4).

Of the 20 respondents driving to JCW, the following reasons were given for why they did not use LSPPR: 45% stated they were unaware of LSPPR; another 15% had either free or reduced parking elsewhere; and 30% thought it was inconvenient or too far from their workplace (Figure 5).

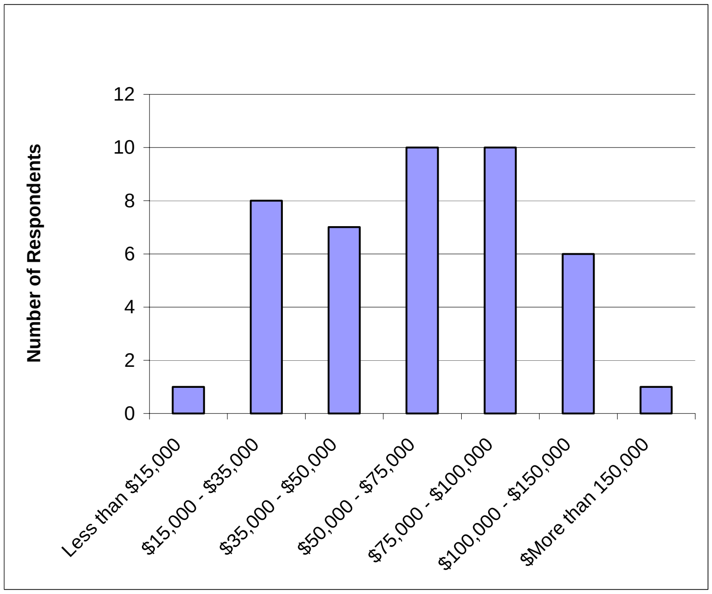


FIGURE 4 Annual household income of respondents.

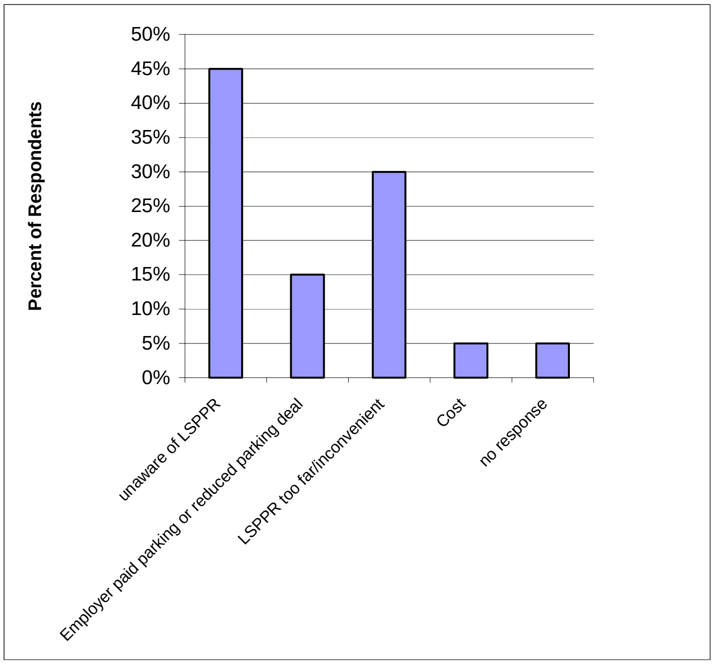


FIGURE 5 Respondent reasons for not currently using LSPPR (drivers to JCW only).

Stated Preference Responses and Mode Choice Model

Survey respondents completed a set of stated preference choice experiments in which they were asked to choose between using their current travel mode versus using the new HBLRT service at the LSPPR facility. Each choice experiment included LRT variables that were customized based on the way the respondent traveled to JCW. As discussed earlier, travelers were categorized into three current travel mode segments:

- Drive to JCW (including people who continue on to NYC by transit);
- Park-and-ride—currently park at LSPPR and take a bus to JCW; and
- Bus—take a bus to JCW (without parking at a park-and-ride lot).

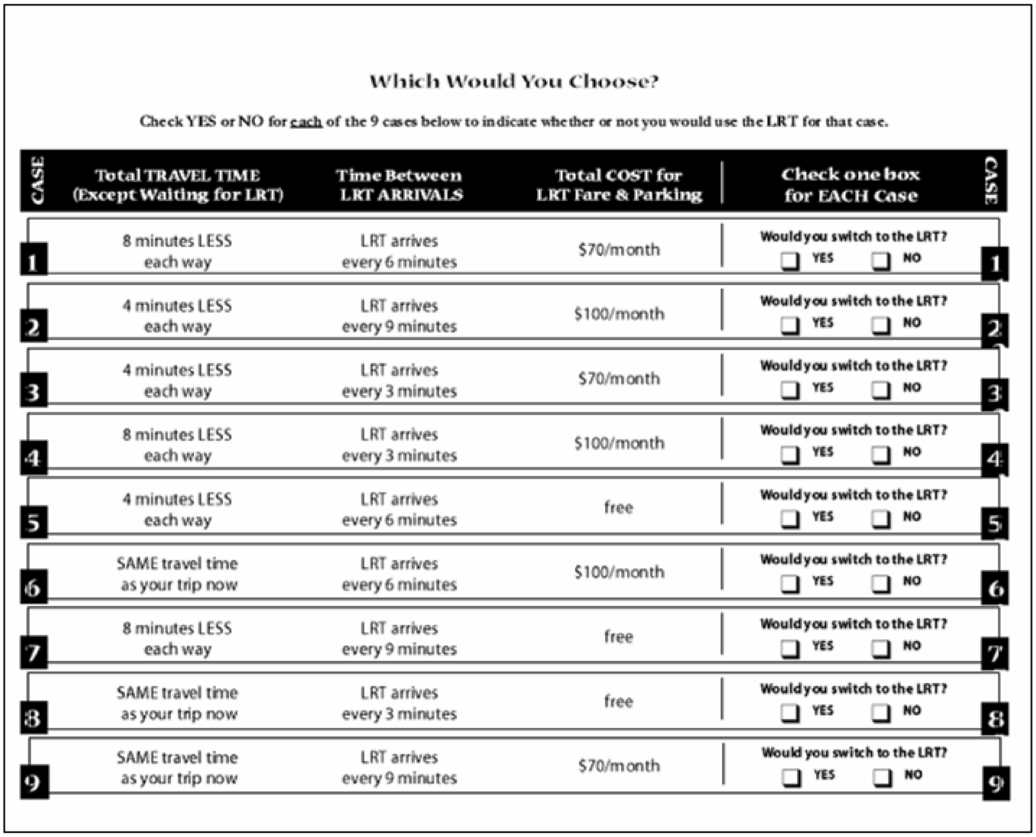
Respondents evaluated the choice alternatives based on travel time, headway (time between LRT arrivals), and travel cost. Levels of the LRT variables varied by travel mode (Table 3).

Figure 6 shows an example of the stated preference experiments presented in the survey to auto users going to JCW. These experiments are analogous to what other survey segments received in their surveys.

The stated preference survey results were used to estimate a multinomial logit mode choice model (Tables 4 and 5). Logit models using choice-based-conjoint stated preference techniques are widely used for modeling travel mode choice (*1*).

TABLE 3 Stated Preference Levels for LRT Option for Different Respondent Types

	Drive to JCW	**Park-and-Ride at Liberty State Park**	**Bus to JCW**
Travel Time	Total TRAVEL TIME (Except Waiting for LRT) 8 min less each way 4 min less each way SAME as your trip now	Total TRAVEL TIME (Except Waiting for LRT) 10 min less each way 5 min less each way 3 min less each way	Total TRAVEL TIME (Except Waiting for LRT) 8 min less each way 4 min less each way SAME as your trip now
Headway	Time Between LRT ARRIVALS LRT arrives every 3 min LRT arrives every 6 min LRT arrives every 9 min	Time Between LRT ARRIVALS LRT arrives every 3 min LRT arrives every 6 min LRT arrives every 9 min	Time Between LRT ARRIVALS LRT arrives every 3 min LRT arrives every 6 min LRT arrives every 9 min
Travel Cost	Total COST for LRT Fare and Parking free $70/month $100/month	Total Travel COST for LRT Option (includes parking) travel cost is the SAME $1/day more ($20/month MORE) $3/day more ($60/month MORE)	Total Travel COST for LRT Option (includes parking) travel cost is the SAME 25¢/day more ($5/month MORE) $1/day more ($20/month MORE)



Which Would You Choose?

Check YES or NO for each of the 9 cases below to indicate whether or not you would use the LRT for that case.

CASE	Total TRAVEL TIME (Except Waiting for LRT)	Time Between LRT ARRIVALS	Total COST for LRT Fare & Parking	Check one box for EACH Case	CASE
1	8 minutes LESS each way	LRT arrives every 6 minutes	$70/month	Would you switch to the LRT? ☐ YES ☐ NO	1
2	4 minutes LESS each way	LRT arrives every 9 minutes	$100/month	Would you switch to the LRT? ☐ YES ☐ NO	2
3	4 minutes LESS each way	LRT arrives every 3 minutes	$70/month	Would you switch to the LRT? ☐ YES ☐ NO	3
4	8 minutes LESS each way	LRT arrives every 3 minutes	$100/month	Would you switch to the LRT? ☐ YES ☐ NO	4
5	4 minutes LESS each way	LRT arrives every 6 minutes	free	Would you switch to the LRT? ☐ YES ☐ NO	5
6	SAME travel time as your trip now	LRT arrives every 6 minutes	$100/month	Would you switch to the LRT? ☐ YES ☐ NO	6
7	8 minutes LESS each way	LRT arrives every 9 minutes	free	Would you switch to the LRT? ☐ YES ☐ NO	7
8	SAME travel time as your trip now	LRT arrives every 3 minutes	free	Would you switch to the LRT? ☐ YES ☐ NO	8
9	SAME travel time as your trip now	LRT arrives every 9 minutes	$70/month	Would you switch to the LRT? ☐ YES ☐ NO	9

FIGURE 6 Stated preference experiments for automobile users going to JCW survey.

TABLE 4 Choice Modeling Results

Variable	Units	Coefficent	T-Stat	Coefficient Lower Confidence Interval (alpha=.05)	Coefficient Upper Confidence Interval (alpha=.05)
Total Travel Time	minutes	-0.158	-4.4	-0.088	-0.229
Total Travel Cost	dollars	-0.660	-7.4	-0.484	-0.835
LRT Headway	minutes	-0.058	-1.3	0.030	-0.146
Current P&R Constant	utils	3.061	3.0	1.014	5.108
Current Bus Constant	utils	4.622	4.6	2.638	6.606
LRT Constant	utils	4.516	4.3	2.451	6.581
Age	years	0.085	3.2	0.033	0.137

TABLE 5 Choice Modeling Results (continued)

Variable	Mode to Jersey City Waterfront: Drive	Park & Ride	Bus	LRT
Total Travel Time	X	X	X	X
Total Travel Cost		X	X	X
LRT Headway				X
Current P&R Constant		X		
Current Bus Constant			X	
LRT Constant				X
Age	X			

(Xs show modes to which coefficients apply)

The mode constants in these models can be used to compare the preferences of the transit modes relative to each other, regardless of time and cost. The bus mode constant for current park-and-ride users at Liberty State Park is less than the LRT constant (3.1 versus 4.5), indicating LRT is the preferred mode for this survey segment. However, users going directly to JCW by bus slightly prefer their current bus mode over the LRT mode (4.6 versus 4.5). These results indicate that the introduction of HBLRT would be an additional incentive for the current LSSPR respondents to use the LSPPR facility and provide no disincentive for current bus users.

The model results indicate the sensitivity of survey respondents to travel time, cost, and LRT headway. The value of time implied by the time and cost coefficients is about $14.50 per hour or 24¢ per minute (in 1999 dollars). The model's value-of-time indicates people are willing to pay an extra $2.40 to save 10 min of travel time. Alternatively, they are willing to have travel take an extra 10 min to save $2.40 on their travel cost. The introduction of LRT was expected to reduce travel time as much as 10 min each way, thus providing a benefit of $2.40 in value to respondents. In addition, the LSPPR lot could save respondents $100 or more in direct expenses per month, depending on their parking situation. This money savings clearly creates an incentive for potential LSPPR users.

A variety of income effects were tested in the model and not found to be statistically significant. Of the demographics that were tested (e.g., age, gender, number of household vehicles, vehicles per adult in household, presence of children, and occupation), only age systematically affected mode choice, with older travelers more likely to use auto.

SUGGESTED STRATEGIES FROM STUDY AND WHAT REALLY HAPPENED

The first conclusion from the study was that LSPPR usage could be improved by increasing awareness of the lot and with the upcoming LRT service. It was clear from both the qualitative and quantitative analyses that there were good reasons for potential users to use LSPPR but that respondents were simply unaware of the facility. NJ Transit did conduct a marketing and communication initiative for HBLRT as a whole, which they perform as a matter of course for all major service introductions. While the LSPPR was not targeted directly, potential riders from the LSPPR catchments area were targeted with various marketing materials and campaigns, including print and outdoor advertising (roadside billboards), special events (including a Liberty

Park Science Center event adjacent to the LSPPR facility), and other awareness-generating techniques. These methods were targeted to make people aware of HBLRT service, not the LSPPR facility itself. As noted above, most respondents knew about HBLRT before it had even been put into service. However, not even 50% of respondents knew about the LSPPR facility, which was in operation at the time of the 1999 study.

In fact, upon the opening of HBLRT, the LSPPR facility was still underutilized, and ridership was lower than projections for the entire HBLRT system. As indicated in comments in the focus groups and seen in the empirical results, respondents believed a total daily LSPPR cost of approximately $5, or $100 per month, including both parking and LRT fare, was reasonable. It was recommended that NJ Transit stay in a range close to these daily cost numbers when pricing the LSPPR facility for the introduction of HBLRT.

NJ Transit did price the daily HBLRT ticket/LSPPR parking cost as the research suggested—$5 per day ($2 per day to park, and $1.50 per one-way trip on HBLRT). Furthermore, NJ Transit priced the monthly parking and transit pass at $93, which was less expensive than what the respondents indicated they would be willing to pay ($100). But the LSPPR was still not being well utilized.

NJ Transit therefore decided in September 2000 (4 months after service began on HBLRT) to implement free parking. Free parking continued for 7 months until April 2001 when the $5 per day daily parking/LRT cost was reinstated as well as the $93 monthly cost (about a year after the HBLRT's initial opening). The free parking served to be a good method to generate awareness of the LSPPR facility, as after the free parking was taken away in April 2001, ridership at the LSPPR continued to increase, and this LSPPR increase was greater than the average ridership increase at all other stations in the HBLRT system. Furthermore, the survey conducted by NJ Transit in January 2001, when free parking was still in effect, indicated that 26% of respondents used the HBLRT to avoid expensive parking costs at JCW.

By August 2001, parking at the LSPPR was at 92% of capacity, or about 1,150 spaces out of the 1,250 spaces were used on an average weekday. This was a very significant increase from the opening of LRT service 18 months earlier, when utilization of the LSPPR lot was below 50%.

The LSPPR capacity of 1250 was originally based on land availability and constructability during the construction phase of the project. Actual ridership forecasts in the Final Environmental Impact Statement were substantially higher than the 1,250 capacity for year 2010. Given cost and space limitations it was decided to construct the LSPPR with 1,250 spaces and revisit parking needs after the system had begun operation, as forecasts were based on the year 2010. The revised forecasts completed just before the system opened indicated a need for 2,500 to 3,000 spaces. Current forecasts are for an estimated 3,000 spaces, but not until the year 2020. This longer time frame accounts for reduction in demand due to September 11, 2001, (9/11) and the NYC area's slower growth forecasts resulting from a loss of jobs in lower Manhattan and the recession in general. Preliminary planning for an expanded structured parking garage option for the 3,000 total spaces is underway, including possible joint residential development. Since 2002, LSPPR has operated at 100% capacity for its 1,250 spaces.

Also in April 2001, full LRT service to Newport was started, which expanded the reach of the system to a regional mall, office complex, and connection to Midtown NYC via PATH at the Newport station. This increased reach of destinations from the LSPPR lot (as well as all stations on the HBLRT) served to improve its attractiveness to new users. Since then, HBLRT service has been completed to Hoboken, increasing reach again to a major urban center and transit hub.

It should also be noted that ridership was growing across the HBLRT system during the first 5 months of 2001. However, ridership at stations other than LSPPR was not growing as fast as the LSPPR station ridership. Specifically, LSPPR station ridership increased from 1,200 boardings per day to 1,650 from January 2001 to May 2001, an increase of 38% (over 80% of these boardings were people using the park-and-ride facility at the LSPPR station). The average increase at all other stations on the system was 28% from January 2001 to May 2001. Finally, the JCW was also growing and it has become the major “back office” area for Wall Street. Due to general development patterns as well as the events of 9/11 the JCW area continues to grow, with many firms relocating to the area.

As seen from the model constants, the LRT mode was favored over the previous shuttle and had nearly the same utility to bus users as their current bus mode. It was concluded that with competitive pricing and door-to-door travel time, assuming an awareness of the facility, the LSPPR facility should attract a number of new users with the introduction of HBLRT service. Competitive pricing and travel time became a reality when HBLRT service began.

CONCLUSIONS AND LESSONS LEARNED

The main lessons to creating a successful park-and-ride facility that serves an LRT system are based on both common sense and business sense:

- Potential customers must be aware of the park-and-ride facility in order to use it;
- It can take significant time for awareness of the park-and-ride facility to grow (over 2 years from the time LSPPR was built in late 1998 to August 2001);
- The park-and-ride facility must be priced correctly based on the demand for it and based on competitive alternatives; and
- There needs to be a market for the park-and-ride facility.

In general, system operators must be patient. LSPPR ultimately fit very well into the HBLRT system. However, awareness needed to be generated, HBLRT ridership needed to take form and stabilize, and the HBLRT system also needed to complete its expansion plans north to Hoboken before the LSPPR facility finally reached its potential.

While it is not always possible to conduct market research on underperforming facilities, the example of LSPPR indicates the benefits of such research. Surveying customers about the facility both qualitatively and quantitatively improved NJ Transit’s understanding of the LSPPR to help turn it around. The research showed NJ Transit where they needed to focus their activities, and it gave them a good baseline to understand what parking costs should be and how parking and transit services should be offered.

All these factors eventually came together, and the result is that the LSPPR is a thriving facility that now needs to expand.

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LOW-FLOOR
LIGHT RAIL VEHICLES

Structural and Crashworthiness Requirements of Light Rail Vehicles with Low-Floor Extension

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This study explores the option of integrating a low-floor extension (LFE) module into the existing light rail vehicle to augment current service with low-floor boarding and simultaneously to increase passenger capacity. In an effort to minimize the overall weight of the LFE, this study examines two feasible approaches for specifying the longitudinal strength of the LFE that are consistent with current industry practice. The two alternatives considered are the "strength-based approach" and the "energy-based approach." The de facto industry practice is a strength-based approach where the buff strength is specified to meet two times the AWO weight of the vehicle, commonly referred to as the "2-g buff load." The feasibility of an alternative approach, using crash energy management (CEM) principles to limit the longitudinal loads in a controlled manner, was also examined in detail. In a collision, the CEM zone would generate predetermined peak and average reaction loads, thereby limiting the longitudinal load transmitted to the LFE, while still meeting minimum static strength values. These zones would be designed to deform or crush in a controlled manner, thereby absorbing collision energy and minimizing the potential for deformation and acceleration in the passenger compartment.

Since structural strength is fundamental to passenger safety, the new structure of the LFE module and any modifications made to the existing vehicle must meet the same structural standards used originally or must provide an equivalent level of performance in a collision. For this study, collision performance is being measured only in terms of peak and average accelerations and deformation.

BACKGROUND

Currently, light rail vehicles (LRVs) comply with the federally mandated Americans with Disabilities Act requirements by providing access to disabled patrons through the use of wayside high blocks combined with onboard bridge plates. This set-up has limited access to the leading doors on each train for passengers using the high block, which is typically used by passengers who are disabled or those with luggage or strollers.

The Authority wanted to investigate the possibility of replacing the existing method of providing access and increasing system capacity at a lower cost. The concept under consideration is the addition of an low-floor extension (LFE) to the center of existing LRVs. The driving force for investigating this concept is that the "non-powered LFEs may be added to the entire fleet at a significantly lower cost, as compared to procuring a fleet of new low-floor LRVs."

LFE CONCEPT

The conceptual LFE modification to the existing LRV may include the insertion of a 30-ft-long low-floor section between the two existing car bodies. The low-floor section is constructed of steel in a similar manner as the existing car. For the purposes of this study, the existing propulsion capacity was assessed only for an LFE constructed from steel similar to that used in existing LRVs. As the propulsion capacity remains unchanged, the heavier steel LFE was used in all calculations. Two articulation joints identical in design to the existing joint are located at each end of the LFE body. Conventional un-powered trucks identical to the existing center truck design support each articulation joint. Doors located on each side of the car body at the middle provide easy entrance and exit from the car at curb level. The LFE section provides 20 seats, standing area for 43 passengers at crush load, and air comfort through an independent heating, ventilation, and air conditioning system.

The LFE concept developed employs the existing propulsion equipment with no changes to the principal physical components such as traction motors, gear units, propulsion inverter, and high-voltage systems. As a consequence, the maximum acceleration rate is reduced.

Among other issues, structural strength and crashworthiness are two performance parameters being reviewed because the available designs for the LFE section do not meet the same structural requirements as those designed for the existing vehicles. Since structural strength is fundamental to passenger safety during a collision—for example, it acts to prevent the collapse and gross penetration of occupied volumes—the new structure of the LFE module and any modifications made to the existing vehicle must, at minimum, meet the same structural standards used in the existing vehicle so that the LFE structure provides an equivalent level of performance in foreseeable collision scenarios. An LFE design with less strength than the existing passenger compartment would be at risk of sustaining a large part of the deformation in a collision, potentially endangering passengers.

LFE STRUCTURAL ISSUES

To determine the technical feasibility of implementing the LFE from a structural perspective, the primary structural characteristics of the LFE LRV, namely the car body compression strength and crush strength, were studied. The key issue is in determining the load values to use in the design of the LFE such that adequate structure strength is provided without excessive weight. One of the main parameters considered in the design of railway structures is the longitudinal yield strength or buff strength of the vehicle. This load requirement is important because when vehicles are properly designed to this load, they are protected against large-scale deformation, penetration, and damage during a variety of collision events ranging from hard couplings to end-to-end collisions with other rail vehicles, and, to some degree, collisions with highway vehicles.

Typical industry practice for LRVs has been to design the vehicle structure to resist a static load equal to two times the empty weight of a ready-to-run vehicle applied at the ends of the vehicle without permanent deformation (yield or buckling), often called the “2-g buff load” criterion.

STRUCTURAL STRENGTH OVERVIEW

As the LFE concept has been popular in Europe exclusively, the structural characteristics and crashworthiness of the LFE need to be reviewed thoroughly to account for the differing design philosophies between Europe and North America. In North America, traditionally a 2-g load (two times vehicle ready-to-run weight) has been required, in some cases by law (California CPUC).

In Europe, the compression strength is typically specified according to the vehicle type, category, or rail service and not necessarily according to the tare or ready-to-run weight only. For instance, in Europe, the typical compression strength of an LFE LRV is in the range of 40,000-100,000 lbs; however, the requirements for North American LRVs are in the range of 140,000-200,000 lbs. Caution must be used when comparing requirements for European LRVs with their North American counterparts, particularly for structures and crashworthiness, because the operating speeds in North America tend to be higher, even though the classification or label of “LRV” is used in both regions.

CRASHWORTHINESS—STANDARDS AND INDUSTRY PRACTICE

In the past, the crashworthiness of LRVs was mostly defined by their buff load. A high buff load was seen as the most straightforward path to ensuring that the vehicle structure did not suffer large-scale collapse in collision, hence providing protection to passengers. Traditionally a 2-g buff load has been required for LRVs in locations such as Baltimore, Maryland; San Francisco, Santa Clara, San Diego, and Los Angeles, California; Denver, Colorado; St. Louis, Missouri; Pittsburgh, Pennsylvania; and Boston, Massachusetts. The exception is New Jersey, where 1.0 to 1.1 g was specified. The Parsons Brinckerhoff study for NJ Transit’s LRV revealed that the working team could not determine the technical rationale behind the 2-g buff load. The 1-g requirement could not be explained convincingly either. Furthermore, specifying a minimum buff load does not necessarily limit the peak loads and accelerations experienced during a collision because the collapse load of the structure is often higher than the static buff load.

Today, the industry is considering an alternative approach. The strength-based crashworthiness approach is augmented with energy-based crashworthiness requirements; the ultimate goal is to reduce passenger deceleration rates during a collision while controlling the absorption of collision energy to minimize loss of space in the occupied volume of the vehicle.

The strength-based philosophy is currently the most widely used approach to ensure some level of rail vehicle crashworthiness. Under this approach, vehicle specifications typically limit the various strength requirements of the structure. The most significant strength requirement is the buff strength. Ultimately, the strength requirement does not consider the energy-absorbing capability of the vehicle structure. If the structure were designed not to crush by utilizing very high strength, then the load and decelerations would also reach very high values during an accident. Depending on the design, collision energy might be dissipated as fracture, derailment, or override—all of which are generally uncontrolled and undesirable outcomes.

The energy-based crashworthiness (or CEM) philosophy is based on providing protection against one or more specific collision scenarios. These scenarios are used to determine, by considering the physics of collisions, an estimate of the energy that must be absorbed and the structural components that must be used to absorb the energy. Selection of specific collision scenarios is the most difficult step in this approach because there must be a rationale underlying selecting parameters such as speed, consist configuration, and impact angle. The selected parameters must be representative of the most likely collision in a given system. Such a scenario can be derived from the review of accident data or from a careful review of proposed operations and the types and likelihood of various accidents. A common accident scenario for passenger train operations is the collision of a moving train with a stationary train. The moving train is often considered to be traveling at a speed substantially lower than its maximum operating speed because the collision event is envisioned to occur as a train is entering the station or has its brakes applied in anticipation of the collision. Once the accident scenario is selected, it is necessary to decide how the energy will be dissipated between various vehicles in the train and the individual ends of a vehicle. A very conservative approach is to require the impacted ends of the lead vehicles to absorb all of the collision energy in its couplers and end structure. However, optimized designs tend to distribute the collision energy along the entire train consist. Collision dynamics computer models can be used to obtain estimates of the distribution of collision energy in the train consist.

The energy-based approach also requires carefully designed structural features in order to ensure that a survivable volume remains after collision energy is absorbed. Limiting accelerations, which can result in secondary impact injuries to passengers, is also a main goal of this approach. To ensure that passenger areas maintain a survivable volume, the passenger compartment structure should have greater strength than the crushable zones, and the amount of deformation or crush required to absorb specified collision energy must be limited. An equally important consideration is the secondary impact injury to passengers. Secondary impact injuries can be controlled by limiting the strength requirement for the crush zone (the maximum force required to initiate controlled deformation), thereby limiting the maximum passenger accelerations.

The use of CEM principles is also being considered for new standards currently developed by industry committees. The American Society of Mechanical Engineering Rail Transit-1 (ASME RT-1) standards committee is in the process of developing a standard for structural requirements for LRVs, which includes CEM specifications similar to European standards, although important revisions are being made to meet North American standards. The standard will include the same general approach for crashworthiness as that discussed above—absorption of collision energy in a controlled manner at a predefined location on the vehicle structure. Typically, collapsible structural elements are located either at the end(s) of the car or within the end structure. Depending on the type of vehicle and the collision scenario considered, the energy absorption structure could have a static “end” strength lower than the typical buff strength (2-g) value in order to minimize the average deceleration in the passenger compartment. To guard against loss of occupied volume, passenger compartments will be specified to have a higher strength than the crush zone to sustain loads from the collapsing structure.

An example of a crash energy design requirement in the proposed RT-1 standard is that each car end should be designed to absorb 350 kJ of energy with a collapsing distance of 20 to 28 in. for a collision between two LRVs: one moving at 12 mph, the other parked with its brakes off. [Development on the RT-1 standard continues; discussions during the American Society of Mechanical Engineers (ASME) meeting in March 2002 will likely result in further revisions to the requirements.] Another example is New Jersey (Hudson–Bergen) where 308 kJ was required. It should be noted that these requirements are specified for new vehicle procurements.

LRV–LFE DESIGN ALTERNATIVES

This study was focused primarily on the overload conditions resulting from vehicle collisions in order to assess the buff strength requirements for the LFE module. From the structural perspective, the design of LFE can be executed using the following criteria for the longitudinal strength of the vehicle:

- Design the LFE to follow the traditional 2-g criteria based on using the new total weight of a vehicle with an LFE.
- Design the LFE to match the existing LRV buff load and collapse load; for example, use the strength-based LRV design philosophy.
- Design the LFE using a strength-based approach in conjunction with the CEM applied to the existing vehicle structures to definitively limit the longitudinal loads during a collision.

These design approaches are not new to LRV designs and have all been applied on various light rail projects throughout the United States, with the most typical approach being the 2-g criteria. (Examples include San Francisco Municipal Rail LRVII; Pittsburgh Stage II; Boston #8; and Southern New Jersey Light Rail, to name a few.)

Industry Practice—Traditional 2-g Criteria

The most straightforward approach for sizing the buff strength of the LFE would be to maintain the 2-g ratio based on the overall weight of the modified vehicle. This is the strength-based approach, which has the benefit of simplicity and service history. However, when compared with the other approaches, the 2-g criteria could result in added weight from the structure, which is undesirable. If the 2-g ratio is strictly maintained, the empty weight of a vehicle with a 30-foot-long LFE is estimated to be in the range of 145,000 to 147,000 lbs. Therefore, the buff load of the LFE would need to be approximately 294,000 lbs plus some additional factor to ensure that the LFE would not collapse. In addition, the 2-g approach, again if strictly followed, would require some structural modifications to the existing cars, which were designed for a buff load of 200,000 lbs, although some excess capacity might already exist in the structure. The disadvantages of this approach are excessive weight from the LFE and the possible modifications to the existing vehicle. The increased vehicle buff strength, as discussed before, does not necessarily provide for a crashworthy design because the higher longitudinal body stiffness can result in higher passenger decelerations in a collision.

Strength-Based Design: Match the Existing Buff Strength

Another option for the LFE design could be to follow a second strength-based design philosophy—that is, to match the existing buff load (for instance, 200,000 lbs). The main advantage of this approach is that the existing cars remain unchanged or may need fewer modifications than with the 2-g design. The weight of the structures would also be lower as compared with the traditional 2-g approach. Using the LFE AWO weight of 33,000 lbs, the “g” ratio of the LFE LRV would be approximately 1.4 g; the traditional industry practice of 2-g would not be achieved. Therefore, the performance of the structures during a collision must be carefully examined to ensure that the LFE module will not suffer loss of occupied volume during a collision. Hence, the difference between the buff strength, which is typically specified as a minimum value, and the actual collapse strength of an existing vehicle must also be examined relative to the design of the LFE.

One disadvantage of this approach that must be considered is legality. If some of the revised strength requirements are lower than those traditionally used—for example, lower than the 2-g industry practice without any other reinforcements or changes—there is potential exposure to a legal argument in case of injury or fatality. The inevitable argument would be that, if the LRV had been designed to “industry standards,” then this scenario would have never happened.

Strength-Based Approach with Crash Energy Design Principles

This approach is essentially a variation of the strength-based approach as described above. In this case, it is assumed that the existing structure requires modification in order to achieve the desired force level and deformation response during collision. The foundation of the CEM concept is the definition of crush zones where impact energy is absorbed in a controlled manner. The structure in the CEM zone is designed based on vehicle weight, estimated velocity at impact (i.e., kinetic energy), available energy absorption via the coupler, available space, and passenger deceleration limits. By limiting the peak buff load generated during the collision event via the CEM zones, the overall weight of the structures may be reduced as compared with the strength-based (2-g) approach. Deceleration levels could also be lower with CEM, thereby reducing the potential for injury to passengers. The CEM zone must be optimized such that the desired amount of energy absorption is achieved without creating forces that exceed the strength and space limitations of the vehicle structure.

APPROACH AND METHODOLOGY

The use of CEM principles includes the important step of defining the collision scenario used to size the energy absorption structures. For typical LRV specifications written to date, the collision scenario is based on LRVs colliding with other LRVs on the system. [Examples of where CEM concepts using pre-defined collisions have been utilized include Southern New Jersey Light Rail, Hudson–Bergen Light Rail, John F. Kennedy (JFK) Airport Access, and the ASME RT-1 Light Rail specification, which is currently under development.] Collision scenarios are typically defined by specifying the following:

- The track geometry and conditions (typically dry, level tangent track);
- The couplers and anticlimbers fully engaged;
- The number of vehicles in the consists involved (typically the maximum consist size for both trains);
- The vehicle weights, including passenger loads; and
- The impact speed, also called closing speed (the maximum value often used is 15 mph for systems with a 55 to 60 mph maximum design speed).

The values noted are examples. These variables must be reviewed for each system when defining a scenario so that the CEM zone is custom-designed for the intended service. When defining the design collision scenario, it is particularly important to consider the system speed (since the collision energy to be absorbed by the structure increases with the square of velocity). Once the collision scenario is defined and the resulting collision energy is determined, the CEM zones can be designed.

Again, the force level and available space must be considered so that the smallest possible deformation is achieved without unduly high accelerations. The desired deceleration rate, location, available space, and strength of the existing structure are all key variables in determining the size and force level of the energy absorption devices. In general, the longer the absorption device, the lower the force level (deceleration rate) can be to absorb a given amount of energy. As part of this study, the use of the energy-based design approach will be considered in an effort to limit the peak longitudinal loading on the vehicle, and hence the LFE.

Approach

A variety of collision scenarios were analyzed using dynamic motion analyses to estimate acceleration (or deceleration) levels in each vehicle and overall deformation. The analyses use lumped mass-spring models to estimate the interaction and response of vehicles.

These analyses are first-order approximations of the collision events. The response of the structure on a detailed level is not obtained from this approach. Rather, the global structural characteristics needed to achieve a desired response (such as a limited deceleration rate, limited peak force, etc.) can be ascertained from the results. Collision scenarios similar to those discussed previously will be defined and simulated. The analysis is conducted using the following steps:

- Define the vehicle characteristics to use as model input data;
- Define the collision scenarios;
- Build the model and run the analyses;
- Collect the data generated from the simulation and examine the results; and
- Formulate conclusions.

The simulation is based on the dynamic analysis of mass-spring systems. A commercially available computer program, Working Model 2D, was used to formulate the analysis and solve the resulting system of equations. (Working Model 2D has been used by Booz Allen on the JFK Airport Access project, on the Southern New Jersey Light Rail project, and for the development of the ASME RT-1 standard to simulate vehicle collisions.) Working Model 2D can simulate the static and dynamic (including impulse) response of any combination of masses, springs, dampers, pulleys, and gears under external loads such as forces, friction, and torque. All of the elements and parameters in the program can be customized to simulate any desired scenario, including non-linear or time-varying inputs such as a spring with non-linear stiffness or a pulsating force.

In the simulation, vehicle consists were placed in motion at the envisioned collision velocity and collided with standing vehicles that had their brakes on. Vehicle configurations included in the study were

- Existing vehicle with no LFE;
- Existing vehicle with an LFE and CEM zones (strength-based approach with CEM); and
- Existing vehicle with an LFE both designed to 2-g based on the new total weight.

These configurations were selected because they represent the possible range of vehicle strengths. The strength-based approach was not modeled because it is essentially a variation of the CEM approach.

These configurations were analyzed under four different scenarios, each scenario having three closing speeds. The collision scenarios included single- and multi-vehicle consists, modified vehicles with LFEs, and the existing vehicles.

For each analysis conducted, the vehicles were modeled as a rigid block or series of blocks connected by springs with stiffness values selected to simulate the crush strength of the vehicle structure or couplers. The stiffness and crush strength of the structures were represented as spring elements located between the respective mass elements. Where possible, a single spring was used to represent components that act in series, for example, couplers between vehicles in a train. Couplers at the front of the colliding trains have been modeled individually to explicitly determine deflection at the impact point. Connections such as articulation joints are not modeled directly; sections of a complete vehicle are connected directly by spring elements simulating the stiffness of the structure so that load transfer between sections (the end car and LFE) is properly simulated. A two-step approach was used for this study:

- Simulation 1 included a number of analyses to determine the worst-case combination of speed and number of vehicles in terms of both deformation and accelerations. Particular attention will be given to deformation because the available space on the existing cars is a clear constraint. For this simulation, the mass of the LFE was lumped into the mass of the end cars and the LFE structure was simulated by the springs between the end cars. Hence, acceleration values will be average values since the LFE mass is not discretely modeled.
- Simulation 2 was conducted using refined models so that the worst-case scenario determined from Simulation 1 can be examined in more detail. The refined model included additional mass-spring elements to depict the LFE unit separately.

For this study, the collision performance has been measured only in terms of peak and average accelerations and deformation.

Methodology and Definition of Vehicle Model

The vehicle characteristics in the models were selected using data and structural analysis information from the procurement project records. The data collected from previous evaluations or studies of the LFE concept were also used. Where noted, estimates were made for any missing details based on established industry standards and past experience. The main input data for the vehicle model are weight, coupler force data, and structural stiffness (force deformation characteristics).

For the purposes of this study, it is assumed that the collapse load will be higher than the buff load and will remain constant as the end car structure is crushed. Although this assumption is highly dependent on the structural geometry of the under-frame, the intent of the study is not to evaluate a specific design, but rather to compare vehicle design philosophies and how they might influence the design loads for the LFE. In order to limit the number of permutations in the analysis, the LFE buff strength was selected based on a reasonable maximum value given consideration for weight limitations.

The weight for the LFE using CEM on the existing vehicle was estimated using the unit weight of the existing vehicle: 1,100 lbs/ft. This value is assumed to include the weight from structures added for the CEM zone. The unit weight estimate is somewhat conservative because it includes the weight of subsystems, such as propulsion inverters, that will not be present on the LFE. For this study, it has been assumed that the collapse strength of the LFE is equal to the buff strength, which is a very conservative assumption. In reality, collapse strength or ultimate strength is typically higher than the static buff strength.

Additionally, models with CEM zones require the maximum length of crush to be specifically defined in order to properly simulate the difference between CEM and the passenger compartment collapse. The following lengths were used:

- Crush zone length for Simulation 1 is 21 in. (this value was selected as a base point). The zone is assumed to begin at the back of the anticlimber, extending 21 in. into the cab area.
- Crush zone length for Simulation 2 is 30 in., extending from the back of the anticlimber inwards.

The springs that represent the passenger compartments and the LFE structure have been modeled with sufficient length to capture the full dynamic response of the system; therefore, the maximum crush can be estimated. In other words, a crush length was specified for CEM zones only.

Generation of Characteristic Force Deflection Curve for the Vehicles

The individual structural characteristics and the crush zone lengths noted in the previous section were combined in the models to represent the response of the structure under different collision scenarios. The simulation depicts the response of the vehicle as a whole and of the separate “cars” or modules (such as the leading car or LFE). To achieve this, the idealized force-deflection curves were generated using the strength characteristics. The curves represent the average force generated as the coupler and structure collapse over distance. These curves are idealized to simplify the calculation; they are estimations with sufficient accuracy for a preliminary study. In reality, a rail car structure collapsing under dynamic loading displays highly varying force deflection curves with many peaks, although an average level is typically maintained.

The force versus deflection curves used in the simulations represent

- The existing vehicle, including the couplers;
- The end cars of a vehicle with CEM zones designed to 200,000 lbs buff strength;
- The end cars of a vehicle designed to a 2-g (based on total weight of end cars and the LFE) buff strength;
- The LFE module designed to the 200,000 lbs buff strength; and
- The LFE designed to 2-g (based on total weight).

Once all properties (i.e., velocity and static/dynamic frictions) of the mass and spring elements are defined and connected, the model is ready to be analyzed.

Analysis Assumptions and Collision Scenarios

The analysis is based on assumptions that are commonly used in recent vehicle specifications (for example, Southern New Jersey Light Rail and JFK Airport Access), which include crashworthiness and CEM requirements. The assumptions are:

- Both consists are on level tangent track;
- The standing vehicle(s) is fully braked and the coefficient of friction between the wheel and the rails is equal to 0.3;
- The couplers fully engage and absorb energy during all collisions;
- The moving vehicle(s) is not in braking mode—for example, it maintains a constant velocity up to impact;
- The maximum number of vehicles in any consist is two; and
- Collisions with vehicles of dissimilar strength may occur.

The following collision scenarios were analyzed as part of Simulation 1:

- Scenario 1: One existing vehicle colliding into two vehicles with an LFE and CEM.
- Scenario 2: One vehicle with an LFE and CEM running into two existing vehicles.
- Scenario 3: Two existing vehicles running into two existing vehicles.
- Scenario 4: Two vehicles with LFEs and CEM running into two identical vehicles.

Each of these scenarios was analyzed at 5, 15, and 17.5 mph closing speeds. The first two speeds were selected based on industry practice. Typical LRV specifications with crashworthiness requirements call for a maximum collision design speed of 15 mph. The 17.5 mph was selected because it is approximately half the estimated average system speed. It has been included for reference only.

RESULTS

The following table shows the results obtained for the simulations conducted. In Simulation 1, several different scenarios were analyzed to determine the worst-case scenario. Typically, the scenario with the highest speed and largest consist proves to be the worst case for consists of the same vehicle strength, although this may not always be the case when vehicles of mixed strength are considered.

Results of Simulation 1: Determining Worst-Case Scenario—Simplified Model

In Simulation 1**,** all of the scenarios noted previously were analyzed. The results of these scenarios, shown in Table 1, indicate that, in collision Scenario 4, two modified vehicles (with LFE and CEM zones) colliding with the same two vehicles consist is the worst case, assuming

TABLE 1 Summary of Results for Collision Scenario 4 (Simplified Model)

SIMULATION 1

Scenario 4: Two Vehicles with LFEs and CEM Colliding into Two Similar Vehicles

A) Speed = 5 mph

Vehicle	Total Coupler Deformation (in.)	CEM Zone Deformation (in.)	Passenger Compartment Deformation (in.)	Max. Accel (+)/ Decel. (-) (g)	Avg. Accel (+)/ Decel. (-) (g)
Vehicle 2	0.39	---	---	-0.51	-0.51
Vehicle 1	9.8	---	---	-0.51	-0.51
Vehicle 3	12	0.5	---	0.51	0.51
Vehicle 4	0.49	---	---	0.51	0.51

B) Speed = 15 mph

Vehicle	Total Coupler Deformation (in.)	CEM Zone Deformation (in.)	Passenger Compartment Deformation (in.)	Max. Accel (+)/ Decel. (-) (g)	Avg. Accel (+)/ Decel. (-) (g)
Vehicle 2	10.6	0	---	-0.51	-0.51
Vehicle 1	12	21	4	-1.18	-1.18
Vehicle 3	12	21	2	1.18	1.18
Vehicle 4	11	0	---	0.51	0.51

C) Speed = 17.5 mph

Vehicle	Total Coupler Deformation (in.)	CEM Zone Deformation (in.)	Passenger Compartment Deformation (in.)	Max. Accel (+)/ Decel. (-) (g)	Avg. Accel (+)/ Decel. (-) (g)
Vehicle 2	12	2	---	-1.35	-1.35
Vehicle 1	12	21	15.6	-1.20	-1.20
Vehicle 3	12	21	4	1.20	1.20
Vehicle 4	12	2	---	1.35	1.35

the entire fleet is fitted with LFEs (mixed scenarios—i.e. vehicles of different strength colliding together—were also considered and will be discussed in a later section).

At 15 mph, the coupler and the CEM zone are expended completely and deformation has begun in the passenger compartment on vehicles 1 and 3, which are at the impact interface. This result indicates that a 21-in. CEM zone at 200,000 lbs does not have sufficient energy absorption to prevent deformation of the passenger compartment at 15 mph. In Simulation 2, the CEM zone was increased to 30 in., but the force level stayed the same. This was examined closer in the refined analysis (Simulation 2) with multi-spring models. The average accelerations are about the same for each of the respective vehicles in the train consists.

The main goal of this simulation was to confirm that the two-cars-into-two-cars scenario is the worst case, which has been proven. Thus, Scenario 4 can be used in the refined analysis without the need to check all other scenarios.

Results of Simulation 2: Refined Analysis for Scenario 4

Using the three-block model refinement and collision Scenario 4, another analysis was conducted for 5, 15, and 17.5 mph speeds. Note that the length of the CEM zone is increased to 30 in. (versus 21 in. from Simulation 1). This was done to allow for sufficient deflection so that the maximum length required in the CEM zone could be determined. As in Simulation 1, the crush force of the CEM zone was 200,000 lbs. All of the parameters and assumptions noted previously were also retained. The impact occurs at the same interface as Simulation 1, between vehicles 1 and 3. The results for this simulation (at 15 mph) are presented below.

Vehicles 1 and 2—Moving Consist

- Coupler stroke is used entirely at both ends of vehicle 1, one end located at the impact interface and the other coupled with vehicle 2.
- The entire coupler stroke is expended on vehicle 2, indicating that the collision energy has been distributed in part along the length of the vehicle through the couplers. Although the deformation-to-crush zones show that the majority of the energy was absorbed at the impact ends.
- The CEM zone crushed on vehicle 1 (at end car 1A only) was over 28 in. No damage occurred in the passenger compartment. This indicates that, in principle, a 30-in. crush zone with an average force of 200,000 lbs is sufficient to absorb the collision energy generated from this scenario.
- The LFE deformed approximately 1 in. in total (the sum of the deflections at both ends). Hence, the LFE had just begun plastic deformation in this model, but extensive collapse (loss of occupied volume) did not occur. Peak deceleration was 1.72 g.
- Since the LFE did not significantly crush, the CEM zone in this model was effective in limiting peak loading.
- Peak deceleration levels occurred in vehicle 1 at 2.21 g. This deceleration level is not excessively high and it occurred over a very short duration. The average accelerations were lower.

Vehicles 3 and 4—Standing Consist (Brakes On)

- The coupler stroke was used entirely at the impact interface of vehicle 3. At the coupling interface, between vehicle 3 and vehicle 4 only, 11.3 in. was used.
- The CEM zone on vehicle 3 was crushed almost 19 in. Peak acceleration was 2.7 g. The length of crush was not the same as vehicle 1 because of the brake force (simulated as a friction force). It is expected that one vehicle would sustain more damage than another when the standing vehicle has its brakes applied.
- As in vehicle 3, the LFE deformed approximately 1 in. in total (the sum of the deformations at both ends). Hence, the LFE has likely just begun plastic deformation, but extensive collapse (loss of occupied volume) did not occur. The maximum deceleration was recorded as 2.47 g.

Comparison of the CEM Versus the 2-g Approach—Scenario 4.1

An additional scenario similar to Scenario 4 was analyzed using vehicles designed to the 2-g approach. As previously noted, the 2-g strength ratio is based on the assumed weight of the LFE and the existing vehicle. The results of this scenario were compared with Scenario 4 to determine the differences between using CEM and the 2-g approach:

- In comparing the 2-g results with the CEM design, it can be seen that the CEM zones limit the peak and average accelerations in passenger compartments significantly.
- The strength-based approach with a CEM zone was successful in limiting the loading transferred to the LFE body because the acceleration levels are lower at the LFE.
- The strength-based approach with a CEM zone also reduces the acceleration levels in the second vehicle in the train consist.
- The deformation is higher in the ends of the vehicle with CEM, although this is expected. The intent of the CEM zone is to deform in a controlled manner (i.e., at a specific force) over a predetermined distance.
- The second vehicle in both consists sustained structural damage, indicating higher energy levels between coupled vehicles. This did not occur in the CEM case due to the lower weight of the vehicles and the energy absorption at the impact interface.
- The deformation level in the LFE is very low for both the CEM and 2-g vehicle. Hence, loss of occupied volume did not occur. However, the overall weight of vehicle with an LFE and CEM is estimated to be less than the 2-g approach. This weight savings may be significant when considering propulsion and braking requirements. Additionally, the lighter LFE may have lower energy and maintenance costs.

To simplify the comparison, Table 2 shows only the maximum values for the deformation and acceleration along the vehicles in the moving consist from Scenarios 4 and 4.1.

TABLE 2 Comparison of Results between the CEM and 2-g Approach for Collision Scenarios 4 and 4.1 (2 vehicles into 2 vehicles at 15 mph)

	1st Vehicle		**2nd Vehicle**	
	CEM	**2-g**	**CEM**	**2-g**
Max. Deformation (in.)				
Coupler	12	12	12	12
End Car Structure (CEM or Under-frame)	28.4	11.3	0	1.3
LFE Structure (Max. value at any end)	0.5	0.35	0.173	0.3
Accelerations Peak, g				
End Cars	2.2	4.6	0.85	4.7
LFE	1.72	3.7	0.51	4.0
Accelerations Avg., g				
End Cars	1.0	1.5	0.51	2.1
LFE	1.1	1.5	0.51	1.7

SUMMARY AND CONCLUSION

A number of collision scenarios were analyzed via first-order lumped mass-spring dynamic models to examine the feasibility of implementing an LFE module designed to a longitudinal compression specification not based on the 2-g de facto industry standard. In the strictest interpretation of the 2-g approach, both the existing vehicles and the LFE would need to meet this requirement based on their total combined weight. This would result in a buff-strength value for the LFE and end cars that is higher than that of the existing LRVs. Instead, the use of a strength-based approach with CEM principles to limit peak longitudinal loading in the vehicles, and hence the LFE, was examined with the goal of minimizing the added weight from an LFE. Using available data from the records, estimates were made for the weight and strength values of the LFE and for the size and strength of the CEM zone. The maximum longitudinal strength of the LFE, when fitted to a vehicle with CEM, was assumed to be 200,000 lbs.

The dynamic analysis was conducted to examine the acceleration and deformation of various simulated structural elements in the vehicle under different collision scenarios, with speeds up to 15 miles per hour. Analyses with speeds up to 17.5 miles per hour (half the average system speed) have been included for reference.

Based on the data available, the assumptions noted, and the analysis results presented in this report, the following is concluded:

- There is a risk that an LRV LFE designed to the traditional 2-g criterion would not meet the desired structural weight limits needed to reinforce existing structure due to additional weight of LFE.
- It is technically feasible to implement an LFE designed to a specific longitudinal strength value (i.e., using a strength-based approach), instead of applying the 2-g buff load criteria as calculated from the new total weight. The longitudinal strength value for the LFE could be established in two ways.

Option 1 is to maintain a minimum static strength (200,000 lbs for instance). Determine the load generated from the existing end car structure in a collision under a rational collision scenario and design the LFE structure to resist this load without loss of occupied volume. However, due to the structural design of the existing end structures, the end sill and center sill could be very stiff and may generate very high loads before collapsing in a vehicle-to-vehicle collision. The end structures must be capable of progressive energy absorption in order to avoid high load fluctuation and excessive or uncontrolled deformation. It is likely that the significant changes in the existing structure would be required to achieve this.

Option 2 is to augment the end car structure, in accordance with CEM principles, by adding the energy absorption elements designed to mitigate a rational collision scenario. As in Option 1, the minimum static strength must at least match that of the existing structure. The results of the analysis in this study demonstrate how adding CEM can be beneficial in limiting longitudinal loads transferred through a vehicle during the collision scenarios noted. The analysis shows that for a collision of two vehicles into two vehicles at 15 mph, (a) for vehicles with an LFE and CEM zones having an average crush strength of 200,000 lbs, the collision energy could be absorbed with approximately 28 in. of crush at the front of the vehicles involved; (b) as with the CEM zone, the LFE module, having 200,000 lbs of crush strength, sustained approximately 1 in. of total deformation under this scenario; and (c) for vehicles with an LFE designed to the 2-g approach, approximately 12 to 13 in. of deformation occurs at the ends of each vehicle, which is less than the CEM approach. However, the peak acceleration levels are much higher.

For either option, the collapse strength of the structures must be examined in detail. Passenger compartments of the existing vehicle and the LFE must be capable of sustaining the peak crush loads from either the CEM zones or the existing end structure without collapsing. Both options require a significant engineering effort, including detailed linear and non-linear finite element analyses of the structures in order to determine the loads generated during a collision. The optimum location for the CEM zone would be forward of the cab area, configured with minimal effect on visibility. One possible concept could be two tube-like elements with a plunger arrangement that compresses a crushable element designed to achieve the desired force level. Tubes approximately 25 to 28 in. long could be integrated into the end sill structure.

The CEM concept also has technical risks and difficulties that must be considered:

- There are significant engineering costs and a long lead-time for complex analyses and testing.
- The CEM elements are custom designs that could prove difficult to develop.
- There are significant labor costs to retrofit the existing structure.
- Depending on the design, the weight savings may be lower than anticipated. It is estimated that the weight of the LFE–LRV combination designed using the 2-g approach can be approximately 5,000 lbs greater than the CEM approach.

The use of couplers with the highest possible energy absorption level significantly aid in mitigating a collision, regardless of the design approach selected.

Finally, as part of the specification development for a CEM zone and the LFE, many other structural aspects of the vehicle must be carefully reviewed to determine if strength levels are adequate and consistent with the CEM design.

Light Rail Vehicles' Low-Floor Center Section

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The issue addressed is how to increase capacity and update passenger accessibility to keep pace with the "low-floor" trend in the transit industry, without making obsolete an existing fleet.

The benefits of adding a new, low-floor center section to an existing light rail vehicle is discussed, and various issues and characteristics that must be considered and resolved before proceeding are identified, including, but not limited to: size of vehicle, aesthetic appearance, performance, propulsion and braking systems, all other onboard systems, structural strength, size and length of station platforms, interface with station platforms, and maintenance shop and other wayside facilities.

It is concluded that with good base line conditions, the addition of a low-floor center section to an existing vehicle allows a transit agency to upgrade capacity, facilitate passenger access to the rail vehicles, and transition toward the "low-floor" trend in the transit industry without having to either sell or scrap a relatively new, existing fleet or be faced with operating a mixed fleet of existing high-floor vehicles and new low-floor vehicles.

INTRODUCTION

From their inception, rail transit systems have continually expanded, improved service, enhanced availability, and increased the level of comfort for passengers. One of the latest developments in this continuing evolution is the ability to provide direct, level boarding for light rail vehicles (LRVs). Previously, this type of passenger accessibility was an exclusive characteristic of heavy rail systems using high platforms. High platforms are inherently incompatible in city streets with mixed pedestrian and automobile traffic. The new designs of LRVs address and partially mitigate this problem with floor levels that are approximately 14 in. above the top of rail (TOR). The low-floor rail vehicle, combined with a matching station platform, can be accepted into the streets of a city with relatively minor inconveniences. The low-floor, level boarding mode of operation greatly enhances accessibility for all passengers, reduces station dwell times and facilitates overall operation of the system. Also, level boarding accessibility allows the elimination of the special equipment and facilities, both on the vehicles and at the stations that are required for compliance with Americans with Disabilities Act (ADA).

DEFINITION OF THE PROBLEM

Providing level boarding for all passengers with the low-floor vehicle configuration is a very attractive feature. For a new light rail transit system there is almost no decision to make. The design of the new stations, maintenance facility, and other wayside facilities can be matched to the dimensions and configuration of the rail vehicles and the overall low-floor, level boarding concept can be readily incorporated into a new system. For an existing light rail system that is either expanding or upgrading, the decision to change to level boarding configuration is much more difficult. For an existing system there are two choices:

- Continue to operate and expand or upgrade the system, “as is;” or
- Convert to low-floor, level boarding configuration and modify all existing stations and facilities as required.

From a maintenance and operations point of view, continuing to operate “as is” is the path of least resistance. The agency simply buys more vehicles with the same dimensions and characteristics and continues to operate them in the same manner, using the same stations and maintenance facilities. However, the general ridership, ADA community, local and federal government agencies, combined with the transit agency’s inherent desire to improve the system may influence the decision to convert to low-floor, level boarding configuration. Regardless of these influences, the transit agency must consider the financial impact of the modifications and changes that will be necessary to convert to level boarding operation and the disruption caused by the implementation of these changes. Converting to low-floor, level boarding configuration is difficult and expensive. Changing an existing, high-floor system to the low-floor, level boarding mode will require

- A new fleet of low-floor rail vehicles;
- Modifications to all existing passenger stations to provide level boarding onto the new low-floor vehicles;
- Modifications to maintenance facilities to provide for full maintenance access to the equipment installed on the roof of the new low-floor cars; and
- Modifications to any other wayside facilities that are affected by the change in characteristics of the low-floor vehicle.

Additionally, the disposition of the existing fleet of rail vehicles has to be determined. If the vehicles have reached the end of their useful or economic life they can be retired (scrapped), and new vehicles can be purchased as part of the upgrade. Selling the existing fleet of vehicles to another property—while sounding like an easy solution—requires a willing buyer with a compatible system and available funds. With other transit systems also considering and trying to convert to low-floor operation, the sale of a used, high-floor vehicle becomes improbable.

Somehow the existing high-floor and new low-floor vehicles have to be integrated together while still providing the desired, full-time, level boarding accessibility for the passengers. The most direct solution is to establish operational procedures for a mixed fleet of vehicles, requiring that all single car trains and at least one car in any multicar train is a low-floor vehicle. Obviously, these operational restrictions can be implemented, but there will be an adjustment period for the passengers and a continuing complication in the operational and maintenance procedures, to maintain the criteria.

If the decision is to continue “as is,” the course of action to expand is clear: follow the general criteria and guidelines that have been previously established and used for construction of the existing system.

The premise addressed in this paper is that an existing transit agency makes a decision to convert to an overall low-floor, level boarding mode of operation as part of an upgrade or expansion of the system.

The apparent course of action is to define and procure a new low-floor vehicle, modify the stations and facilities to match the new vehicle and establish procedures to operate a mixed fleet of high-floor and low-floor vehicles. However, depending on the characteristics of the existing fleet, another option is available for converting to low-floor, level boarding operation. Insert a new, low-floor center section into the existing, articulated LRV.

The following discussion will explore and analyze some of the more significant issues that must be addressed for each aspect of the system that will be affected by the low-floor, level boarding configuration and compare the differences between the low-floor vehicle and insertion of a low-floor section into an existing vehicle.

REAL WORLD SCENARIO

Many agencies have discussed the possibilities of incorporating a new center section into an existing vehicle configuration. Until now in North America, this has been an intellectual exercise. This paper will discuss the design, review, engineering process, and decisions leading up to the implementation of an actual test program of a low-floor center section by the Dallas Area Rapid Transit (DART).

DART is the newest and fastest growing, fully operational, high speed (65 mph), LRT system in the United States:

- Design and construction of the DART Starter System was initiated in 1990.
- DART issued the first contract for the procurement of LRVs in November 1991.
- Revenue service on the Starter System opened in June 1996 with 21 mi of track and 40 LRVs.
- In November 1997, DART issued a contract modification to procure 34 additional LRVs to supplement the existing fleet and prepare for Build-Out Phase I of the North East Corridor.
- In May 1998, DART issued a new contract for the procurement of 21 LRVs to support service on the Build-Out Phase I of the North Central Corridor.
- At the end of 2002, DART completed the 23-mi, Build-Out Phase I expansion and is now operating a 44-mi system with 95 LRVs.

In less than 10 years DART has doubled the size of the system and the fleet of rail vehicles. Continuing this rapid expansion, DART has initiated design and construction for Build-Out Phase II, which is scheduled for completion by 2012. Build-Out Phase II will again double the size of the system by adding approximately 44 mi of double track and increasing the fleet by at least 100 LRVs.

As part of the Phase II expansion, DART has decided to change to the low-floor, level boarding, mode of operation.

The current fleet of DART LRVs consists of “high-floor” vehicles. Passengers board from an 8 in. platform, step up 8 in. to the vehicle, and then there are three more 8 in. steps up to the passenger floor that is 40 in. above TOR. ADA compliance is provided with high blocks located at the end of the platform combined with a trap/bridge arrangement on the vehicle. The

DART LRVs are all relatively new and hence were not considered for retirement (scrapping). Selling the vehicles to another property was recognized as an unrealistic course of action. To convert to level boarding operation DART either has to procure new low-floor cars and operate a mixed fleet of high-floor and low-floor vehicles or insert a low-floor center section into the existing vehicles. (As of August 2003, DART has not made a final decision with respect to the type of vehicle that will be used for future expansion fleets. The following information is a summary of activities to date. DART's final decision will be based on this information, any new factors that may be identified, discussion with DART member cities, local community and special interest groups, and coordination with FTA.)

The (strong) possibility of a conversion to low-floor, level boarding operation was recognized very early in the Build-Out Phase II program. Preliminary, internal reviews and discussions were initiated to determine if a typical low-floor vehicle could be procured to meet DART's criteria of appearance, operational requirements and performance characteristics. Alternative courses of action were explored as well. Some of the salient characteristics that DART did not want to loose in the conversion to low-floor, level boarding operation were

- "Signature" appearance of the DART LRV,
- Acceleration and braking performance (3.0 mphps), and
- 65 mph operating speed of the rail vehicles.

Vehicles

DART has an existing fleet of 95 high-floor LRVs and is in the process of exercising an option for 20 additional high-floor vehicles, all from the same manufacturer and of the same design. The overall age of the fleet is relatively low. The 40 oldest vehicles started service in 1995–1996. The 55 newer vehicles were put into service in 2000–2001. The 20 additional LRVs are scheduled for delivery in 2005. In general, the fleet is considered to be reliable and is well accepted by the public. The specified design life of the vehicles is 30 years. As discussed previously, the ideas of retiring or selling the fleet were discarded early in the studies. Therefore, the existing fleet of vehicles has to be incorporated into the new level boarding mode of operation, until they reach the end of their economic life. There are two ways of accomplishing this:

- Operate a mixed fleet of vehicles consisting of the existing fleet of DART LRVs combined with new low-floor vehicles; or
- Insert a low-floor center section into the existing vehicles and procure additional vehicles to meet the desired fleet size.

Low-Floor Light Rail Vehicles

Low-floor light rail vehicles (LFLRVs) are considered to be established, proven technology. They are in successful operation on numerous properties in Europe and in North America. At the present time there is no LFLRV in service that is designed for 65-mph operation. With the exception of Metro Rail in Houston, Texas, all of the LFLRVs in operation are designed for 55-mph operation. The LFLRV that is being procured for Houston, Texas, is specified to have an operating speed of 66 mph. Dynamic testing of this vehicle is scheduled to begin in 2003.

Because of the established, acceptable, history of operation, a detailed review of the characteristics of a typical LFLRV was not pursued. LFLRVs are considered to be an acceptable alternative for the DART system and Phase II expansion, with the qualification that an operating speed of 65 mph can be achieved in normal revenue operation.

Low-floor Center Section

Center section inserts are a newer, less established, technology that have not been employed in North America. DART undertook an in-depth investigation to determine if the use of a center section is a viable alternative that could be used as part of the Phase II expansion to both increase capacity and enhance overall passenger accessibility.

Several transit properties in Europe have inserted center sections into existing vehicles to increase capacity. In general, all of these applications have been low-speed (35 mph to 45 mph) applications. With the exception of the prototype operating in Dallas, Texas, a center section insert has not been used for revenue service in North America. A center section can be installed in any articulated vehicle. The age of the vehicle and the technology of equipment used on the vehicle are the determining factors in the decision for installing a center section. If the vehicle is near the end of its useful life it may not be reasonable to invest a large amount of money in upgrades. If the propulsion, braking, or auxiliary equipment cannot support the weight increase and power requirements of the center section, the vehicle would not be acceptable for operations.

Another factor to be considered with the integration of a center section into an existing articulated vehicle is the overall structural strength. The DART LRV was designed to meet a "2g" requirement. That is, the buff load (end compression strength) of the car-body structure is designed to be twice the empty weight of the completed vehicle in the ready to run configuration.

The value of 2g is an historic value selected to represent a car-body strength high enough to withstand minor to intermediate collisions without basic structural damage, but low enough to minimize the potential for passenger injury. The car body must demonstrate both 2g end strength and the ability to crumple from the ends in a controlled manner when collision energy exceeds the structure's strength. This "cushions the blow" of the collision, providing a compromise between two factors that cause injury in collisions: 1) loss of passenger volume (crushing of the structure), by providing a reasonable level of static strength; and 2) controlled crush behavior when the car-body strength is exceeded. The ratio of "actual" weight of the DART LRV (107,000 lb) and "actual" structural buff test load (227,000 lb) is 2.12 g. Compared to similar articulated LRVs, the DART LRV is stronger. This characteristic makes the addition of the weight of the center section much more viable.

The DART LRV is both relatively new, and the propulsion, braking, and auxiliary systems are relatively current technology. These characteristics make the introduction of a low-floor center section into an existing vehicle—while still maintaining similar performance, operational characteristics and a top speed of 65 mph—a viable possibility.

The general technical issues of car-body strength, performance, speed, and so forth, related to the incorporation of a low-floor center section into the DART LRV were reviewed and the results were found to be favorable. The concept that was further developed was to maximize the passenger capacity of the low-floor center section while making the minimum number of changes to the existing vehicle. With no increase in propulsion, the additional weight of the center section would reduce overall acceleration of the modified vehicle to approximately 2.3 mphps. However, the operating speed of 65 mph would be maintained. The addition of a second trailer truck with 4-disc brakes would compensate for the extra weight and maintain the 3.0 mphps deceleration rate. Basically, the concept was to separate an existing LRV at the articulation joint and insert a low-floor center section and a second trailer truck between the two existing sections, creating a 3-section, double-articulated, 4-truck, 8-axle, “super” light rail vehicle (Super-LRV).

Structure

The structure of the DART low-floor center section is designed to be approximately 5% stronger than the existing LRV structure. This makes the center section uniform and consistent with the existing car-body structure and the philosophy of crash worthiness (controlled deformation starting at the ends of the vehicle) that is included in the basic design. The addition of the center section with an actual weight of 31,000 lb changes the weight/strength ratio of the DART Super-LRV to 1.64 g. This is equivalent to the older Type I and the new “Type II” low-floor vehicles currently in service in Portland, Oregon. The actual structural strength, 227,000 lb, and crash-worthiness characteristics of the DART car body structure remain unchanged.

Dimensions and Performance

The height, width, and appearance of the low-floor center section were matched to the existing car. The floor height of the low-floor area was selected to be 16 in. above TOR so that it would match the first step in the stairwells of the existing car. This is 2 in. higher than the typical 14 in. floor height of a low-floor car. While the low-floor center section could have been built to 14 in. above TOR, the 16 in. height was selected to eliminate the trip hazard with 14 in. platforms at stairwells of the existing doors, which are at 16 in. Truck spacing of 31 ft for the center section was selected to match the existing truck-to-truck distance to maximize capacity without changing the static and dynamic envelope, with the exception of the increase in overall length from 92 ft, 8 in. to 123 ft, 8 in. The center section was designed with articulation joint assemblies and electrical boxes for car line and train line signals that would directly match up with the respective A and B sections of the DART LRV. The second trailer truck and bolster is the same as the existing trailer truck.

Using the same articulation and center trucks has several advantages and a disadvantage. The advantages are that no new equipment is added to the vehicle and the use of a traditional truck configuration, with continuous, straight axles and full size, inboard, disc brakes (as compared to a typical low-floor center truck with stub axles and wheel or outboard mounted brake assemblies). The traditional center truck configuration is considered an essential element for maintaining a 65-mph operating speed and a 3.0-mphps deceleration rate of the Super-LRV. The disadvantage is that the area of the low-floor portion is limited to the distance between the center trucks.

Equipment

The capacity of the existing on-board air supply and friction braking systems was determined to be sufficient to support operation of the friction brakes and air spring on the additional truck and the door operators on the center section. The capacity of the low-voltage system was determined to be sufficient to operate all control functions of the center section and the track brakes on the additional truck. It was determined that an additional heating, ventilation, and air cooling (HVAC) unit would be required to be installed on the roof of the center section along with a new 10 kW static inverter to provide power for the HVAC unit and interior lightning. To the extent possible, existing components, equipment, and systems were incorporated into the design of the center section. The door operators, door panels, trailer truck, brakes, HVAC unit, interior lights, passenger seats, passenger side windows, portions of the interior lining, and other miscellaneous parts are identical to those used on the existing car. The operator's cab and all car and train line control functions remain unchanged. The only new or different operating component is a 10 kW static inverter that is used to power the HVAC unit on the center section. Insertion of a completed low-floor center section into a DART LRV was planned to be a simple process of unbolting, disconnecting, and separating a LRV, inserting a center section and trailer truck, and then bolting and connecting everything back together—the ultimate plug and play modification.

Implementation

As with all designs, the Super-LRV met all of the criteria and looked great on paper. The next logical step was to prove the concept in a real world application. As a joint research and development effort DART coordinated with Kinkisharyo International, LLC (manufacturer of the DART LRV), to build a complete, fully operational, low-floor center section, install it in a DART LRV, and test it on the DART system to confirm the results of the studies and reviews that had been performed. The basic agreement was that DART would supply equipment and materials from existing stores for installation on the center section and Kinkisharyo would provide the raw material, coordination, manufacturing, assembly, testing, and transportation of the center section. After inserting the center section into a vehicle, DART and Kinkisharyo would jointly conduct dynamic testing of the Super-LRV to verify the dynamic capabilities and performance. After this, the Super-LRV would be released for revenue service to verify operational acceptability and to gauge the reception by the ridership.

Manufacturing and Testing

The low-floor center section was manufactured at the Kinkisharyo manufacturing facility in Osaka, Japan, in 2001 and delivered to the DART maintenance facility in February 2002. The center section was installed in LRV 170 in May 2002 creating the first, fully-operational, double-articulated, 65-mph, Super-LRV. All of the planned static and dynamic tests have been successfully completed. The initial acceleration rate of the DART Super-LRV is 2.4 mphps, which is a little higher than expected. The Full Service Braking rate, 3.0 mphps, is the same as the existing LRV. Operating speed, 65 mph, remains the same. After completion of dynamic testing the Super-LRV was operated extensively on the DART system as an "out of service" train. Unofficial reports from DART Operations and Maintenance staff indicate the vehicle performed well and was well received by all. Currently, Super-LRV 170 is being used in daily revenue service. The only operational restriction is that the Super-LRV cannot operate as part of a 3-car consist because the resulting train (two standard DART LRVs and one Super-LRV) is too long for some of the existing station platforms

Conclusion

Because of the extensive review that was conducted and actual field-testing of a DART vehicle on the DART system, the addition of a low-floor center section is considered to be a viable alternative for further consideration during the Phase II Expansion plans, without qualifications.

Compatibility with the Rest of the System

Parallel with the review and design of the Super-LRV, the operational issues and interfaces with other systems (electrification, communications, and signals) and wayside facilities (stations and maintenance shop) were also considered. Each of these areas was carefully reviewed to determine what requirements needed to be incorporated into the design of the new line sections in Build-Out Phase II and what modifications needed to be implemented in the existing line sections.

Wayside Facilities

Length of the station platforms was identified as the primary limiting factor for the use of the longer vehicle with the center section. A LFLRV of approximately the same size and length as the current DART LRV will fit into the existing stations and any future plans for capacity increases.

A Super-LRV, with a center section installed is 123 ft, 8 in. overall. This is 31 ft longer than an existing LRV (92 ft, 8 in.). The most critical areas of station length are the 4 stations in the downtown Dallas Central Business District (CBD), because they are constrained by cross streets. The length of the station platforms that are in use in the CBD can accommodate a 2-car consist of Super-LRVs without modification. In terms of passenger seating this is equivalent to the 3-car trains that are being operated during rush hours.

In the future, when increased capacity requires the use of 4-car trains, all of the station platforms will have to be modified to increase platform length by approximately 100 ft. The original design of the Starter System included space for this expansion at all stations, including the four stations in the CBD area. In this event, a 3-car, Super-LRV consist, which has a higher seating capacity, can be used in place of a normal 4-car LRV train.

Wayside Systems: Signal System, Grade Crossings, Traction Electrification System, Overhead Catenary System

If a new LFLRV is selected and specified to have the same operating and performance characteristics as the current LRV, there would be no change in the interfaces with any of the operating wayside systems; Signals, grade crossings, train electrification system (TES) and overhead catenary system (OCS).

Although the Super-LRV has a lower acceleration rate, it has the same braking rate as the current vehicle, so no change would be required for the Signal System block length or the grade crossing approach circuits. With the Super-LRV, each vehicle has the same propulsion system and will have the same maximum current limit as the existing vehicle. However, there will be fewer cars operating for the same number of passenger seats that are in service, resulting in a net reduction in power consumption (cost) and general wear on the OCS.

Operations

A new LFLRV would be specified to have the same level of performance and speed, as the existing DART vehicle, and hence would have no impact on the current operation.

Because of the extra weight of the center sections in the Super-LRV, it will have a lower initial acceleration rate. However, it has been determined that the existing schedules could be maintained on the existing system. Simulations using the lower acceleration rate of the Super-LRV indicate that the worst case run from terminal to terminal results in an increase in the running time of approximately 2 min on one of the lines. Detailed review of the simulations indicates that the majority of this time is lost in central areas of the system where station spacing is reduced to approximately 1 mi and even less in the CBD. This run time increase is considered to be acceptable in the overall schedule of operations and is absorbed in the turn times at the end of the lines. As the DART system expands and station spacing increases in the outer areas, the effect of the lower initial acceleration on overall run time is further reduced.

Capacity

A new LFLRV would have equivalent seating capacity as the current vehicle, as shown in Table 1.

As part of the modification to insert a center section into a DART LRV, two double-flip seats (four seats) that were removed by DART to enhance ADA accessibility will be reinstalled, and four new single seats will be installed. Combined with the 24 seats in the center section, the seating capacity of a Super-LRV is 104. A 2-car, Super-LRV consist can be directly substituted for a 3-car, LRV consist without modification to platform length and provide nearly equivalent passenger capacity. Table 1 lists a summary comparison of the seating capacity of various train configurations.

Maintenance

A new LFLRV would have a high percentage of new components, equipment, and systems. Operations and Maintenance staff would have to be trained on both a new LFLRV and the existing vehicles. Spare parts would have to be stocked for both types of vehicles.

The introduction of a Super-LRV into the DART system has no change in operations and effectively no change to the maintenance procedures, spare parts, and training that are required to keep the Super-LRV in revenue service. With the exception of the new static inverter installed on the roof of the C-car, all of the operating equipment is the same, with complete interchangeability, as the equipment used on the current vehicle.

Service and Inspection Facility

The Service and Inspection (S&I)facility will have to be modified regardless of the type of low-floor vehicle that is selected. For any low-floor vehicle, a second maintenance level would have to be installed at roof height to provide for full maintenance access to the roof mounted equipment. The Super-LRV is 31 ft longer, which requires that the maintenance pits be extended, and the in-floor hoists modified to allow access to the equipment.

TABLE 1 Comparison of Seating Capacity by Car Consist

	DART LRV (# Seats)	LFLRV (# Seats)	Super-LRV (# Seats)
1 Car	72	76	104
2 Car	144	152	208
3 Car	216	228	312
4 Car	288	304	----

Note: In some hours of intermediate, off-peak operation, when passenger volume is lower, it will be possible to operate a single Super-LRV in place of a 2-car normal LRV train.

CONCLUSION

A new LFLRV can be incorporated into DART's plans for system expansion and is considered to be a readily available alternative for the planning and implementation for Phase II expansion and future increases in capacity—with the qualification that a 65-mph operational speed can be provided.

Review of a center section concept and application including actual manufacture and testing of a low-floor center section shows that the Super-LRV concept is also a viable and now proven course of action to support the Phase II expansion and future increases in capacity, without qualification, and has additional benefits when compared to a new LFLRV.

DART BUILD-OUT PHASE II

With the successful completion of the joint development effort of the Super-LRV, DART had two general vehicle designs, LFLRV or Super-LRV, either of which could be used as the basis for conversion to low-floor, level boarding operation, expansion of the system and future increases in capacity for the entire system. Using the two possible vehicle configurations as starting points, DART next began to review the existing lines and the planned expansions to determine what features must be designed into the new extensions and facilities and what modifications would need to be incorporated into the existing lines and facilities in order to convert to low-floor, level boarding operation.

Currently DART operates two lines with 3-car consists during peak hours. The two lines start and end in the Northern and Southern urban areas of Dallas and merge together to go through the CBD creating 4 "branches" (two to the North and two to the South) that feed into the CBD. Build-Out Phase II will add three more branches (two to the North and one to the South), also feeding into the CBD.

All of the existing stations can accommodate 3-car trains. When required to increase capacity the length of all of the existing station platforms can be increased to accommodate 4-car trains. Based on the enthusiastic public acceptance of the DART Light Rail System and a ridership in early 2003 of approximately 66,000 passengers per day, DART expects to increase capacity in the near future. In anticipation of this requirement all of the new stations in Build-Out Phase II will be built to accommodate 4-car trains. Also, in anticipation of the conversion to level boarding, the new platforms will be built at 16 in. above TOR to be compatible with either of the two low-floor vehicle designs.

The new vehicles that DART will purchase as part of the Phase II expansion will have to be operationally compatible with the existing fleet and will have to serve as the basis for level boarding operation.

The advantages and disadvantages of several different fleet configurations were reviewed to determine the best course of action. The existing DART LRV was used as the base line criteria for comparisons with other fleet configurations. Current plans are that DART will procure 20 LRVs to supplement the existing fleet for a total of 115 LRVs. For Phase II Build-Out an additional 100 LRVs (estimated) will potentially be procured. This will result in a total fleet size of 215 cars (95 + 20 + 100 = 215 cars) with 15,480 passenger seats (215 × 72 = 15,480 seats). The total number of passenger seats is the characteristic that allows direct comparison of the different fleet configurations. Of the various fleet combinations that were reviewed, three stand out as being potentially acceptable:

- Base Fleet—Maintain the existing fleet of 115 LRVs (72 seats) and procure 100 additional LRVs (72 seats). Total 215 cars (uniform fleet, high-floor cars) 15,480 seats.
- Option 1—Maintain the existing fleet of 115 high-floor LRVs (72 seats) and procure a new fleet of approximately 95 new low-floor LRVs (LFLRV) (76 seats). Total 210 cars (mixed fleet), 15,500 seats.
- Option 2—Procure 114 low-floor center sections to be installed in the existing fleet of vehicles (104 seats) and procure approximately 47 new LFLRVs (76 seats). Total 162 cars (mixed fleet), 15,532 seats.
- Option 3—Procure 114 low-floor center sections to be installed in the existing fleet of vehicles (104 seats) and procure approximately 34 new Super-LRVs that are the same as the existing fleet with the low-floor center section included (104 seats). Total 149 cars (uniform fleet), 15,496 seats.

All calculations that resulted in a "fraction" of a vehicle were rounded up to the next "whole" vehicle with the corresponding number of seats. It should also be noted that DART has procured one low-floor center section and installed it in LRV 170. In the fleet size calculations above and the cost estimations following, the numbers have been adjusted to reflect that DART already has one fully operational, Super-LRV that is ready for service.

Changes to existing wayside facilities and stations to take full advantage of the low-floor configuration will be required regardless of the course of action. The actual configuration of the vehicles will determine the modifications necessary at all existing facilities and the design and construction of all new facilities. A summary discussion of the various elements that will be affected and a comparison of some of the cost impacts is presented below.

COST—THE DRIVING FACTOR

As a starting point for the Build-Out Phase II studies, cost was used as the primary consideration in DART's review and decision-making process. In a special situation another, more important, factor may override cost as the determining factor. These special situations are addressed and resolved on a case-by-case basis.

After the real estate, the primary capital asset of an existing system, and the primary capital cost for expansion of the system, are the rail vehicles. Additionally the manufacturing lead time for the new rail vehicles is approximately two years from award of contract. Decisions with respect to these two major cost drivers, the existing fleet and the new vehicles, must be established as early as possible in the program, because the modification of all existing facilities and systems and design of all new facilities and systems will be driven by the basic decisions in these two areas. The questions addressed were

- What will be done with the fleet of existing vehicles to incorporate them into the low-floor, level boarding mode of operation?
- What type of new vehicles will be procured to provide service on the expansion portion of the system?
- What modifications will be required for existing stations and facilities?

Vehicles

Using the fleet sizes noted above, a rough order of magnitude (ROM) cost for the different fleet configurations with equal passenger seat capacities could be determined. A summary review of recent LRV procurements indicates that a ROM price for a new, LFLRV is $3 million. The ROM cost of a low-floor center section is assigned at $1 million. Using these values the ROM fleet costs for the “base fleet” and the 3 options above are as follows:

- Base Fleet (115 existing LRVs plus 100 new LRVs): $300 million.
- Option 1 (115 existing LRVs plus 95 new LFLRVs): $285 million.
- Option 2 (114 new low-floor center sections plus 47 new LFLRVs): $255 million.
- Option 3 (114 new low-floor center sections plus 34 new Super-LRVs): $250 million.

Station Modifications

To maximize the accessibility benefits of the low-floor vehicles the station platforms must be designed to be directly compatible with the selected vehicle. All new Phase II station platforms will be built so that the entire platform will provide level boarding with the vehicle regardless of the configuration. The configuration of the vehicle determines the extent of the modifications that are necessary for the existing platforms.

If a LFLRV is selected, the entire length of the platform for each of the existing stations must be raised 8 in. to guarantee that a passenger that boards at a new station (with full length, level board, platforms) is not stranded at an existing station. The implications and complications of this kind of modification are a significant cost factor because of the numerous interfaces with other wayside facilities (doors, elevators, escalators, stairways, columns, seating, ticket vending machines, landscaping, etc.). Almost everything on the platform must be removed, the platform must be raised 8 in., and all equipment and facilities must be reinstalled. There would be a significant disruption of service as each station is closed for this type of modification.

If a Super-LRV is selected, special use platforms (SUP) can be used to modify the existing stations. SUPs are essentially “humps” or localized sections of the platforms that are raised 8 in. so that the door of each low-floor center section lines up with the SUPs when the train stops. There would be relatively minor interface issues associated with the installation of

SUPs on each station platform. This greatly reduces the length of the disruption at each of the stations when this modification is made. To minimize conversion time, confusion, and effect on the passengers during the change over to level boarding operation, temporary or semi-permanent segments of the SUPs could be prefabricated off site and then placed into position on the platforms, until the final configuration SUPs have been installed. Regardless of the use of SUPs, some of the existing platforms will be totally raised 8 in. because of site specific complications and restrictions. (If SUPs were installed for each door of an LFLRV they would overlap each other, which is equivalent to raising the entire platform.)

The cost difference between raising all existing platforms 8 in. for use with LFLRVs versus installing two SUPs on each platform for use with the Super-LRV, for each of the existing stations, is estimated to be approximately $15 million.

Maintenance Facility Modifications

Regardless of the type of fleet that is selected, modifications to the existing S&I facility will be required.

If a LFLRV is selected, with the majority of equipment installed on the roof, the inspection and maintenance areas will have to be modified to provide for full maintenance access to the roof of the vehicle. Essentially a second floor has to be installed at the roof level of the low-floor vehicles. Estimated costs for this are approximately $1 million.

The equipment location of the Super-LRV is the same as the existing vehicle; however, the Super-LRV is 31 ft longer. The maintenance pits will have to be extended and the in-floor hoists will have to be modified to accommodate the longer vehicles. Estimated costs for modifications to the S&I for the Super-LRV are approximately $4 million.

The new maintenance facility that is included in Phase II expansion will be built to accommodate the type(s) of vehicles that are selected.

Fleet Operation

Currently DART operates 1-, 2-, or 3-car consists, depending on the time of day. When system capacity is increased, 4-car consists will be used. If LFLRVs are used to increase the size of the fleet, these configurations will continue without change.

If all Super-LRVs are procured the size of the consists at various times of the day will change. The capacity of two Super-LRVs is equivalent to three LRVs. Therefore, 3-car trains can be replaced with 2-car Super-LRV trains. In the future, 4-car LRV trains can be replaced with 3-car Super-LRV trains. Additionally, a portion of 2-car trains used in intermediate, off-peak hours can be replaced with a single Super-LRV. A single Super-LRV costs the same to operate as a single LRV and costs less to operate than two LRVs. Two Super-LRVs cost less to operate than three LRVs.

Based on the calculated power consumption and the smaller train consists that are possible with the Super-LRV, it is estimated that DART could realize energy savings of approximately $500,000 per year on the existing system if Super-LRVs are used, as compared to the DART LRV. Extending this projection to include the Phase II expansion, which, approximately, doubles the size of the system, it is estimated that a savings of $1 million per year could be realized when Phase II is opened for service.

Fleet Maintenance

Standardization of a fleet of rail vehicles is an intangible but significant benefit to the Maintenance and Operations Department. Operation of a mixed fleet of low-floor and high-floor vehicles with different components and parts will be the source of continuing difficulties for the life of the vehicles. All maintenance staff will be required to be trained on and be familiar with both types of vehicles. The storerooms will have to stock sufficient quantities of separate spare parts for the different types of vehicles.

A standardized fleet of Super-LRVs eliminates these difficulties. Another benefit is having direct interchangeability with all of DART's existing spare parts, effectively reducing the overall capital value of spare parts in inventory. Additionally, the overall quantity and value of spare parts will be reduced, because a fleet of Super-LRVs is approximately 30% smaller than an equivalent fleet of high and low-floor vehicles. While standardization of the fleet is recognized as a benefit both to Operations and Maintenance, no cost has been estimated to reflect this (real) value.

Another maintenance benefit associated with Super-LRVs is that there will be a net reduction in preventative maintenance costs for the fleet. If Super-LRVs are selected there will be 30% fewer vehicles to be maintained for the same number of passenger seats. Because there is physically more equipment installed on a Super-LRV (1 HVAC unit, 1 center truck, 1 static inverter) it is estimated there will be a 20% reduction of the man hours necessary for normal preventative maintenance activities for the entire fleet of Super-LRVs as compared to an equivalent fleet of mixed high and low-floor vehicles. Based on current procedures, this represents an approximate savings for scheduled, preventative maintenance activities of approximately $680,000 per year. In the longer term there will be a reduction in costs for rebuild or overhaul of equipment because there is less equipment to be maintained.

SUMMARY

To be able to address the continued enthusiastic reception and demands for expansion of service and a desire to continue to enhance overall accessibility of the LRT System, DART is in a unique position. The option of introducing a low-floor vehicle into service, with the associated changes in infrastructure, maintenance, and operations is available to all transit agencies. Inserting a center section into an existing vehicle is also possible for all agencies. Inserting a center section into a modern vehicle and maintaining essentially the same performance and 65-mph operating speed is an option that is only available to DART. The results of the static and dynamic testing that were performed confirm that the insertion of a low-floor center section into the DART LRV is a reasonable method of achieving a low-floor, level boarding configuration and reducing cost, while maintaining

- Schedule performance,
- 65-mph operating speed,
- Standardization of the fleet of vehicles, and
- Signature appearance of the DART rail vehicle.

A summary comparison of the cost impacts of the various aspects of the DART System, equipment, and facilities identified in the body of the report is presented in Table 2.

TABLE 2 Comparison of Options for DART Fleet Combinations

	Base Fleet 115 LRV 100 LRV	**Option 1 115 LRV 95 LFLRV**	**Option 2 115 Super-LRV 47 LFLRV**	**Option 3 149 Super-LRV**
Fleet Cost	$300 million	$285 million	$255 million	$250 million
Station Mods		$25 million	$25 million	$10 million
Facilities Mods		$1 million	$5 million	$4 million
*Savings Fleet Power	No Change	No Change	Slight reduction	*$1 million per year
*Savings Fleet Maintenance	No Change	No Change	Slight Reduction	*$680,000 per year
Fleet Configuration	Uniform (High-floor)	Mixed	Mixed	Uniform

The Base Fleet simply maintains the current configuration with high-floor vehicles. Fleet Options 1 and 2 both result in the incorporation of a new low-floor vehicle, potentially from a different manufacturer, into the DART fleet with the associated changes in operations and maintenance. Option 3 essentially has no changes in the maintenance and operation of the fleet.

All transit systems and applications have different criteria and emphasis on different individual characteristics. In this comparison the selection of the Super-LRV will achieve the desired goal of a low-floor, level boarding mode of operation and has a clear cost advantage both in initial procurement and future operations and maintenance, with no significant operational or interface disadvantages. In another situation with the emphasis on a different aspect or requirement, a similar study may result in a different indication.

Integrating New Light Rail Vehicle Technology into Mature Infrastructure

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The Massachusetts Bay Transportation Authority operates the oldest light rail system in North America, known as the Green Line, with sections dating back more than 100 years. In order to improve accessibility to the Green Line, in 1995, MBTA ordered 100 partial low-floor, double-articulated light rail vehicles (LRVs) from AnsaldoBreda of Italy. These vehicles will operate in consist with existing high-floor, single-articulated LRVs. Some of the challenges faced by the project team are discussed, and some lessons learned that may be of value to other mature light rail operations contemplating such procurements are highlighted.

Derailments of the leading axle of the center truck of the No. 8 Low-Floor Car have been the most challenging aspect of the procurement. Following a comprehensive study of the vehicle dynamics and an investigation of the effects of track quality on derailment performance, several modifications were implemented to correct the problems. While some of the characteristics of the Green Line are unique, the important lessons learned can be usefully applied to other procurements involving the introduction of low-floor LRVs to systems with older infrastructure.

INTRODUCTION

The Massachusetts Bay Transportation Authority (MBTA) operates the most intensive light rail service in the United States, over some of the oldest infrastructure to be found in the world. This position as "grandfather" of the light rail industry means that the MBTA and its predecessor agencies have frequently faced the need to introduce new technology into the existing infrastructure. For the MBTA light rail system (the Green Line), vehicle technology has been an area where there has been frequent technological change. The original streetcar lines were developed for four-wheeled, horse-drawn trolley cars. The MBTA is currently deploying the eleventh generation of electric trolley vehicles to operate over these same lines.

Boston's transit providers have never been shy of introducing new technology. From the early introduction of the first electric streetcars, through the President's Conference Committee (PCC) car era, to the (then) advanced Boeing Vertol Standard Light Rail Vehicle (SLRV) in the

1970s, Boston has often been at the leading edge of vehicle technology. This trend continues, with the MBTA becoming the second North American property to order low-floor light rail vehicles (LFLRVs), and the first "mature" U.S. light rail system to procure these vehicles.

Introducing new technology is not always easy, and the introduction of the low-floor car (LFC) to Boston has been no exception. As this project has been covered at length in previous papers (*1–4*), only a brief summary of the highlights is discussed below.

The procurement of LFCs was driven by two factors: the desire to make the Green Line service accessible to all, in compliance with the Americans with Disabilities Act (ADA) requirements, and the need to replace the aging and unreliable Boeing SLRV fleet. After extensive investigations and reviews of available vehicle designs, the MBTA decided to procure a fleet of partial (70%) LFLRVs. These vehicles were specified to occupy the same physical envelope as those that they will replace in order to avoid the need for infrastructure modifications. The new vehicles were also required to be compatible with the workhorse of the Green Line fleet, the Kinkisharyo-built No. 7 Surface Rail Car (SRC), permitting operation of mixed consists to ensure there is at least one accessible vehicle per train.

In 1995, after a competitive procurement, MBTA awarded a contract to Breda Costruzioni Ferroviarie of Italy (now AnsaldoBreda) for design and supply of 100 LFLRVs, to be known as the No. 8 LFC. The contract also includes requirements for upgrading the 115 No. 7 SRCs to make these cars compatible with the systems installed on the No. 8 LFC.

Unfortunately, technical problems were encountered that required the fleet to be withdrawn from revenue service and which significantly delayed the project. These problems illustrate some of the challenges faced when integrating new vehicle technology into an existing, and aging, light rail system.

SUMMARY OF THE NO. 8 LFC PROJECT

The Vehicle

The No. 8 LFC is a new design (Figure 1), although its design solutions and systems were proven on other AnsaldoBreda products or on other LFLRVs. The three-section vehicle has an articulated frame motorized truck at each end, with an independent wheel trailer truck (also an articulated frame) beneath the center body section. The majority of equipment is roof mounted, including the IGBT propulsion inverters. Braking is electro-hydraulic, with truck-frame mounted hydraulic pressure control units. Key parameters are listed in Table 1.

Program Summary

An extensive prototype and development-testing program followed delivery of the first car to Boston in early 1998. This program focused on areas such as vehicle clearance, dynamic performance, propulsion and braking integration, and car monitoring systems. The first cars entered revenue service in March 1999. In the fall of that year, concerns with poor braking performance under low adhesion conditions forced withdrawal from service, and an intensive slide control system investigation program began. The fleet re-entered service on two further occasions, only to suffer a series of derailments, which caused further withdrawals. After a very extensive investigation and corrective action program, revenue service resumed in March 2003.

FIGURE 1 Prototype No. 8 LFC at riverside carhouse.

TABLE 1 No. 8 LFC Main Features

Type	Bidirectional, double-articulated LRV
Configuration	Bo’ 2’ Bo (2 motor trucks, 1 trailer truck)
Low Floor Area	Approx. 70%
Track Gauge	4 ft 8.5 in. (1435 mm)
Minimum Curve Radius	42 ft (12.8 m)
Catenary Voltage	620 Vdc nominal
Length over Coupler Faces	74 ft (22. 6m)
Max. Overall Car Width	8 ft 8 in. (2.64 m)
Max. Height, Equipment Included	11 ft 10 in. (3.6 m)
Wheel Diameter (new)	28 in. (711 mm) motor, 26 in. (660 mm) trailer
Floor Height from TOR	14 in. (356 mm) Low Floor, 35 in. (889 mm) High Floor
Side Door Opening Width	50 in. (1270 mm)
Seated Passengers	44
Standing Passengers	77 @ AW2, 154 @ AW3
Empty Weight	86,000 lbs (39,090 kg)
Maximum Speed	55 miles/h (88 km/h)
Maximum Acceleration	2.8 mphps (1.24 m/s^2)
Full Service Brake Rate	3.5 mphps (1.55 m/s^2)
Emergency Brake Rate	6.0 mphps (2.66 m/s^2)

Integration with Existing Vehicles

To operate in compliance with ADA regulations, at least one car per train must be "accessible." Given the continuing use of the No. 7 SRC fleet on the Green Line, this meant that the No. 8 LFC was to be operationally compatible with the No. 7 SRCs to operate as a two- or three-car consist. For successful consist operation, an important goal is to closely match performance of the two vehicle types in order to avoid uncomfortable and potentially damaging coupler action. The challenge for the No. 8 LFC designers was to match the performance of the AC drive No. 8 LFC, with its fast acting hydraulic brakes, to the performance of the DC drive No. 7 SRC, with its air brakes. The different propulsion characteristics and system reaction times of the two vehicles required extensive fine-tuning of the control systems on the No. 8 LFC.

Slide Control Challenges

The performance demanded of the No. 8 LFC is quite high, particularly in braking. With the streetcar nature of parts of the Green Line, the ability to brake a train rapidly and stop within short distances is vital. The No. 7 SRC is equipped with track brakes on all trucks, but space constraints on the No. 8 LFC prevented installation of track brakes on the center truck, which placed this heavier car at a stopping-performance disadvantage. This situation was complicated by the configuration of the center truck, which has four independently braked low-inertia wheels, the sliding of any one of which could reduce effort on other trucks. By contrast, the No. 7 SRC has a much simpler system, which did not react to some of the slippery conditions detected by the No. 8 LFC and, as a result, stopped in a shorter distance.

Extensive testing and software changes eventually resulted in a design that offered stopping performance equivalent to, or better than, the No. 7 SRC under all foreseeable conditions (naturally occurring friction coefficients of as low as 0.043 were measured during night testing along the tree-lined Highland Branch). Comparative testing with application of a soap solution to the rails was used to confirm the equivalence of the stopping performance under controlled conditions. It is testament to the ability of the control system that it is able to overcome disadvantages of weight, low-inertia wheels, and less track brake effort compared with the No. 7 SRC, and yet still deliver equivalent performance.

DERAILMENT OF INDEPENDENT WHEELED TRUCK

Derailment Incidents

Derailments of the center truck of the No. 8 LFC have been the most challenging aspect of the project to date. The derailments started at a time when basic qualification testing (including ride quality and stability) had been completed, and revenue service had commenced. Significant mileage had been accumulated on the fleet in test and revenue service without incident and deliveries were starting to ramp up following the suspension of service due to braking problems. With the good equalizing properties of the articulated frame trucks, derailments were also unexpected. The derailments started in April 2000, when final preparations were being made for the fleet to return to revenue service. While the first two derailments were under investigation, two further derailments occurred, at different locations and with different vehicles. Following an initial investigation, three further derailments occurred. All derailments were unusual in that they occurred on main line (rather than yard) track at higher speeds than is expected for derailments on the Green Line. All incidents involved flange-climbing derailment of the leading axle on the independent wheel center truck. In all cases, the vehicle was lightly loaded, resulting in the minimum load on the center truck wheels.

Derailment Investigation Outline

A comprehensive Corrective Action Plan (CAP) was initiated, focusing on three key related system elements:

- The No. 8 LFC and its dynamic performance;
- The Green Line track condition and future maintenance standards (Table 2); and
- The existing No. 7 SRC and its impact on track condition.

The CAP was developed jointly between the MBTA and its consultants—Booz Allen Hamilton (coordination), HNTB (track issues) and Transportation Technology Research Center (TTCI) (vehicle dynamics). The CAP also involved the carbuilder, AnsaldoBreda, supported by vehicle dynamics experts from the Politecnico di Milano (PdM). The MBTA sought confirmation of its CAP process by requesting peer review from a panel assembled through the American Public Transportation Association. Finally, the CAP was submitted to and approved by the MBTA's State Safety Oversight body, the Massachusetts Department of Telecommunications and Energy (DTE).

As the nature of the derailment problem and the necessary corrective actions became clear, the MBTA decided on a phased approach to restoring the No. 8 LFCs to revenue service on a route-by-route basis. The initial phase, Phase 1, was focused on an interim return to service on one route [the Commonwealth Avenue (B) line]. This line operates at relatively low speed but presents many different track geometry and condition challenges, and thus forms an ideal basis for testing No. 8 LFC operation. Phase 1 was used to establish the baseline requirements for operation of the cars at limited speeds of up to 35 mph (56 km/h) and included work related to wheel profiles, track maintenance standards and upgrades, and validation testing. Subsequent and current work, under Phase 2, will see a return to service on a line-by-line basis and will include the work necessary to validate safe performance up to the maximum required speed of 55 mph (88km/h).

TABLE 2 MBTA's New Track Maintenance Standards

Maximum track gage [tangent and curves greater than 1000-ft (305-m) radius]	56-⅞ inch (1445 mm)
Horizontal alignment, 31-ft (9.4-m) chord	⅝ inch (16 mm)
Runoff over 31 ft (9.4 m) at end of raise	1-¼ inch (32 mm)
Deviation from uniform profile–62-ft (18.8 m) chord	1-⅝ inch (41 mm)
Variation in cross level on spirals over 31-ft (9.4 m) chord	⅞ inch (22 mm)
Deviation from zero cross-level	1-⅛ inch (28.6 mm)
Difference in cross-level over 62 ft (18.8 m)	1-⅝ inch (41 mm)

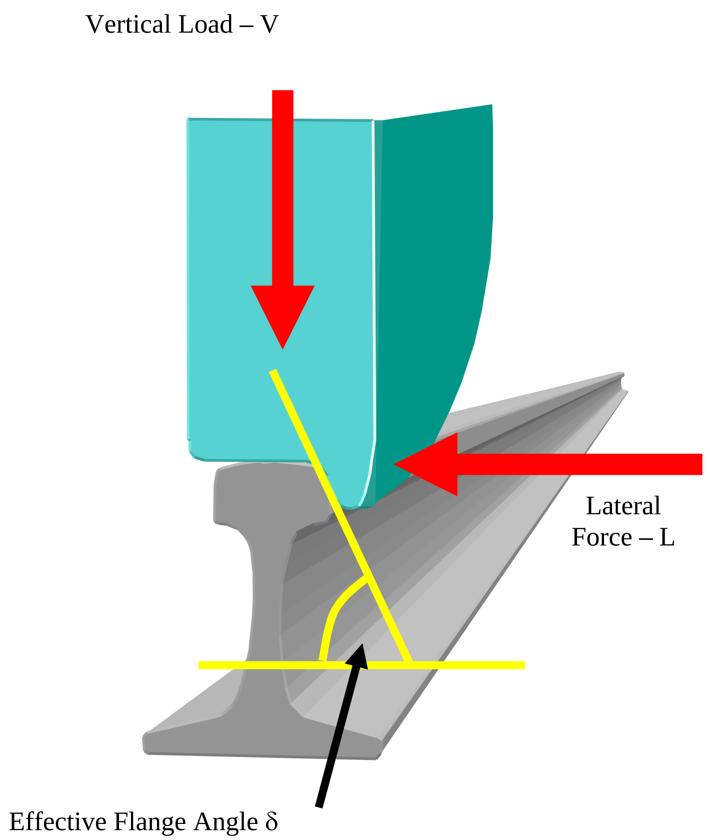
NOTE: Maintenance standards for unrestricted speed.

Derailment Investigation Approach

The wheel to rail interface was exhaustively investigated, and complex mathematical models were developed to simulate the behavior of the vehicle on measured Green Line track geometry and irregularities. The aim of this investigation was to isolate the detailed mechanics of the derailment, and to identify appropriate corrective action strategies.

Initial work focused on addressing the derailments using the simple Nadal theory as a safety limit (Figure 2). This limit remains a conservative one; although, for an independent wheel, more accurate approaches can be employed when full details of the wheel-to-rail interface are available. Initial efforts were focused on increasing the Nadal limiting value by addressing the most controllable variable—the effective flange angle. The original wheel profile design employed a 63-degree flange angle, driven by the fact that all other vehicles on the Green Line use such a profile. Analysis quickly showed that a change to a more modern 75° flange angle was feasible and should deliver significant increases in the derailment safety margin by increasing the Nadal limit. Considered simply, for a constant vertical load, the tolerable lateral force between wheel and rail could be increased by 53% by changing the flange angle. In order to confirm the validity of this premise, an extensive investigation was launched.

The conceptual approach followed during the investigation is shown in Figure 3. This approach was followed to develop, refine, and validate an accurate dynamic model of the vehicle



Nadal's limit:

$$\frac{L}{V} = \frac{\text{Tan}\,\delta - \mu}{1 + \text{Tan}\,\delta}$$

Where μ is the coefficient of friction between wheel and rail

FIGURE 2 Nadal's derailment theory.

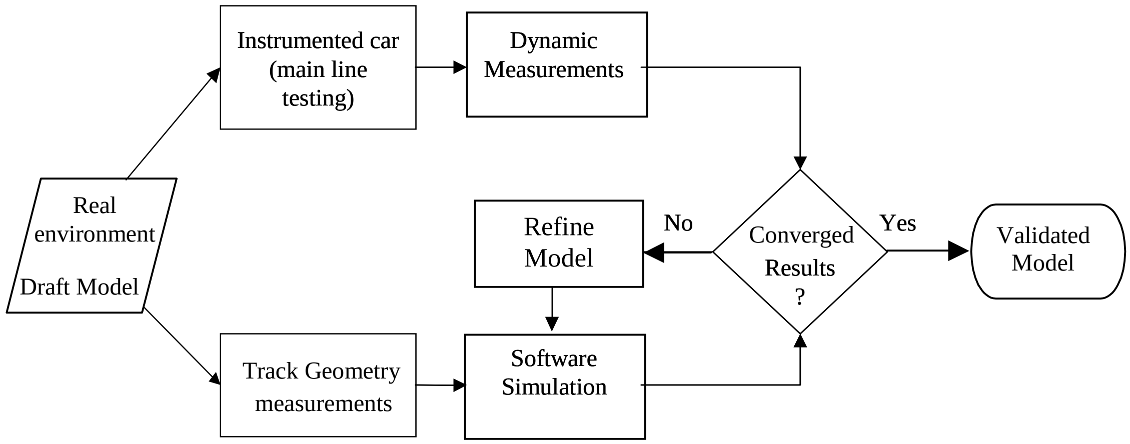


FIGURE 3 Outline of derailment investigation approach.

for use as a predictive tool for derailment performance. Two independent mathematical models were developed (using NUCARS™ by TTCI and ADTres by PdM). These models used some different approaches and assumptions, but ultimately converged to give comparable results. Both models were also validated by real world testing, building confidence in their accuracy.

The model was used to develop the new wheel profile for use on the No. 8 LFC. This new profile was designed to optimize wheel-to-rail contact and increase the effective contact angle. In conjunction with this investigation, extensive activities were carried out to upgrade the condition of the Green Line track. Modeling showed that a common defect on the Green Line, cyclic side wear, or scalloping, was particularly dangerous for the dynamics of the independent wheel design. In addition, during the investigation of the new profile, some rail wear conditions were identified that would compromise the effectiveness of the new wheel profile. These conditions manifested as side wear, with a “lip” of flowed metal formed immediately beneath the tip of the existing wheel flange. The new wheel profile would interfere with this lip, so an unprecedented rail side-grinding program was initiated, which removed this condition on the entire Green Line.

New, viable, track maintenance standards were identified and implemented by the MBTA. In parallel, through extensive modeling and testing, the maximum line defects (alignment, gauge, and cross level) acceptable to the No. 8 LFC were identified and compared with the new maintenance standards.

Test Track Testing

While all this was good in theory, it was agreed that physical testing was necessary to confirm the true benefits of the wheel profile and track condition changes. The first stage in the process was to construct a test track, into which predetermined perturbations were installed (Figure 4).

This test track was instrumented with strain gages to measure the actual forces in the rails due to wheel-to-rail interaction. In addition, a test vehicle was extensively instrumented to monitor movements and accelerations at various locations throughout the car. One of the key elements in this was the development by AnsaldoBreda of an instrumented wheelset (Figure 5).

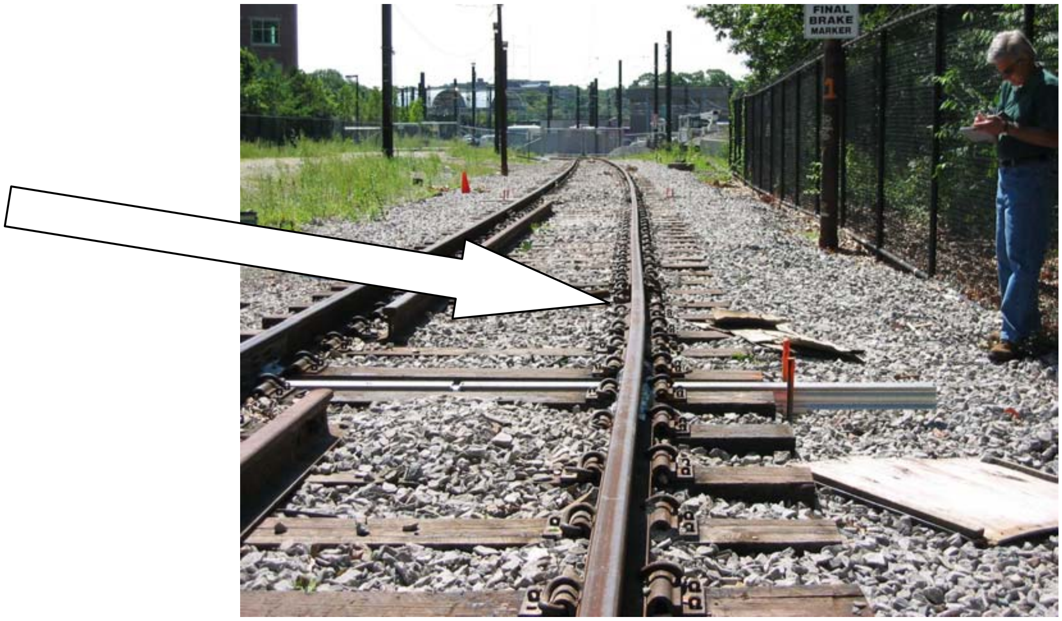


FIGURE 4 Perturbation in test track.

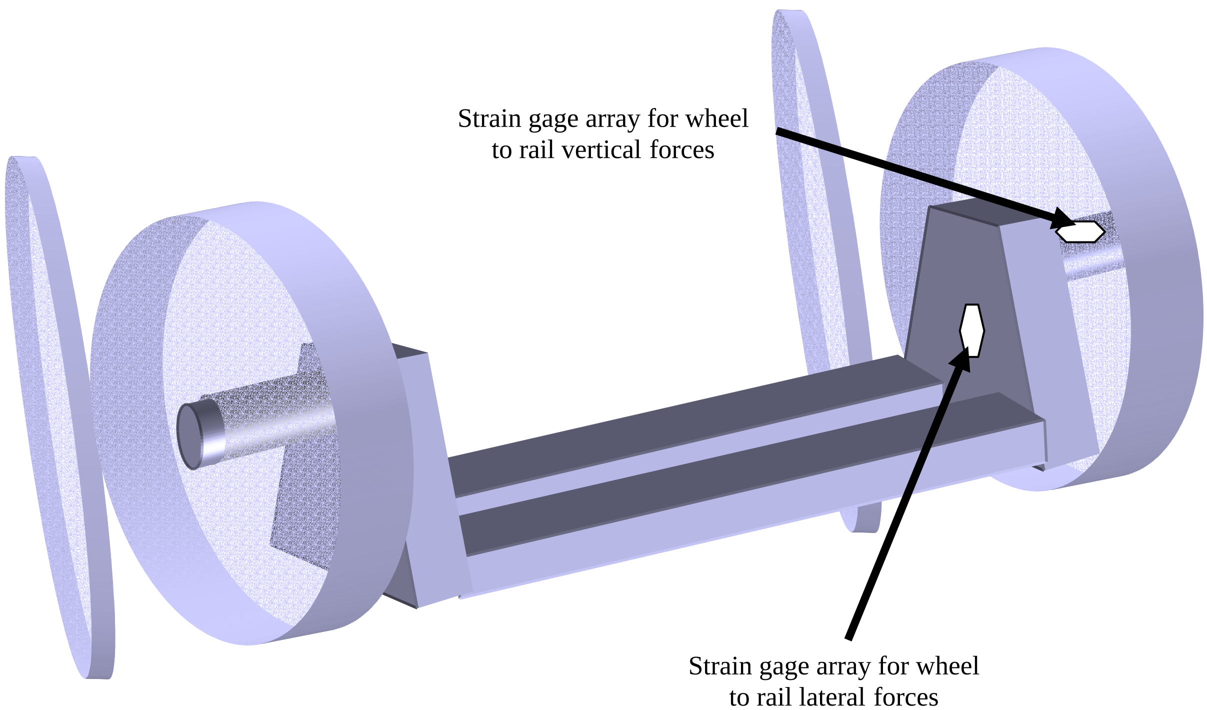


FIGURE 5 Instrumented axle.

This innovation used the drop axle arrangement of the center truck as a system for measuring the actual wheel-to-rail forces, in close to real time. This system proved much quicker to produce and more cost effective than a more traditional instrumented wheel and formed an invaluable part of the investigation.

The perturbations introduced into the test track were quite extreme—1⅝-inch (42-mm) horizontal alignment, ⅝-inch (16-mm) gage, and ¾-inch (19-mm) cross level, all measured over a 31 ft (9.4 m) chord—to deliberately provoke high L/V ratios at the maximum design speed for the test track of 25 mph (40 km/h). Under the high friction levels encountered in the summer months, L/V levels of 0.95 were reached at speeds of up to 28 mph (45 km/h). No derailments were experienced.

The test track testing program permitted a direct comparison of model predicted, and actual measured, vehicle reactions to the controlled perturbation inputs. Good correlation was found between the predicted and measured wheel-to-rail forces and thus L/V ratios. Good correlation was also achieved with other vehicle parameters such as modes of vibration and acceleration levels. The program thus achieved its primary objective of validating the mathematical model(s) of the vehicle and resulted in a believable predictive tool for derailment behavior.

Main Line Testing

The next step was to use the model to predict vehicle behavior in the real world, represented by the Commonwealth Avenue (B line) of the Green Line. Detailed Track Geometry Measurement System (TGMS) data was collected, using a vehicle mounted non-contact (laser) system, to obtain the most reliable loaded track geometry data. One of the challenges of this process was to filter the data, as the system was originally designed for the relatively large curve radii and smooth transitions found on railroads. The tight curves with short or missing spirals found on the MBTA's 100-year-old streetcar system often confused the system into reporting major alignment errors rather than actual curvature. Problems were also encountered with the laser system detecting wayside features, such as restraining or girder rail and road crossings as rail positions, and thus reporting gage as tight as 54 in. (1372 mm).

With the TGMS data filtered, the vehicle models were used to predict vehicle performance over the alignment and to identify problem areas of the track. Certain of these problem areas were used as focal points for later dynamic testing. The same test vehicle, with its instrumented axle, was used to conduct tests at various speed increments over the test locations, in addition to a line speed "minesweep" run of the entire line. The results from this test program both confirmed vehicle performance and identified a number of locations where corrective action was required for the track.

Having confirmed that the vehicle performance would be acceptable within the newly defined track maintenance standards, the track on the B line was upgraded to comply with these new standards. As a final step, a repeat TGMS run was performed to confirm that the upgrades had delivered a line that complied with the new standards.

Revenue Service

After a period of test running, and upon receiving CAP approval from the Massachusetts DTE, on March 22, 2003, revenue service resumed with the No. 8 LFC fleet on the B line. Revenue operation of the No. 8 LFCs is currently restricted to this route, pending upgrades of other routes to the new track standards and further investigations and possible changes to raise the current vehicle maximum speed of 35 mph (56 km/h) to 55 mph (88 km/h).

Summary of Findings

Derailment Causes

The fundamental reason for the derailments was found to be the Green Line track conditions (type and severity of irregularities) that proved to be critical for the dynamics of the independently rotating wheel design (Figure 6). In addition, the Green Line fleet original wheel profile, specifically the flange angle of 63º, resulted in a low L/V limit (under high friction levels), preventing any additional derailment safety margin. Vertical truck performance was not found to play a significant role in the derailments, as the articulated frame design provides for excellent load equalization.

The modeling process identified lateral alignment as the predominant critical track condition, particularly short wavelength lateral alignment perturbations—magnitude greater than ⅝ in. on a 31-ft wavelength. The problem of lateral perturbations is compounded when these perturbations are cyclic in nature. Track surveys identified that such cyclic alignment conditions were to be found especially on the higher speed sections of the Green Line, and it has been hypothesized that these are the result of interaction between the track structure and older generations of vehicles. The situation is more severe with combination defects, where perturbations in alignment are compounded with gage and or cross-level defects.

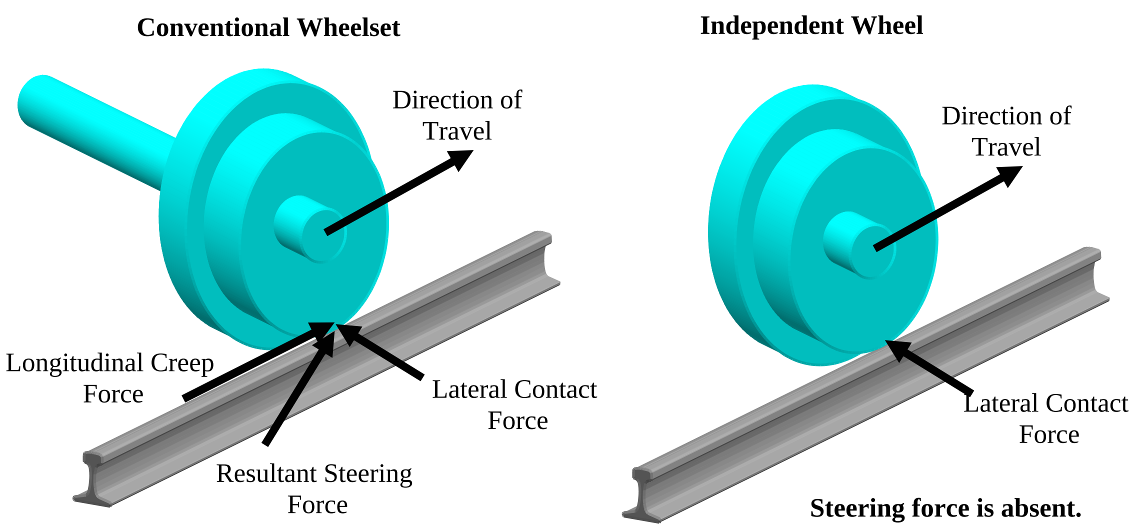


FIGURE 6 Comparison of independent and coupled wheel steering.

However, the work to date has confirmed that the No. 8 LFC, with the new wheel profile, has acceptable margins of safety against derailment at speeds of up to 35 mph (56 km/h) when operated over track that is maintained according to the MBTA's newly developed and implemented track maintenance standards, even in the presence of cyclic alignment defects.

Friction Levels

One of the other contributing factors to the derailments was the magnitude of the coefficient of friction between the wheel and the rail present on the Green Line, that was greater than expected in the Northeastern United States. To ensure the correct Nadal limit was used, tribometer measurements were taken. The results showed levels as high as 0.6 under extreme conditions and consistent levels of 0.5 over a prolonged period, including overnight. The effect of the coefficient of friction on the Nadal limit is well known, and the maximum L/V level permissible under Nadal with a 0.5 coefficient of friction is 0.74. This increases to 1.13 with the new, steeper, flange angle of the new wheel profile.

Corrective Actions

Wheel Profile

The new 75º wheel profile (Figure 7) designed during the investigation has been implemented, to all trucks, on all No. 8 LFCs, and the MBTA is investigating changing its existing fleet to this profile in order to maximize wheel-to-rail compatibility. The MBTA has addressed rail profile compatibility through the initiation of a rail side-grinding program, and there are plans to develop a new rail head-grinding profile to optimize compatibility with the new wheel profile.

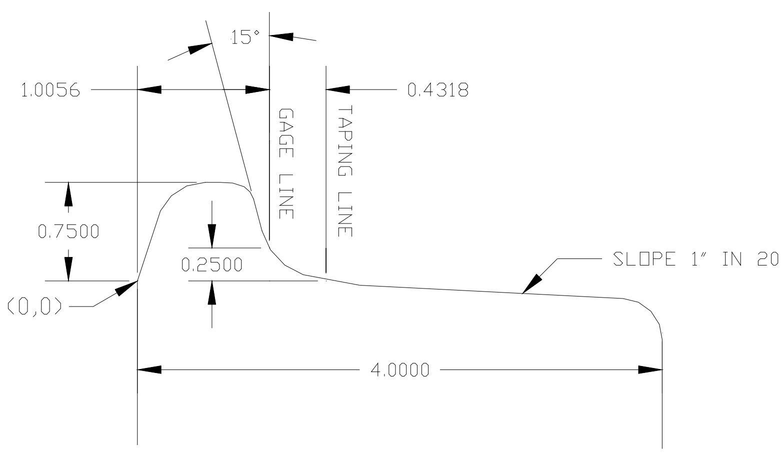


FIGURE 7 New wheel profile for No. 8 LFC.

Track Condition

Track maintenance standards and procedures were developed and implemented as a result of the investigation. One aspect of these standards is to adopt the current FRA (*5*) approach for alignment measurement, over a 31-ft (9.4-m) chord (older standards required measurement of alignment only over a 62-ft (18.9-m) chord). Track geometry is therefore now measured over a 31-ft (9.4-m) chord for both curved and tangent track, and new limits have been established for the various irregularity parameters.

The MBTA currently plans to perform TGMS data collection every three months to monitor track condition, supplemented by track walking three times per week. In addition, the rail profile will be optically measured every six months to ensure that an appropriate rail side contact angle is maintained. This aspect is expected to be particularly critical during the transition of the vehicle fleet from the existing to the new profile.

Future Efforts

The current derailment investigation (Phase 2) is focused on re-introducing revenue service on other routes, based upon the results from the Phase 1 investigation. The investigation continues to investigate possible methods of increasing the safety margin against derailment at higher speeds. Other efforts under active investigation are the introduction of the new wheel profile to the No. 7 SRC fleet, changes to the rail profile, and adoption of friction management techniques. Although flange lubrication should not be depended upon to prevent derailments, it does have a role as a mitigating method and brings other benefits of reduced wear and noise.

CONCLUSIONS

The introduction of new LRV technology into a system built around very different requirements many years ago can cause unexpected problems. Problems have been encountered with matching brake performance with the existing fleet, under extreme rail conditions, and with compatibility of the new independent wheel center truck design, dictated by the low floor requirement, with the existing Green Line track infrastructure.

There are valuable lessons to be learned from this project, which are applicable to older properties that are contemplating introducing new vehicle technology that differs significantly from that currently in use.

In particular, independent wheel truck designs require careful integration of track maintenance standards with the vehicle design since such designs are less forgiving of track irregularities than conventional rigid axle trucks. The track irregularities that appear to cause the most problems are lateral, whether due to wide gage, side wear, rail deformation, or misalignment. Reverse curves with short tangent lengths are also particularly challenging for these trucks, as they are not able to steer themselves correctly through such geometry. It is important to note that these problems have been the experience with trucks that have good vertical equalizing properties. Stiffer trucks may also suffer problems due to vertical alignment and track twist or warp. From the No. 8 LFC experience, the following lessons learned are offered:

- Ensure that all parties are fully aware of exactly what track conditions (geometry and quality) and maintenance standards will be maintained (taking into consideration the inherent characteristics of independent wheel designs). Reliable line geometry and defect measurements should be taken to avoid any misunderstandings. Such information should be included in the specification, and must be used as a design input.
- Focus on early identification of any track features that may cause derailment potential, so that they can be addressed before the vehicles are delivered.
- Perform rigorous and truly representative dynamic modeling of the vehicle design over the actual track conditions that will be encountered.
- Validate the dynamic model by track testing at the earliest opportunity.
- Recognize that track maintenance standards must be rigorously enforced and may need to be raised to a higher level.

ACKNOWLEDGMENTS

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LIGHT RAIL TRANSIT AND OTHER MODES

Blurring the Light Rail Transit–Bus Rapid Transit Boundaries
Rapid Light Transit

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Parsons Brinckerhoff Quade & Douglas

During the last 30 years, light rail transit (LRT) has overtaken heavy-rail rapid transit as the high-capacity, high-performance transit mode most often chosen for new urban transit corridors in the United States. Now one may find that bus rapid transit (BRT), typically with lower cost than light rail but similar capabilities, may overtake LRT as the mode of choice for corridors in which capital-intensive transit is justified. What is involved in deciding upon a best course of action? Are these "either–or" technologies, or simply different expressions of the same concept? The author argues in favor of the latter, and suggests a new term encompassing common forms of both modes, rapid light transit (RLT).

LRT and BRT in terms of the functions to be served, the forms fulfilling those functions, similarities between BRT and LRT regarding those forms, and issues of cost, funding, and implementation are explored. It is noted that the BRT form of RLT is almost always the lower-cost alternative; a metropolitan area will be able to deploy a network of high-performance transit more extensively and quickly as BRT rather than as LRT. Also noted are reasons why LRT may be chosen despite its higher cost, but the potential for using BRT as a first step, with later conversion to LRT, is also discussed. An RLT facility might also share BRT and LRT vehicles, or even be converted from LRT to BRT—a simple transition if light rail has been built with tracks embedded in pavement suitable for BRT vehicles.

INTRODUCTION

Consider this description of a public transportation technology:

- Operates in a reserved guideway with at-grade crossings; the guideway sometimes shared with other vehicles;
- Stops only at dedicated stations, more widely spaced than local bus stops;
- Has vehicle floors level with station platforms;
- Has off-vehicle fare collection;
- Has multiple doors, all for combined entry and exit;
- Uses traffic signal priority or preemption and other traffic and operations management methods and technologies to provide on-time, predictable arrival times with minimal delay;
- Provides a smooth, quiet ride at average speeds often competitive with travel by private car; and
- Can provide ample passenger capacity for most corridors in major U.S. cities.

What transit mode or modes fit that description? Light rail transit (LRT) certainly comes to mind immediately, but all these characteristics can be true of bus rapid transit (BRT) as well. The thesis of this paper is that both LRT and a particular definition of BRT conform to the functional definition listed above. If that is true, is it not appropriate to establish a name for this "mode"? The name rapid light transit (RLT) is proposed.

There are advantages in having such a term. One reason is that it will differentiate between this special form of BRT and the wide variety of other valid but different physical and operational characteristics currently encompassed by BRT as it is being applied in the United States. Another reason is that the broader definition of RLT would be less prescriptive of investment and operational characteristics than are the terms LRT and BRT; if a broader technological envelope is specified initially there is less likelihood of studying technology-specific alternatives that may prove to be infeasible.

THE ISSUE

During the last 30 years (1972–2001), light rail has overtaken heavy-rail rapid transit (HRT) as the mode most often chosen for high-capacity, high-performance transit corridors in the United States.

Within that period there have been more miles built as HRT than as light rail, but those miles include three major new systems all under construction by the 1970s—San Francisco, California; Atlanta, Georgia; and Washington, D.C. Three other cities built or expanded HRT during that period, the most recent in 1993 (*1*). All these projects together have added about 40% to HRT route miles in the United States (*2*).

New light rail lines opened during this period in 12 cities (*1*), expanding total light rail route mileage by some 65% (*2*). Opening of these light rail lines occurred between 1981 and 2001 (*1*). Figure 1 illustrates the numbers of HRT and LRT projects carried out during this period.

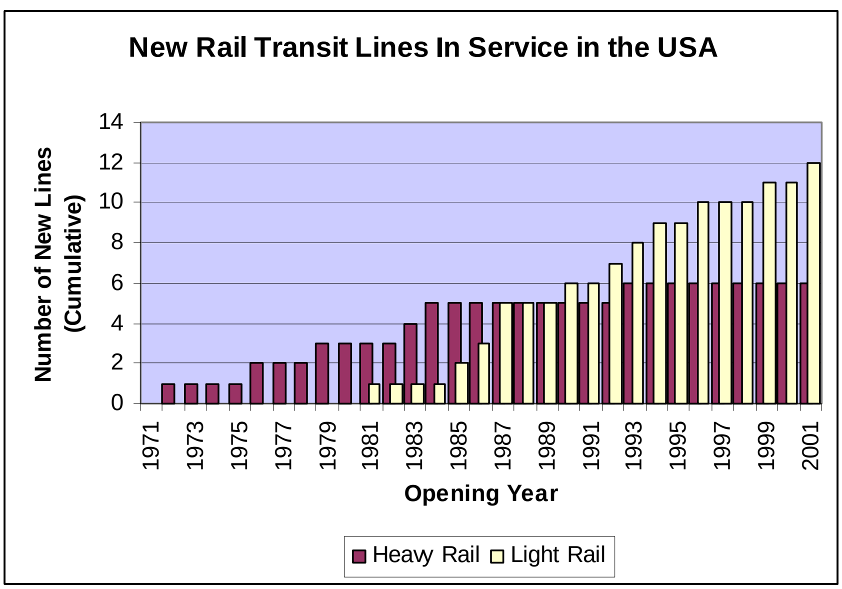

FIGURE 1 Light rail implemented more frequently than heavy rail rapid transit. Source: American Public Transportation Association, 2003.

As of September 2002, there were 21 light rail, or Diesel Multiple Unit, projects in the FTA New Starts pipeline, contrasted with 6 heavy rail or guideway projects (*3*).

This shift from HRT to LRT is logical, considering the fact that in the United States there are progressively fewer corridors in which there is sufficient demand potential to justify fully grade-separated transit, while at the same time, many cities are growing beyond the level at which conventional local and express bus services can provide an adequate public transportation solution.

In recent years, another candidate technology for high capacity, high level-of-service transit corridors is growing in prominence. In transit corridor studies, BRT, by one definition or another, is often an alternative to LRT. One view of this development is that BRT, typically with lower cost than light rail but similar capabilities, may overtake LRT as the mode of choice. What is involved in deciding upon a best course of action? Are these truly “either–or” technologies, or simply different expressions of the same concept?

It is proposed here that LRT and similarly configured BRT are different expressions of the same functional concept, and as such deserve a new term encompassing both modes: “rapid light transit.” Why? To help transit professionals avoid the persistent planning problem of dealing with a technology in search of an application, rather than a need met by a best solution. How will RLT be of help? By providing a transit form identifier that is function-oriented rather than technology-specific, avoiding premature focus on technology differences that may not be relevant to the transit problem being addressed. Another advantage of the term is that it can identify a form of BRT that has a more specific definition than is currently found in the United States, where a variety of features and operating modes have been gathered within the umbrella of BRT.

THE CONCEPT—FUNCTIONS TO BE PERFORMED

One must recognize that what is being accomplished in terms of mobility objectives, when choosing light rail or a similar technology, is the introduction of public transportation measures that achieve improved speed, predictability, passenger amenity, and passenger capacity. This is accomplished by means of features such as providing a reserved guideway, limiting the number of stops, collecting fares in stations rather than on vehicles, minimizing traffic conflicts, giving priority or pre-emption at traffic signals, providing stations that offer more comfort and amenity than ordinary bus stops, and using large vehicles or trains with multiple doors. Minimization of air pollutant emissions and noise may also be an objective.

There may also be objectives pertaining to ease of understanding the route (e.g., by means of prominent stations with names related to neighborhood features). This can be beneficial to all passengers, but perhaps is appeals especially to visitors or others who are not familiar with a city’s transit system. A sense of physical presence and permanence may also be desired to encourage economic development, transit-oriented development, or sustainable development.

To expand upon these points, an effective LRT or BRT route normally would minimize passenger waiting times, stopped time, in-vehicle time; maximize capacity; provide a smooth and quiet ride along an understandable route; and achieve sense of permanence.

Minimal Passenger Waiting Times

Service is frequent and predictable; ideally, service at least during peak periods is so frequent that passengers feel no need to refer to timetables or to time their arrival at stations. At other times of day, service should be on time and preferably at easily remembered "clock-face" times, for example, on the hour, quarter hour, half hour, and so forth. Both LRT and BRT can fulfill this requirement, especially if operating mainly in reserved right of way, with traffic signal priority, and with advanced-technology operations management. BRT typically uses a smaller-capacity vehicle than LRT's individual vehicles or trains, so service frequency tends to be higher and waiting times less.

Minimal Stopped Time

As little time as possible is lost due to stopped time at stations, traffic signals, or other traffic conflicts. Stopped time at stations can be minimized by collecting fares on station platforms rather than as passengers enter vehicles, by providing station platforms level with car floors, for rapid entry and exit, by meeting requirements of the Americans with Disabilities Act (ADA) without resort to bridging plates, wheelchair lifts, or other mechanical devices, by use of vehicles with multiple doors, and by avoiding excessive crowding on vehicles. LRT typically meets all these requirements, especially if low-floor vehicles are used. BRT has these capabilities, possibly including the use of automated guidance at stations to position vehicles precisely in relation to station platform edges. Traffic management methods apply equally to LRT and BRT.

Minimal In-Vehicle Time

Vehicles should operate in a reserved right of way, and use traffic management methods including traffic signal priority to minimize delay due to other traffic. Station spacing should be set for optimal passenger travel times, considering passenger trip lengths and the interfaces with access modes, including other transit services, walking, and park-and-ride opportunities. Vehicle performance (acceleration, deceleration, and maximum speed) should be suited to the route and station spacing. This functional requirement is largely based on LRT capabilities. BRT is easily conformed to the same requirement, with the possible exception that currently available articulated buses may have lower acceleration rates, and some have lower maximum speed capability than typical light rail vehicles (LRVs) deployed in the United States.

High Capacity

The system should have ample capacity for anticipated passenger demand within major transit corridors in U.S. cities where it may be deployed. LRT achieves high capacity by operating large vehicles operating singly or in trains. BRT provides conventional or articulated buses, which have lower capacity but can operate at higher frequency, since multiple buses can be stopped at a station simultaneously, depending upon station length.

Understandable Route

The attractiveness of the service to passengers—including visitors to a city—will be enhanced if the route is visible, clearly mapped on information sources (e.g., on vehicles and at stations), and it is understood that the service is constrained to that route. LRT readily satisfies that requirement; BRT can be built in this form.

Smooth, Quiet Ride

The system is attractive to passengers and not an imposition on neighborhoods through which it passes. Ride comfort is ample and both in-vehicle and external noise levels are well within accepted limits. LRT achieves these requirements. Bus technology is addressing these requirements through developments such as automated vehicle guidance by mechanical, optical, or magnetic means, and the introduction of better sound suppression including use of electric drive motors in hybrid or all-electric applications. The running surface is also a key variable in ride quality, and is, for buses, much more manageable in a reserved right of way than with ordinary in-street operation.

"Presence" and Sense of Permanence

This is a key not only to public understanding of and comfort in using the system, but also in attracting transit-oriented sustainable development. Suitably prominent well-designed infrastructure (guideway and especially stations) satisfies this requirement. A natural attribute of LRT, these design characteristics can apply equally to BRT.

FORMS OF AVAILABLE RLT (BRT AND LRT) TECHNOLOGIES

Those functional attributes can be achieved in more than one way, as already noted in the preceding section. Within the range of transit and transportation professions, the attributes of LRT are well known, and understood to satisfy the functional characteristics described above.

Light Rail Transit

Features of LRT as commonly found in the United States include:

- Articulated reversible LRVs around 90 ft in length;
- Capability to operate LRVs individually or in trains two to three or more cars in length;
- Low-floor vehicles with multiple doors and doorway floors at the same level as station platforms;
- Electric propulsion using overhead electrification;
- Reserved right of way operation on ballasted or embedded track; and
- Traffic signal priority and other traffic management techniques to minimize delay and service unpredictability.

Bus Rapid Transit

With the exception (usually) of operation in trains, buses operating on "guideways" of appropriate design can also achieve those requirements. The perfect BRT vehicle for applications in this country may not yet be "off the shelf," but it is not far from being in production. Buses now available or under development, based in part upon European technologies, include features such as:

- Clean-fuel, fuel cell, electric, or various hybrid motive power sources;
- Effective quieting of engine noise;
- Low-floor design for ease of entry and exit from low station platforms;
- Multiple doors, and doors on both sides if needed;
- Articulated and even double-articulated design, for high passenger capacity; and
- Vehicle guidance technologies (e.g., curb, optical, magnetic, or center-track guidance), enabling positioning at stations with the precision necessary to comply fully with ADA requirements without resort to bridging plates or other mechanical devices. Automated guidance may also be appropriate for an entire line rather than just at stations.

Regarding the capacity issue, stations can be built to accommodate several buses simultaneously, allowing operation of buses at closer headways than are advisable for light rail trains, and thus providing capacity not too far below that of light rail trains.

FACTORS IN CONSIDERING RLT APPLICATIONS

It has been shown in the previous sections how both rail and bus fit within a common functional description of high capacity, high performance urban transit routes and services – Rapid Light Transit. To reinforce this concept, it is worthwhile considering some of the factors that have tended to interfere with this view. The discussion in this section also suggests how RLT can be considered without predisposition toward rail or bus, and how, finally, the differences between rail and bus RLT may be brought into the picture and expressed.

Factors that Separate Rail and Bus

Typically, the image of light rail, to the public, is of a "permanent," understandable facility and service, quiet, comfortable vehicles, and a general impression of high quality. The public image of buses, in contrast, tends to be formed by the character of local buses operating in traffic on city streets. Street design typically has included no special provision for bus operation. Both vehicles and streets may be inadequately maintained. Lacking knowledge of BRT examples, the public tends to think of BRT as a mode that will share those same undesirable characteristics. The image is further distorted, even among those with more knowledge of public transportation, by the fact that there is no universally accepted definition of BRT, and by the temptation in BRT applications to exploit the "flexibility" of buses by designing services that are not exclusively within fixed-guideway alignments.

Similarly, to the developer, light rail possesses that image of permanence, with fixed station locations that are readily accepted as nodes of accessibility having the potential to support and reward investment in residences or businesses. This same vision is not necessarily accorded to BRT, not because it cannot have those same attributes, but because the term "bus" invokes images of ordinary bus service and tends to cloud the image actually consistent with the LRT-like concept of BRT described here.

As noted briefly above, because buses can operate anywhere there are streets, there is a tendency to exploit that feature in a BRT application, by designing service that includes operation both on and off the guideway portion of a route. On paper, at least, this appears to optimize the transit solution. In reality, it may remove too much of the understandability, predictability, and exclusivity of the service, with the result that it does not truly meet the service criteria being sought, nor stand to win the acceptance accorded to LRT. In some cases, that type of "compromised" system may be the right answer.

Describing Rail and Bus as RLT

The operational concept proposed here is a limited one, as relevant for rail vehicles as for buses. After all, in public transportation there are many vehicle systems that run on rubber tires but only on fixed guideways. They range from Metros in Paris, Montreal, and Mexico City to numerous automated guideway systems and most monorail systems. Why not also define a form of BRT that is equally exclusive, and a true alternative or companion to LRT?

If this is accepted, then it is appropriate to have a new name for the technology. The name should not contain the word rail or the word bus. It should express the fundamental functions and advantages provided. The term RLT, as introduced earlier in this paper, is proposed. This name should be readily understandable: there is widespread understanding of the term rapid transit, and of the kind of difference expressed by inclusion of the word *light*. At the same time, the unnecessarily restrictive words *rail* and *bus* are omitted.

Use of this functional classification, so named, should give a planning framework that does not require premature selection of all the physical characteristics of the technology. An RLT route would be described generically as a major corridor high capacity route operating primarily or entirely in reserved right of way (with at-grade crossings as required), providing frequent, limited-stop service significantly faster than local bus service, providing stations rather than simple stops, and employing traffic signal priority (or pre-emption, if appropriate) and other traffic management methods to achieve a high level of predictability.

Applicability of Differences between Rail And Bus

Ultimately, a RLT route will be either bus or rail, although at different points in time it may change from one to the other or even have periods when bus and rail share the use of a guideway. This flexibility is a valued characteristic and an integral part of the rationale for use of the term RLT. Nevertheless there will be times in the process of planning and implementing a route, or its later modification, when rail versus bus decisions will be made.

In this section of the paper, factors that may lead toward bus or rail are explored. Every city, and every corridor within a city have unique circumstances that affect decisions, so the information presented here provides only general guidelines. Nevertheless, this material may provide a useful reference.

Comparative Costs

How do rail and bus, as alternate forms of RLT, relate to one another in terms of cost. One reason why this may be important is to demonstrate that BRT may justify as much specialized design and investment as LRT—design and investment necessary if BRT is to emulate the exclusivity found in a well-executed LRT project. To that end, an example is given here in the form of a brief analysis of a typical RLT line, as implemented for various demand levels and using rail and bus technology. The analysis is based on the author's recent experience in transit major investment, alternatives analysis, and preliminary engineering studies, and uses methodologies and cost models derived from those sources.

Capital Cost An understanding of cost differences between LRT and BRT is not easily found, due to the limited number of cases for which there are directly comparable actual cost data. Furthermore, although many studies consider both modes, there is little consistency among them in the definition of each mode, and especially in the design features of the BRT alternative. Even if one adheres to design criteria calling for an identical alignment and stations, there can be differences in assumptions about the extent of construction work associated with features such as the relocation of underground utilities, ways of dealing with drainage, extent of road reconstruction, or other aspects of design. From the author's planning-level experience, it is seen that a BRT system designed to adhere as closely as possible to light rail design, short of the installation of tracks and overhead electrification, and using vehicles of uniquely high quality, can be expected to cost no more than two-thirds to three-fourths the amount required for implementation of the system as light rail.

For purposes of illustration, an aggregate capital cost model based on such assumptions was applied to a hypothetical RLT route having the following characteristics:

- Route length: 10.4 mi (16.7 km);
- Number of stations: 14;
- Right of way:
  - 5.2 mi (8.4 km) in-street,
  - 4.7 mi (7.6 km) in median or separate right of way, at grade, and
  - 0.5 mi (0.8 km) on elevated structures or bridges;
- Park and Ride: 1,200 spaces;
- Vehicle fleet size: variable (see discussion of operating and maintenance cost); and
- Maintenance and storage facility: sized to accommodate vehicle fleet.

The true test of cost is, of course, the life cycle cost, which accounts for the initial capital outlay in terms of the useful lives of the individual components of capital cost including land, infrastructure, systems, and vehicles. In this way the capital cost can be considered on an equal basis along with the annual cost of operating and maintaining the system.

Life-cycle accounting for capital cost can be calculated in various ways, one of the simplest being to apply the FTA procedure for determination of total annual cost, in which each major capital cost category is assigned a percentage to be applied to the total initial capital cost, to provide a discounted equivalent annual cost (*4*). This figure then can be combined with the annual operating and maintenance (O&M) cost to provide a total annual cost. This result can then be compared with the similarly calculated annual cost of any alternative actions being considered.

The results of this approach are shown in the discussion of equivalent annualized cost, addressed below.

Operating and Maintenance Cost Conventional wisdom is that LRT, due to the opportunity to operate an entire train with only a single operator, is less costly to operate and maintain than an equivalent BRT system. This opinion is sometimes based on comparison with typical urban bus system operating costs, not reflecting the effect of higher average travel speed attainable under LRT or BRT service conditions.

Using the hypothetical route described above, and an estimated one-way trip time of 35 minutes, operations statistics were generated for four cases of varying passenger demand. Typical weekday, Saturday, and Sunday/Holiday service patterns were defined for each of the four cases. Each case addressed satisfaction of a specific value for peak-hour, peak-direction passengers at the maximum load point of the route. These assumed demand levels were 970, 1930, 2,900, and 3,870 passengers per hour, which correspond with total weekday ridership of 12,000, 24,000, 36,000, and 48,000, respectively.

Further assumptions were that light rail could be operated as one-, two-, or three-car trains, each car having a capacity of 165 passengers. BRT articulated buses were assumed to have a capacity of 100 passengers. Two alternative service strategies were defined for the LRT case, one based on providing the shortest reasonable headways, and the other based on using longer trains operating less frequently. In both cases, headways were used that would result in patterns that are repeated hourly. For BRT service, headways during each service period were determined by demand except for low-volume cases in which policy headways were observed.

This operations modeling provided estimates in each case of fleet size, vehicle miles, and vehicle or train hours. Applying O&M cost models using these results together with route length and the number of stations as variables, annual O&M costs were estimated for each case. The results are shown in Figure 2. As shown in the figure, BRT would have the lowest operating cost only at the lowest level of passenger demand, or by inference, in cases of hourly demand (maximum vehicle loading) up to around 1,500 passengers per hour in one direction.

Equivalent Annual Cost The annualized capital cost estimates were combined with the annual O&M cost for each of the LRT and BRT cases, with the results shown in Figure 3. This shows that in all the cases examined, despite the shorter lifespan of buses compared to light rail vehicles, and despite having higher operating cost over most of the system capacity range assumed, BRT would be the less expensive approach. For a corridor expected to grow quickly into the realm of high bus operating costs, especially if the need to achieve higher capacity by conversion to LRT is anticipated, economic and financial studies might show the conversion cost to tip the scales toward initial implementation of rail. It should be noted also that funding sources for capital cost may be different from those available for O&M cost, and these differences may affect selection of the most advantageous RLT solution.

Funding and Implementation Issues

Transportation professionals may recognize the capabilities and merits of alternative technologies more readily than the public, but normally the public is closely involved in funding major transportation improvements. For the public to make optimal decisions about any aspects

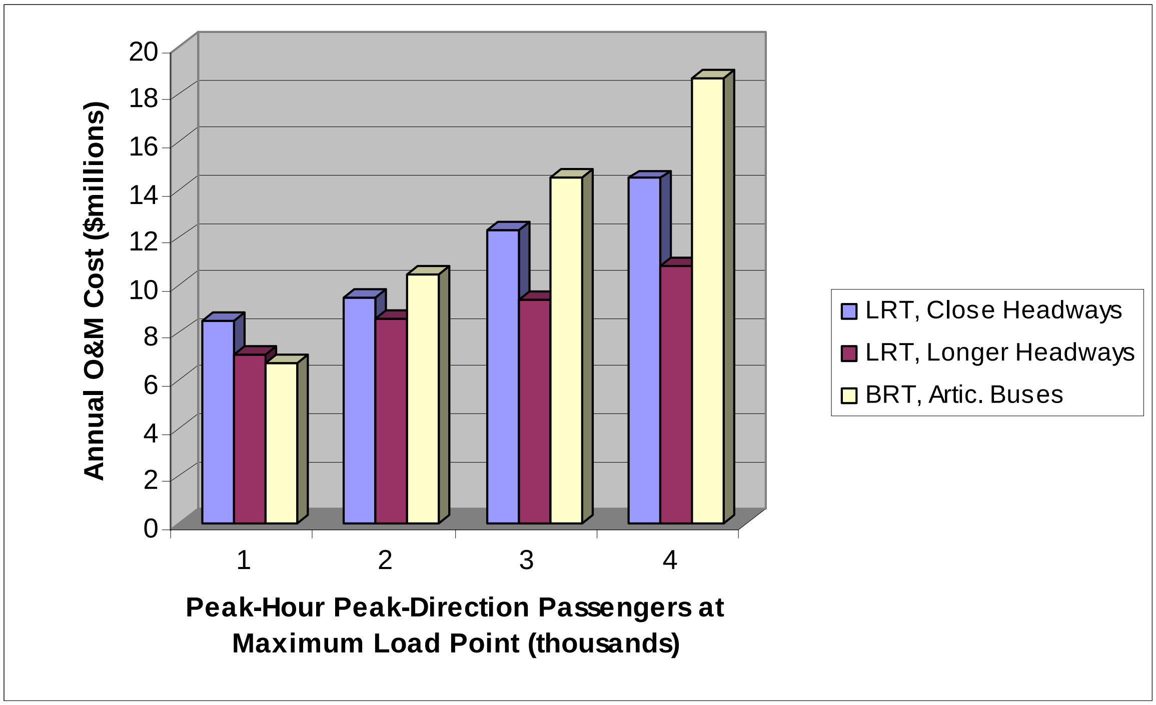

FIGURE 2 Comparative O&M costs of BRT and LRT.
Note: See text for route and service assumptions. BRT headways are better (service more frequent) than LRT headways over the range of passenger volumes shown.

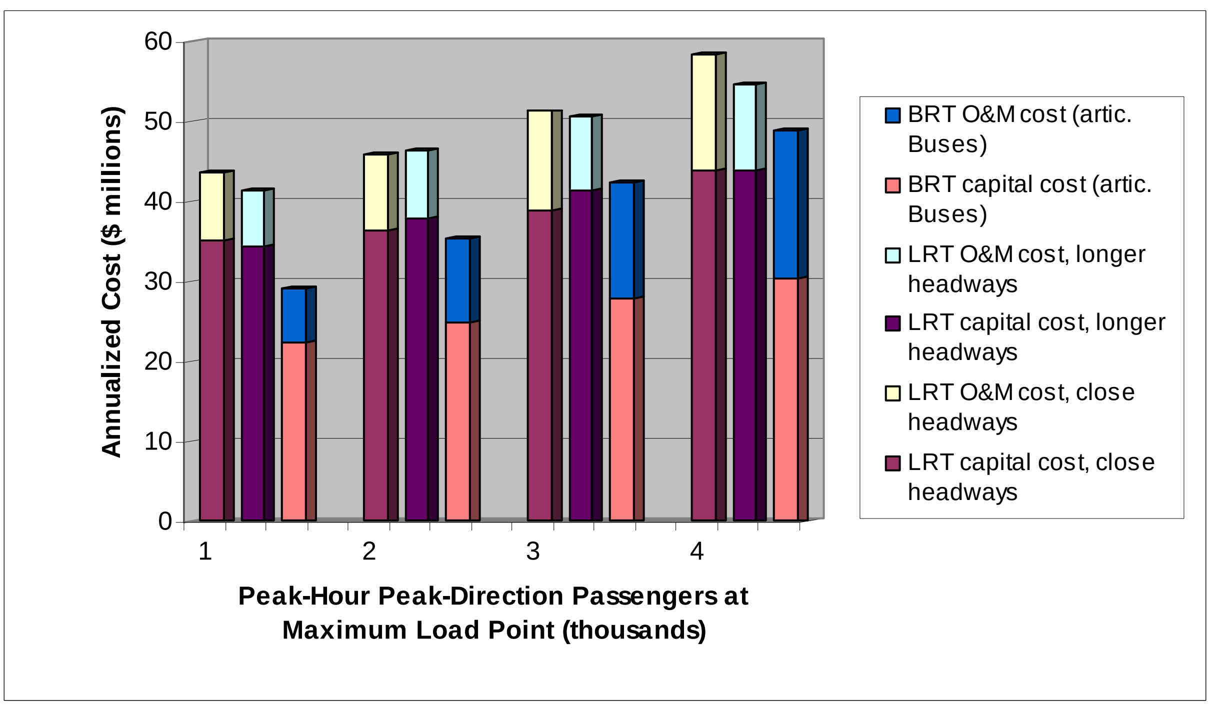

FIGURE 3 Annualized costs of a corridor RLT project.

of transit improvement alternatives, they need a clear understanding of those alternatives. Adoption of a descriptive term such as RLT may provide an envelope that will help professionals to communicate technology choices and their characteristics more clearly by associating the rail and rubber tire options more closely with one another and with the functional characteristics they share in common.

One aspect of RLT that should not be overlooked is the issue of convertibility. As a practical matter, this is unlikely to apply if LRT is the initial choice, but it could, as reiterated later. Certainly it may apply if one plans initial implementation as BRT. In that case, conversion to LRT requires the paved guideway to be replaced with a rail guideway, with or without pavement, and overhead electrification must be installed (unless one of the emerging technologies for in-guideway electrification is implemented). Of course, there are many design issues to be addressed if the design has future conversion from bus to rail in mind. Issues include not only the horizontal and vertical alignment, but also details such as utility relocations, provisions for drainage, design for both bus and rail vehicle clearance envelopes, design at some level to assure that future electrification including the overhead contact system will fit, and possible guideway construction details to facilitate later removal and replacement with rail track, imbedded or otherwise. One of the key points in the possible appropriateness of this approach is that the lower cost of bus RLT gives latitude to include design and construction features that will simplify and streamline later conversion, if this becomes the desired action.

A major obstacle in such a conversion process is the maintenance of service during construction. In most cases, this will be achievable by having buses run around guideway sections during the conversion process, which can be staged as desired. If the LRT guideway includes pavement, then it may be possible to reintroduce BRT service on the completed guideway sections until such time as LRT operation is introduced.

The use of track embedded in pavement also means that it is possible, though perhaps seldom desirable, to convert RLT from light rail to bus, possibly with no disruption in service. It is also possible for LRVs and buses to share the use of the guideway, as found, for example, in Pittsburgh, Pennsylvania.

CONCLUSIONS

During the last 30 years, LRT overtook HRT as the technology most often deployed in new major transit corridors. There are good reasons for this, including the fact that there have been fewer candidate corridors with the passenger demand potential to justify fully grade-separated transit, while at the same time many cities have grown beyond the size at which conventional local and express bus services provide adequate public transportation.

Recently, BRT has attracted increased attention as a high capacity corridor solution. Although BRT has been defined very broadly in recent projects in the United States, the more exclusive forms share most if not all of the functional characteristics of LRT. The need for deployment of major corridor transit solutions having these functional characteristics is substantial, and it is satisfaction of the functional characteristics rather than the choice of a specific technology that is the first and most important decision in selecting each corridor solution.

Accepting the thesis that attainment of the functional solution is of overriding importance, rather than the choice between rail and bus, it is logical to have a name for the "mode" that responds to this set of functional characteristics, and RLT is proposed. This name contains three key transportation descriptors: *rapid*, which in urban transit terminology refers to a service that significantly shortens travel times within a corridor without failing to serve the extent of the corridor (in contrast with express services which only serve points at the ends of a corridor); *light*, which has the connotation of less massive vehicles or trains than are used by HRT, and of surface rather than grade-separated routes; and *transit*, to make clear the fact that it is a public transportation system.

The introduction of a new functional mode, RLT, also can help to avoid ambiguity that may arise when the term BRT is used, by defining a very specific form within the BRT mode. With regard to the bus form of RLT, this name may also help to distance the mode from ordinary bus service, with its characteristic environment of operation over streets maintained (or not maintained) by others, and inevitable conflicts with other vehicular traffic.

The functional definition proposed for RLT is that it provides

- Minimal passenger waiting times,
- Minimal station dwell times,
- Minimal in-vehicle times,
- High capacity,
- A readily understandable route,
- A smooth, quiet ride, and
- "Presence" and sense of permanence.

The forms that satisfy these functions are much like the definition of LRT, and would be the following:

- Reserved right of way, and high quality track or running surface;
- Level entry and exit, full ADA accessibility, off-vehicle fares, and multiple doors;
- Limited-stop operation, ample acceleration, deceleration, and maximum speed;
- High frequency of service;
- Large vehicles or trains that are distinctive and high-quality;
- Quiet, clean for passengers and "neighbors;" and
- Visible, substantial, high quality investment.

This paper includes material that may serve as a general guide in the ultimate definition of RLT corridor projects, which will inevitably be a city-specific, corridor-specific decision. This includes "typical" results of comparative costs, and comments on design and implementation issues. Bus-based RLT is generally less expensive to build than rail, and at low corridor passenger volumes, cheaper to operate. At higher passenger demand levels, buses are more expensive to operate than light rail, although the combined capital and operating costs may remain lower than the rail option. In terms of design and implementation, advantages are seen in setting design criteria that are fully compatible with rail, and possibly including, in initial construction of a bus option, some of the features that will be needed if later conversion to rail should occur—examples are horizontal and vertical alignments, clearance envelopes, station design particulars, and utility relocation performed.

Within the RLT envelope, there will sometimes be reasons to select BRT, and under other circumstances, LRT. Examples of the latter may include extension of a pre-existing LRT system, the use of alignments in which the lower service frequency of LRT is preferable to the frequency of BRT service that would be required, corridors in which passenger demand levels will soon exceed the capabilities of BRT, or clear evidence that achieving certain development goals or public acceptance targets requires adoption of LRT. Different ways in which capital and operating costs are funded may also be a decision factor.

All of these possibilities suggest advantages in adopting and using terminology that does not draw the typical sharp distinctions made between LRT and BRT. RLT may be an important step in achieving more widespread understanding of the technological options available in the urban transportation toolbox.

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LIGHT RAIL TRANSIT
TRAFFIC ENGINEERING

Application of Part 10 of the *Manual on Uniform Traffic Control Devices* to Light Rail Transit Projects
A Review of Its Strengths and Weaknesses

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An evaluation of Part 10 of the *Manual on Uniform Traffic Control Devices*, following nearly 2 years of experience with its practical application subsequent to its addition to the manual, is presented. Elements are identified that have been useful as well as those which should be considered for revision or deletion.

Each section of the new Part 10 was reviewed and evaluated against the background of current design and operating practices in the United States. These evaluations identified (1) those that are particularly useful in that they formalize, confirm and, in some cases, clarify successful practices, and (2) those that are inconsistent with current design or operating practices.

It is concluded that Part 10 is a valuable new tool for transportation engineers and planners. It will promote useful standardization, while allowing some leeway to address local conditions. Nevertheless, some of the strictures appear to be arbitrary or inconsistent with past or current practices that have been largely successful and should be reconsidered. The review also revealed a number of editorial deficiencies and discrepancies, which are not uncommon when a new document is published for the first time.

INTRODUCTION

Until the current edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) was issued in late 2000, traffic engineers participating in the development of new and upgraded light rail transit (LRT) lines had no national standards that were specific to the purpose of guiding the design of traffic control at street and trackway interfaces.

Part 8 of the MUTCD addresses crossings of highways and railroads, but LRT lines can be quite different from railroads. Not all interfaces of LRT trackage with streets and highways are simple, railroad-type crossings. There are numerous configurations. The requirements and recommendations in Part 8 were often insufficient or inappropriate for LRT crossings.

Part 10, the newest addition to the MUTCD, establishes standards and provides guidance and options for traffic control measures that are more appropriate for the greater variety of interface configurations.

Designers and planners of LRT systems have now had some opportunity to apply the standards, guidances, and options contained in Part 10 to both operating systems and those in development. Those applications are explored here. Elements that have been helpful and those that have not are identified. Some changes that might be considered when the MUTCD is next updated are also suggested.

COMMENTS AND SUGGESTIONS

Section 10A.01—Introduction

The purpose of Part 10 is to guide the design of traffic control at interfaces of two transportation modes, highway and LRT. The highway mode is the focus of the entire MUTCD and its nature is well understood. The matter of interfacing streets and highways with the LRT mode is new to the MUTCD, and this section addresses that advent by providing, at the outset, an explanation of the nature of LRT.

The second "Support" paragraph in this section describes LRT as the mode of metropolitan transportation employing "light rail transit cars that operate on rails in streets in mixed traffic, in semi-exclusive rights-of-way, or in exclusive rights-of-way." This description clearly distinguishes these LRT cars from the railroad trains addressed in Part 8. The nature of the LRT car is further clarified by formally linking the name with the most common alternative names—light rail vehicles, streetcars, or trolleys.

That clarification is especially helpful because, prior to the publication of Part 10, there was considerable divergent professional opinion as to the status of streetcars or trolleys within the general rail transit mode. A segment of the professional community argued that any electric railway car capable of feasible operation in both a street and an off-street environment (above-grade, at-grade, or underground) was an LRT car. This obviously included streetcars and trolleys. Others dismissed that notion categorically and sought various ways to define a line that would differentiate them from contemporary electric railway cars.

That endeavor proved to be difficult, largely because designers of light rail systems take full advantage of the ability of the LRT car to function in the same environments long served by streetcars and trolleys. Although many light rail transit systems comprise only trackage that is separate from vehicle lanes, save for some street crossings at grade, other systems are served by electric rail cars that operate partly on trackage from which motor vehicles are excluded, but elsewhere they travel in mixed traffic on public streets.

Examples of the latter can be found in Boston, Massachusetts; Philadelphia and Pittsburgh, Pennsylvania; and San Francisco, California, where the cars run in tunnels beneath the downtown streets, but in mixed traffic in some outlying areas. Another example is in Sacramento, where the cars operate in general traffic lanes on several downtown streets, but on segregated trackage farther out. If the rail cars of these systems, when operating in the mixed traffic sections, were to be classified as streetcars, but not as LRT cars, it would suggest they undergo some sort of metamorphosis from LRT car to streetcar or vice versa in a single one-way trip.

The publication of Part 10 has essentially resolved this issue. Section 10A.01 clearly establishes that streetcars and trolleys *are* LRT cars. Hence, the services provided by streetcars or trolleys are LRT. There is no need to continue the aforementioned quest for a defining line.

However, it is unfortunate that, after establishing the term "light rail transit car" as the basic name of the conveyance, it is not used consistently throughout Part 10. Substitute terms appear elsewhere in this section as well as in Sections 10C.02, 10C.10, 10C.12, 10D.02, 10D.05, 10D.06, 10D.07, 10D.08 and in Figures 10C-1 and 10C-4. These inconsistencies need editorial attention and they can be easily rectified in the next edition of the manual.

The nomenclature adopted by Section 10A.01 also addresses a potential difficulty with the term *light rail vehicle*. While this appellation is perhaps more popular than some others, its use could be problematic in certain circumstances, particularly where legal matters relating to at-grade crossings are involved.

Section 1A.13 of the MUTCD contains the following definition: "Vehicle—every device in, upon, or by which and person or property can be transported or drawn upon a highway, except trains and light rail transit operating in exclusive or semi-exclusive alignments. Light rail transit operating in a mixed-use alignment, to which other traffic is not required to yield the right-of-way by law, is a vehicle." Aside from its somewhat garbled wording of the last sentence, this definition suggests an en route status change of LRT cars akin to the streetcar "metamorphosis" discussed above.

An interesting test of the logic of this definition can be found on Essex Street in downtown Jersey City, New Jersey. When traveling westbound on this one-way street the LRT cars run in the general traffic lane, but when traveling eastbound they operate against the current of traffic in an exclusive lane. Hence, according to the Section 1A.13 definition they are vehicles when traveling westbound, but are not when traveling eastbound. At the same time, the definition of "vehicle" in New Jersey statutes excludes all devices that operate on stationary rails and makes no exception when the rails are in a traffic lane. Thus, according to state law, they are not vehicles when traveling in either direction.

The Section 1A.13 definition of "vehicle" is also inconsistent with other parts of the MUTCD. The thread pursued by this review in that regard begins with the following excerpt from Section 1A.11:

> 23 CFR, Part 655.603 adopts the MUTCD as the national standard for any street, highway, or bicycle trail open to the public in accordance with 23 U.S.C. 109(d) and 402 (a). The "Uniform Vehicle Code (UVC)" is one of the documents referenced in the MUTCD. The UVC contains a model set of motor vehicle codes and traffic laws for use throughout the United States.

The thread then continues with the UVC definition of "vehicle":

> Every device in, upon or by which any person or property is or may be transported or drawn upon a highway, *excepting devices used exclusively upon stationary rails or tracks*.

Incidentally, this UVC definition is not unique. Most state codes include the same or a similar definition.

The inclusion of a definition of "vehicle" in Part 1 that is different from the UVC definition does not appear to serve any positive purpose. Serious consideration should be given to deleting this definition from Section 1A.13, thereby allowing the UVC definition to prevail.

This could open the door to various clarifications and simplifications. For instance, in situations where it is necessary to establish that a particular law or regulation applies to conveyances other than rail cars, the term "motor vehicle" is sometimes used to exclude the rail mode. However, that also excludes bicycles, tricycles, and other human-powered vehicles, because they are not motor vehicles. If it were the intention to include them in such a law, they would have to be specifically named. Yet, since those devices are all vehicles, they would be included automatically if the "motor" prefix were dropped.

Another term sometimes used in lieu of “vehicle” is “road user”. However, it is ambiguous as to whether this includes or excludes pedestrians. Furthermore, a rail car operating in a general traffic lane (e.g. in downtown Sacramento, California) could be considered to be a “road user”.

By faithfully restricting the use of the word “vehicle” in the MUTCD to those devices specified in the UVC, these problems could be largely avoided. That having been said, this restriction of the use of the term “vehicle” in regard to LRT cars need not extend to all printed literature. Light rail vehicle has become a popular name that can be useful in media such as commercial and public information literature to identify rail cars that are different from those comprising traditional subway, elevated, and commuter railroad trains. Deletion of the “vehicle” definition from the MUTCD would not preclude popular application of the term to LRT cars.

Section 10A.05—Temporary Traffic Control Zones

The second Standard refers twice to a “highway-rail grade crossing,” which is the term used in Part 8 for railroad crossings. The crossings addressed by Part 10 are referred to as “highway-light rail grade crossings.” This and the reference to “railroad” tracks appear to be editorial errors and not an intentional use of the Part 8 terminology. They can be easily rectified in the next edition of the manual.

Section 10B.01—Introduction

In the Standard paragraph, the reference to “traffic gates” should be changed to “automatic gates” for consistency with Part 8 and the various documents related to the MUTCD.

Section 10C.03—Stop or Yield Signs (R1-1, R1-2, W3-1a, W3-2a)

The final paragraph of the “Guidance” portion of this section is unrelated to all other portions. The content of this paragraph has a very worthy purpose, but its inclusion in this particular section seems inappropriate. The Stop or Yield signs referenced are not an actual part of the crossing control, but rather a peripheral condition that could influence the design of that control. A reworded version might be included in Section 10C.04, and consideration should be given to re-classifying it as a Standard in that section.

Section 10C.04—Do Not Stop On Tracks Sign (R8-8)

This section recommends the placement of this sign on only one side of the crossing. Consideration should be given to adding an “Option,” comparable to the one in Section 8B.06, which would allow the installation of this sign on both sides of the crossing. The purpose of imposing this limitation of design flexibility in the case of highway-light rail grade crossings is not readily apparent, nor does it seem justified.

Section 10C.10—Do Not Pass Light Rail Transit Signs (R15-5, R15-5a)

The intention of the "Support" paragraph is worthy, but the wording is awkward and possibly confusing. The following re-wording should be considered: A Do Not Pass Light Rail Transit Sign (R15-5) is used to indicate that vehicles are not allowed to pass light rail transit cars that are loading or unloading passengers where there is no raised platform or area that is physically separated from the adjacent vehicle lane.

Section 10C.11—Highway-Rail Advance Warning Signs (W10 Series)

Where the alignment of the LRT trackage is comparable to that of a railroad and a crossing is controlled by railroad-type devices (i.e., flashing light signals, with or without automatic gates) the posting of a W10-1 sign may be appropriate. However, where the trackage is situated along the right-of-way of a public roadway, whether in exclusive lanes or in general traffic lanes, the crossings are in fact intersections of public streets that are controlled by either traffic signals or Stop signs. The value of supplementing these control devices with a W10-1 sign is not readily apparent. Nor is it made clear why this posting would be needed in a residential district, but not in a business district. Consideration should be given to limiting the use of these signs to non-intersection crossings and to re-classifying it from a Standard to "Guidance."

Section 10C.12—Light Rail Transit Approaching-Activated Blank-Out Warning Sign (W10-7)

The potential usefulness of this device goes beyond warning motorists who are approaching on a parallel roadway. There are situations other than a parallel roadway approach in which this device could be beneficial. In practice, signing of this type was already in use on non-parallel approaches to roadway interfaces (e.g. a mid-block driveway) prior to the publication of Part 10. The current uses of this warning measure on non-parallel approaches might now be considered non-compliant with the MUTCD because of the restriction imposed by this section.

Consideration should be given to restoring the flexibility of application that this device had prior to the publication of Part 10. This could be accomplished by replacing "turning across the tracks of an approaching parallel light rail transit vehicle." with "preparing to cross the tracks when an LRT car or train is approaching."

Section 10C.15—Dynamic Envelope Delineation Markings

To the great credit of the authors of Part 10, this section establishes that the use of dynamic envelope markings is not mandated, or even recommended. They are not needed as a matter of course. When LRT cars are operating in general traffic lanes or through intersections, they are not materially different from large buses and tractor-trailers—vehicles that travel the roadways without dynamic envelope markings.

Very occasionally there might be particular circumstances in which marking the path of a rail car would be useful. Thus, the option of installing these markings, as provided in this section, is appropriate. However, the associated figures in this section could be improved.

In the MUTCD, Figure 10C-1 (Figure 1) offers an opportunity to illustrate graphically the effect of the lateral motion or suspension failure mentioned in the Support paragraph, but that opportunity was missed.

Consideration should be given to adding supplementary outlines of the car body, showing it leaning, both clockwise and counter clockwise, to touch the dotted lines that represent the edges of the dynamic envelope.

A major deficiency of this figure is its failure to show the stop lines that are necessarily associated with whichever devices (traffic control signals or flashing-light signals and automatic gates) are used to control traffic at the crossing. Those lines would be the primary markings and the placement of additional markings at the actual edge of the envelope would have little

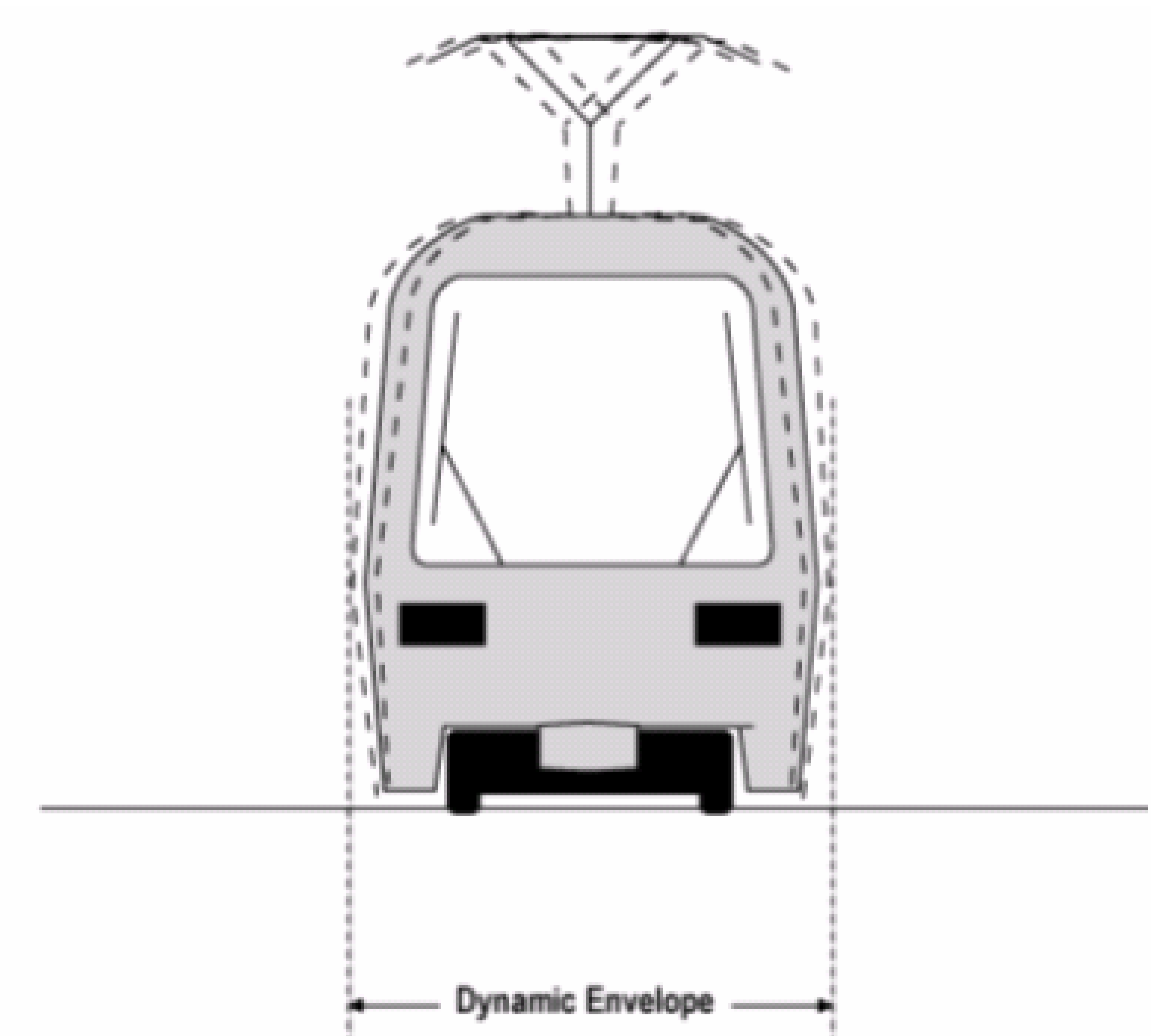


FIGURE 1 LRT car dynamic envelope.

purpose. In fact, to the extent that they might draw motorists beyond the stop line, they could be detrimental.

This figure should be revised to address these issues. An illustration comparable to the upper portion of Figure 8B-2 (Figure 2), which shows both the stop lines and the dynamic envelope markings would be more accurate and useful. It is noteworthy that the Part 8 figure indicates that the dynamic envelope markings are optional, which is consistent with Section 10C.15.

This figure attempts to illustrate the impact on the dynamic envelope of the overhang of the corners of an LRT car on the outside of a curve and of the middle of the car on the inside of a curve. The purpose is well intentioned, but the figure is not well executed.

Although characterized as typical, it shows the improbable configuration of a single LRT track embedded in the paving in the middle of a 3-lane street with operational directions of both the railway and the street undefined. The figure does not indicate whether the track lane is exclusive or open to general traffic. This imprecision makes it difficult for the reader to correlate it with actual field conditions.

It might better serve its intended purpose if it were revised to show a 4-lane, 2-way street with tracks occupying the two center lanes. This is a configuration that actually exists in several U.S. cities. Also, it should clearly indicate whether the lanes hosting the tracks are exclusive, or open to general traffic. Perhaps a figure could be presented for each situation. The markings illustrated in the figures (lane lines and, if two-way operation is depicted, centerlines) should be consistent with Chapter 3B.

Figure 10C-3 and Figure 10C-4, shown here as Figure 3, depict the same improbable configuration. All of the above comments apply to these figures as well.

Section 10D.01—Introduction

The first sentence of the first Support paragraph seems unnecessarily wordy. It would be clarified (and would be more consistent with the chapter title and its counterpart in Part 8) if the first “light rail transit” phrase were simply deleted.

The second sentence of that paragraph is inconsistent with its Part 8 counterpart. Flashing-light signals are, by far, the most common active traffic control device at railway grade crossings that are not controlled by traffic signals. Automatic gates, conventional and four-quadrant, are not control devices in their own right, but rather a supplementation of the flashing-light signals. Of these two types of gates, the four-quadrant version is much less common. This logical hierarchy is followed in Part 8. The reversal in Part 10 is not helpful to the reader. Thus, the paragraph might be re-worded to read: Active traffic control systems inform drivers, bicyclists, and pedestrians of the approach and presence of light rail transit cars at grade crossings. These systems include flashing-light signals, which may be supplemented with automatic gates or four-quadrant gate systems; traffic control signals; actuated blank-out and variable message signs; and other active traffic control devices.

The next three sections should then be rearranged to reflect the logical hierarchy. This would make Chapter 10D consistent with Chapter 8D, which arranges the sections to present the basic device (flashing-light signals) first, followed by the common supplementary device (automatic gates), and then finally the uncommon the supplementary device (four-quadrant gate systems).

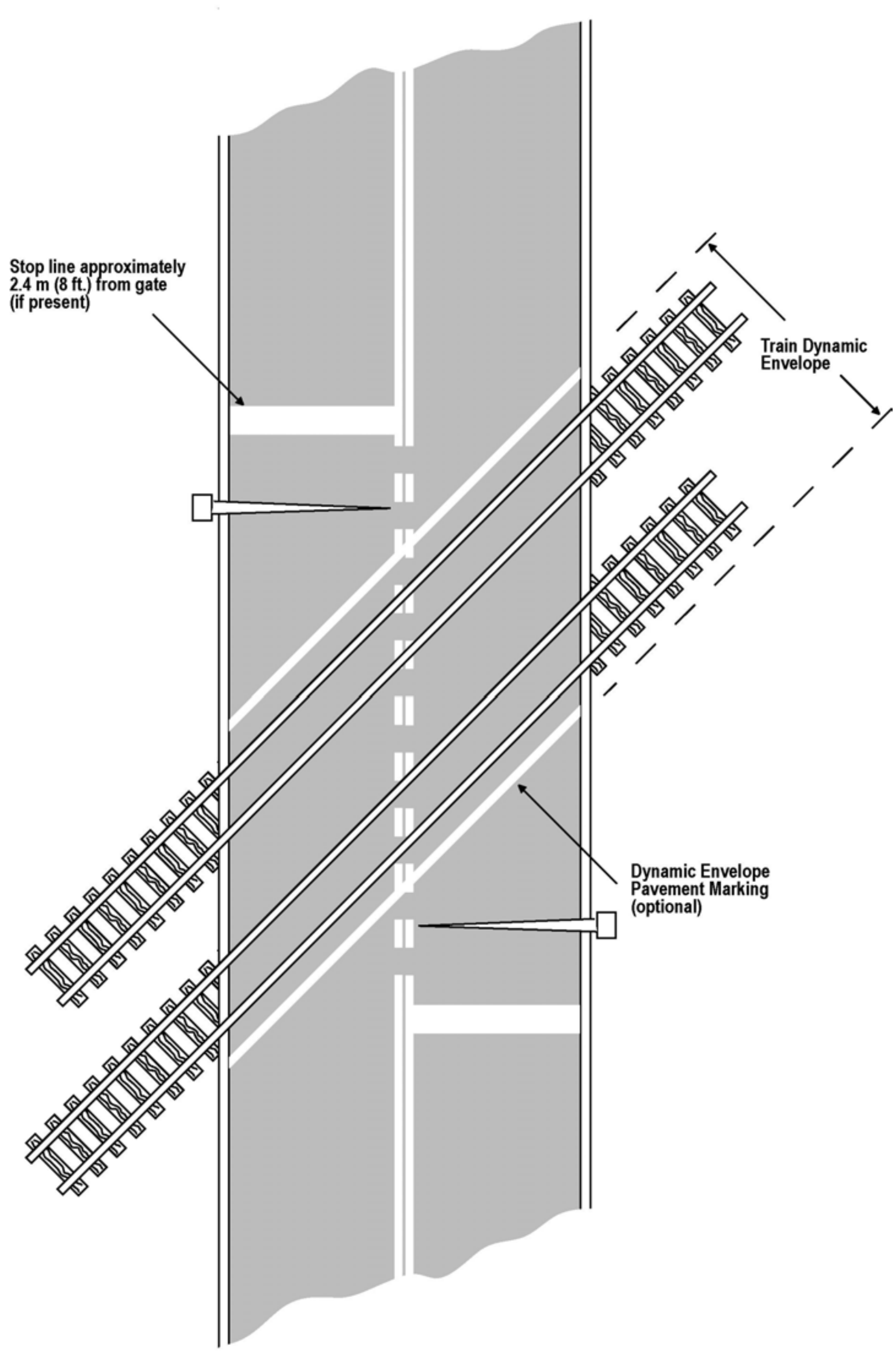
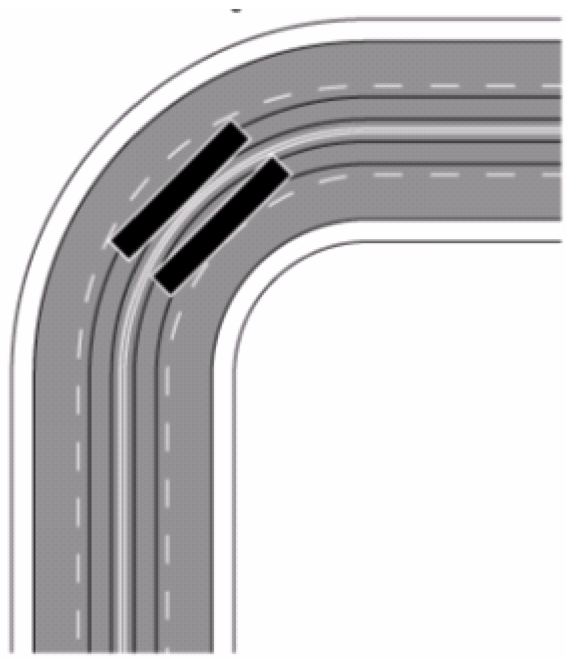
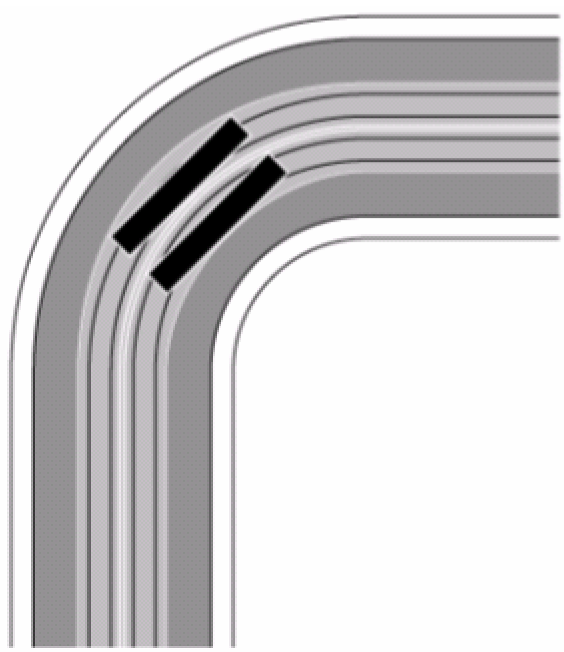


FIGURE 2 Impact of LRT car overhang on dynamic envelope.



(a)



(b)

FIGURE 3 Figures 10C-3 and 10C-4 from Part 10 of MUTCD: (a) 10C-3: Typical LRT car dynamic envelope delineation pavement markings; and (b) 10C-4: Typical LRT car dynamic envelope delineation contrasting pavement texture.

Section 10D.02—Four-Quadrant Gate Systems

According to the reordering suggested above, this would become Section 10D.04. This positioning, with respect to the other sections covering traffic control methods, would also be consistent with the (correct) classification of this device as an option, but not a recommendation.

Section 10D.03—Automatic Gates

The conditions under which automatic gates should be installed are essentially the same as those described in Section 10D.04 for the installation of flashing-light signals. With the suggested reordering of the three sections it would be unnecessary to reiterate the conditions in this section, because they would already be documented in the previous section. There are no circumstances in which automatic gates would be installed in the absence of flashing-light signals. As noted in the first Support paragraph, they are an adjunct to flashing-light signals.

The last paragraph of the Option portion of this section includes the term *traffic gates*. For consistency, not only within Part 10, but also within Part 8 and various other official documents, this and other uses of that term in the MUTCD should be replaced by *automatic gates*.

Section 10D.04—Flashing-Light Signals

According to the reordering suggested above, this would become Section 10D.02. It would then precede the sections that address the supplementary devices, such as conventional and four-quadrant automatic gates.

There is some logic in the concept of precluding traffic signals at a crossing control method when the LRT speed limit is above some maximum. However, the particular speeds chosen seem unreasonably low. The following examples would seem to support a higher limit.

Highway vehicles, including a significant volume of 36.3-tonne [80,000-lb] tractor-trailers, routinely and legally pass through intersections controlled by traffic signals at speeds up to 88.5 km [55 mi] per hour. This often occurs on divided highways. Under the strictures of this section LRT cars operating in the median of such a highway at the same speed would have to slow to 60 km [35 mi] per hour during their passage through a traffic signal-controlled intersection and then re-accelerate. Meanwhile, the trucks and buses on the abutting parallel roadway could continue to travel through the same intersection at speeds almost 50% greater than the rail cars.

Streetcars, which are a version of LRT cars (as clearly established by Section 10A.01), routinely travel at speeds of 55 to 65 km [35 to 40 mi] per hour through non-intersection crossings, primarily mid-block driveway interfaces, and have been doing so for nearly a century. This section could be interpreted as requiring them to slow to 40 km [25 mi] per hour when passing through these interfaces.

Consideration should be given to the following: (1) a review of current practices at non-gated crossings, particularly those on seasoned systems that may have a long history of operating at speeds higher than those set forth in this section; and (2) a revision that would limit the speed of LRT cars through intersections controlled by traffic signals to the design speed of the parallel roadway, rather than specific numerical speeds.

Section 10D.05—Traffic Control Signals

In the first sentence of the first Support paragraph the phrase “vehicular and” should be deleted and “of the two modes” should be replaced by *“with roadways*.” LRT signals do not control vehicular traffic.

The content of the Standard paragraph is subject to two different interpretations. It could be argued that in a situation where none of the warrants in Chapter 4C (which are among the referenced provisions of Part 4) are satisfied, that type of control cannot be installed. Conversely, it could be contended that the current warrants are not “appropriate” for light rail interfaces and therefore, they are not applicable. Based on actual design experience the latter position seems justified.

The traffic signal warrants were originally developed long before the resurgence of light rail transit. Although they have been revised and expanded in the recent past, they are still based entirely upon matters related to controlling conflicting vehicle and pedestrian movements. They do not take into account the conflicts that can result when LRT movements that do not coincide with any vehicle movement are introduced at a particular interface.

Rather than further expanding the current warrants to address light rail factors, consideration should be given to revising the subject standard by definitively stating that the warrants are not included in the referenced provisions of Part 4. The revision might also be used to correct a discrepancy in the standard. The phrase “traffic gates or” should be deleted. There are no circumstances in which gates would be installed other than as an adjunct to flashing-light signals.

The following rewording is suggested:

> The provisions of Parts 4 and 8 relating to traffic control signal design, installation, and operation, including interconnection with nearby flashing-light signals, shall be applicable as appropriate where these signals are used at highway-light rail grade crossings, with the specific exception of the warrants contained in Chapter 4C.
>
> Traffic control signals may be installed in lieu of flashing-light signals at crossings and/or intersections within 60 m (200 ft) of a crossing where no warrant is satisfied if an engineering study identifies one or more potential hazards involving the light rail transit operation that would exist in the absence of such control.

In the first Option paragraph, the reference to bicycles is redundant and could be deleted. Bicycles are vehicles. Also, the 40-km/hr LRT speed limit is questionable, as discussed previously.

In the second Option paragraph, the restriction of the use of traffic control signals at crossings controlled by flashing-light signals only if automatic gates supplement them is not rational. If the requirement for the satisfaction of a traffic signal warrant is rescinded, as discussed above, this paragraph could be deleted.

Section 10D.06—Traffic Signal Preemption Turning Restrictions

In the first Standard paragraph the conjunction “and/or” should be replaced with “and.” There is no circumstance in which the subject signals should not display a red indication when an LRT car is passing through a crossing.

The second Standard paragraph contains a restriction that appears to be unnecessary. There could be conditions in which it would be useful to display a message between activations, such as advising motorists that trains may approach from behind. Consideration should be given to a revised wording that would allow the display of messages when no approaching LRT car has been detected, provided that those messages do not actually prohibit movements.

Section 10D.07—Use of Traffic Control Signals for Control of LRT Vehicles at Grade Crossings

For consistency, and to provide a clearer description of the subject of this section, the title "Use of Signals for Controlling Light Rail Transit Movements at Crossings" should be considered.

The first Support paragraph refers to the signals depicted in MUTCD Figure 10D-1 (Figure 4) as "typical." In actuality some of the displays shown are not used anywhere in the country and others are far from typical. At the same time some displays that are in current use are not shown. This paragraph should be changed to read, "Some examples of light rail transit signals are shown in Figure 10D-1."

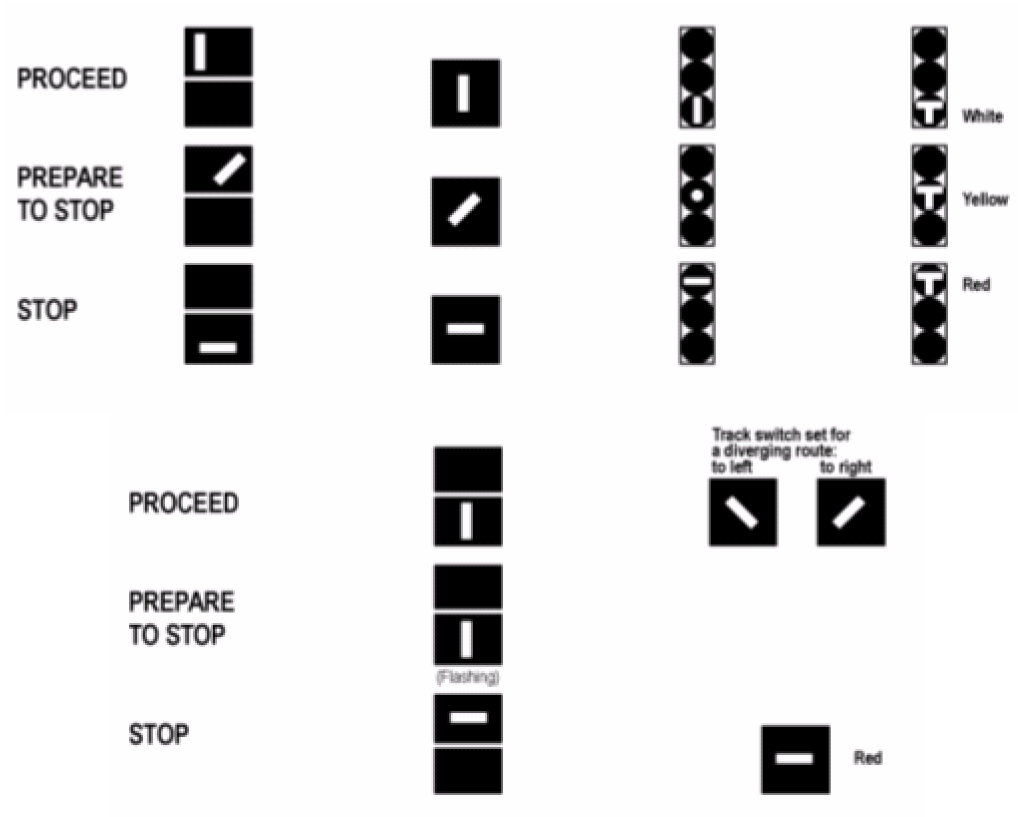
The second Standard paragraph imposes a restriction on signal timing and phasing programs. It requires the signal controller(s) to be programmed to suspend the cycling and remain in the phase serving the rail movement until the LRT car has cleared the crossing. There are three issues related to this requirement that should be considered.

First, the need for this restriction is questionable. In metropolitan areas throughout the country there are hundreds, if not thousands, of instances every day in which vehicles, and in some cases LRT cars, remain in an intersection after their signal phase has been terminated. These conditions impede movement and are certainly undesirable, but they are not categorically hazardous. When motorists on the intersecting street receive a green signal they do not proceed into the intersection and collide with stationary objects already occupying it.

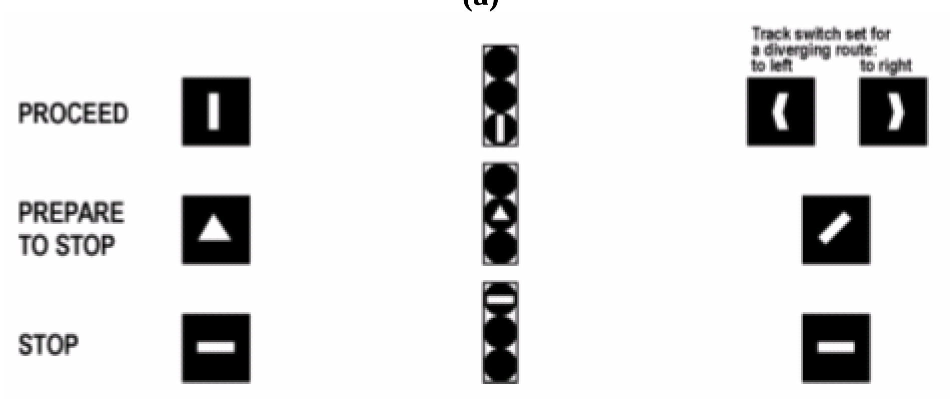
Second, this requirement could cause negative impact wherever the crossing control is part of a coordinated signal system. In order to maintain a progression in such a system, all of the signal controllers have to operate with a common cycle length. Phases within that cycle can be skipped, shortened, or extended modestly to expedite particular movements, provided that the total cycle length remains the same. (The cycle length can be changed from one time of day to another, but it must be done in common with the other controllers in the system.) If, in order to comply with this Standard, a particular phase were to be extended indefinitely at one crossing or intersection in a coordinated system, the integrity of that common cycle would be ruptured, resulting in a loss of coordination. Travel time and delay for all traffic in the vicinity would likely increase dramatically.

Third, no detection system is infallible. Situations in which an LRT car or train has physically cleared the crossing, but the detection system has failed to transmit that information to the controller are inevitable. To address such situations there should be a provision whereby, in the absence of any detection of its departure from the crossing, the cycle would be resumed after some predetermined maximum time has elapsed. The requirement in this standard for an indefinite suspension of the cycling precludes such a provision.

It might be argued that, since the standard applies only when the vehicle and LRT movements are regulated by signals operated by separate, interconnected controllers, the requirement might be circumvented by using a single controller to operate the traffic signals and the LRT signals. That argument would be tenuous because it is probable that this obscure differentiation was not intentional. A better solution would be simply to delete the last sentence of this standard.



(a)



(b)

FIGURE 4 Examples of LRT signals as shown in MUTCD Figure 10D-1: (a) Examples of LRT signals in current use; and (b) other possible aspects.

Section 10D.08—Pedestrian and Bicycle Signals and Crossings

Whatever the degree of hazard to pedestrians may be at light rail grade crossings (where the approaching trains, with multiple braking systems, often have a reasonable chance of stopping to avoid a collision with a pedestrian), that hazard is certainly less than it is at railroad grade crossings (where approaching trains have virtually no capability of stopping quickly enough to avoid striking a pedestrian in their path). Inasmuch as Part 8 has been, and continues to be, silent on the matter of pedestrian gates, it is curious that Part 10, which addresses potentially less hazardous situations, dwells extensively on the design of pedestrian gates without any support of their implied necessity.

A general review of accident information seems to indicate that nearly all direct collisions of trains and pedestrians occur at locations that are not legal crossings as a result of trespassing. At the legal crossings those persons who are injured or killed at are generally not pedestrians, but occupants of vehicles struck as a consequence of motorist violations. There is little documented evidence of direct collisions between trains (railroad or light rail) and pedestrians at legal crossings. A widespread need for pedestrian gates seems to have been assumed with no basis in fact.

The first Guidance paragraph wisely recommends against a design that would cause pedestrians to wait between sets of tracks or between tracks and the road. Unfortunately, it fails to provide a comparable recommendation against designs that could cause pedestrians to wait between a track and a lowered gate arm. The good intention of this section in recommending methods of deterring pedestrians from *entering* a crossing when a train is approaching could encourage a design that would result in preventing people from *vacating* the crossing as the train approaches.

This concern for pedestrians who could be entrapped in the path of an oncoming train is illustrated in Figure 10D-5. A person proceeding on the sidewalk who has already entered the crossing when an approaching train activates the control equipment would have three seconds to vacate the trackway before the gates begin to descend. This time allowance is marginally sufficient for those who have no physical impairments. Those who are mobility or vision-impaired would likely be trapped, either between the two tracks, or between one of the tracks and a gate arm. If the gates were designed to block only vehicle passage, then pedestrians would have at least 20 seconds to vacate the trackway following activation of the control devices.

Considering that the installation of pedestrian gates could create hazards that would not otherwise exist and that the need for these devices is questionable, it might be wise to insert, following the Guidance paragraphs, another Option paragraph such as “Pedestrian gates may be installed in circumstances where an engineering study has determined that less restrictive measures, such as flashing signal lights and traditional automatic gates, are determined not to be effective.”

CONCLUSION

The development of new LRT systems and the expansion and improvement of existing networks is continuing at a healthy pace, and there is every indication that it will continue to do so. Prior to the publication of Part 10, designers of new lines had no national standards to guide them. On the “seasoned” systems there was a tendency to design traffic control according to prevailing local practices. This resulted in some inconsistencies that, while they were not problematic, neither were they desirable.

Part 10 is an initial effort to establish standards, recommendations, and options to guide designers. The more than two years that have elapsed since its publication have provided the opportunity to apply and test its content. This has revealed some possible weaknesses, which should not be unexpected with any pioneer undertaking. The comments and suggestions in this paper are presented to stimulate discussion in the professional community with the goal of providing quality input for the next version of the MUTCD.

Preemption Versus Priority Service for Light Rail Transit Vehicles

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Naztec,Inc.

Naztec, Inc. developed light rail preemption software for the $1.26 billion Hudson–Bergen Light Rail Project for New Jersey Transit in 1998 as a sub-contractor to Raytheon Engineers & Contractors, Inc. This system preempts approximately 100 traffic signals located on the rail between Newark, New Jersey, and Manhattan and provides status information to the NJ Transit control center. This system has been in operation for over 4 years; when the Hudson–Bergen Project is completed in 2005, the rail system is expected to carry in excess of 66,000 passengers per day.

The Hudson–Bergen light rail software supports a dual-track system with separate advance call, check-in, and check-out detectors installed in the track. These detectors insure that the light rail vehicle is serviced without stopping and that the track is clear before returning to normal operation. The controller software allows overlapping light rail operation on the dual track system and provides several features that improve the stability of the system.

Naztec, Inc. is currently developing transit priority software based on NTCIP 1211 that can be applied to light rail as well as transit operations. The issue of preemption versus priority service involves competing demands between roadway users and transit. The object definitions from NTCIP 1211 can be applied to "compromise" both approaches.

An overview of Naztec's experience developing traffic signal controller software for light rail preemption and priority service is provided. It is also explained how NTCIP 1211 can provide a common framework for preemption and priority based service to strike a balance between transit and system needs.

Light rail preemption developed for the Hudson–Bergen Project in light of the emerging national standard, NTCIP 1211—"Object Definitions for Signal Control and Prioritization"—is discussed (*1*). Currently, there is a lack of uniformity in how preemption and priority service is applied to light rail operations around the country. Hopefully, the features and operation described here for the Hudson–Bergen Project will provide insight for those charged with developing standards for light rail operation.

HUDSON–BERGEN LIGHT RAIL PREEMPTION

The local intersection software for the Hudson–Bergen Light Rail Project (Figure 1) was designed to provide advance detection of a light rail vehicle (LRV), terminate normal stop-and-go operation of the signal after a user specified arrival time, and transfer the right-of-way to the rail phase prior to the arrival of the LRV. Once the LRV clears the crossing, the signal returns to normal operation. The advance detection is provided by a detector located in the track or by a Psuedo output call when the LRV clears the last upstream intersection.

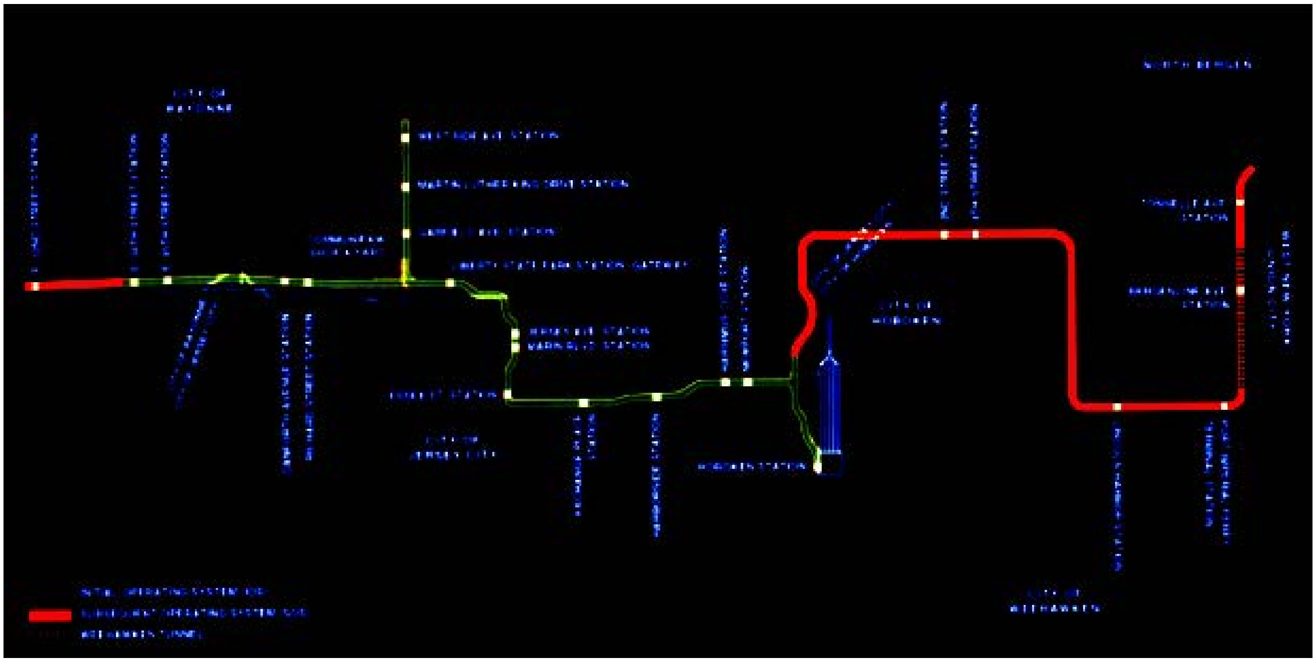

FIGURE 1 Hudson–Bergen LRT system.

Figure 2 shows the TS2 D-connector inputs specified by Raytheon for this project. Two Advance Call detector inputs and two separate Check-In and Check-Out detector inputs are required for each track. The software also supports four Pseudo outputs used to send an advance call to the next signal downstream when the LRV clears the crossing. Pseudo outputs are used in place of actual light rail detection when the spacing between signals precludes the use of advance detectors. Five external alarm inputs are also provided to relay status information to the central system (status for cabinet door open, etc).

Two advance detectors for each rail are required to place a preempt call in each approach direction. An approaching train activates the Advance Call detector and preempts the controller to turn the rail signal green after a specified Arrival Time period. The rules for transferring the right-of-way to the specified rail phase are similar to those used for high priority rail and emergency vehicle preemption. This design insures that a vertical Go-bar is displayed for the LRV prior to arrival. Phases may be skipped in the controller sequence to return to the rail phase.

Optional track Clearance Phases may be specified to clear vehicles on the tracks prior to the arrival of the LRV. The time specified to clear the track phases must be included in the Arrival Time after the Advance Call is received. A Freeze on Advance option is provided to prevent exiting to a non-rail phase when the Advance Call is received. If Freeze on Advance is not set, the controller will continue to cycle normally until the Arrival Time expires and it must return to the rail phase(s).

Right-of-way is transferred to the light rail phase(s) as a vertical Go-bar signal on the rail approach. Then, a user specified Minimum Green period begins timing until the train is detected at the Check-In detector. If the Minimum Green period expires before the LRV arrives at the

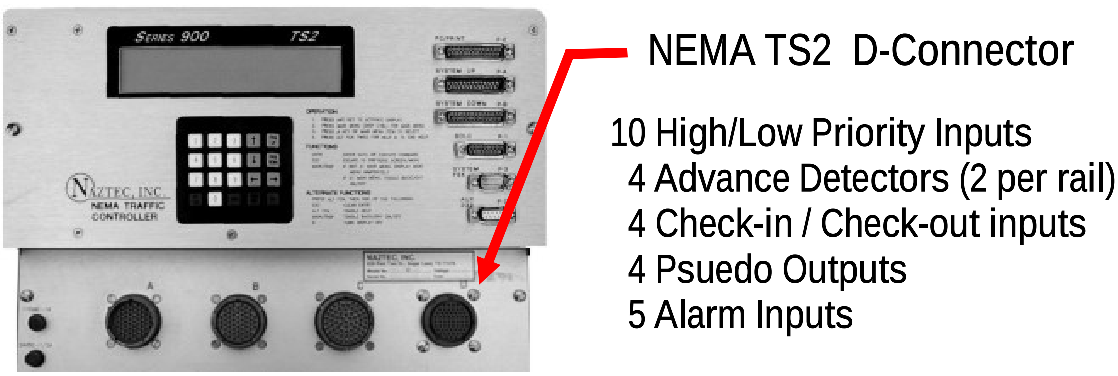

FIGURE 2 TS2 Controller inputs and outputs used for light rail preemption.

Check-In detector, the rail phase will clear and return to the horizontal Go-bar position. A late arrival will be serviced once the rail vehicle arrives at the Check-In detector; however, a Check-In Alarm will be reported by the controller to the central system.

The Clearance Green insures that the LRV has not stopped on the crossing without clearing the Check-Out detector. Clearance Green begins counting down after the vehicle is detected at the Check-In detector before the Minimum Green period expires. If the Clearance Green timer expires before the train is detected at the Check-Out detector, a Failed to Clear Intersection Alarm is sent to notify the central office that the train is stalled on the crossing. However, normal operation holds the track signal green until the end of the train clears the intersection and is released by the Check-Out detector. Once the vehicle clears the Check-Out detector, a Pseudo output is generated for a user specified Pseudo Time. This output is used to generate an Advance Call to the downstream signal using hardwire interconnect if the spacing between the signals does not allow sufficient advance detection.

The controller software also provides a Maximum Green timer to limit the extension of the light rail phase beyond a desirable period. The Maximum Green timer prevents the situation when two rail vehicles overlap and hold the preempt call while a third Advance Call attempts to extend the preempt (a situation called "pinging"). Unless this Maximum Green timer expires, the controller software logic is designed to maintain the Go-bar indication for the rail phase until the last train crosses the Check-Out detector.

The normal sequence of calls issued by the LRV is *Advance Call* followed by Check-In then Check-Out. The controller reports a Detector Sequence Failure Alarm if a different sequence of calls is received. The controller also logs the last ten light rail events and records the preempt direction, advance time, and clearance time for each preempt event. This status information is useful to adjust the timing parameters and insure that transit vehicles are being serviced within the Arrival Time and Minimum Green window specified. The software also applies maximum Advance Call, Check-In, and Check-Out on-times to report Stuck Detector Alarms to the central system.

The light rail controller software is designed to accommodate advance calls from overlapping LRVs on adjacent rails. In this situation, the Go-bar called in one direction may be extended by an advance call on the adjacent track system. The last vehicle to exit the Check-Out detector releases the preempt. A user specified Separation Time prevents re-servicing the rail phase in the same direction of travel. Also, a Lock Out option is provided to lock out any additional preempt calls until all conflicting vehicular phases have been serviced.

Return Phases may also be specified to return to normal stop-and-go operation. However, if no Return Phases are specified, the controller will always return to the phases in the sequence following the rail phase. If the Return to Interrupted Phase option is set, the controller will exit the rail phase and return to the signal phases that were interrupted when the preempt was received.

The real-time status screen (Figure 3) reports second-by-second status information from the local controller at each intersection. Note in this example that the rail phase (phase 10) is provided in ring 3 and is concurrent with the arterial phases in rings 1 and 2 (phases 2 and 6). This allows the rail Go-bar to service independently from the vehicular phases in rings 1 and 2. The light rail software supports up to four Concurrent Phases operating in separate rings while the light rail phase is being serviced.

The following controller menu (Figure 4) is provided to input the timing parameters discussed above for the New Jersey light rail preemption.

PREEMPTION VERSUS PRIORITY AND SYSTEM DESIGN GOALS

Light rail operation attempts to find a balance between the following conflicting goals:

1. Provide a vertical Go-bar indication for the light rail without deceleration, and
2. Maintain non-interrupted arterial progression.

Light rail preemption, such as the system developed for the Hudson–Bergen project, achieves the first goal without consideration of the impact on arterial progression. Preemption works exceptionally well for the Hudson–Bergen project because most of the light rail system is located on collector streets parallel to the major arterials going into Manhattan. Preemption can be the best alternative if good planning and route design insures the impact on the arterial is minimal.

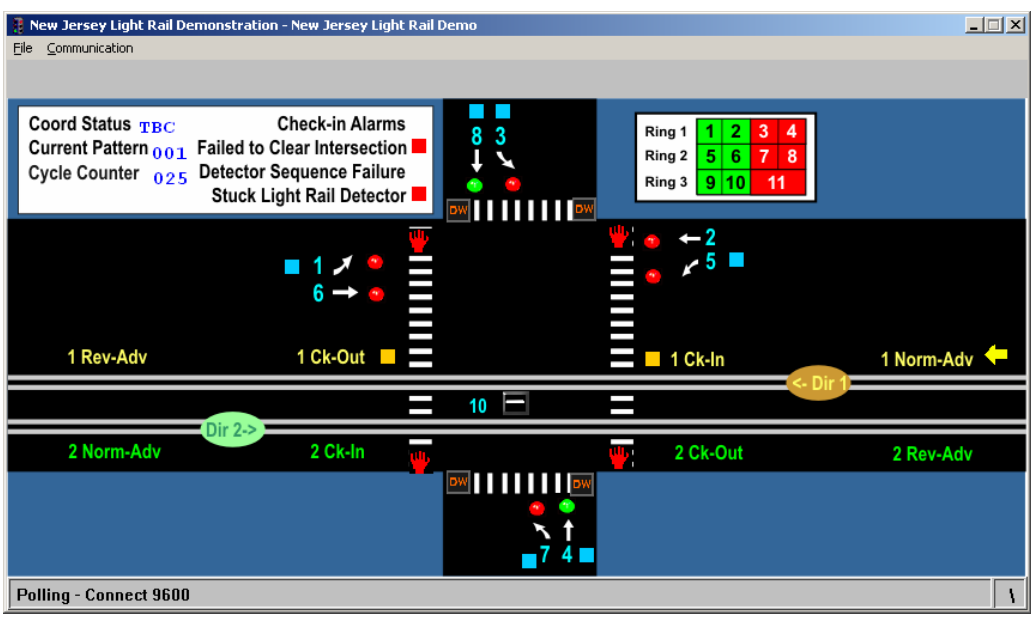

FIGURE 3 Real-time status screen of light rail operation at central office preemption.

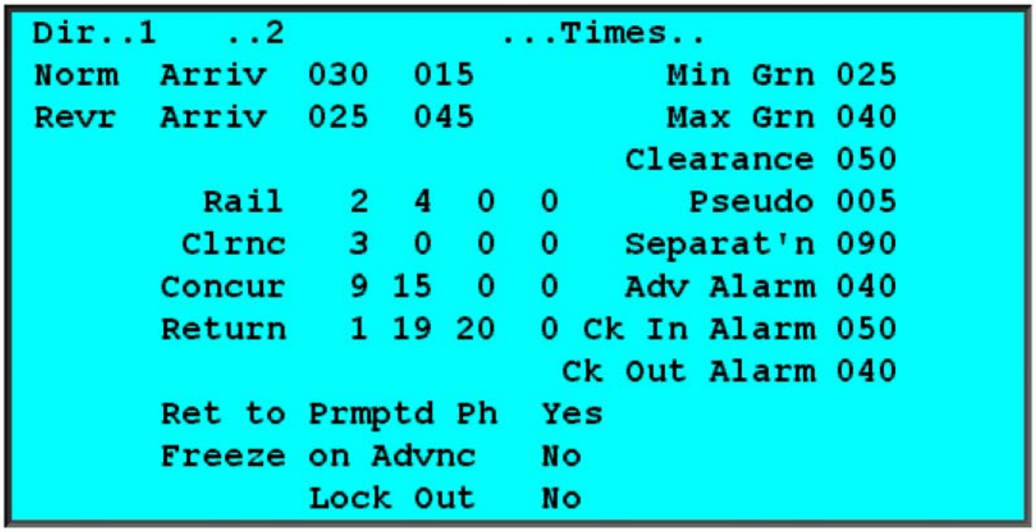

FIGURE 4 TS2 controller screen used to manage light rail parameters.

Transit priority focuses on the second goal and as defined in NTCIP 1211 and a recent report published by ITS America (*2*). Naztec is currently developing controller software to implement transit priority based on the emerging NTCIP 1211 standard. In this design, the Priority Request Server is tightly coupled with the controller software to process all preempt and transit priority requests (see Figure 5).

A Priority Strategy Table (PST) defines the level of preemption or priority for each request and may be varied by time-of-day through the controller pattern. The controller also provides the ability to relay advance calls to the next downstream intersection as NTCIP-encoded messages or as a contact closure if required by the hardware configuration (similar to the Pseudo calls used for the Hudson–Bergen system).

PRIORITY STRATEGIES USED FOR TRANSIT PRIORITY

NTCIP 1211 allows a priority-based system to

1. Skip programmed vehicle phase(s);
2. Skip programmed pedestrian phase(s);
3. Shorten phase(s) during coordination to provide early return to the priority phase (Figure 6);
4. Extend phase(s) during coordination to adjust the start of the priority phase in the next signal cycle; and
5. Extend the priority phase(s) beyond the programmed force-off point during coordination (Figure 7).

A priority request for service (PRS) is used to project the time service is desired (TSD). TSD may be immediate or projected in time into the next signal cycle. NTCIP 1211 allows programmed phases and pedestrian intervals to be skipped to provide a priority phase early return. A priority strategy that allows all phases to skip to return to the priority phase is equivalent to the light rail preemption used in the Hudson–Bergen project.

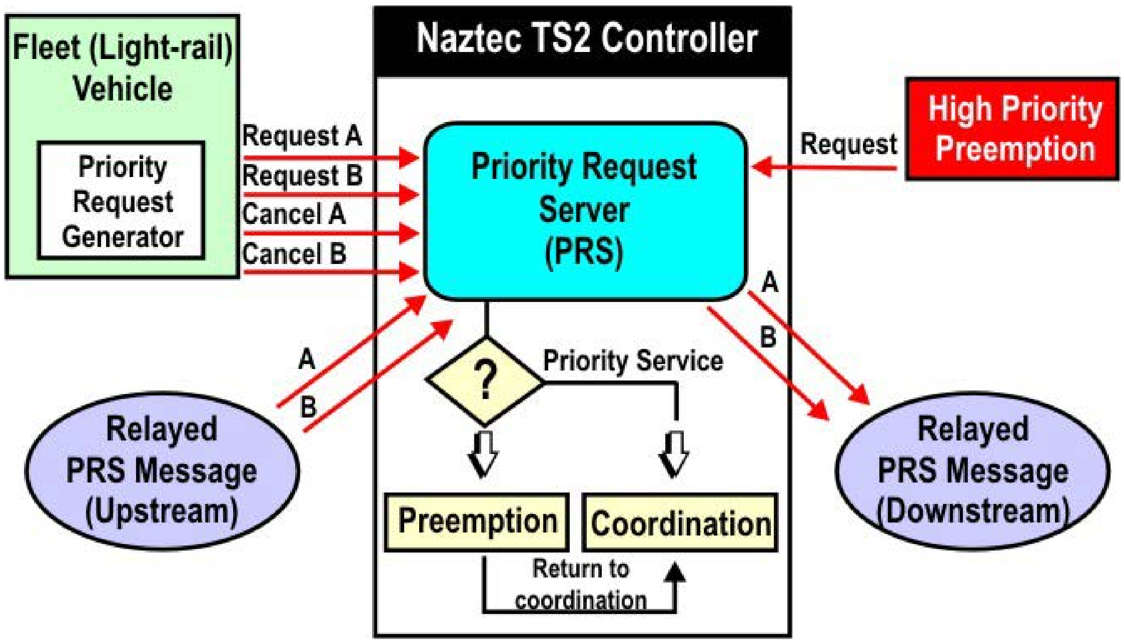

FIGURE 5 Naztec preemption and transit priority model.

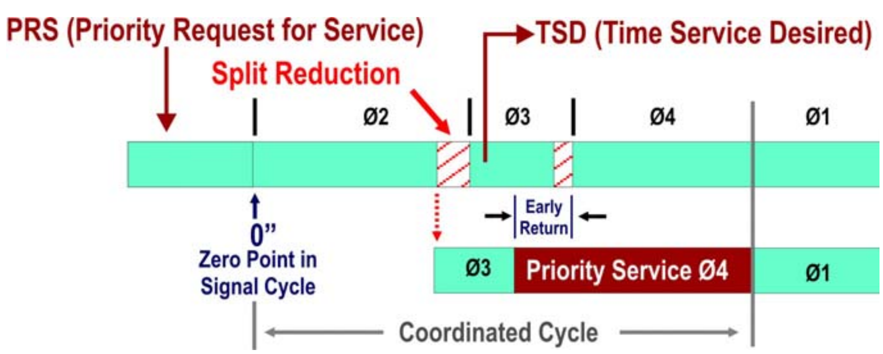

FIGURE 6 Phase Reduction provides an Early Return to the Priority Service Phase.

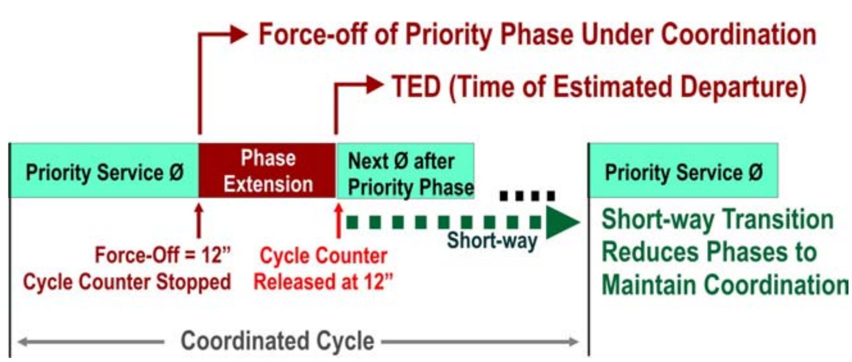

FIGURE 7 Phase extension extends the Priority Service Phase during coordination.

Priority-based systems also allow the priority phase to be extended beyond the force-off point during coordination. NTCIP allows the local controller to provide a short-way transition to quickly resynchronize the controller's offset and return to coordination in this case. Naztec controller features can re-synchronize the controller offset within one cycle by applying short-way transition.

Naztec implements low-priority preemption using a Type option to define operational requirements that vary from agency to agency for low-priority and transit priority. High-Priority (HP) and Low-Priority (LP) inputs follow the industry standard defined by 3M Corporation. HP inputs are "ground true" inputs applied at zero volts while LP inputs apply a 6.25Hz, oscillating signal. This allows low-priority service (transit) to be interrupted by a high-priority preempt (heavy rail and emergency vehicles).

Naztec currently implements HP and LP inputs in addition to the four light rail inputs described for the Hudson–Bergen light rail system. A Transit-Priority (TP1) type was developed for Santa Clara County, California, 10 years ago. The TP1 type allows phase skipping to return to the TP1 transit phase early; however, the phase being serviced at the time the TP1 call is received will continue to service until it is terminated normally in free or coordinated operation.

Naztec is currently developing another Transit Priority type, TP2, that implements the Priority Strategy Table (PST) defined in NTCIP 1211. Separate PST tables may be assigned to transit priority service by associating the PST table with the NTCIP pattern currently in effect. This scheme allows the PST table to vary by time-of-day.

Caution must be exercised when specifying Phase Reduction in the PST table because split times must insure that minimum vehicle and pedestrian time requirements are met for each phase. Figure 8 illustrates the method currently being developed to implement Phase Reduction for priority service. Users are allowed to specify Reduce times in the PST table that violate minimum phase times; however, the controller software insures that phases cannot be reduced beyond minimums established in the controller internal coordination diagnostics.

CONCLUSIONS

Naztec, Inc. developed light rail preemption software for the Hudson–Bergen Project in New Jersey in 1998 to detect a LRV far enough upstream and provide a vertical Go-bar indication prior to the vehicle arrival. This system provides additional features and detection not provided with heavy rail preemption such as overlapping service on a dual track system and the ability to re-service the LRV if it arrives late at the Check-In detector. Additional status information is relayed to the New Jersey Transit control center to help fine-tune and manage the system. This system works exceptionally well because the track system is located primarily on the collector street system parallel to the main arterials going into Manhattan from Newark.

Naztec, Inc. is also currently developing transit priority software based on the emerging NTCIP 1211 standard, "Object Definitions for Signal Control and Prioritization." The PST in NTCIP 1211 provides a framework for defining the level of preemption or priority needed for any application. Under NTCIP 1211, preemption may be accomplished by specifying the Priority Service Phase and omitting all vehicle and pedestrian phases in the PST. Varying levels of priority service may be accomplished by specifying phase skipping and how much each phase may be shortened or extended to service the Priority Service Phase when the transit vehicle is expected to arrive.

	Ø..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PST for the active Pattern# & Preempt# — Strategy 1	Ø..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Priority Serv		.	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Extend		0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduce		5	10	3	12	5	10	5	15	0	0	0	0	0	0	0	0
Phase Omit		X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ped Omit		.	.	.	X	.	.	.	X	.	.	.	.	.	.	.	.
Active Split Table for Pattern# 1	Ø..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Splits (sec)		18	44	14	28	18	44	14	28	0	0	0	0	0	0	0	0
Min Green:		5	10	5	11	5	10	5	11	0	0	0	0	0	0	0	0
Max Initial:		0	18	0	0	0	18	0	0	0	0	0	0	0	0	0	0
Walk equal to TP2 Walk (if not zero):		0	3	0	3	0	3	0	3	0	0	0	0	0	0	0	0
Ped Clearance:		0	12	0	22	0	12	0	22	0	0	0	0	0	0	0	0
Rest-In-Walk (not a factor):		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ped Clear Thru Yellow:		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ped Delay :		.	.	.	X	.	.	.	X	.	.	.	.	.	.	.	.
Grn/Ped Delay Time (sec):		0	0	0	7	0	0	0	7	0	0	0	0	0	0	0	0
Yellow Vehicle Clearance:		3.8	4.7	3.8	4.2	3.8	4.7	3.8	4.2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Clearance:		2.3	0.7	2.3	1.1	2.3	0.7	2.3	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Minimum Phase Time for the Pattern	Ø..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(see assumptions below)		12	24	12	17	12	24	12	17	5	5	5	5	5	5	5	5
Adjusted Reduce Value	Ø..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lessor of Reduce value or (Split-Min Phase)		5	10	2	11	5	10	2	11	-5	-5	-5	-5	-5	-5	-5	-5
Zero if the phase is Priority Serv Phase		5	0	2	11	5	10	2	11	-5	-5	-5	-5	-5	-5	-5	-5
Final adjustment (zero if negative)		5	0	2	11	5	10	2	11	0	0	0	0	0	0	0	0

FIGURE 8 Split times cannot be reduced below minimum phase time requirements.

Preemption and priority based systems become more effective as more advance notice is provided by PRS. In the New Jersey light rail system, an Advance Call can be relayed to the next signal downstream using the Pseudo out call when the LRV clears the Check-Out detector. A similar strategy following NTCIP 1211 can be used to relay a PRS to the downstream controller as either a peer-to-peer message or as a hardwire interconnect contact closure. The approach taken depends on the hardware requirements of each system and often requires the controller manufacturer to interface protocols for existing devices that do not comply with NTCIP protocols and messaging schemes.

Light rail preemption with adequate advance detection can insure that the LRV clears the downstream signal. The tradeoff decision between preemption and priority service accepts the risk of stopping the transit vehicle when more consideration is given to arterial progression and priority service.

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Application of NTCIP Standard 1211

Framework for Upgrading Downtown Baltimore Light Rail Transit Signal Priority

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The Maryland Transit Administration, in collaboration with the city of Baltimore, has developed a concept of operations for light rail transit (LRT) signal priority along the Howard Street corridor in Baltimore, Maryland. The National Transportation Communications for ITS Protocol (NTCIP) 1211 standard was relied upon heavily by the project team to provide a framework to describe the functional requirements for the priority system. The project team analyzed the existing system and its limitations to determine changes that would be needed to implement signal control priority in a fashion that was amenable to both the transit agency and the city traffic engineer. The result will be a priority control system that provides time savings for LRT vehicles while maintaining coordination of traffic signals in order to prevent congestion caused by more disruptive traffic signal preemption.

The importance of the NTCIP 1211 standard is that it defines priority as an operational concept that provides preferential service for selected vehicles based upon agreed criteria while not losing coordination. This type of operation meets the objective of providing signal timing that is transit friendly without degrading service to other vehicles to a level that causes disruption to the overall operation of the system. Baltimore's Howard Street LRT corridor will be used as a case study to demonstrate the benefits of NTCIP 1211 on transit and street operations.

INTRODUCTION

The city of Baltimore has undertaken a project to replace the traffic signal controllers and the traffic signal system and the existing light rail transit (LRT) preemption system on Howard Street in downtown Baltimore. The Maryland Transit Administration (MTA) was a member of the selection team to address issues related to the transit signal priority system that was a part of the signal system replacement project. The current signal priority system was developed several years prior and was the result of several years of cooperation between the city and the MTA. The current system uses a preemption along the corridor which was implemented using a Type 170 traffic controller, and the BiTrans signal controller software.

Design of the existing LRT system presented significant challenges for the city and MTA, as the north–south alignment bisects many of the city's key east–west arterials. The inherent conflict of freight, personal automobiles, and buses with the light rail line preemption system resulted in significant disruption to the transportation system, as the preemption routine developed for the corridor results in a loss of signal coordination throughout the downtown network.

Due to the nature of involvement with the city in the development of the original system, MTA was invited to participate in the signal system replacement process. The city had recently completed a traffic signal controller selection process that identified a NEMA TS2 Type 1 controller for the citywide standard (to be supplied by Naztec, Inc.). MTA's primary concern related to the selection of the NEMA TS2 controller was the fact that this specific standard (developed in 1992) does not include a priority algorithm, nor does it provide an open architecture that would allow the selection of a particular software to implement a signal priority system. This limitation would preclude selection of off-the-shelf software and the interchangeability that would allow MTA and the city to secure a priority system that takes advantage of new techniques developed as a part of the NTCIP 1211 standard development process.

Background

MTA is a statewide transit agency that serves Baltimore. In Baltimore, the MTA operates 47 bus routes, light rail, heavy rail, commuter rail, and a paratransit service for seniors and people with disabilities. The light rail line was constructed in 1992 and has provided a primary north–south corridor for the transit system that compliments the commuter rail in the region.

Short-term and long-term goals for MTA were outlined in the *Maryland Comprehensive Transit Plan* in December 2002. Of these, improving the service and operations of the existing light rail was identified. Specifically, this means reducing travel time and increasing reliability. In spring 2002 the Baltimore Region Rail System Advisory Committee agreed on the

priority projects that should move into MTA's project planning process. Of the short-term projects slated for Phase 1, "the improvement to light rail travel times on Howard Street" tops the list for light rail enhancement. The light rail line runs parallel to the queue shown in Figure 1 at the Camden Street and Howard Street intersection. Additionally, a Double Track Project is currently underway to reduce passenger delay and increase reliability. MTA's hope is that with the completion of this project, travel delays will be reduced and provide an opportunity to decrease headways between trains to 10 minutes. However, passenger delay and unstable travel times currently experienced by the LRT on the Howard Street corridor would limit the success and effectiveness of the Double Track Project. From MTA's perspective, the development of a signal priority system would help achieve these goals.

The city of Baltimore is in the process of replacing their existing signal system software to improve the monitoring and management capabilities of the Office of Transportation. The city and MTA have a long history of working together on the downtown street system dating back to the early 1990s when LRT was introduced to the Howard Street corridor. In association with this signal system replacement request for proposal and vendor selection, MTA participated on the Selection Committee for the Signal System Replacement Project.

MTA's primary interest with respect to the signal system operations is how the signal system will interact with the signal controllers to provide preferential treatment to transit vehicles. Light rail vehicles (LRVs) currently suffer from long cycle lengths at signalized

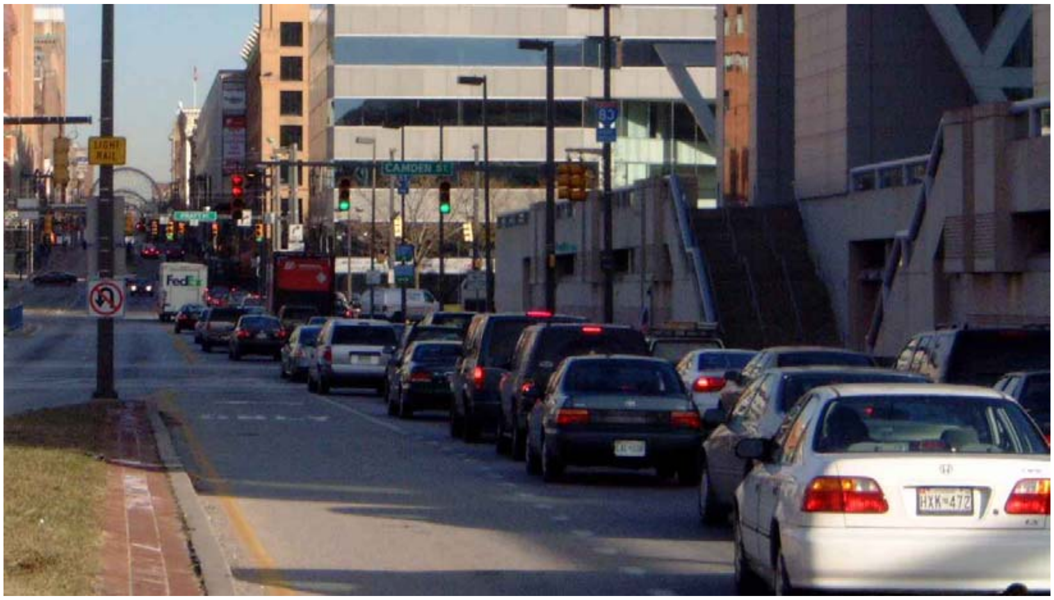

FIGURE 1 Significant queuing on Howard Street during the a.m. and p.m. peak period.

intersections that have the potential to delay vehicles as much as 80 seconds during the evening rush hour. The city has suggested that signal retiming will not be considered until the signal system has been replaced and an improved interface to time signals is secured. From MTA’s perspective, the existing system needs to be revisited, to address signal priority in conjunction with the signal system replacement project, as this is vital element to the MTA’s operations along this corridor.

Use of an Evolving Standard

The Signal Coordination and Prioritization Working Group under the sponsorship of the NTCIP Joint Committee developed object definitions for signal control and prioritization (NTCIP 1211). The evolving standard was developed concurrently with the signal system replacement project. The NTCIP 1211 standard is specifically intended to provide a standard means to provide traffic signal priority that previously did not exist. The standard includes a basic transit priority capability as well as the necessary data elements to provide more advanced applications.

In the process of developing our recommendation for the Project Team, consideration was given to the evolving NTCIP 1211 standard and its potential for application on the Howard Street corridor. Prospective vendors were asked to indicate the extent to which their solutions for signal priority were consistent with the evolving standard, and to describe the reason for deviations where inconsistent, as well as the ramifications of the inconsistency. Use of the NTCIP 1211 standard allows the opportunity to utilize signal priority, which will reduce the disruption preemption has on traffic flow in downtown Baltimore.

EXISTING PREEMPTION SYSTEM ON HOWARD STREET

The LRV preemption system on Howard Street involves 17 signalized intersections. Howard Street runs in a north–south direction and intersects several major arterials, many of which are one-way streets. The light rail tracks run in the roadway, adjacent to vehicular traffic along most of the Howard Street corridor. Figure 2 shows the alignment of the light rail within the downtown street system.

The LRVs on Howard Street operate with light rail stations that are spaced every three or four blocks. The stations are both near side and far side throughout the downtown depending on the location. Typically, a LRV stops at a station and dwells for approximately 30 to 45 s while passengers get on and off. When boarding is completed, the LRV operator requests preemption service by pushing a preemption request button on the LRV control panel. The nearest intersection and all intersections between the station and the next station (at most five intersections) may be preempted from this single call. The preemption signal is relayed from controller to controller via modem. This approach assumes that the train will not be delayed between stations, which occurs on occasion due to vehicle queues from cross streets blocking the tracks, or an emergency vehicle preemption call that conflicts.

Preemption at each intersection may be delayed for a programmable period to ensure minimum pedestrian clearance before the active preemption clearance phase is actually displayed. This procedure is employed for both northbound and southbound LRVs. If a LRV is delayed before entering the intersection, the LRV operator may request another preempt at the next downstream intersection.

Impetus for Change

The existing approach to traffic control on Howard Street (preemption) is perceived by the city of Baltimore as too disruptive to the vehicular traffic operating on the intersecting arterials of the city street system. One of the key changes in system operations since inception of the system was the increase in the number of trains during the peak hours to handle the ridership which resulted in more preempt requests on the corridor. Based on the city's field experience monitoring the preemption system during the peak periods, the decision was made to suspend preemption along Howard Street at the 17 signalized intersections through the downtown area.

The decision to limit preferential treatment for transit vehicles is common in many U.S. cities because of the impacts preemption has on the remainder of the transportation system. In most cases, preemption results in a drop of coordination between adjacent traffic signals which may cause unnecessary queue spillback between intersections and excessive delays to the intersecting street and have cascading effects throughout the arterial network. For this reason, the recommendation was to provide *priority* as an alternative to preemption that can be used during the peak periods where preemption is perceived as undesirable by the city Traffic Engineering Department. The concept of priority and preemption is defined in Table 1.

Use of NTCIP 1211 Standard

The NTCIP 1211 standard identifies functional requirements for a variety of priority service use cases. The implementation of a signal control and prioritization system has two primary components: a Priority Request Generator (PRG) and a Priority Request Server (PRS). These elements are not

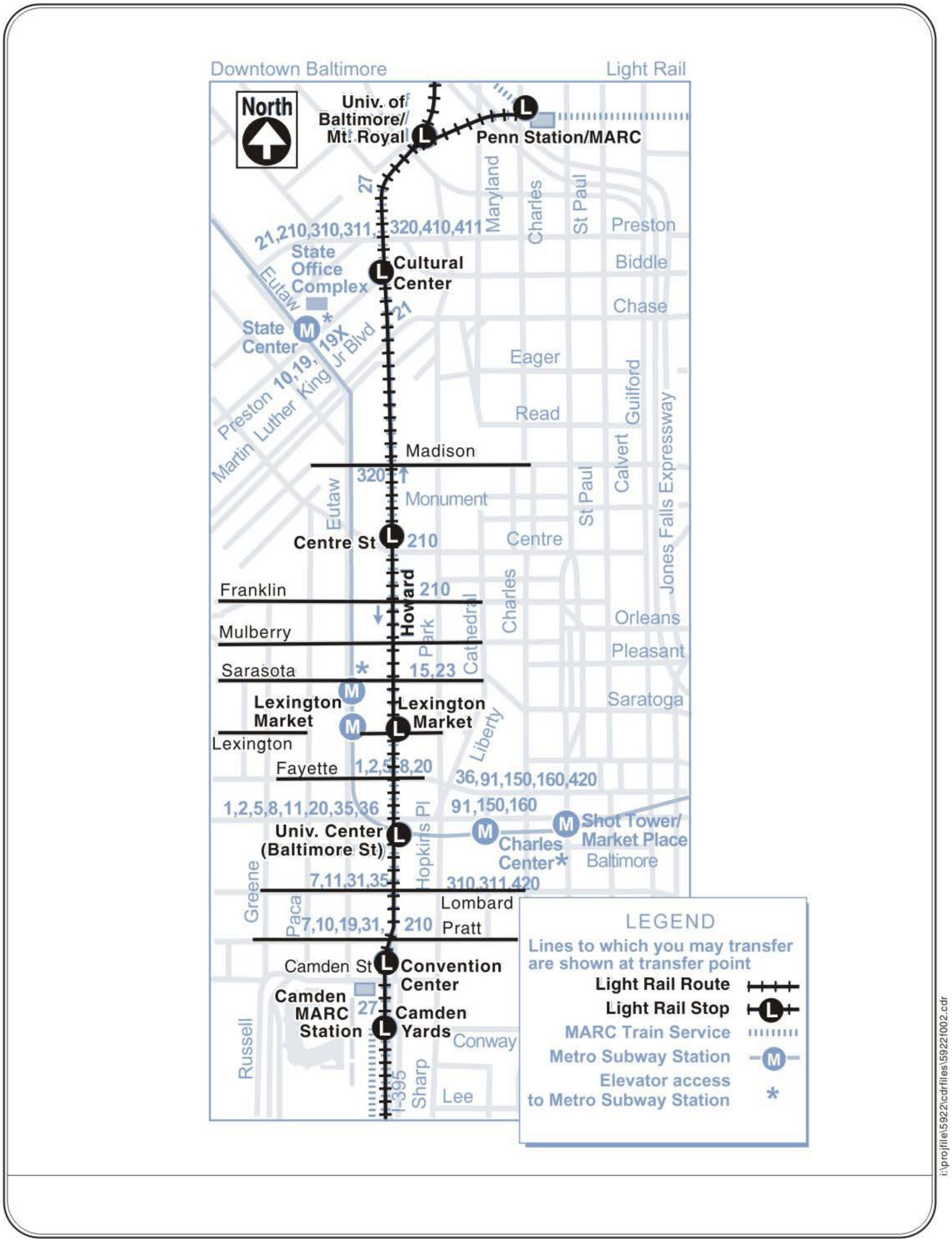

FIGURE 2 LRT corridor study area.

TABLE 1 Definitions for Signal Priority (*1*)

Preemption	The transfer of the normal control (operation) of traffic signals to a special signal control mode for the purpose of servicing railroad crossings, emergency vehicle passage, mass transit vehicle passage, and other special tasks, the control of which requires terminating normal traffic control to provide the service needs of the special task.
Priority	The preferential treatment of one vehicle class (such as a transit vehicle, emergency service vehicle or a commercial fleet vehicle) over another vehicle class at a signalized intersection without causing the traffic signal controllers to drop from coordinated operations. Priority may be accomplished by a number of methods including the beginning and end times of greens on identified phases, the phase sequence, inclusion of special phases, without interrupting the general timing relationship between specific green indications at adjacent intersections.
NTCIP 1211	A standard in development that defines the requirements that are applicable in an NTCIP environment that is consistent with other traffic signal controller standards.

necessarily new pieces of equipment that need to be implemented in the field, but rather descriptions of processes necessary to accomplish priority.

Priority Request Generator

The PRG is the process that generates the request for service, whether the message generator originates from an emitter on a vehicle or the vehicle passing a designated detection point. The primary functions of the PRG are as follows:

- Determine whether a vehicle is in need of preferential treatment (priority) at a signalized intersection according to the transit agency's needs.
- Produce an estimate of the vehicles estimated time for service desired at the signalized intersection. This estimate, measured in seconds, is intended to represent the vehicles arrival time at the intersection and can range from zero (representing a request for immediate service) to some time in the future.
- Communicate the vehicle's request for priority and its time of service desired to the PRS.
- Produce a log of all priority requests for processing by a fleet management agency.

The NTCIP 1211 standard allows that the elements of the PRG be physically located in different locations depending on the system architecture.

Priority Request Server

The PRS is a process that would review messages from the PRG, considering the information within the message and resolving competing requests before sending a service request to the traffic controller. It is also possible for the process to be incorporated into the traffic signal controller and for the controller to accept multiple requests. The primary functions of the PRS are as follows:

- Receive Priority Requests from one or more PRGs.
- Prioritize all the different Priority Requests for priority based on the vehicle class, vehicle level, and time of service desired.
- Generate a Service Request that defines the strategy to be used by the Traffic Signal Controller to provide priority to vehicle.
- Communicate the Service Request to the Traffic Signal Controller to be processed by the PRS.

The PRS has the primary responsibility for sorting through messages that are generated by the various vehicles on the system.

Supporting Elements

The scope of the standard also considers supporting elements such as the traffic signal system which may offer maintenance functions to support the signal priority system. Similarly, transit monitoring or fleet management systems may provide communications to the transit vehicles that permit supervisory functions.

There are a variety of physical implementation scenarios identified with the emerging NTCIP 1211 standard. This paper outlines the proposed concept of operations that would provide MTA and the city of Baltimore with a signal system that allows varying levels of priority (and preemption where appropriate) to be implemented in a manner that improves the performance of LRT vehicles along the corridor.

CONCEPT OF OPERATIONS

The concept of operations is partly constrained by a desire to minimize modifications to the existing system while retaining the current distributed approach. A distributed approach is characterized by the presence of local controller intelligence (on the street) that would provide efficient operations and reduce the need to rely on the communications infrastructure as a centralized system would. The system consists of three basic components: the detection equipment, the signal control software, and an online monitoring system.

These three basic components combine to form the PRG and the PRS and provide the necessary links to the Fleet Management and Signal System components identified as supporting elements of the signal priority system as outlined in the emerging NTCIP 1211 standard. Figure 3 shows each of those components in both the physical (within the rectangular boxes) and the logical (items circled).

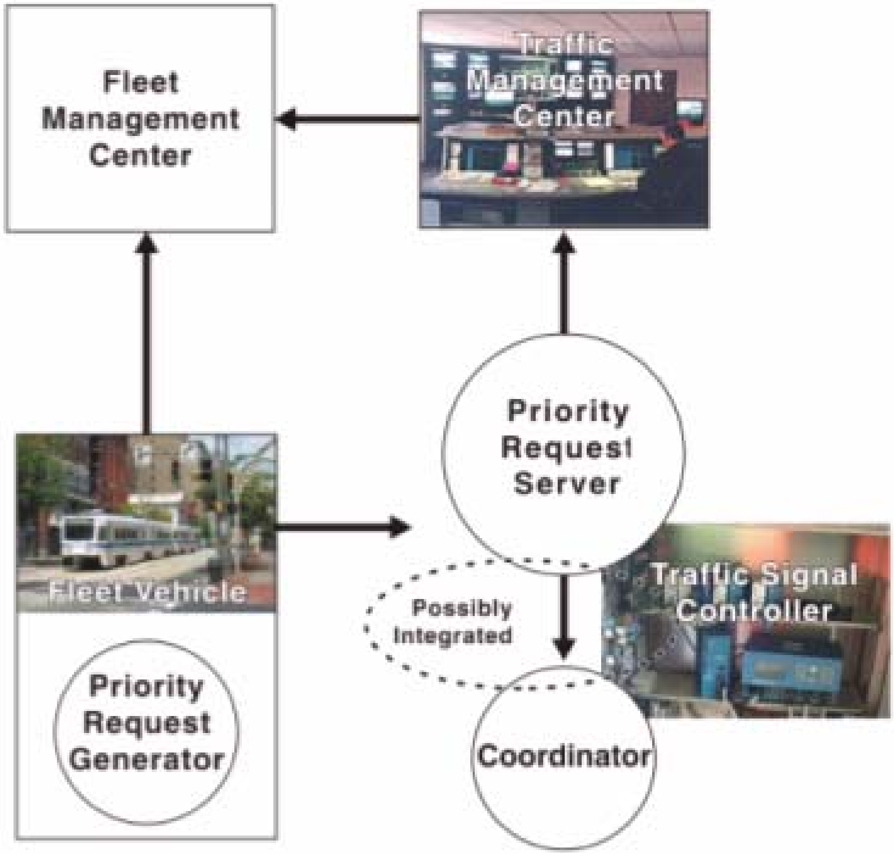

FIGURE 3 Signal priority communication paths (concept of operations).

At the most basic level, the LRV must be detected by the control system and the traffic signal must accept the request for priority. The proposed monitoring system will be established to allow the MTA to receive automated reports related to the operations of the signal system and its LRVs along the Howard Street corridor.

Existing System

The existing system uses a Wayside Detector Unit at each intersection that can receive preemption requests from the LRV and the calls can be placed on an intersection-by-intersection basis. Once a LRT vehicle departs a station, the LRV can send a request that triggers a message at the first intersection as a request for service at a particular "time service desired" (TSD). This call is serviced by a cascading call in an attempt to reach the 2 to 5 intersections downstream of the initial intersection. The preemption occurs throughout the intersections between the departing station and the next station in a routine that reduces the chance that the vehicle may stop between stations.

Proposed System

The proposed concept of operations is to provide separate TSD requests at each intersection. This provides more flexibility in the ability of individual intersections to respond to the priority request without the loss of coordination. Thus, the LRV would issue multiple requests for service as it departs each station. The transit agency and the city has the option to establish acceptable criteria for service. Depending on the algorithms chosen, the solution could be done either centrally or in a more distributed manner

While the existing system assumes no barriers between the intersections or operational limitations, this revised approach carefully considers the potential for conflicting calls or other operational considerations such as pedestrian operations, vehicles queued in the intersections, or conflicting priority requests that might suggest a different priority strategy. Intersection by intersection signal timing settings will be based on the needs of each intersection and the modifications that can be made when the LRV arrives.

As in the existing situation, the PRG resides within the Fleet Vehicle and relies on operator input to generate a preemption request. In the proposed concept, however, the PRG sends the priority request along with additional information such as shown in Table 2. The PRS process receives priority service requests, and resolves them to one or more priority service requests that are passed to the Traffic Signal Controller to be processed by the Coordinator.

Priority Request Generator

A key challenge for implementing transit priority within the NTCIP 1211 framework is the detection system, which must place a request for priority into the system. The detection systems for generating a request could take many forms. The city of Portland's transit agency, TriMet, utilizes a track detection system (Vetag) for its LRT vehicles, and an optical detection system (3M Opticom) for its bus priority system as shown in Figure 4. The Vetag system utilizes track detection for signal priority requests, while the 3M Opticom emits an infrared message to the traffic signals for priority requests.

Prior to the implementation of the NTCIP 1211 standard, many of these earlier systems had to place a call at an appropriate time in order to be effective. Consideration of competing calls was not possible because once a priority request was initiated, service was implemented and there was no recovery feature for changing the priority request once it has been initiated. In some systems, messages were screened using historical data and using policy decisions to reduce ineffective calls (*2*). Incorporation of the NTCIP 1211 standard suggests that the detection system should not only detect, but also transmit messages that include information such as the information listed in Table 2.

It is this additional data that can be used by the PRS to sieve through the requests in order to provide an effective priority system.

TABLE 2 Transit Priority Data Elements

Transit Priority Data	Measure
Vehicle Location	Speed, Location to determine TSD
Door & Lift Status	Predictions based on Historical Data
Ridership	Historical Data or APC
Stop Location	Near side or Far side
Schedule Adherence	Lateness
Vehicle Identification	

(a)

(b)

FIGURE 4 Transit detection options from the Portland, Oregon, LRT system: (a) Vetag system; and (b) 3M Opticom detector (shown here mounted on top of a bus).

Priority Request Server

The PRS has the primary responsibility for of sorting through messages that are generated by the various requests generated. The PRS must validate the messages received and determine whether the requests are valid and whether the traffic signal controller (system) is prepared for the priority request. The server provides the implementing agency with an opportunity to serve multiple requests and modify or prioritize these requests based on incoming messages.

The benefit of the PRS is that it can either be developed as a separate entity, designed to communicate with the Coordinator, or it can be integrated into the controller. This allows for an evolutionary path to development of traffic signal priority without the need to immediately replace all existing equipment.

Signal Priority Algorithm

Signal priority systems vary in complexity. Simple systems that rely on operator intervention reduce the amount of on-vehicle technology that is needed. Figure 5 illustrates both red truncation and green extension associated with an active signal priority implementation (*3*). The primary difference between the existing preemption system and the priority system as proposed is that the priority system allows the traffic signals to maintain coordination with adjacent signals while providing preferential treatment for the transit vehicles.

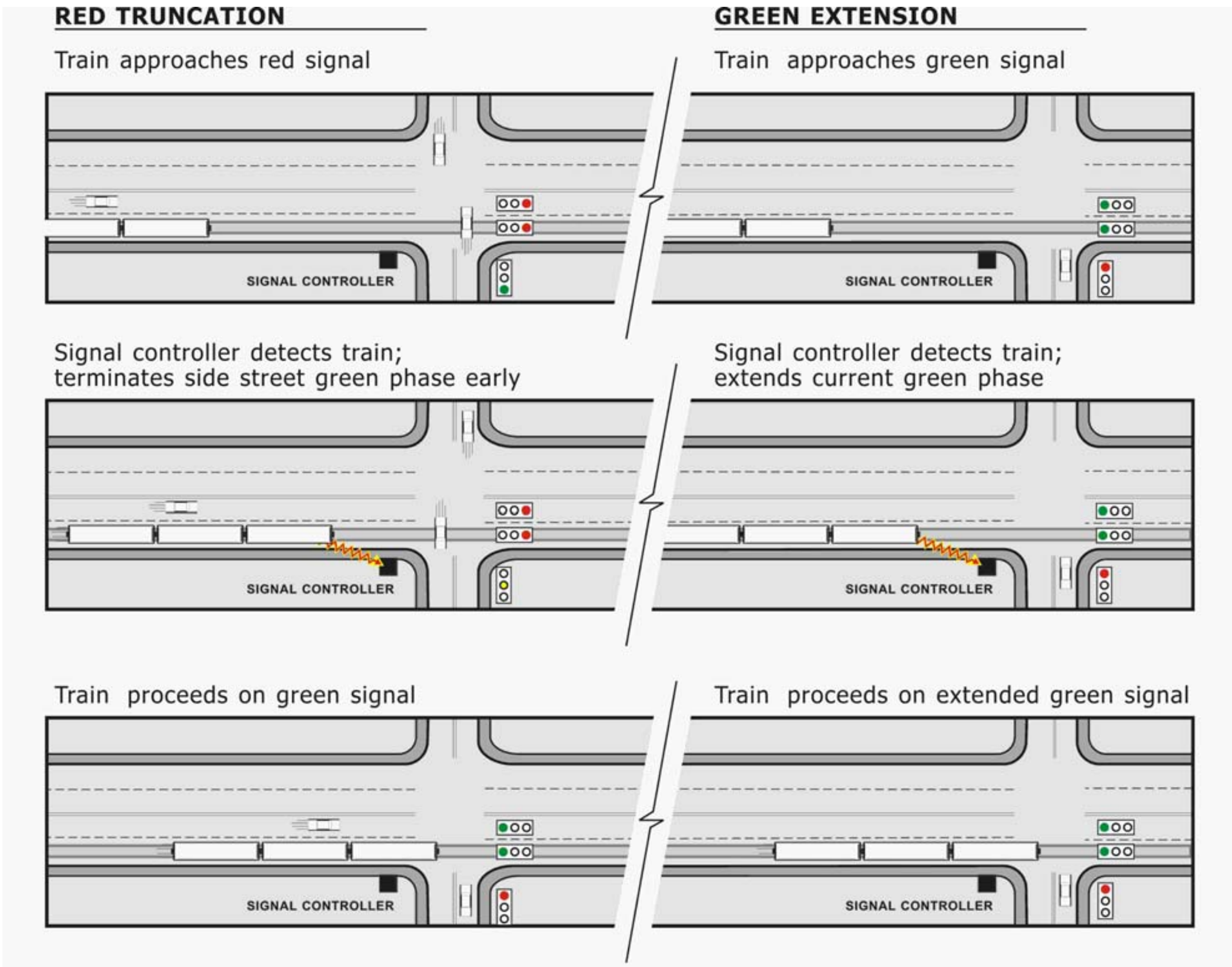

FIGURE 5 Signal priority concepts (red truncation and green extension).

CONCLUSIONS

The importance of the relationship between transit staff and traffic engineering staff cannot be overemphasized. Coordination between these groups is necessary for effective implementation of transit priority measures.

To make an informed decision on selecting an upgrade path for a signal system for the city of Baltimore, the Office of Transportation has utilized many of the standards identified as a part of the NTCIP process. For transit agencies interested in implementing transit priority within an existing signal system, the upgrade path should consider the capability to accommodate the operational possibilities enabled by NTCIP 1211. NTCIP 1211 is not prescriptive in its approach to transit priority, and allows a number of implementation alternatives, which allows flexibility in the design of each system depending on the local conditions.

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LIGHT RAIL TRANSIT AND TRANSIT-ORIENTED DEVELOPMENT

Light Rail and the American City
State-of-the-Practice for Transit-Oriented Development

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Over the past two decades a growing number of communities have married light rail transit (LRT) and transit-oriented development (TOD) as part of an integrated strategy to revitalize American cities. Along the way LRT has evolved to become both a people-moving and a community-building strategy. The FTA has come to recognize that link in elevating land use as an important consideration for New Starts recommendations. With the competition for federal funding at an all time high, land use can make a difference in which projects are recommended for federal funding. Yet transit-adjacent, not transit-oriented, development remains the norm in most communities.

Capturing the opportunities and benefits of TOD has important implications for the planning, design, and implementation of LRT systems. The essential elements of a successful integrated LRT and TOD strategy—designing development-oriented transit and achieving supportive public policy—are examined along with the underlying market forces helping to drive a growing demand for transit-friendly compact, urban living. There is a wide diversity of TOD implementation approaches and agencies in a lead role across the country. A snapshot is provided of TOD implementation experience in Dallas, Texas; Portland, Oregon; Denver, Colorado; and San Jose and San Diego, California. Finally, communities interested in pursuing an integrated LRT and TOD strategy are offered five lessons learned and ten steps to success in planning for LRT and TOD.

Over the past two decades a growing number of communities have pursued LRT and TOD as part of an integrated transportation and land use strategy to help revitalize American cities. This paper looks at the progress and implications of that journey for the planning, design, funding, and implementation of new LRT systems.

The first wave of LRT systems was justified largely on conventional measures—ridership, efficiency, and energy savings. Broader community measures such as economic development and land use were not allowed as a consideration in the federal funding. To the consternation of many in the transit industry, the Urban Mass Transportation Administration (UMTA) argued that those "secondary benefits" of transit were "captured in the single roll-up measure" of cost effectiveness.

Times have changed. UMTA has become FTA, and the New Starts evaluation process has taken on a new character. Where it was once off the table, FTA now gives special consideration to land use in their New Starts evaluation.

Subsequent generations of cities interested in implementing LRT systems have learned from the experience of early systems like Portland, Oregon, and San Diego, California. LRT in combination with land use planning can be a powerful tool to help shape growth. Land use is now playing an increasingly important role in local and federal decision-making for new LRT investments.

WHAT IS TOD?

Transit-oriented development (TOD) focuses compact growth around transit stops, thereby capitalizing on transit investments by bringing potential riders closer to transit facilities and increasing ridership. At an individual station TOD can increase ridership by 20% to 40%, and up to 5% overall at the regional level (*1*) (Figure 1).

TOD can also produce a variety of other local and regional benefits by encouraging walkable compact and infill development. Just as importantly, TOD is being embraced by a growing number of communities as part of a strategy for accommodating growth without diminishing livability

TOD draws on many of the same planning and development principles embraced by New Urbanism, Smart Growth, and the Livable Communities Movement:

- Moderate to high density development in relation to the existing pattern of development;
- A mix of land uses, horizontally or vertically;
- Compact pedestrian-oriented design and streetscapes;
- Building design and orientation to street which allows easy pedestrian and transit access;
- A fine-grained connected street pattern without cul-de-sacs; and
- A system of parks and open spaces.

By focusing compact growth around transit stops, TOD capitalizes on transit investments by bringing potential riders closer to transit facilities and increasing ridership. TOD can also produce a variety of other local and regional benefits by encouraging walkable compact and infill development. A successful TOD will reinforce both the community and the transit system. TOD has broad potential in both large and small communities using bus and rail transit systems. Figure 1 illustrates all the basic elements of good TOD design in a development along the Embarcadero line: moderate to higher density, a mix of uses, development at a pedestrian scale and civic spaces. The similarly designed Eastside Village station in Plano, Texas, is shown in Figure 2.

FIGURE 1 Embarcadero light rail transit, San Francisco, California.

FIGURE 2 Eastside Village, Plano, Texas.

NEW STARTS AND LAND USE

With national interest in new light rail projects at an all time high, the demand for federal funding far outstrips the supply. In the scramble for federal funding, land use has become an important differentiator in determining which projects FTA recommends to Congress. In FTA's evaluation of projects, land use is second only to the strength of the local financial commitment. In choosing what projects to fund, FTA and Congress are interested in projects that demonstrate merit; they want to see projects receiving federal funding succeed. Current and future land use patterns are important indicators of that success.

A review of the fiscal year 2004 New Starts Report reveals that land use is having a material effect—both positive and negative—on how FTA rates the justification of projects. Communities such as Charlotte, North Carolina, have seen their rating improve: "The *Medium* project justification rating reflects the strong transit-supportive land use policies in place to support the proposed light rail project." In communities such as Miami, Florida, land use has had a different impact: "The *Medium* project justification rating reflects the marginally transit-supportive policies and existing land use along the proposed alignment" (*2*).

FTA's land use criteria have provided additional motivation at the local level to incorporate TOD early in the planning and design of New Starts projects. In evaluating the land use potential for a successful New Start transit project, FTA applies eight transit-supportive land use measurement factors on a sliding scale. The closer the project is to moving into construction, the higher the standard. The significance for projects chasing federal funding is that the bar for a high rating will literally be a moving target as the project progresses through the project development cycle. The eight land use factors FTA uses to evaluate local projects are:

1. Existing land use;
2. Impact of proposed New Starts project on land use;
3. Growth-management policies;
4. Transit-supportive corridor policies;
5. Supportive zoning near transit stations;
6. Tools to implement land use policies;
7. The performance of land use policies; and
8. Existing and planned pedestrian facilities, including access for persons with disabilities.

TOD OR TAD: TRANSIT-ORIENTED OR TRANSIT-ADJACENT DEVELOPMENT?

To realize the benefits of TOD it is not enough for development to be *adjacent* to light rail. The development must be shaped by transit. Within the family of TOD you might say there are two "brothers"—TOD and his "evil brother," transit-adjacent development" (TAD). TAD can be defined broadly as development in close proximity to transit, generally within one-quarter mile. The development is close to transit, but not oriented to transit. Unfortunately for light rail transit (LRT) in America there are many more TADs than TODs.

Comparatively, in the case of TOD, the projects are also located within a quarter mile of the station, but the development has been, through public policy or private initiative, partially molded by transit. The reshaping in relationship to transit might include one or all of the following:

- A compact site design, oriented for the pedestrian;
- Higher density and intensity of uses, in relation to the norm for the community;
- Buildings oriented to transit, (i.e. doors located convenient to a transit stop);
- Limited parking, the parking supply has been "pinched" or placed in multi-level parking structures; and
- Pedestrian access and high-quality, safe facilities.

TOD OVERLAY ZONES

One of the reasons we have more TADs than TODs is that in most of the United States, TOD is "illegal"—illegal in the sense that local development codes and zoning do not allow for the compact, mix of uses, with reduced parking requirements, urban style setback, and side yard requirements typical of TOD-style development. An essential first step in planning for TOD is to change local planning codes and ordinances to allow TOD where it is desired.

Transit overlay zones are an approach that has been used in a variety of American cities to further TOD implementation. In 1978, Dade County, Florida, established a Rapid Transit Zone along the entire length of Miami's heavy-rail system. In San Diego and Los Angeles, California, their TOD overlay is an option developers can use. San Diego's "floating" Urban Village Overlay Zone allows developers to apply TOD principles to any site adjacent to a planned or existing light rail station. Both the cities of Phoenix and Tempe, Arizona, have developed TOD overlay zones for their proposed Valley Metro LRT line. The City of Mountain View, California, has likewise established a combination floating-overlay zone called the Transit District, or "T" Zone. Use of this designation is restricted to properties currently zoned for either industrial or commercial and that lie within 2000 ft of a rail-transit station (*3*).

Portland, Oregon, and Seattle, Washington, have taken a different tactic and used the overlay to replace underlying zoning. In Portland, the city has instituted an overlay zone called the Light Rail Transit Zone. This designation increases permitted densities, restricts auto-oriented uses, and encourages pedestrian-oriented development in LRT station areas, including small retail shops, restaurants, outdoor cafes, benches, and kiosks.

DETAILED STATION AREA PLANS

LRT communities have come to learn that "build it and they will come" is a theory that has not played out in reality without supportive public policy. For the areas up to .25 to .50 mi around proposed LRT stations, detailed station area plans have become a popular way to help leverage the development potential of TOD. Station area plans can offer both the neighborhoods and the development community certainty and predictability. The planning is typically funded as an activity eligible for federal funding as part of the transit investment, just like the engineering of the line.

Communities that have undertaken detailed station area plans for LRT include San Diego and Sacramento, California, Minneapolis, Minnesota, Portland, and the San Francisco Bay Area. San Jose has successfully used the Planned Unit Development designation to shape the location and design of several TODs near its light rail system stations, such as the Almaden Lake Village. An example of the use of Specific Plans to implement TOD policies comes from Mountain View. Called "Precise Plans" by the city, the Whisman Station Precise Plan introduced land-use and design standards for properties near this Silicon Valley light-rail stop (*4*).

A detailed station area-planning program typically involves a detailed assessment of the area up to .25 to .50 mi around each station area resulting in:

- The preparation and local adoption of a station area plan including a vision;
- A land use plan map of future land uses;
- A description of zoning to accompany the land use map; and
- An urban design plan and a schedule for TOD and economic development projects and programs.

Communities along Portland's East and Westside Light Rail lines adopted station area plans for each of the areas surrounding the stations well before the lines opened for service. Local governments along the corridors participated in a coordinated multi-jurisdictional planning program, because they saw light rail as a means to implement their comprehensive plans.

The core objectives of station area planning in Portland have remained pretty constant over the years. They include

- Reinforcing the public's investment in light rail by assuring that only transit friendly development occurs near the stations;
- Recognizing that station areas are special places, and the balance of the region is available for traditional development;
- Seizing the opportunity afforded by light rail to promote transit-oriented development as part of a broader strategy;

- Rezoning the influence area around stations to allow only transit supportive uses;
- Targeting public agency efforts at stations with the greatest development opportunity;
- Building a broad-based core of support for transit-oriented development with elected officials, local government staff, land owners, and neighborhoods; and
- Setting up a self-sustaining framework to promote and encourage transit-oriented development once the planning is complete (*5*).

DESIGNING LRT WITH TOD IN MIND

Successful TOD starts with the earliest decisions on the shape and design of the transit system. It is amazing how many new LRT lines have been designed in a manner that is hostile to TOD—surrounding the stations with parking, locating stations in areas with little or no development potential, and providing for poor pedestrian connections from the station to the community.

Communities that have constructed a second, third, or forth LRT line have started the process of planning for TOD earlier than with their previous line. San Diego, Sacramento, San Francisco, Baltimore, Maryland, and Salt Lake City, Utah, are all examples of systems where their interest in TOD manifested itself after their first line opened for service.

Transit agencies have come to realize decisions on alignment, station locations, and station layouts can have a large impact on the success of a TOD strategy. By bringing engineers, transit planners, architects and urban planners into the process early, the opportunity to meet multiple community objectives is enhanced. The earliest decisions on alignment, station location, and design can have a major impact on TOD, as seen in developments like Central Park Commons in Denver, where the Central Platte Valley LRT is expected to be the focus of more than 2,000 residents along its 1.6-mi length (Figure 3).

FIGURE 3 Central Park Commons, Central Platte Valley LRT, Denver, Colorado.

Portland's Westside LRT alignment was designed specifically with future development in mind. As *Newsweek* put it in May 1995, Portland is "building transit first, literally in fields, in the hope development will follow." All told, in 1994 there were approximately 1,500 acres of vacant developable land in the vicinity of Westside stations. That gamble paid off. Before the Westside LRT opened for service in 1998, more than half a billion dollars in new development consistent with the TOD plans had occurred (*6*).

In a similar innovative twist on rail design, the Purple Line, a proposed circumferential light rail line in suburban Washington, D.C., is being designed around TOD. Rather than approaching TOD as an after thought, the state of Maryland sought to identify the opportunities for TOD in advance of the engineering so the rail line could be designed with TOD in mind. Once the best opportunities for stations are located they can be linked with the rail line to create a classic "string of pearls"(*7*).

There are a series of design principles to keep in mind in designing a new transit facility with an eye toward enhancing the opportunity for TOD. The principles of "development-oriented transit" include:

- Is the station located in an area with development potential?
- Are transit facilities designed in a compact manner with pedestrians in mind?
- Does the design of station facilities allow for direct pedestrian connections from the transit facility to adjacent communities?
- Has the park-and-ride been designed in a manner that is does not separate the station from the community it is intended to serve?
- Has TOD been appropriately incorporated into the transit facility design?

Designing a new LRT line to be development friendly does not mean that any of the transit requirements will be sacrificed. They will be successfully incorporated, and the system can be integrated into the community. LRT designers can learn a lot by looking at how older established commuter rail, such as Metra in Chicago, has been well integrated into the communities it serves. For example, Metra parking tends to be dispersed in a number of small lots.

COMMUNITY BUILDING AND MOVING PEOPLE

There is no simple recipe for TOD implementation. The ingredients for successful TOD implementation are part community partnerships, part understanding real estate, part planning for growing smart, part transit system design and part offering the right mix of incentives to make TOD work in a particular station area market.

More often than not, the "master chef" for successful TOD implementation has been the local jurisdiction, not the transit agency. This certainly has been the case in Portland. Indeed, cities and counties are equipped with the right tools to realize TOD—they have the planning, development, and political clout necessary to succeed.

The nature of TODs is that their implementation tends to involve many public and private players. Transit agencies can play an important role in the education, advocacy, and planning of TOD. Local governments can play a significant role in promoting TOD through plans, policies, zoning provisions, and incentives for supportive densities, designs, and a mix of land uses.

As the motivation and support for LRT has morphed from simply an alternative way to provide transportation to being part of a broader transportation, “community building,” and “economic development” strategy, new partnerships and skills are essential for success. The communities that have tended to be the most successful with TOD are the ones that use the coming of rail as a means to the end of achieving their community’s vision for growth. Few communities are willing to embrace the notion that their community needs to accommodate more density to make the rail line more successful.

One of the important lessons for transit agencies is that getting the city to the table as a partner in TOD can be an essential step toward success. The communities that have cities playing a strong role in TOD are the communities that are the most successful with TOD.

GROWING MARKET FOR TOD

TOD has evolved from balloon adorned architectural renderings of “what could be,” to an increasing inventory of “what is”—built projects. Across America, more and more TODs have been built and are performing well in the marketplace. This indicates that the viability of TOD at many locations in today’s real estate market is not a significant concern. Over the past decade, development trends have demonstrated the growing attractiveness—and market value—of TOD projects.

Successful TOD projects all have one common thread—the development project has to be successful without transit in order to be successful with transit. In other words, these are transit-oriented, not transit-dependent projects. LRT lines do not deliver the volume of customers on their own to make TOD viable.

Underlying the growth of TOD is a fundamental shift in demographics that is helping drive market demand for more compact, urban living. New Urban News cites the following factors as helping to drive the trend:

- A doubling of the demand for homes within walking distance of stores;
- An increase in buyers who prefer dense, compact homes (this market segment is expected to account for 31% of homeowner growth between 2000 and 2010); and
- A decline in the number of U.S. households with children. In 1990 they constituted 33.6% of households, by 2010 they will drop to 29.5% of households (*8*).

The country’s most respected real estate investment forecast—*Emerging Trends in Real Estate*, published by Lend Lease Real Estate investments and PricewaterhouseCooper—gives special attention to TOD market fundamentals in their review of 2002: “Markets served with mass-transportation alternatives and attractive close-in neighborhoods should be positioned to sustain better long-term prospects as people strive to make their lives more convenient;” they also state, “Interviewees (real estate leaders) have come to realize that properties in better-planned, growth-constrained markets hold better value in down markets and appreciate more in up cycles. Areas with sensible zoning (integrating commercial, retail, and residential), parks and street grids with sidewalks will age better than places oriented to disconnected cul-de-sacs subdivisions and shopping strips, navigable on by car” (*9*).

That demand is reflected in the rent and sales premiums commanded by locations next to rail stations like Orenco Station in Portland (Figure 4). These “transit-oriented” premiums for

FIGURE 4 Orenco Station Town Center, Portland, Oregon.

commercial and residential development have been definitively documented for numerous light rail systems (Table 1). The research shows that for both commercial and residential development, values become greater as properties are closer to a light rail station—the closer the higher the value. Moffett Park in Sunnyvale, California, is an illustration of the value of proximity. The developer, Jay Paul Company, approached the transit operator Valley Transportation Authority (VTA) and offered to pay the full cost of constructing a station to serve the site (estimated at $2.5 million) (*10*). The station opened for service in December 2001.

TOD IN AMERICA

A TOD renaissance is underway today across the country. TOD implementation has come in all shapes and favors with varying degrees of involvement from the public sector. To provide a better understanding of the range of TOD planning and implementation, this section provides a brief snapshot of TOD at five established LRT systems – Dallas, Denver, Portland, San Jose, and San Diego.

San Diego is widely acknowledged as a leader in TOD within the state of California. San Diego opened America's first modern light rail system in 1981, but did not initiate any TOD planning until several years later (*11*). Whereas TOD was not considered in planning the first light rail line, TOD projects and plans are now in place at over 15 of the system's 49 light rail stations, such as America Plaza in Figure 5 (*12*). The transit agency, Metropolitan Transit Development Board (MTDB), has been active in pursuing TOD.

At a regional level, the San Diego Association of Governments approved a Regional Growth Management Strategy that calls for increased development in "transit focus areas" (*13*). The city of San Diego has been a willing partner in supporting both mass transportation and TOD. In a unique arrangement, the city has had a land use planner working full-time on TOD

TABLE 1 LRT and Property Values (*29*)

Study	System	Property Type	Result
Dallas (Weinstein & Clower 2003) (*30*)	DART LRT	Office & Residential	Residential values near a station increased 39% more than comparable properties not served by rail. For office buildings, the increase was 24.7% for properties near a station versus 11.5% for other properties, so office values near LRT increased 53% more than comparable properties not near rail.
Santa Clara, County (Cervero & Duncan 2002) (*31*)	VTA LRT	Commercial	Commercial space within ¼ mi of a station received a capitalization benefit of $4 more per square foot, or by more than 23% in relation to parcels further away from a station.
Portland (Dueker & Bianco 1999)	Eastside LRT	Residential	Median house values increase at increasing rates as move toward an LRT station. The largest price difference ($2,300) occurs between the station and 200 feet away.
Portland (Chen et al. 1998)	Eastside LRT	Residential	Beginning at a distance of 100 m from the station, each additional meter away from decreases average house price by $32.20.
Portland (Lewis-Workman & Brod 1997)	Eastside LRT	Residential	On average, property values increase by $75 for every 100 feet closer to the station (within the 2,500 ft. – 5,280 ft. radius).
Portland (Knaap et al. 1996)	Westside LRT	Residential	The values of parcels located within ½-mi of the line rise with distance from the lines, but fall with distance from the stations.
San Diego (Landis et al. 1995)	San Diego LRT	Residential and Commercial	The typical home sold for $272 more for every 100 m closer to a light rail station. No effect found for commercial impacts

within the planning staff of MTDB. The city was one of the first in the nation to adopt "Transit-Oriented Development Design Guidelines" in 1992 (*14*). San Diego has also adopted a unique transit overlay zone that requires reduced parking in areas with a high level of transit service.

With the completion of The Promenade at Rio Vista San Diego's largest TOD will be complete. Developed at 70 units per acre by the Greystone group, the Promenade is the culmination of phased development of a 95-acre site fronting on the San Diego River and the Mission Valley line. According to the promotional literature the 970-unit apartment and retail features "a beautifully landscaped Esplanade of boutiques and retail conveniences surround a majestic fountain. Plus, the Rio Vista Trolley Station is integrated within the south end of the Esplanade, highlighting the stunning urban design plan."

FIGURE 5 America Plaza, San Diego, California. In a pattern repeated with most LRT systems, San Diego's TOD program has grown with the expansion of the system. While TOD was not a consideration in the first line, TODs are now in place at 15 of the systems' 49 LRT stations.

Rio Vista is an important example of the challenges and opportunities with a phased TOD project. The 1985 Mission Valley Plan designated urban nodes and supports higher density in this area. Early phases of the project included a K-Mart and were criticized by some for being too automobile-oriented. Conversely, the high-density Promenade at Rio Vista holds the promise of being one of the most transit-friendly suburban projects in California. The TOD has pushed densities in the area over 10 fold from 4 to 5 units per acre upwards to 70 units per acre.

The Mission Valley LRT line marked the first-time San Diego took extra steps in rail design to accommodate existing and future development. The rail line crosses back and forth over the San Diego River to better link with development, and with the extension to San Diego State University an underground station will allow the line to penetrate the middle of the campus.

Portland, Oregon has pursued an aggressive policy driven strategy of linking transportation and land use supportive of TOD at a number of levels. Planning and implementation programs for TOD are being actively pursued by TriMet (the transit agency), Metro (the regional government), and each of the cities along the region's three LRT lines. Legally binding station area plans were funded by TriMet and adopted by local governments before the East and Westside MAX lines opened for service. Prohibition of auto-oriented uses, minimum densities, parking maximums, and design requirements are features of the plans for areas within walking distance of the stations.

The Portland region arguably has the nation's most aggressive TOD program, but it has also placed the highest stakes on what it expects from its TOD strategy. The region's vaunted growth management strategy is built around transit. The 2040 Growth Management Strategy features a tight Urban Growth Boundary, focusing growth in transit centers and corridors, and requires local governments to limit parking, and adopt zoning and comprehensive plan changes to be consistent with the plan. Two-thirds of jobs and 40% of households are designated to be in centers and corridors served by buses and LRT (*15*).

More than a $3 billion investment in new development has occurred within walking distance of the stations along Portland's light rail lines (*16*). While the vast majority of those TOD projects received no form of public subsidy, the Portland region uses a series of incentives to achieve more density, a greater mix of uses, better design, and lower parking ratios than the market would otherwise provide in TODs. The Oregon legislature enabled 10-year property tax abatement for TOD in 1995. Portland and Gresham currently use abatements. By 2000, Portland had abated seven projects with a combined value of $79.6 million (*17*). Metro operates a TOD revolving fund capitalized with federal clean air Congestion Mitigation and Air Quality funds.

The Portland region's most adventuresome endeavor into TOD has been with the Airport light rail extension. The financing package for the project is built around TOD. Bechtel Enterprises contributed $28.3 million toward the $125 million light rail project. In return, Bechtel, in partnership with Trammell Crow, is developing a 120-acre TOD with office, retail, and hotel uses called Cascade Station at the entrance to the airport. The rail line opened in September 2001, but a slow economy has frustrated the realization of any development so far.

The region's most celebrated TOD is Orenco Station**,** a 199-acre new community being developed by PacTrust and Costa Pacific homes on the Westside Light Rail line. Its pedestrian-oriented master plan provides for a minimum 1,834 dwelling units, including single-family homes, townhouses, accessory units, loft units, and apartments. The project also includes a mixed-use town center with offices and housing above ground-floor retail. Residential sales prices at Orenco Station are running 20% to 30% above the local area average. Commercial occupancies have been high, and rents are estimated to be roughly 10% higher than surrounding properties (*18*). Surveys of residents reveal that 18.2% of work trips are on bus or LRT, and nearly 7 in 10 residents report that their transit use has increased since moving to the neighborhood (*19*).

Efforts to achieve TOD in San Jose have accelerated with the opening of the Tasman West light rail line in December 1999. According to VTA (the transit operator), the Cities of Mountain View and Sunnyvale have actively pursued policies that promote development in proximity to light rail. Mountain View, for instance, rezoned 40 acres of industrial land for 520 housing units adjacent to the Whisman station (*20*).

The City of San Jose has taken an important leadership role in providing a framework for TOD. The city's general plan was revised to provide for high-density development around transit stations (*21*). The Housing Initiative Program and Intensification Corridors Special Strategy targets station areas for high and very high-density housing (*22*). The construction of San Jose's largest TOD is now underway.

Spanning two generations of TOD, Ohlone-Chynoweth on the Guadalupe Light Rail line in San Jose includes housing and community facilities developed on an under-used light rail park-and-ride lot. The former 1,100-space park-and-ride now includes a variety of uses: 240 park-and-ride spaces, 330 units of affordable housing, 4,400 square feet of retail, and a day care center. At 27 dwelling units per acre, the residential density is relatively high compared to the predominantly single family neighborhood surrounding it. The housing was developed by Eden Housing and Bridge Housing in two separate projects (*23*). Ohlone-Chynoweth is a rare example of where a park and ride has been converted to TOD without replacement of the commuter parking in structures or on another site.

In terms of the sheer number of residential units, San Jose has one of America's largest LRT TODs under construction next to the light rail line on North First Street in north San Jose. The Irvine Company is constructing the North Park Apartment Village, an upscale rental project with 2,600 units. Under a unique California program the city was able to receive additional transportation funding as an incentive for each new residential unit.

Dallas stands out as an example of where market factors, more than supportive public policy, are leading to development next to transit. Since the opening of the Dallas Area Rapid Transit (DART) light rail system in 1996, *The Dallas Morning News* reports more than $800 million in new commercial and residential investment within walking distance of the DART line has either been constructed or is in progress. Arguably, much of this development is transit-adjacent rather than transit-oriented. In the 7 years since the start of DART operations, the city of Dallas has yet to take any steps to change plans or zoning to encourage TOD. From a policy context TOD remains illegal within the city of Dallas.

DART has staff dedicated to TOD, but has adopted no specific policies supporting TOD. However, the agency's mission and goal statement refers to economic development and quality of life. DART is working with its member cities and the Council of Governments to determine ways to link its stations with pedestrian networks. Other than the Cedars Project where an old vacant Sears warehouse was transformed into 450 loft apartments with ground-floor retail space, there has been virtually no TOD subsidy or supportive public policies by the regional planning agency, the City of Dallas, or DART along the starter line in Dallas (*24*).

Dallas's best example of TOD is Mockingbird Station**,** a stunning 10-acre mixed-use TOD. The $145 million 10-acre mixed-use project being developed by UDC Urban features an art house movie theater, 211 loft apartments, upscale retail, a planned new hotel, offices, and restaurants (*25*). Mockingbird Station is the first mixed-use project in Texas specifically designed and built for a LRT station. With the exception of federal contributions towards local infrastructure, the development has been 100% privately financed.

Following a familiar pattern in virtually every LRT city, policy support for TOD has increased after the initial experience. Suburban communities along DART's extensions have been much more aggressive in pursuing TOD. The suburban cities of Richardson and Plano are a case in point. The City of Plano has been actively working to take advantage of the opening of a new light rail line in July 2002 to create Plano Transit Village in their core. The city took one of the first steps in creating their transit village by working with Amicus Partners to redevelop a block of land for a mix of apartment, retail, restaurant and office uses. Eastside Village is a 239,000-square-foot commercial and residential project immediately adjacent to DART's light rail station. The $16 million project includes 246 apartments with space for small shops and other commercial development. The project offers a variety of floor plans including efficiencies, lofts, live/work spaces, and one- and two-bedroom apartment homes. A five-level parking garage is surrounded by the buildings in the interior of the property, providing resident parking as well as public parking on the first level during business hours (*26*) .

Denver is another example of a community that has seen its TOD program grow with the expansion of their system. Both the City of Denver and the Regional Transportation District (RTD) have raised the profile of TOD within each organization. RTD now has a full-time TOD person and has recently forged a partnership with the city and the Denver Urban Renewal Authority to collectively and more efficiently provide TOD incentives. Like other communities, Denver's TOD approach is evolving as it gains experience.

Denver's newest LRT line opened in April 2002. The Central Platte Valley Spur was innovatively financed with RTD, City of Denver, and private contributions. The 1.6-mi line extends from Union Station with stops at Auraria Higher Education Center, Invesco Field at Mile High Stadium, and the Pepsi Center. The 340-unit Central Park Commons apartments are the largest of recent developments. The area is planned to grow into a mixed-use neighborhood with more than 2000 housing units and more than 3 million square feet of commercial and retail development (*27*).

The region's first TOD is the 55-acre Englewood Town Center, a mixed-use TOD created on the site of the failed Cinderella City mall. Adjacent to Denver's Southwest Corridor light rail, the one million square foot, $160 million TOD combines a transit hub with a civic and cultural center, as well as retail uses and entertainment. The city and RTD made $21.2 million in public improvements to the site. More than 500 residential units have been constructed by Trammel Crow along park and open space. The city purchased the property, developed a master plan focused on light rail, and sold parcels to developers (*28*). RTD built the track and paid for a 910-space park-and-ride.

RTD is now actively involved in pursuing TOD at the 13 stations on the "T-REX" LRT line now under construction in the Southwest corridor along 1-25 and I-225.

FIVE LESSONS LEARNED AND TEN STEPS TO SUCCESS

After nearly two decades of experience, a growing list of communities have come to learn that in combination with supportive public policy LRT can be a powerful tool in the regeneration of American cities (Table 1). Along the way these communities have also come to understand that capturing the development opportunities afforded by LRT has important implications for how they plan, design, and implement LRT. If LRT is to be both a community building and a people-moving tool, transit agencies and cities will need to bring a new cast of characters to the table in order to plan, design, and implement development-oriented transit.

At the risk of being overly simplistic, there are 5 lessons and 10 steps to success (Table 2) communities should keep in mind as they plan for TOD:

1. The early bird catches the TOD—the earliest decisions on the planning and design of LRT systems shape the opportunities for TOD. Without exception, transit agencies are undertaking TOD work earlier with each of their subsequent LRT lines.
2. TOD can enhance LRT project viability—TOD can add riders to the system, increase property values, enhance the prospects for federal funding, and leverage additional local government support for LRT.
3. TOD is illegal in most of America—most of the development near LRT is transit-adjacent, not transit-oriented development. Changes in local land use plans will be necessary to achieve more TOD. Much of this planning can be done with flexible federal transportation funds.
4. The market for TOD is real and growing—the market desire for compact, urban residential development is growing significantly. Locations next to LRT demonstrated average land value premiums as great as 39% for residential and 53% for offices.
5. Success means bringing new people to the table—the communities with cities playing a strong role in TOD have been the most successful with TOD. Designing for TOD needs to involve developers, local planners, architects, transit planners and engineers.

TABLE 2 Ten Steps to Success in Planning for TOD

1. Transit Village Partnerships Successful TOD planning is done in partnership with local governments, transit agencies, neighborhoods, and developers.	**2. Station Area Planning** "Flexible" federal transportation funds have been used in many communities as a source to pay for TOD land use plans up to .5 mi from stations.
3. Revise Development Codes In most communities development codes will need to be revised to allow TOD as a clearly permitted use.	**4. Development Ready Transit** Plan and design transit improvements to welcome and encourage TOD by connecting transit to the community.
5. Plan for a Mix of Uses Mixing uses in a TOD or along the line (residential, shopping, work, leisure) helps reduce automobile use and increases walking and transit use.	**6. Link TOD to Community Livability** For most communities a successful TOD strategy and a successful community livability strategy are one and the same.
7. Pedestrian-Friendly Projects Focus on pedestrian-friendly projects to avoid the complication of sequencing development with new transit facilities.	**8. Put Limits on Parking** Parking is one of the most important land uses in a TOD. Attention needs to be put on controlling the amount and location of parking.
9. Increase Density Density makes a difference in travel behavior, establishing minimum densities and raising maximums are effective strategies.	**10. Places to Come Back To** When done best, transit investments can be a powerful place-making tool to help create places to come back to, not simply to leave from.

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Hudson–Bergen Light Rail System and Economic Development on the Waterfront

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The introduction of the Hudson–Bergen Light Rail (HBLR) line on the Hudson River waterfront in April 2000 was the result of a long planning and construction process that largely started in the mid-1980s. The system has both benefited from and helped shape an even longer cycle of economic recovery, redevelopment, and expansion in Jersey City, New Jersey, and on the waterfront.

Development activity in the area, key HBLR project milestones, and some lessons learned along the way are described. While it would be unreasonable to directly attribute the many economic successes on the waterfront to the development of the light rail line, clearly there is a symbiotic relationship between the two that has existed over the past 15 years as the system has been planned, constructed, and implemented.

Major development projects were constructed on the waterfront in the late 1980s and through the 1990s because of factors such as the proximity to New York City and the access provided by Port Authority Trans-Hudson (PATH), the aggressive upfront planning process, and the available tax incentives or other economic benefits that could be realized.

Now, as light rail has been implemented, the pace of development appears to have quickened, and the expansion is beginning to move away from the core waterfront areas developed first. Developers have begun to shift away from the PATH stations hubs. They are investing in properties along the light rail alignment, they are showing more attention to the residential market, and they are "selling" the amenities and connectivity that the light rail line provides.

INTRODUCTION

Jersey City, the second largest city in New Jersey and just across the Hudson River from lower Manhattan, was first and foremost an industrial center. It was home to thousands of immigrants who passed through nearby Ellis Island. These newcomers found work in its factories, and the railroads carried manufacturing products throughout the region. Here in the shadows of Wall Street's financial mecca, Jersey City grew as a thriving manufacturing town.

But over the last half century, population has shifted to the suburbs and a once dominant rail freight industry has seen traffic greatly diverted to trucks and other modes. With these overriding trends and the decline of manufacturing in the inner cities, Jersey City changed. The booming waterfront rail yards and ports were abandoned, the economy declined, and by the 1960s and early 1970s, the future looked dim.

But it was the vacant waterfront and its empty industrial centers that ultimately led Jersey City to once again be considered a land of opportunity. Through the late 1980s and early 1990s, things started to change for an area that was now sometimes called "Wall Street West."

Tomorrow's history is now being made, as abandoned properties are being developed, new businesses are arriving, and thousands of residents are settling in the area. The transportation network is one of the critical elements shaping the re-emergence of Jersey City as a thriving community, and the new Hudson–Bergen Light Rail (HBLR) transit system is certainly a key part of the story.

The Light Rail System

The planning for a light rail system to serve New Jersey's Hudson County waterfront area started well before it was ever termed the Gold Coast, with its majestic office towers across from Manhattan and upscale luxury housing. In the early 1980s, the waterfront was a different kind of place—a wasteland of abandoned rail lines, rotting piers, and vacant lots. Drug abuse plagued the area, along with the crime that goes with it. However, rents were cheap and an arts community began to emerge because of the proximity to New York City (NYC).

A small handful of firms like Nat West had located at Exchange Place largely because of the direct Port Authority Trans-Hudson (PATH) connection to NYC and the cost benefits of being outside Manhattan. These were pioneers who sought office space adjacent to the PATH station, and worked here for some 15 or 20 years before the HBLR system emerged to tie together the various waterfront parcels lying north and south along the Hudson River.

By 1984, a planning study was underway, looking at the area's transportation needs. A draft transportation plan for the Hudson River waterfront was released in 1985, with recommendations on a new north–south transit system stretching between Bayonne, Jersey City, Hoboken, and other New Jersey municipalities to the north. The study called for a transportation solution that could address the long-term needs of the area.

This was an area with much potential. In 1987, the forecasts called for 35 million square feet of new office space; 36,000 new residential units; 3.2 million square feet of retail space; and numerous hotels, restaurants, marinas, and other attractions.

The Alternatives Analysis and Draft Environmental Impact Statement (EIS) was begun in 1989 and completed in 1992. The Locally Preferred Alternative Report was issued in 1993, and in summer 1994, a decision was made by NJ Transit to utilize an unconventional (for transit projects) turnkey approach to build the initial 10-mi segment of the HBLR line. The use of this design-build-operate-maintain (DBOM) procurement strategy was employed to shorten the construction cycle and allow a faster delivery of the needed transit service.

A supplemental EIS report was issued in 1995 for Bayonne. By 1996, the Final Alternatives Analysis and EIS Document was issued, and the Full Funding Grant Agreement was received from the FTA. In September, a contractor was hired and given notice to proceed on building the light rail system. Under the DBOM terms, this same contractor who handled the construction would also be responsible for the operation and maintenance of the line over a 15-year term. This shift to a single entity streamlines the process and encourages quality control because the contractor has an ongoing role.

Construction of the HBLR system was completed by fall 1999, and after a period of system testing and required operating demonstrations, the service was implemented on April 15, 2000, between Bayonne and Southern Jersey City to Exchange Place, as depicted in Figure 1. Future segments were completed and the alignment reached Hoboken in September 2002. A southern

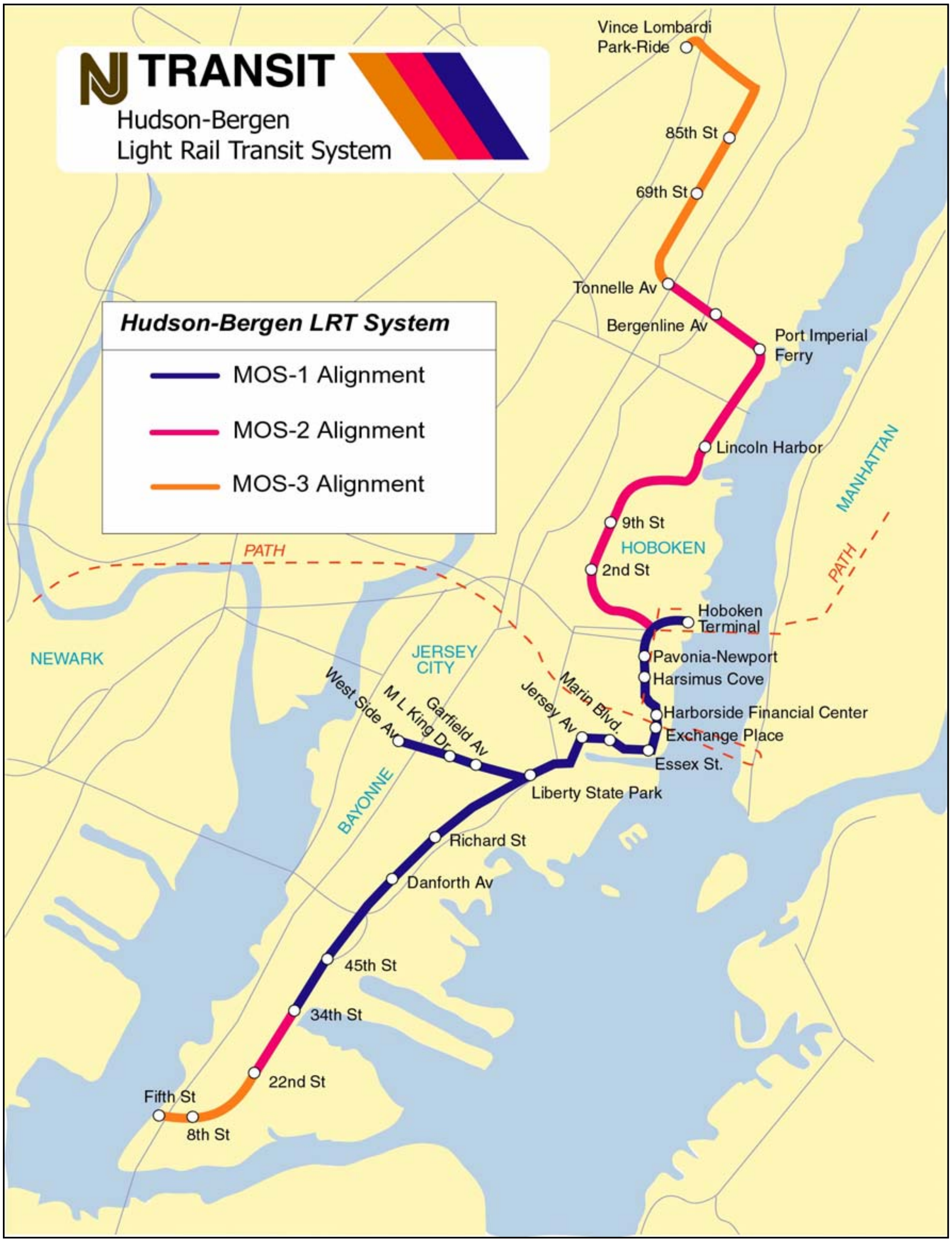

FIGURE 1 HBLR system.

extension further into Bayonne is planned to open in late November 2003. In February 2004, a northern extension to Weehawken and the Port Imperial ferry complex will open. A future extension north and west to Tonnelle Avenue will be put in place in 2005.

Development Activity

Exchange Place

The focus for much of the development along the Hudson River waterfront, from the beginning, was Exchange Place in downtown Jersey City. As an employment center, Exchange Place boasted those few early companies and a handful of restaurants which were perhaps the only real amenities on the waterfront. Things improved with the success of the huge Harborside complex, which benefited from being directly adjacent to PATH and also included a small indoor strip of stores and restaurants facing out on the river. Furthermore, Exchange Place was home to numerous vacant or abandoned parcels of land in the Colgate section, just south of the PATH station. There was a key alignment decision by NJ TRANSIT, and the Hudson–Bergen line followed the “City South” routing rather than a “City Center” option that would have served the already established Grove Street area. With this choice, the southern Exchange Place section of the waterfront was essentially primed for redevelopment, with its light rail stations stretching away from the PATH through vacant parcels.

Buildings went up quickly, and major tenants began to move in, such as Merrill Lynch, Morgan Stanley, and Lehman Brothers. More recently, in the late 1990s, the investment firm Goldman Sachs decided to build its 1.3 million square foot complex in the Colgate section of Exchange Place. As New Jersey’s tallest building, this project is just being completed, and will be well served by the PATH system and the Hudson–Bergen line at both the Exchange Place and Essex Street stations.

Newport

Another key location in between Exchange Place and Hoboken, in the center of Jersey City’s waterfront, is Newport. Once home to a large rail freight yard, the Newport site was mostly vacant in the early 1980s. It had its own PATH station, and a pair of residential towers that offered quality housing just a few minutes by train away from New York City jobs.

In the mid-1980s, with the aid of a massive $40 million Housing and Urban Development block grant, Newport began to expand. While preserving that critical transit corridor through the very heart of the waterfront region, Jersey City worked with the development community and in 1988, a one-million square foot retail shopping mall, Newport Centre, was opened along with four high-rise residential towers. Initially, PATH provided the critical transit linkage and later the promise of the north–south Hudson–Bergen line brought more activity. Through the latter half of the 1990s, the Newport site grew dramatically, with large-scale office and residential development following the earlier residential and retail investments.

Growth occurred on the fringes of these major sites, between Exchange Place and Newport and the PATH stations that had once offered the only quality transit connectivity in the area. Sites like Harsimus Cove developed later and now continue to expand, along with other locations that were no longer within an easy walk of the PATH station. Areas that had remained vacant for a decade or more, in times of economic prosperity, were now building up. With the light rail line funded and under construction, the developers turned their attention in the later 1990s to the pockets of open space too far from PATH. The pace of development moved south following the light rail alignment, with office and residential activity that was unquestionably spurred by the mass transit line.

Away from the Waterfront

Just south and west of Exchange Place, and well away from the waterfront, lies the Liberty Harbor North site. On a location that essentially spans the Jersey Avenue and Marin Boulevard station stops on the HBLR line, there is only now in the last 18 months a viable plan for a major office and residential complex. On a vacant 70-acre parcel that has been undeveloped for decades, located about five or six minutes by train (light rail) from Exchange Place, there will likely one day be more than 6,000 new residential units. There are proposals for office space here too, on a huge scale up to 4.5 million square feet.

To the west, across Jersey Avenue, the Jersey City Medical Center complex will be relocated to a site that boasts convenient access on HBLR to points throughout Hudson County. This Medical Center was originally built in the early 1930s, and it is being moved to a brand new state-of-the-art facility located next to the Jersey Avenue light rail station. This center is proposed to open fully in 2004, serving thousands of patients, visitors and hospital employees each day.

On the western side of Jersey City, an economically depressed urban neighborhood appears to be rebounding. Alongside the light rail station at Martin Luther King Drive, a new retail shopping center is now in place and other residential construction is underway. This is unusual, as most of the retail centers are located on the highways that surround the city. At West Side Avenue Station, one stop further west, joint development is being discussed as the Hudson–Bergen line and the link to the waterfront and PATH has created new opportunities.

In sum, the story of development in Hudson County and on the Hudson River waterfront is largely the story of what happened and is happening in Jersey City. This is the result of many different factors, including the up-front planning steps taken by the Jersey City Department of Planning, the existence of available land, the presence of the PATH access to New York, and certainly supported by the early phases of the HBLR line built within Jersey City (and northern Bayonne).

The type and rate of the changes in Jersey City are dramatically different than those occurring in virtually all of the other major urban centers in New Jersey. From 1980 to 2000, Jersey City's population increased to more than 240,000 while the population in other major cities such as Newark, Camden, and Trenton all experienced major declines. State forecasts for the period between 2000 and 2020 project an increase of nearly 28,000 new residents, or 11 percent growth, and the residential development occurring on the Hudson Waterfront is cited as a contributing factor.

To illustrate the role that Jersey City has with regard to the area growth, Figures 2 and 3 show the proposed and approved commercial and residential development, respectively, that is occurring in Hudson County. Of note, the four municipalities on the left (Bayonne, Hoboken, Jersey City and Weehawken) have HBLR station stops existing or under construction.

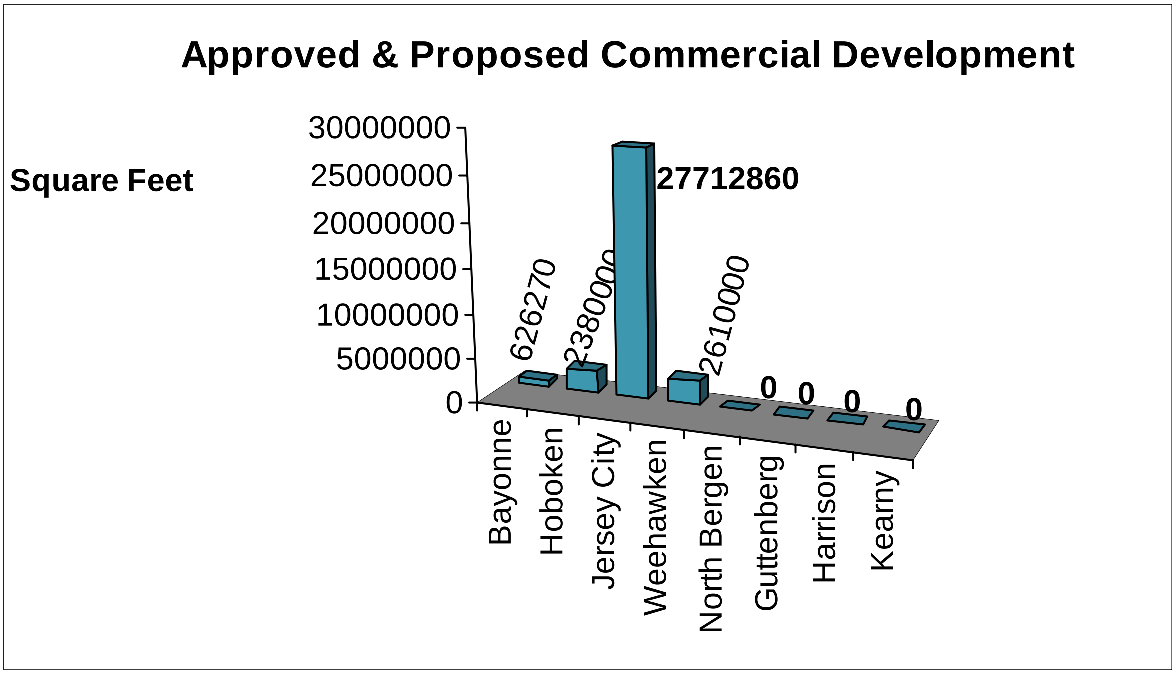

FIGURE 2 Commercial development in Hudson County. (Source: Jersey City Planning Department.)

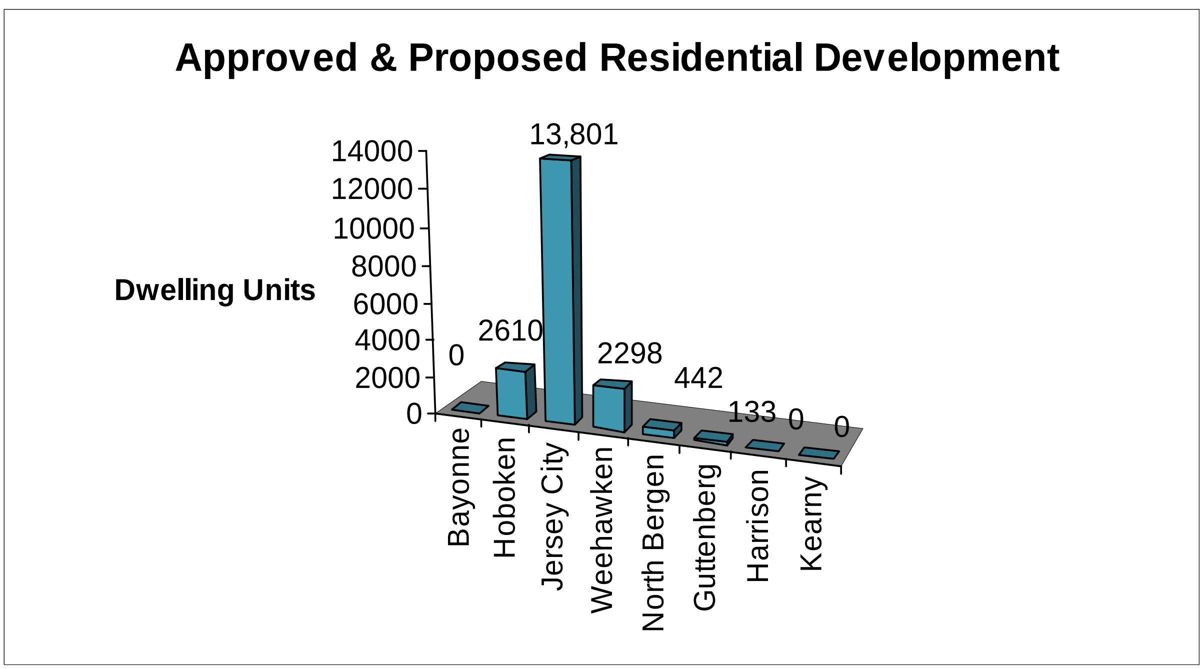

FIGURE 3 Residential development in Hudson County. (Source: Jersey City Planning Department.)

The Future

Even if we look only at those firmly committed projects on the waterfront, the fast pace of development is not slowing. In Figure 4, the office, retail and residential development on the Hudson River waterfront has been broken down into different stages. Beyond what is shown as existing in 2002, there is significant activity on projects that are either under construction or are proposed or approved.

This development of committed projects adds a total of nearly 7.5 million square feet of new office space, which would project to a workforce of up to 22,000. This tally shows 6,489 new residential units as well.

The Hudson–Bergen line is a stimulus for the development that has occurred and what will occur in the future. With the dramatic data in Figure 5, the investment value of the area's construction has been compared with the key milestones in the development of the light rail system over the past 12 years.

Development projects have come on line rapidly as the construction on the rail alignment and stations has been completed. From 1996, with the selection of the contractor up to the opening of the first two segments of the system in 2000 and 2001, the construction activity on new development projects has been impressive.

Lessons Learned

There have been many successes in Jersey City, with both the waterfront development and the implementation of the light rail line. And there are lessons learned and inferences that can be drawn.

Jersey City is a prime example of where, if you can "get your planning in place," the

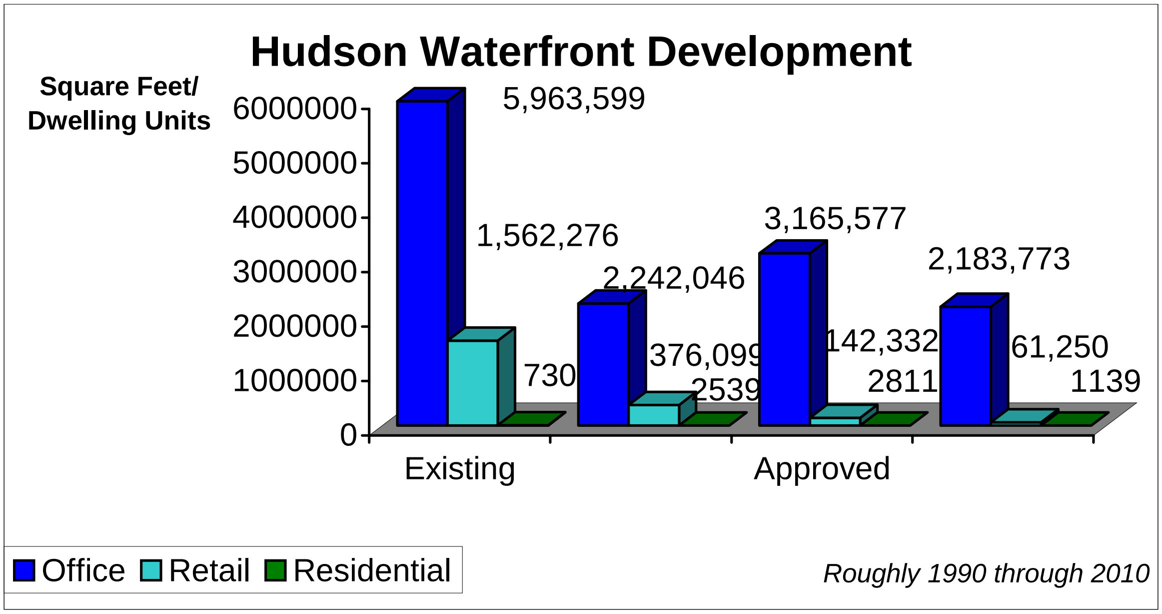

FIGURE 4 Office, retail, and residential development in Hudson County. (Source: Jersey City Planning Department.)

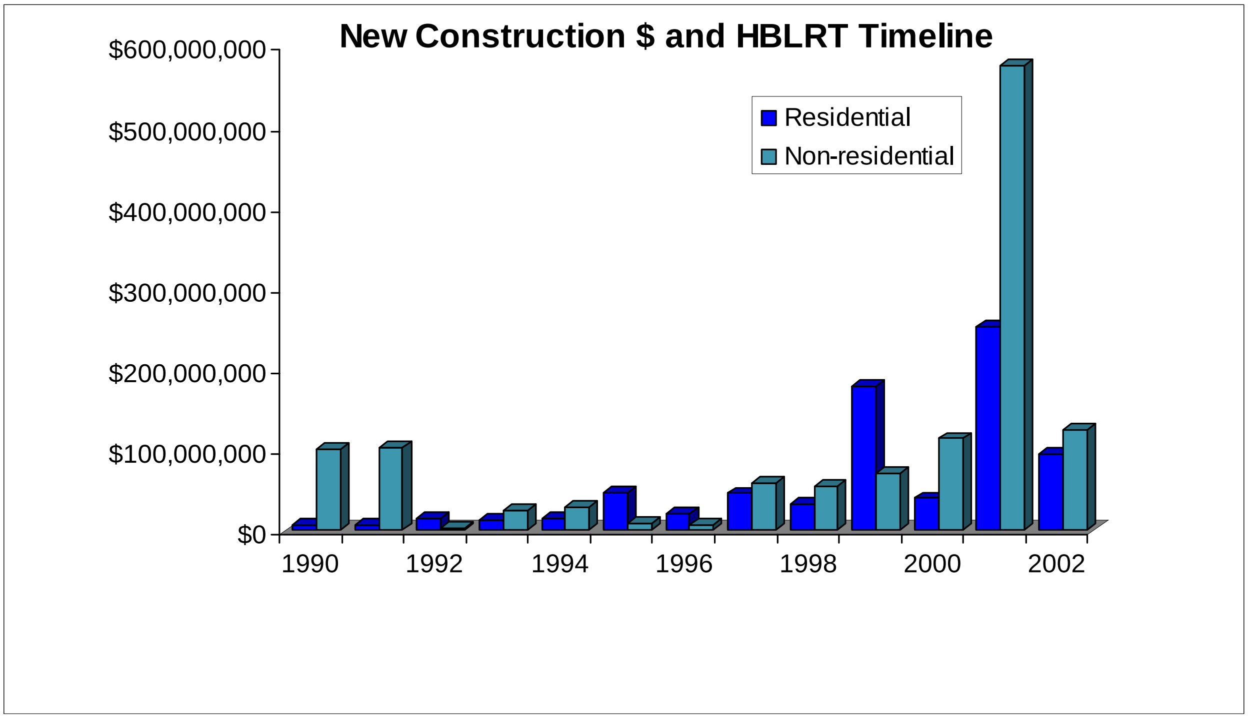

FIGURE 5 Investment value of Hudson County construction and light rail system timeline. (Source: Jersey City Economic Development Department.)

development will follow. At the municipal level, time was spent early in the process on the needed zoning changes and on other efforts that would support and encourage future development. According to Bob Cotter, long time Planning Director for Jersey City, decisions were made and the necessary steps were taken in the mid-1980s. The municipality spent time developing a Master Plan for the waterfront area that assumed mixed-use development and the inclusion of a light rail system even before the system had been designed.

Through a three-part process that addressed site acquisition, custom zoning, and tax abatement, Jersey City was prepared. As a result, when major corporations were looking to invest in properties with good transportation access, the waterfront area was attractive. This worked in the late 1980s and into the 1990s, with the PATH system, and it is working perhaps at a more feverish pitch now with the arrival of the Hudson–Bergen line.

There was regular ongoing dialogue between the development community and Jersey City. Ultimately when the formal site plan application was submitted, the planning approvals could literally be handled in 20 minutes because it was consistent with the Master Plan requirements. When considering the cost of money, this resulted in significant savings to developers and it offered new tenants the ability to quickly relocate. Jersey City was an attractive alternative, in comparison to many of the other sites in the New York City region.

Waterfront development permits administered by the Department of Environmental Protection were essentially the mechanism used to regulate any developments proposed within 200 ft of the Hudson River. Through this process, a number of state agencies were brought in to evaluate proposals and approvals were typically granted with a series of conditions.

The state transit agency secured no-cost transit easements through the waterfront area and developers were also required to provide a continuous waterfront walkway that allowed public access all along the river. This 3- to 6-month process included a public hearing, and identified and addressed issues associated with the particular development.

In approving developer projects on the waterfront, Jersey City was able to implement a very aggressive parking ratio policy, at only one parking space per 1,000 square feet of office space. Currently, this ratio is even lower, at .67 space per 1,000 square feet. It is important to note that this policy was not a deterrent, either to the project lenders or the development community. In fact, it allowed them to maximize the tenant space in the building while minimizing the investment in parking. This worked in large part because of the transportation alternatives that were in place. While this was begun initially with PATH and local and regional bus service, it was given a dramatic boost as the connectivity of the HBLR line encouraged development with the institution of low parking space ratios.

The initial growth on the waterfront, especially with office space, was most dramatic at Exchange Place and Newport, as developers built and tenants settled alongside the PATH stations offering the direct PATH link to nearby Manhattan. This space filled, and the light rail line emerged to connect the other developable properties up and down the waterfront. This is illustrated in Figure 6. With these changes, and in a positive economic climate, the development activity continued but it has moved away from PATH. Perhaps as a result of the fixed rail connection, office development and dramatic residential growth are occurring further and further from the heart of the Gold Coast waterfront. Space that will be served by the Hudson–Bergen line, in western Hoboken and Weehawken and in southern Bayonne, is being cleared, construction is underway, and expansion is continuing.

The residential activity has jumped also, following the initial success of office development on the waterfront and along the Hudson–Bergen alignment. Since the light rail line opened in April 2000, there has been a major expansion of residential space. The residential decision seemed to come later, as the employees waited to see the light rail system in operation, to see what the service would be like and whether they wanted to live nearby.

Due to the closer spacing of light rail stations, the Hudson–Bergen line may have also facilitated greater density over the line than could be achieved with the localized, concentrated, heavily office-based development occurring within a .25-mi radius around PATH stations. In other words, the light rail line has facilitated the infill of residential properties, and this has brought development into locations that office space developers would not be interested in.

Part of this expansion by residential properties farther out from the central hub is simply explained by basic land economics, with higher-order uses locating near the core. Further, however, it can show how the new transportation access from the rail line has helped to make otherwise undesirable locations attractive. In doing so, it also helps to facilitate a twenty-four hour environment around the hub location as residents are now in a position to support other mixed uses in the area.

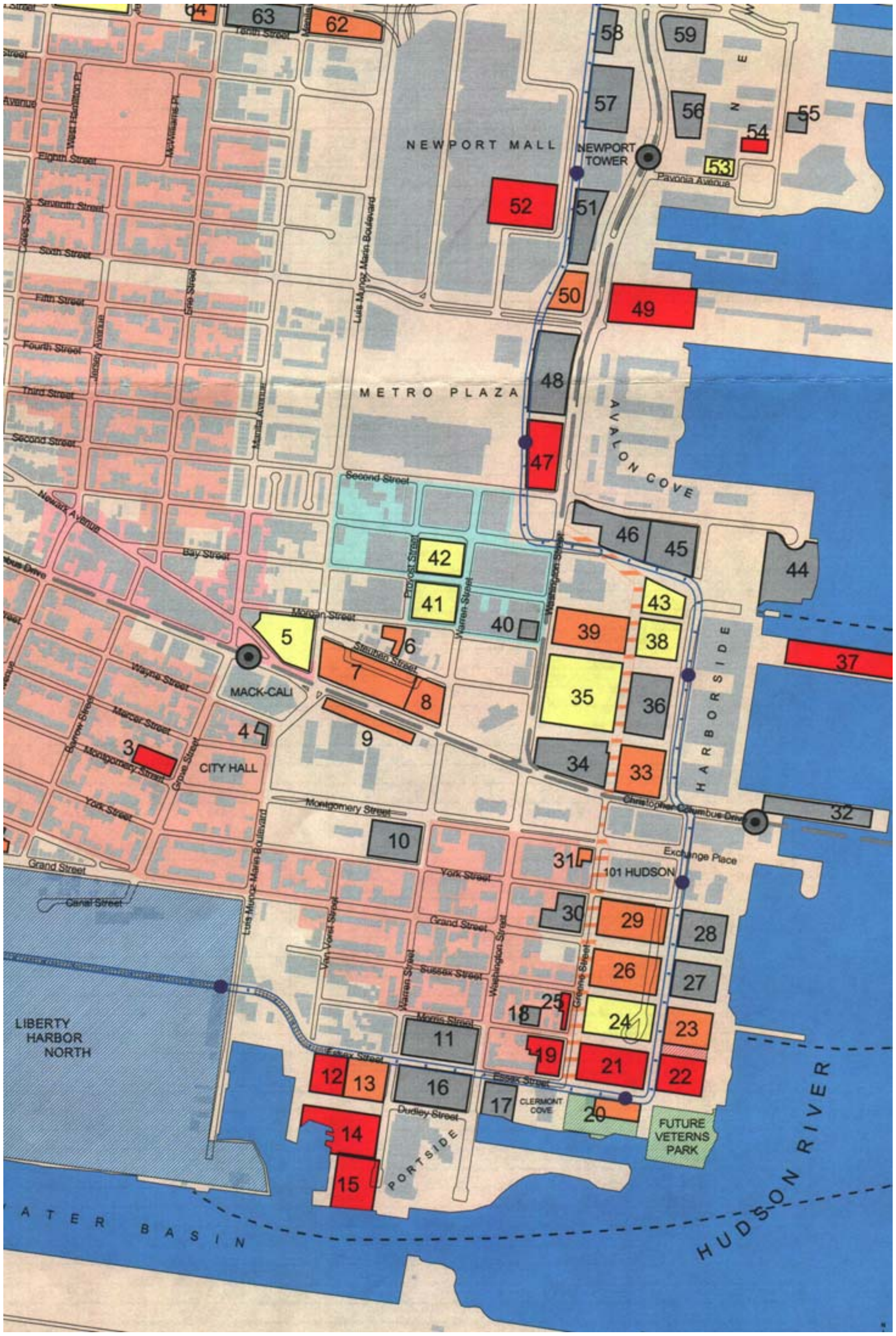

FIGURE 6 Jersey City downtown development map, October 2002. (Source: Jersey City Economic Development Department.)

Third Street Light Rail Project Southern Terminal

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Much of San Francisco's recent growth has been south of its traditional center, and public transportation has been following this growth with new service. The existing southern leg of the Route N Judah line service runs south from the foot of Market Street along the Embarcadero to its terminus at Fourth and King Streets near Pacific Bell Baseball Park and the Caltrain Terminal. The recent extension is proving successful in attracting riders. San Francisco is building the dual track Third Street Light Rail Project from the end of the current line near Pacific Bell Park to the city and county southern boundary. A public transportation terminal is needed at the southern end to complete the transportation infrastructure for the future urban corridor. The Southern Terminal at San Francisco's southern boundary would be the southern gateway to the San Francisco Municipal Railway system. It would be the public transportation center for the southern end of the Third Street corridor. The proposed Southern Terminal location actually lies in the neighboring city of Brisbane, which increases the complexity of its development, but also increases it potential.

THIRD STREET LIGHT RAIL SYSTEM

Third Street will be a major north–south transportation corridor in San Francisco between the city's downtown Market Street area and its southern boundary. The corridor begins at Market and Third in San Francisco's downtown and continues south through the south of Market area, Mission Bay, Central Waterfront, and the communities of Baypoint and Visitation Valley. The San Francisco Municipal Railway (Muni) Metro Third Street Light Rail Project in the center of the corridor will provide light rail public transportation from Union Square and Chinatown in the city center on the north to Visitation Valley on the San Francisco southern boundary.

Phase 1 of the Third Street Light Rail Project is currently under construction. It begins at Fourth and King Streets and extends the existing Route N Judah Line approximately 5.4 mi further south along Third Street and Bayshore Boulevard to its southern terminus at the San Francisco county line. Phase 2, the new Central Subway, in preliminary engineering, will follow the initial operating segment and will complete the line segment. It will extend the Third Street light rail transit (LRT) system north from Fourth and King Streets to a new downtown terminus in Chinatown at Stockton and Clay Streets in a new subway section that begins near Bryant Street, crosses beneath Market Street, Geary, and Stockton Streets, and ends at the downtown terminus.

A primary objective of Phase 1 is to serve as a catalyst for new development through improved public transportation along Third Street. The city's plan is for a public transportation corridor south of the downtown that will enhance the areas it passes through. It is investing in landscaping and street amenities in an established business district between Evans and Donner Avenues in the Bayview Hunter's Point area, which will serve as the entrance to the new redevelopment area of the former Hunters Point Naval Shipyard. Phase 1 construction will provide public transportation rail service connections to this corridor from the Muni light rail lines in the central downtown tunnel and Bay Area Rapid Transit (BART) to the north and from Caltrain at the San Francisco limits to the south.

REDEVELOPMENT ALONG THIRD STREET

San Francisco is structuring its urban development to balance employment and housing. Businesses have stated that affordable housing is the biggest problem facing them when considering San Francisco against other competing business locations. There is a lack of middle-income housing that is forcing non-executive workers to commute large distances, up to 60 mi or more from San Francisco. Most new development projects in San Francisco are required to include affordable housing to get permitted.

The Third Street LRT line passes through a traditional industrial and blue-collar residential area that is changing. Development plans for the corridor include 10,700 new residential units and 5 million ft^2 of new commercial space. The major north south commercial corridor south of the city's center should develop along Third Street. The largest redevelopment projects underway in San Francisco are along the Third Street corridor in former industrial sites (Figure 1). Mission Bay, a former Southern Pacific rail yard and associated industrial area, is at the north end. Hunters Point is just east of the corridor at the central portion. Redevelopment of these sites is important part of San Francisco's general plan. The available of the large sites reflect a loss of many traditional industries along the southern waterfront. The replacement of traditional housing and commercial uses in the area is a sensitive issue.

Mission Bay is a 300-acre redevelopment between Pacific Bell Park and 20th Street that is centered on the new University of California at San Francisco Medical Research Center. The 2.65 million ft^2campus will employ 9,100 scientists, researchers and students. Adjacent to the medical center, the developer is planning to build a 500-room hotel, 6,000 residential units, 750,000 $ft^2$of retail space, and 49 acres of parks and open space. Third Street bisects Mission Bay and will be the primary street access.

Hunters Point is a redevelopment of the former U.S. Navy Shipyard. The shipyard is being developed in four parcels. Approximately 63 acres of Parcel A, being developed first, will include 1,600 new homes for ownership and rental, 300,000 $ft^2$of commercial space, and a 5-acre multipurpose community campus. The developer will set aside 32% to 44% of the homes for low- and moderate-income residents. The current schedule is having build-able lots in early 2005 and the first housing units by the end of 2005. The primary street access into the first phase of the Hunters Point development is through Innes and Galvez Avenues to Third Street.

SOUTHERN TERMINAL REDEVELOPMENT AREA

The Southern Terminal is in a redevelopment area straddling the boundary between the cities of San Francisco and Brisbane. It is situated in an industrial area that includes a former Southern Pacific rail yard and adjacent factory sites. The development site is one of the last large redevelopment sites fronting San Francisco and an opportunity for a new direction. As a major residential and commercial center at the southern boundary, the southern terminal center can

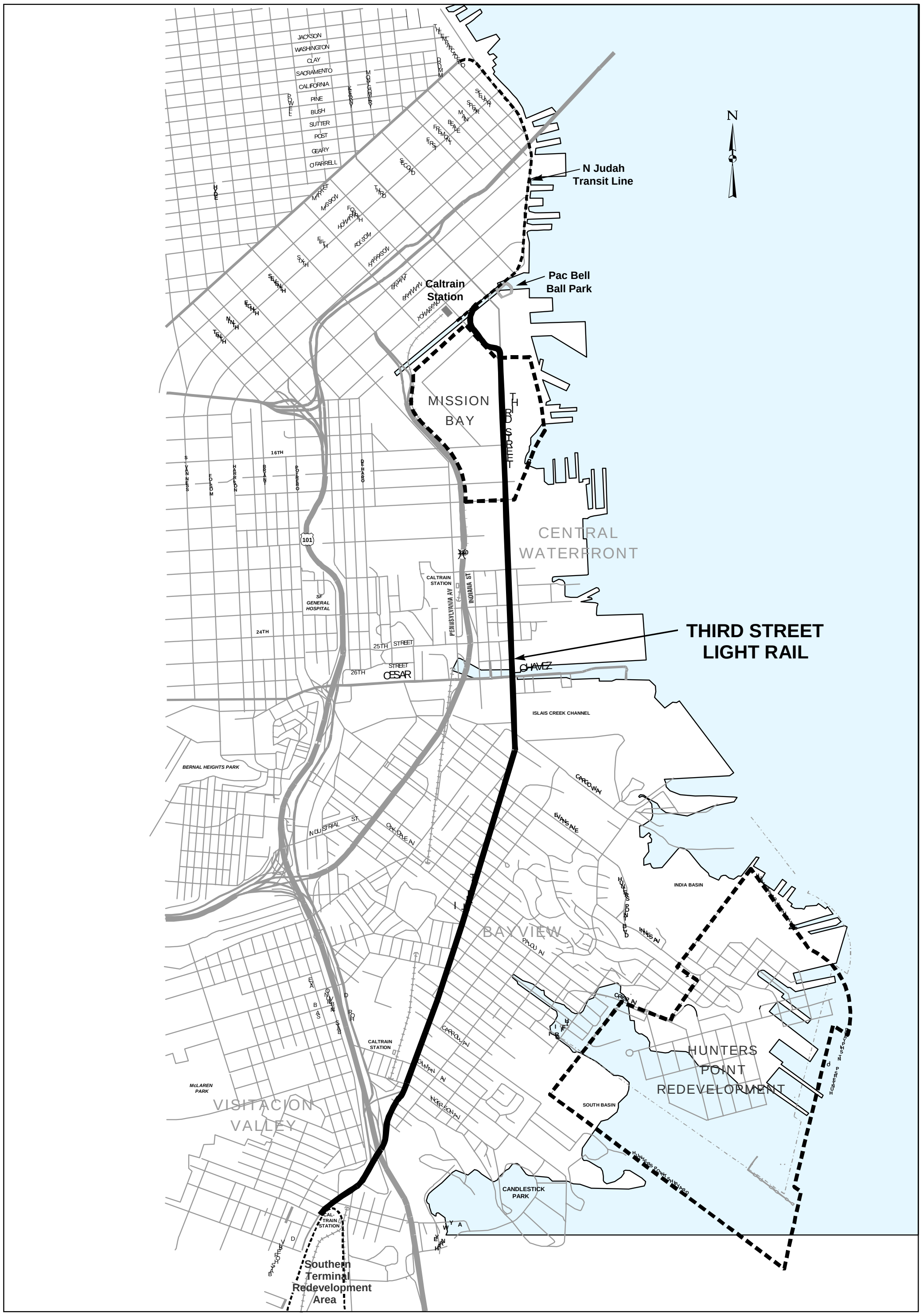


FIGURE 1 Third Street light rail corridor.

anchor the southern end of the Third Street corridor. Infill development associated with the Mission Bay, Hunter's Point, and Southern Terminal should grow towards each other along the corridor.

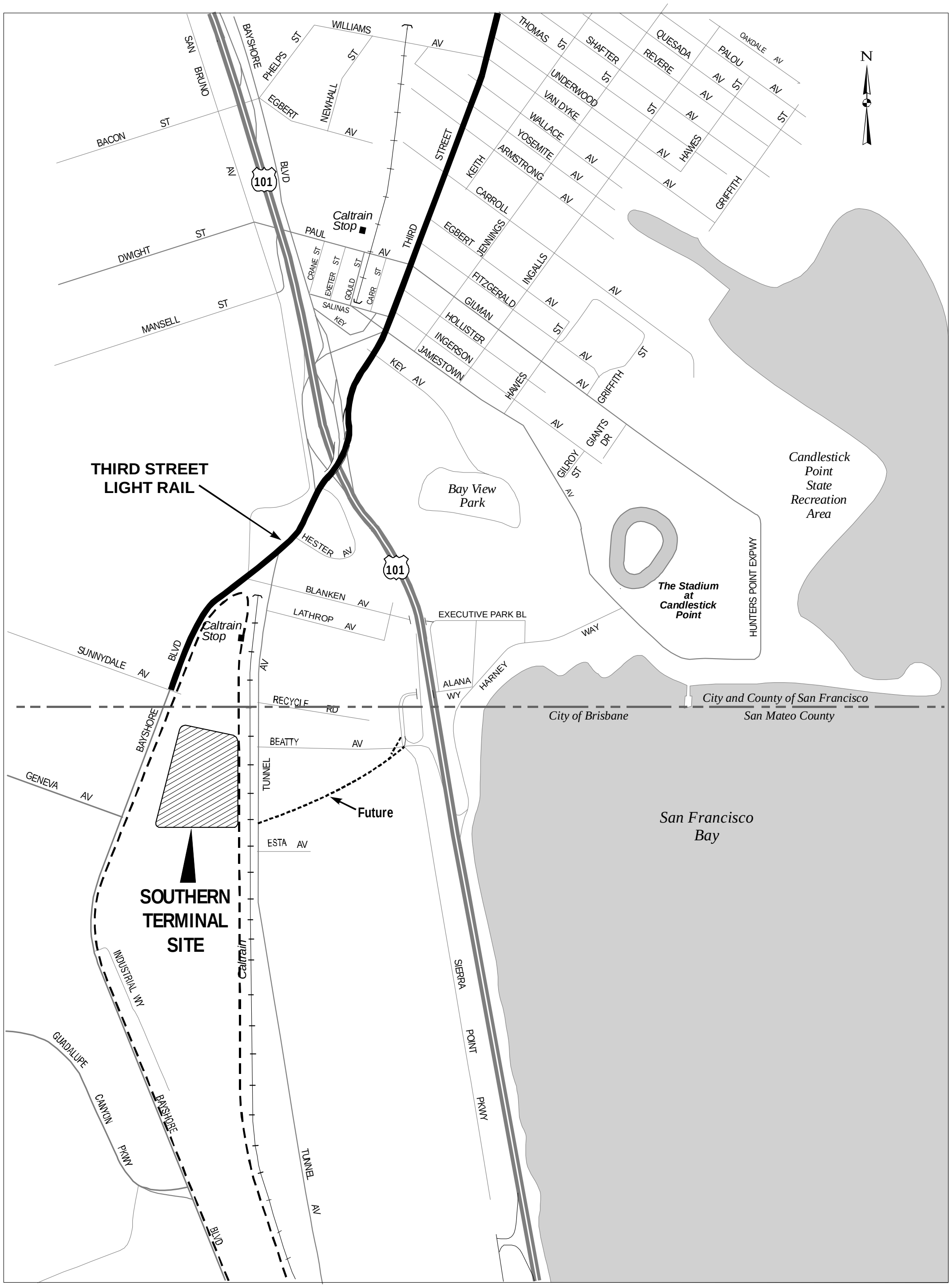
Universal Paragon Corporation (UPC), as the owner/developer, is redeveloping the site working with both the city of San Francisco and the city of Brisbane. UPC, in the planning and environmental phase of the project, is in the process of obtaining permits for this area is negotiating the type of development with both cities. UPC has recognized the advantages of good pubic transportation access to the development area from San Francisco to the north and the Peninsula to the south. In early planning efforts, UPC has studied building residential space in San Francisco coupled with commercial space in Brisbane. Both types of developed could be centered on the Southern Terminal. UPC would donate land to Muni to build the Southern Terminal in the redevelopment area. The land for the terminal was located just over the Brisbane city limits. The location would also serve as transportation center for new development in Brisbane.

Within San Francisco, the owner/developer will build a transit village that will provide much needed housing and associated residential activities. The transit village concept promotes a life style that is centered on public transportation and orients development to public transit. Conversely, it also designs transit facilities to be compatible to the development. Its intention is to divert travel away from the single passenger automobile to public transit and other high vehicle occupancy alternatives. The Southern Terminal, as the village transit center will be the physical center for the redevelopment area's transportation system.

SOUTHERN TERMINAL JOINT DEVELOPMENT

The Southern Terminal is an ideal site for joint development. It is adjacent to the major San Francisco Peninsula corridor for north and south regional travel. The combined Route 101/CalTrain transportation corridor connects San Francisco with the Peninsula and is the primary corridor for this market. The peak travel demand along this corridor is both north- and southbound, which reflects strong employment centers in both San Francisco to the north and the Silicon Valley to the south. Job growth has been good to the south creating a reverse commute business. Muni would also serve workers coming from the peninsula to jobs south of the downtown. The role of the Southern Terminal is to divert personal trips to public transportation along this corridor providing congestion relief to Route 101.

The convergence of alignments at the Southern Terminal site (Figure 2) offers opportunities for a public transportation center. At the southern end, the Third Street LRT tracks in the median of Bayshore Boulevard, cross over Route 101, and run parallel to the west of the original Southern Pacific track alignment, which is used for the Joint Power's Board Peninsula Commuter Railroad (Caltrain) service. An intermodal station that provides bus and light rail connections to the Caltrain service by taking advantage of a convergence of alignments can be the primary connection for long haul commuter service south to the peninsula and San Jose. The Southern Terminal location adjacent to the Caltrain Bayshore Station can link the LRT and the commuter rail systems within walking distance.



THIRD STREET LIGHT RAIL CORRIDOR STUDY
Figure 2
SOUTHERN TERMINAL SITE

FIGURE 2 Southern terminal site.

PUBLIC TRANSIT IMPROVEMENT

The natural features surrounding the city and county of San Francisco limit the available area for development and its associated transportation infrastructure. In response, the city has promoted public transportation as a solution to development within its confined area. Its goal is to significantly enhance the role of public transit in personal trips to decrease passenger car trips. This strategy is important in reducing traffic congestion impacts and the rate of traffic growth on major corridors.

Muni is the public transportation agency within San Francisco responsible for building and operating its bus and rail systems. Most Muni service is structured in a hub and spoke system with lines centered on the downtown business center along Market Street. The primary light rail lines radiate out from the foot of Market Street to the western areas. Connecting bus service is provided from the stations along the rail system. Because there is no current light rail service to the southeast, the area is served by buses. Routes 9, 15, and 52 provide bus service along Geneva Avenue, serving the southern end of San Francisco to the downtown; but the service tends to be indirect and slow.

The Third Street Light Rail System will replace the Route 15 Third Street bus service. It will provide a higher speed service along the eastern end of the city and will connect to feeder bus service. The Southern Terminal will be a transfer point for Muni service for the southern part of San Francisco. It is a good location for connections to the Geneva Avenue corridor. Initially, the service will be bus service feeding the Third Street line. In the future, a light rail line could be built along Geneva Avenue connecting into existing systems on the western and eastern ends.

The Southern Terminal bus and LRT service with the adjacent commuter rail service at the Bayshore Caltrain station could provide service by three transportation agencies: Muni, San Mateo County Transportation Agency (SamTrans), and Caltrain. Muni will operate light rail service on the Third Street LRT and bus service to the north and west into San Francisco. SamTrans will operate bus service to the south into San Mateo County. Caltrain will operate commuter rail service to the peninsula down to San Jose and Gilroy.

INTERMODAL POTENTIAL

The terminal would be a major sub-regional transfer point for bus service. Three types of bus service could be provided. The primary service would be Muni and SamTrans scheduled bus service using the terminal as a layover and passenger transfer point for inter-county service. The second type of bus service would be Caltrain and BART shuttles operating between Bayshore and Balboa Park stations via San Mateo and San Francisco neighborhood collector routes. The third type of bus service would be dedicated shuttles sponsored by organizations such as UPC and the San Francisco 49ers Football Club operating between the Southern Terminal and nearby developments.

Caltrain and the Bay Area Air Quality Management District sponsor dedicated shuttles with participating employers. Caltrain also sponsors special service for events at Pacific Bell Park and Candlestick Park. An arrangement for dedicated shuttles with an organization like the 49ers is an example of the potential for expanding this type of service at Bayshore Station. Special service for events at the nearby Candlestick Stadium where the 49ers play would provide an attractive alternative to private passenger cars. It would help eliminate vehicle congestion leaving the parking areas.

Caltrain has embarked on the largest track improvement program in its history. This ambitious track program is building express tracks to reduce the current 1½-h trip time between San Francisco and San Jose through a Baby Bullet express trains. The program improvement from Bayshore to Brisbane will add two express tracks and rebuild the train control system. The improved track section at Bayshore Station has two express tracks in the center and two local tracks on the outside. Although Bayshore Station has local service only, passengers could board local commuter trains at Bayshore and transfer to express trains at a station further south. The reconstructed track section will have a new centralized traffic control system. Constructing the new tracks for express service involves realigning tracks, reconstructing the signal system, and the relocation of the existing Bayshore Station south. A new intermodal station with BART has been built at Millbrae, two stations south of Bayshore Station. The Southern Terminal would be the intermodal station with Muni.

ORGANIZATIONAL ISSUES

The connection between these services involves the developer and three public transportation agencies with the resulting organizational issues. Muni, Caltrain, and UPC have continued to negotiate for several years to reach agreement on access and facilities. An agreement is needed that will allocate responsibilities based on the resources of each party. In general, Caltrain would retain commuter rail capital improvements, constructing a new station with outside boarding platforms to the south of the current Bayshore station and constructing track improvements within its right of way. Muni would construct the bus and LRT turnaround and platforms and construct heavy rail track improvements outside the Caltrain right of way. UPC will provide land for Muni bus and LRT turnarounds to the terminal and platforms including public access and substation. The three organizations have been planning the intermodal terminal and working on developing a conceptual plan that is acceptable to all parties.

A fourth participant is the Union Pacific Railroad (UP) because of operating rights for freight trains on the Caltrain tracks. Caltrain has to maintain UP's customers sidings to accommodate the UP's continuing freight operations. This requirement is complicated by the centralized traffic control system in the segment, which adds to the cost of siding relocation.

Stakeholder interests limit the potential size and cost of the Southern Terminal site. Cost is important to all the major stakeholders, who have budget constraints for various reasons. Market forces and investment return criteria limit the possible developer investment. Muni and Caltrain must work with funding limits. Revenue for both agencies is down in the current economic slowdown.

THE SITE

The temporary southern terminus for the Third Street LRT System is in the center of Bayshore Boulevard just north of Sunnydale Avenue. It is a double crossover with tail tracks that allows trains to reverse direction and change tracks. The tail tracks provide for train storage between runs. A double crossover was also used at the existing terminus at Fourth and Townsend near

Pacific Bell Park. A double crossover is not the most efficient track layout at a terminus, because the operator is required to change from one end of the train to the other end. But a more efficient loop track layout requires land outside the street right of way. The ultimate Southern Terminal would have a loop track south of Sunnydale Avenue and east of the temporary terminus. The terminal site is located just south and across the tracks from the existing Caltrain Bayshore Station.

Access to the Southern Terminal site from Bayshore Boulevard and the interim terminus needs to be improved. Sunnydale Avenue east of Bayshore Boulevard is a very narrow little used street. The public right of way on Sunnydale is 66 ft from property line to property line. The minimal public access easement width requirement is 53.5 ft for combined LRT and street access for buses and emergency vehicles. If LRT tracks were placed along the south right of way limit for Sunnydale Avenue, it would provide a 30-ft roadway width. This location affects access to the property owners on the south side of Sunnydale Avenue, but it could be a short-term expediency until a larger right of way is developed.

The new Bayshore Station will have a pedestrian overpass for pedestrians to reach the outbound platform on the west side of the tracks from the inbound platform and parking on the east side of the tracks. The existing Bayshore Station is on the east side of the tracks and has limited parking, which will be retained. The overpass connection to the outbound platform could also provide pedestrian access to the Third Street LRT System and the San Francisco and San Mateo bus systems.

Caltrain must maintain existing UP freight service in their track section, which affects the design of the Southern Terminal tracks. A still active existing freight spur cuts through the redevelopment site on a long arc leaving odd shape parcels on either side. The existing turnout for the freight siding is part of the track relocation. Caltrain will construct a new relocated UP freight spur switch and stub out to its right of way just south of the Southern Terminal, put the new switch into service and take the old switch out of service. Muni will construct the spur track from the Caltrain right of way to the freight customer's sidings.

The relocation of the freight spur further south and out of the way will help the redevelopment planning. UPC is interested in developing large build able blocks on its site, and the freight spur cuts across a block of land on a diagonal. A new turnout and connecting spur are being built to the south using either a new track crossing of Bayshore Boulevard or the existing track crossing of Bayshore Boulevard. The existing crossing required a back in movement, which was acceptable to the UP. A new crossing requires California Public Utilities Commission (CPUC) approval, which is a time issue due to the schedule for Caltrain's express tracks. A new Bayshore crossing for the spur remains an issue.

TERMINAL REQUIREMENTS

Adequate dedicated public land is needed for the LRT turnaround, LRT platform, and bus platform and traction power substation. The bus platform and substation require street access. The site allocated to the Southern Terminal is compact, providing enough land for the turnaround and connections using minimum criteria. The terminal is planned within a constrained space.

As the Third Street Light Rail southern terminus, the Southern Terminal requires a loop track for southbound LRT trains returning north, queuing tracks for service requirements and storage tracks for breakdowns. It also requires tracks for access to the revenue tracks on

Bayshore Boulevard at Sunnydale Avenue. The most direct access is along Sunnydale Avenue. The turnaround will operate in counter clockwise direction to avoid the need for a track crossing. Trains will not wait at the boarding platform prior to a scheduled departure, since Muni has found that passengers expect a train to leave shortly after they board.

Trains in revenue service can operate in one-, two-, and three- or four-car consists, but the platforms along the Third Street operating segment are sized for two-car consists. Required terminal track speed is within the terminal is low, 5-mph with a maximum speed through the turnouts of 3 mph. Following Muni practice, station facilities for light rail vehicle (LRV) operations at the turnaround will be minimal. There will not be an operations office or waiting room for operators.

Parking will not be provided for LRT passengers at the intermodal terminal, since Muni does not build parking around their platforms, relying instead on passenger use of feeder bus services. Parking is usually provided for commuter rail stations, but limited parking is provided at the existing Bayshore Station. There is a possibility that commuter rail passengers will park in the redevelopment area and then use the pedestrian walkways and grade separations to reach the commuter rail platforms. Diverting commercial development parking spaces to transportation parking use could reduce spaces available to commercial tenants. The control of parking will be addressed as the Southern Terminal planning progress.

Efficient and safe passenger movement between the different modes is a key to the success of the terminal. Pedestrians will move between the three public transportation modes and potential car parking areas nearby. Passenger circulation between the different modes involves three different property owners with different requirements. Within the Southern Terminal site, pedestrians will use sidewalks, signals, and gates to move safely between private property and public transportation platforms.

COMPLETED PLANNING

Muni retained Korve Engineering, Inc. to help with conceptual track and bus design issues at the Southern Terminal. UP retained the services of Chi-Hsin Shao to develop transportation plans for development and to work with Muni on the Southern Terminal conceptual plan.

The LRT track layout for the conceptual design followed criteria established for the line segments of the Third Street Project, which is based on the basic physical and operating characteristics of the Breda Costruzioni Ferroviarie LRV-2 as the primary vehicle with provisions to accommodate Muni’s President’s Conference Committee (PCC) car and Historic Streetcar (HSC) fleets as the secondary vehicles. The Breda LRV-2 car is a double-ended, single-articulated car with six axles in three trucks. It is double-sided with four high/low-level doors per side. The Breda LRV-2 has a car length over couplers of 22.86 m (75 ft) and a minimum turning radius of 13.72 m (45 ft).

In California, CPUC General Orders determine track clearances for the LRT tracks. These are related to worker and pedestrian safety on and adjacent to the tracks. Relevant General orders include Nos. 95, 128, 143A, section 9.6 and 143B. On station platforms and other locations where passengers are permitted while trains are in motion, the minimum clearance is 30 in. At locations and in areas where passengers are normally prohibited while trains are in motion, the minimum clearance is 18 in. The minimum clearance can be less than 18 in. for fixed wayside structures less than 5 ft in length like catenary and signal pole.

The clearance envelope of the LRV-2 was set by combining the dynamic envelope, construction and maintenance tolerances plus mid-overhang, end-overhang, and super elevation adjustments. Construction and maintenance tolerances include track wear, wheel wear, track construction tolerances, and wayside structure construction tolerances. These clearances also accommodate the dynamic envelope of a number of historic PCC and the HSC street cars being used by Muni. The track alignment criteria are shown in Table 1.

RAIL PLATFORM HEIGHTS

A common platform and loading area for LRT and commuter rail passengers would improve efficiency of passenger movement between these systems, aid transfers and reduce loading times. Alternatives using a common platform between adjacent LRT and commuter rail tracks were studied, but use of different platform heights by the adjacent causes construction problems. The commuter rail platform height is at 8 in. (.192mm), while the LRT platform height is at 30 in. (813mm). To achieve a common track height, the LRT track would have to be lowered, since it would be costly to raise an active commuter rail track. There are technical problems with lowering the LRT tracks, involving drainage and grading within the plaza area, and unknown underground risks. It was determined that the preferred alternative is to keep the platforms at separate heights. Ramps approximately 34 ft in length and stairs have to be located at points along the platform to accommodate the height differences. The net affect on the terminal layout is a requirement for a greater site width for adjacent platforms.

BUS PLATFORMS

The Southern Terminal will provide bus platforms for Muni and SamTrans scheduled inter-county bus service, scheduled shuttles, and dedicated shuttles. This requires accommodating a range of different bus sizes. The platforms will accommodate buses that are loading and unloading passengers and holding on layover for later scheduled departures. The buses will have a turnaround off Sunnydale Avenue to enter, turnaround, and exit in the opposite direction similar to the LRT operation.

The bus platform layout is based on the basic physical and operating characteristics of the combination of articulated bus types as the primary buses with single unit bus types as the

TABLE 1 LRT Track Geometry and Clearance Requirements

Preferred minimum curve radius	22.9 m (75 ft)
Absolute minimum curve radius	19.8 m (65 ft)
Preferred minimum length of tangent between curves	7.62 m (25 ft)
Minimum length of tangent preceding a point of switch	3.05 m (10 ft)
Preferred curve length (one car length)	22.9m (75 ft)
Minimum track spacing for tracks without OCS poles between tracks	4.3 m (14 ft)
Minimum clearance from LRT track center to platform edge	1.5 m (5.2 ft)
Minimum clearance from LRT track center to fence line	6.1 m (20 ft)
Minimum clearance from freight track center to fence line	4.6 m (15 ft)
Minimum platform length (2 car train)	43.1 m. (150 ft.)

secondary bus type. The articulated bus is 60 ft long, and single-sided with three low-level doors. The standard single unit bus is 35 ft long, and single sided with two low-level doors. The articulated and standard buses would board at a low saw tooth platform with six articulated positions and four standard single unit positions. A single unit bus could also use an articulated position.

PEDESTRIAN SAFETY

Passenger movement across LRT tracks will be controlled by signals similar to the rest of the Third Street system. Train speeds will be low coming into the terminal and LRT system operators are trained to move with pedestrians crossing or near the tracks. Pedestrian crossings are only permitted across commuter rail tracks with gates or grade separation for safety reasons because of the train speeds and tain stopping capabilities. The connection to Bayshore Station within Caltrain right of way will use a pedestrian overpass, and it is logical that the overpass would be continued for access to the LRT area.

CONCEPTUAL PLAN

The initial alternative track and bus platform layouts for the Southern Terminal were reduced to three alternatives that had the most potential. These were continued and developed further. At the completion of the initial conceptual work, one alternative was selected as a basis for an agreement and further development. Based on planned scheduled service and operating procedures, the turnaround has two loading positions on two sides at the platform that accommodate up to eight LRVs in two to four trains depending upon consist size. There is an additional five LRV queuing positions on the inbound side and return curve. On the inbound side there is one siding track for train breakdowns.

The developer has recommended shortening the 99.06- (325-ft) outbound platform to 74 m (242 ft), which reduced the platform length capacity from two two-car trains to one three-car train, and replacing the lost storage track length with a second storage track on the inbound platform side. This would shorten the track turnaround to match the shorter platform. Their second suggestion was to shorten the bus platform and to use a saw tooth edge layout, reducing the platform length capacity from eight buses to six buses, and shortening the bus turnaround to match the shorter platform.

There was concern about reducing the bus platform length at that time, since the extent of bus service anticipated was unknown and the requirement for the number and type of buses loading at the platform was still not determined. The types and levels of feeder service at the commuter rail Bayshore Station is being studied by the Caltrain and the bus service routes that would serve the Southern Terminal are being studied by Muni. As this work becomes available, the Southern Terminal layout can be refined to incorporate the recommendations.

The city of Brisbane has taken an interest in the project. Since the Southern Terminal is located within its boundary, it will be an active stakeholder for further development and will be providing its requirements and goals. The addition of another interested public entity at the site increases the number of issues, but it also increases the planning area and expands the joint development potential. The addition of a larger area should improve the joint development plan.

The growth of the Southern Terminal planning area means that the project is early in its development and could be revised substantially before it is built.

CONCEPTUAL PLAN REFINEMENT

One joint development goal is a terminal that is efficient and fits into new commercial and retail and even residential developments. The models would also work with other similar intermodal locations. The most efficient intermodal exchange between commuter trains, light rail, and buses is by a parallel arrangement of alignments. The most restrictive alignment is the commuter rail system, which is established in a straight alignment. The second most restrictive alignment is the light rail tracks, which typically have a minimum radius of approximately 75 ft. The Third most restrictive alignment is for buses, which typically have a minimum radius of 45 ft. Automobiles provide the fourth tier.

Conceptual alternatives have been developed based on a tight loop versus large loop track layout. Alternative 1 uses Sunnyvale Avenue as the entrance and exit corridor while Alternative 2 uses separate streets for an entrance and exit. Two options were developed for Alternative 1. The primary difference was the location of LRT and bus platforms in relation to the commuter rail platform. One option is to have separate debarking and boarding platforms and the second is to have one platform for both debarking and boarding.

ALTERNATIVE 1A

LRT inbound platform for debarking is on west side of terminal (Figure 3). The outbound platform for boarding is adjacent to the commuter rail southbound platform. The commuter rail and LRT outbound platform could be merged and at the same height or at different heights. In the figure the commuter rail and LRT outbound platforms are at different levels. The platform could be placed either on the left or right of the outbound track or on both sides. The bus platform is in the center of the terminal close to the LRT platforms. Drop off parking is along curbs adjacent to the LRT platforms that could be used by small vans, cabs and passenger cars. Pedestrian access between passenger vehicles, buses, and LRT/commuter rail is at the north and south ends of the terminal platforms.

The Alternate 1A terminal site requires an area approximately 232 ft by 400 ft for the LRT turnaround and platforms, bus turnaround, and platform and drop-off curb. Retail, commercial and residential land uses that are compatible with a transportation center could be placed along the west side of the terminal opposite the commuter rail station.

ALTERNATIVE 1B

The combined LRT inbound platform for debarking and LRT outbound platform is adjacent to the commuter rail southbound platform separated by an outbound track (Figure 4). The commuter rail and LRT platforms are at different heights. The platform is a center platform between two outbound tracks. There is a siding on the west side of the terminal for one two-car train. The bus

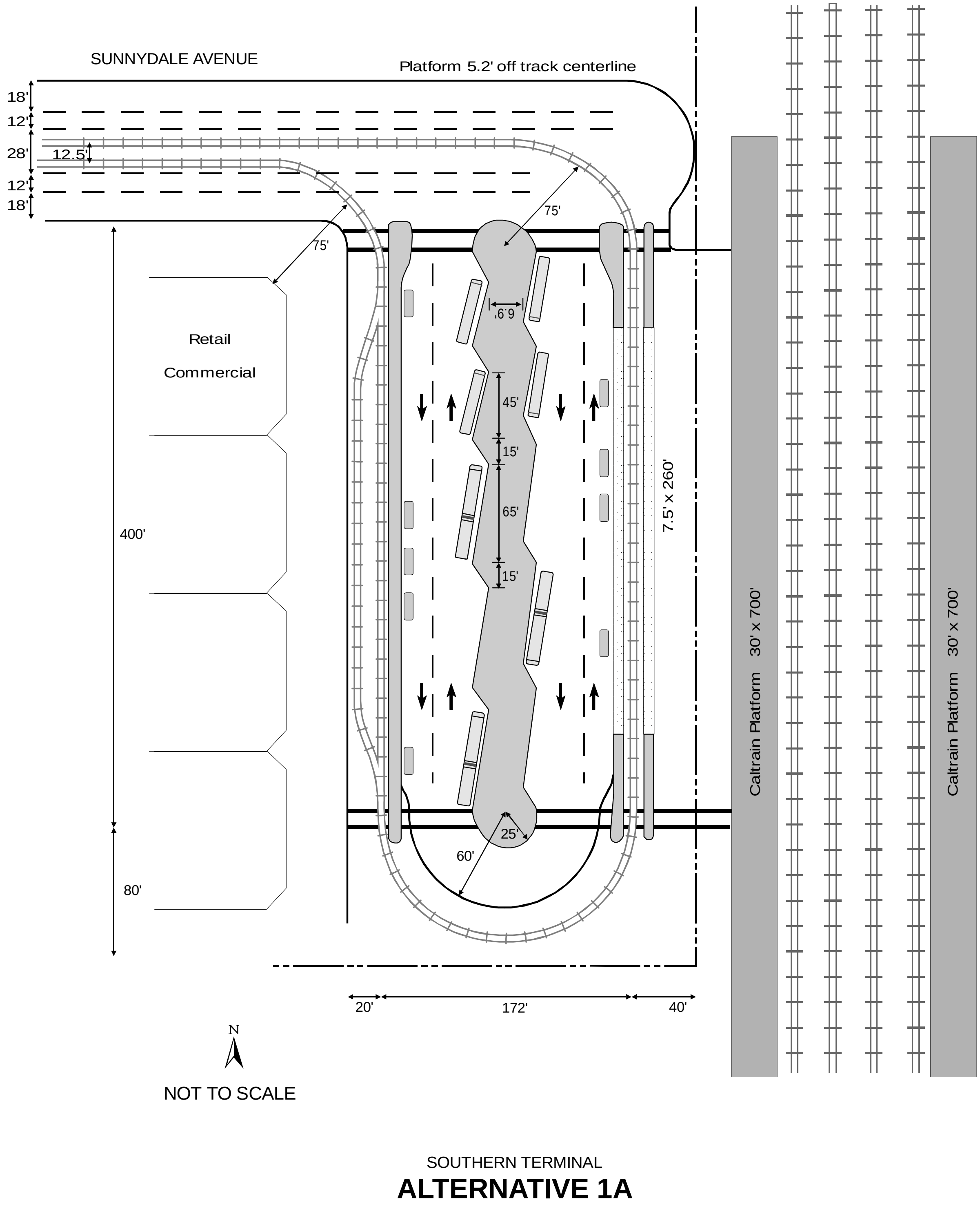


FIGURE 3 Alternative 1A.

platform is in the center of the terminal close to the LRT platform. One drop-off parking curb is adjacent to the LRT platform, and the second is along the siding on the west side of the terminal for small vans, cabs, and passenger cars. Pedestrian access between passenger vehicles, buses, and LRT/commuter rail is at the north and south ends of the terminal platforms.

The Alternate 1B terminal also requires an area approximately 232 ft by 400 ft for the LRT turnaround and platform, bus turnaround, and platform and drop off curb. Retail, commercial, and residential land uses that are compatible with a transportation center could be placed along the west side of the terminal opposite the commuter rail station.

ALTERNATIVE 2

Alternative 2 uses a large loop circling one block (Figure 5). The combined inbound/outbound platform for debarking and boarding is a center platform between two outbound tracks adjacent to the commuter rail southbound platform. One LRT track separates the platforms. The commuter rail and LRT platforms are at different heights. There are two approach tracks on the south side of the terminal. Each track for has space to hold one two-car train. The bus platform is in the center of the terminal close to the LRT platform. One drop-off parking curb is on the west side of the terminal for small vans, cabs, and passenger cars. Pedestrian access between passenger vehicles, buses, and LRT/commuter rail is at the north and south ends of the terminal platforms.

The Alternate 2 terminal site requires an area approximately 116 ft by 520 ft for the LRT turnaround and platform, bus turnaround, and platform and drop off curb. Retail, commercial, and residential land uses that are compatible with a transportation center could be placed along the west side of the terminal opposite the commuter rail station. Since this alternative requires less area, the additional space could be used for a plaza serving the passengers or as additional retail, commercial, and residential space.

Planning efforts are continuing. A conceptual layout and facility requirement analysis have defined land and access requirements for a successful operation. The next phase will depend upon the developer and city of Brisbane. The developers will establish their requirements at the terminal site based on market conditions and costs. The city of Brisbane, who is the public entity, will confirm the plan. Input from local residents, officials from the cities involved, Caltrain, and landowners will address land use in the Southern Terminal vicinity and station access for pedestrians and vehicles.

CONCLUSION

Redevelopment of the Third Street corridor is an important part of the general plan for San Francisco. The area is one of the few available for development. The Third Street corridor provides sites for large urban centers at either end and the center. Redevelopment of these sites will anchor infill development generated between the centers. The resulting developed corridor should provide a balanced mix of residential, commercial, and industrial land uses with a mix of buildings reflecting different periods. It will also provide public transportation access.

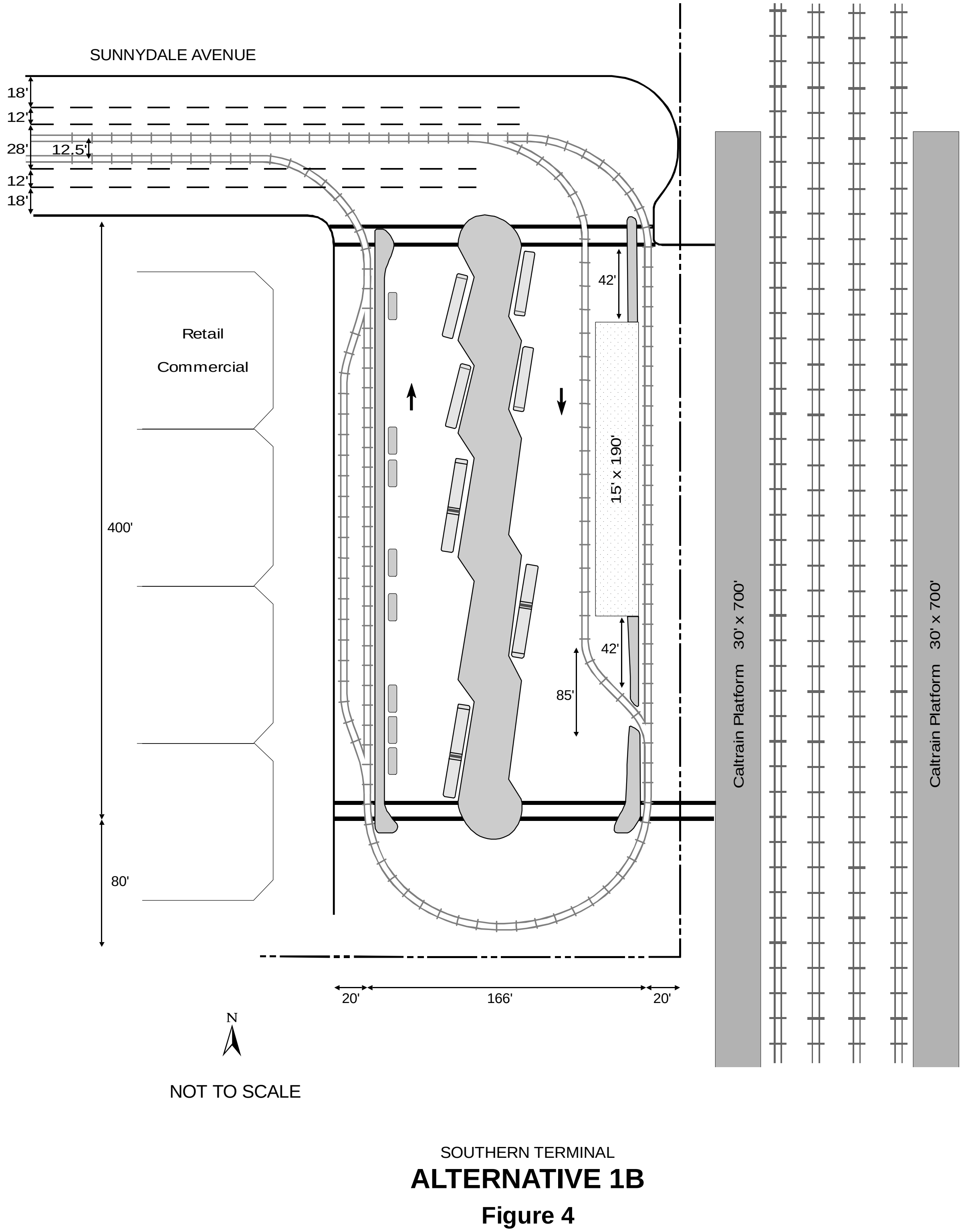
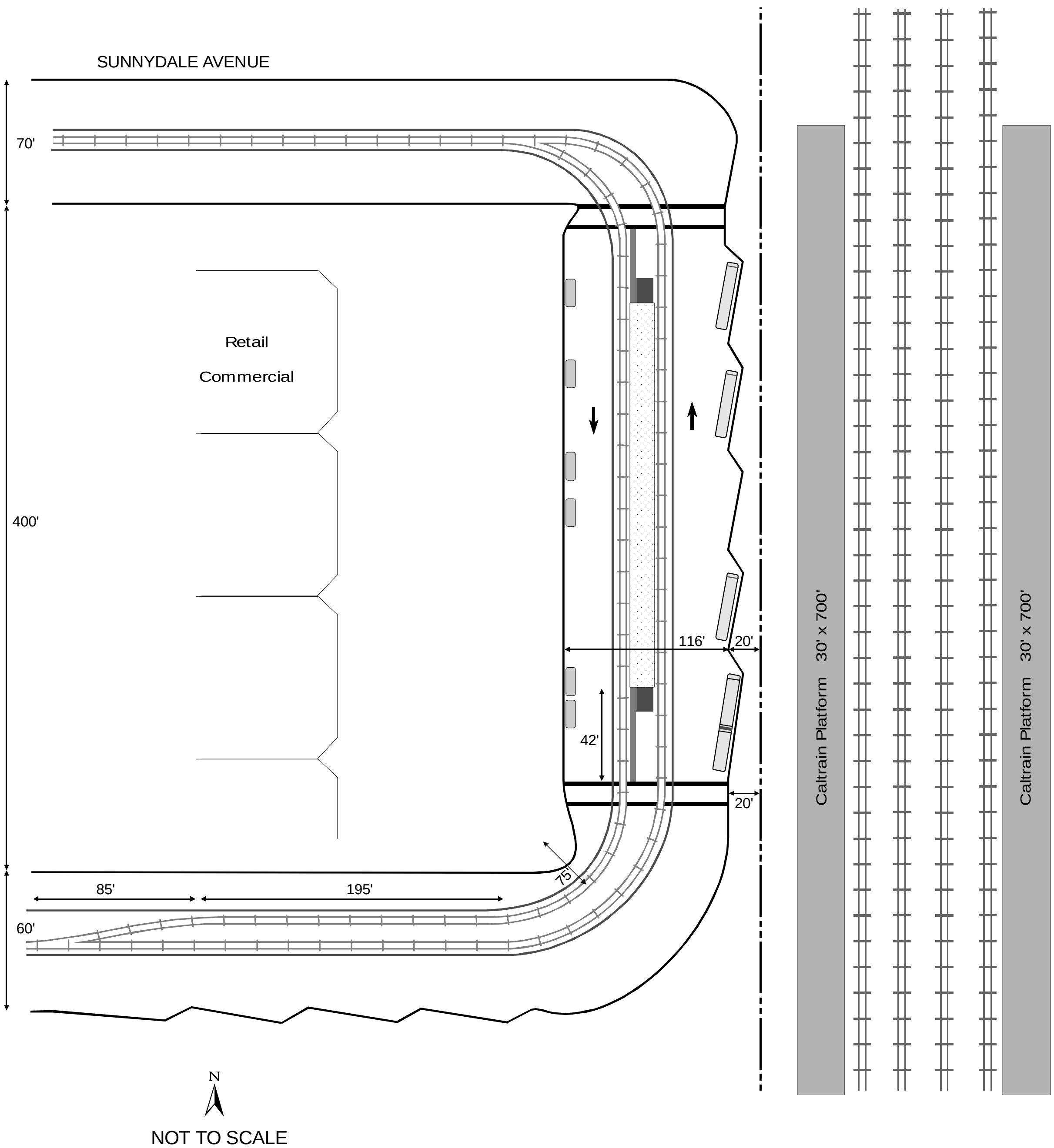


FIGURE 4 Alternative B.



SOUTHERN TERMINAL
ALTERNATIVE 2
Figure 5

FIGURE 5 Alternative 2.

The Southern Terminal is a key element of that plan. It provides a public transit center for the southern end. It works well with the Transit Village concept favored by San Francisco for development in its limits. It is important to the commercial development planned for the city of Brisbane in its limits. Building a major intermodal station at the southern terminus for the Third Street LRT will generate benefits to the stakeholders in the redevelopment, which include the owner/developer and the cities of San Francisco and Brisbane. It could become a major public transportation interchange. The Southern Terminal will provide residents and workers with a selection of public transportation services.

The Southern Terminal, as a joint development, could become a center and focus for the redevelopment based on good public transportation. The city and county of San Francisco could achieve a transit village that provides needed housing served by public transportation. The city of Brisbane could achieve a commercial center served by three different public transportation systems. It has potential to become an asset for the owner/developer, the transportation agencies and the cities, but it requires a collaborative effort between these parties to address and resolve the major issues early with their goal of a major intermodal public transportation facility that enhances the adjacent community.

Delineating an Integrated, Multifaceted Light Rail Corridor for Northeast Baltimore City

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Limited transit options not only impact individual residents but also relate to the economic development opportunities of a community. Growth patterns have separated people from the goods and services they require. During the past two decades, numerous metropolitan areas in the United States have embraced the concept of transit-oriented development (TOD) as a means to control and manage the negative environmental and social impacts of dispersed growth. TOD supports the creation of more concentrated mixed-use activity nodes connected by high-quality public transportation. The city of Baltimore, Maryland, is currently served by one heavy rail line (the Metro) and one light rail line (Central Light Rail Line), in addition to commuter rail service (MARC train) connecting to Washington, D.C. The combined Baltimore transit system now provides limited service to city residents; however, many socioeconomic groups are ill-served due to inadequate or nonexistent linkages to their neighborhoods. As Baltimore begins to expand its transit network, TOD principles are being explored as potential catalysts for neighborhood economic growth. This paper will present the findings of a 2-year research project that defined community-based criteria for decision-making for the provision of light rail into underserved areas of Baltimore, Maryland, and delineated key areas along the light rail corridor to promote economic development opportunities, increase visual character, and strengthen community linkages. The research defined the guiding principles and strategies, hence, the framework in which a light rail line that is a clean, quiet, fast, and efficient mode of urban transportation, and that is likely to attract a diverse ridership, can be developed in Baltimore.

INTRODUCTION

Baltimore, like many cities across the United States, is comprised of numerous neighborhoods, many of which are now aging and in transition. Some of these areas have aged gracefully and offer magnificent houses on streets lined with mature trees. Property values are high and this is reflected in the services that are provided to the residents. Little evidence of neglect is apparent. Contrasted to these areas are those once vibrant neighborhoods that are now experiencing a growing number of social, physical, and economic challenges. Housing vacancy rates are high and homeownership rates are declining. The condition of the effected housing stock is marginal. Limited open space and poor landscaping give the appearance of an overdeveloped, densely populated area. Scattered commercial development does little to stimulate economic growth. Services are scarce and resources are limited. Drug and gang activities are pervasive. In short, the quality of life for individuals and families is decreasing. Some areas within the northeast quadrant of Baltimore, Maryland, face such challenges as these. The question arises as to the best means for balancing these dynamics and for stimulating economic development and overall community revitalization.

Compounding these issues are the impacts of transportation networks that have favored automobile travel and separated residential areas from commercial and employment centers. In many instances, transportation decisions have fragmented neighborhoods leading to decay of the housing stock and overall residential environment. While transportation strategies are often seen as a way to alleviate broader social issues such as employment, housing, and social services, such planning processes have failed to create more livable and sustainable environments. Access is a key component in these strategies—people must be able to reach better paying jobs, higher quality and more affordable housing, and quality social services. Consideration is being given to expanding Baltimore City's transit network to provide service to the northeast section of the city. It will be important to determine the manner in which access can be enhanced or improved to positively impact the personal mobility of a wider range of citizens so that their choices are not limited by an underdeveloped transit system.

Limited transit options not only impact individual residents but also relate to the economic development opportunities of a community. Growth patterns have separated people from the goods and services they require. During the past two decades, transit-oriented development (TOD) concepts have been embraced as means to address the negative and often detrimental social and environmental externalities of dispersed growth, also known as "sprawl." TOD supports the creation of more concentrated mixed-use activity nodes connected by high-quality public transportation. While many jurisdictions have been receptive to TOD, others have not created the policy or regulatory framework to support it which have been shown to stimulate economic development and growth while reducing the negative environmental impacts of transportation and lower density development. As Baltimore begins to expand its transit network, TOD principles are being explored as potential catalysts for neighborhood economic growth.

This project was timely. Until 2001, the interest had been largely driven by business and citizen groups, the media, and universities (e.g., Citizen's Planning and Housing Association, Baltimore Metropolitan Council, and Morgan State University's National Transportation Center). Only recently has the Maryland Mass Transit Administration (2002) begun planning and holding public forums to promote a new regional mass transit system for the Baltimore metropolitan area. Federal initiatives have brought considerable attention to the need for systems that are more responsive to disadvantaged populations and that focus on improving the connection of such communities to local transit systems. The combined Baltimore transit system now provides limited service to city residents; however, many socioeconomic groups are ill-served due to inadequate or nonexistent linkages to their neighborhoods. The city of Baltimore is currently served by one heavy rail line (the Metro) and one light rail line (Central Light Rail line), in addition to a commuter rail service (MARC train) connecting to Washington, D.C. Compared with cities such as Boston and Washington, D.C., Baltimore's rail transit is underdeveloped.

This project continued the 2000-2001 research funded by the National Transportation Center (NTC) that addressed the possibility of expanding Baltimore's light rail network and improving its integration with the Metro line and bus system. Building upon the findings from the prior research, this project created tangible strategies for developing the northeast corridor in Baltimore City as a viable alternative for not only connecting residents and potential users with employment opportunities within the city, but also for creating employment and commercial centers within neighborhoods and communities along the transit line.

The northeast corridor of Baltimore City was identified in the 2000-2001 NTC research as the area that needed better public transportation options. After analyses of numerous corridor options a single corridor—the Harford Road Corridor—was selected for further investigation. The research applied the experience of other North American cities that have implemented (or are in the process of constructing) light rail systems (as studied in 2000-2001 NTC research). It also investigated the opportunities and constraints to TOD by looking at the existing zoning regulations and ordinances in Baltimore City as well as those of other cities with light rail systems. The focus of this research was to define the guiding principles and strategies, hence, the framework in which a light rail line that is a clean, quiet, fast, and efficient mode of urban transportation that is likely to attract a diverse ridership can be developed in Baltimore.

The study addressed the importance of corridor and station design as essential elements of "placemaking" that could help to promote transit-centered community development such as that proposed by Calthorpe (1993). Urban design guidelines and landscape and land use strategies were created to promote a well-designed system. An underlying outcome of this research was to enhance the personal mobility of a wider range of citizens in Baltimore City so that their employment choices are not limited by an underdeveloped transit system.

METHODOLOGY

This research included several types of data collection and manipulation. It relied most heavily on methodology that is accepted practice in the disciplines of urban planning and landscape architecture. Field surveys and site analyses were the primary method used for collecting data. These data were used to: (1) develop urban design principles for TOD based on a review of the literature; (2) develop appropriate landscape/land use strategies; and (3) design TODs or transportation hubs along the selected northeast corridor. Specific tasks include:

- Zoning ordinances and regulations of Baltimore City were evaluated for opportunities and barriers to TOD. As a point of reference, the zoning ordinances and regulations of cities (i.e., Portland, Oregon; Atlanta, Georgia; Denver, Colorado; and Toronto, Canada) studied in 2000-2001 NTC research were reviewed to determine the language that supports such development.
- Conventional or accepted principles of TOD (such as those defining or impacting density, location, and quality of growth) were also evaluated for their usefulness within the Harford Road corridor and for their consistency with Maryland's Smart Growth legislation. These principles were analyzed within a framework that includes elements of the Department of Transportation's strategic plan and within the confines of zoning regulations. A set of criteria and guiding principles were developed that can be used to evaluate alternatives, examine tradeoffs, and define priorities for line and hub locations.

Potential locations for TOD within the Harford Road light rail corridor were determined based on these guiding principles. Goals of the TOD selection process are to maximize opportunities for community-based economic development, improve the overall quality of life of the residents, enhance or improve the personal mobility of a wider range of citizens, and reduce sprawl.

During fall 2001, graduate landscape architecture students developed a Greenway Master Plan and site designs within the Herring Run watershed—which is the watershed for the Harford

Road corridor. As part of the project, the students designed “green” pedestrian and bicycle connections to the adjacent communities and the proposed Harford Road light rail system.

Comprehensive landscape and land use strategies based on TOD principles were developed for the Harford Road corridor. These strategies were based on the outcomes of the 2000-2001 NTC research, site assessments, and other factors. Schematic diagrams of alternative landscape and land use concepts were prepared. The concepts were incorporated into the TOD-based guiding principles. An appropriate strategy is suggested that should maximize development potential while serving a wide range of community members. The strategy also seeks to improve the overall quality of life of the residents in the northeast corridor. Hub design goals included promoting a greater sense of community in neighborhoods and commercial centers, creating multimodal transportation hubs that service the local communities, facilitating opportunities for economic prosperity for the surrounding communities, and providing greater transportation options. Additionally, areas needing streetscape improvements, enhancement projects, and stronger linkages to existing neighborhood assets were identified.

RESULTS

During the first year of this research effort, the project team explored the potential of the northeast quadrant for expansion of Baltimore’s transit system. Six alternative routes were examined for the development potential as a more community-based addition to the existing system. Of these alternative routes, four were determined to fit the criteria that had been developed for analysis. Several factors were used to evaluate the segments of the alternative routes against the criteria for existing conditions and feasibility/impact. Specific factors addressed community profile, commercial/business districts, and transportation issues. One route was determined to score the highest in the evaluation. It is this route, the one that connects to the existing Metro station near the Johns Hopkins University Medical Center and continues to Baltimore County via Harford Road, which has been used for the design exercises in the second year research project. The selection of this alternative route coincides with the rail line corridor proposed by the Maryland Transit Administration (MTA). The proposed Green Line will nearly follow the corridor that was selected by this project team. The difference in the two corridors is that our route turns east to Harford Road (considered to be more community oriented) unlike the MTA route that travels the entire length of Hillen/Perring Parkway. The demographic characteristics of the project corridor were a significant factor in the selection of this route. The selected corridor was deemed to serve a broader range of residents in the northeast corridor.

Promoting Healthier Communities Through Transit-Oriented Development

The dilemma of how to handle the growing problems associated with automobile traffic is being experienced across the country, especially in the Baltimore–Washington metropolitan area, and leaving officials searching for alternatives. A primary focus of this activity is the best manner in which communities can become healthy and more livable without the dependency on car travel. The movement towards creating healthier, more livable communities has been spearheaded by a number of federal agencies. The FTA has been at the forefront of these efforts. With the release of their document entitled, “Building Livable Communities through Transit,” FTA presented strategies for improving personal mobility and hence the quality of life in communities, among other issues. Overall, through its initiatives, FTA is demonstrating "ways to improve the link between transit and communities." The goal is to encourage and promote communities that are less auto-dependent. TOD is a focal point of these initiatives.

The national attention that TOD has received has come from transportation planners and others who are concerned with the negative environmental and social impacts of dispersed growth and subsequent automobile usage and dependency. In fact, during the past two decades, numerous metropolitan areas in the United States have embraced the concept of TOD in an attempt to control and manage the negative environmental and social impacts of dispersed growth patterns (Porter, 1997). It is suggested that TOD will increase pedestrian and transit trip taking while also reducing the number and length of automobile trips. It will contribute to the livability that some feel is lacking in modern suburban development (Calthorpe, 1993).

Phillips and Edwards (2001) reported that TOD calls for the creation of denser, mixed-use activity nodes connected by high-quality public transportation. Proponents believe that a combination of design features will encourage travel mode shifts that result in reduced area-wide traffic congestion and improved air quality. These features include improved street connectivity, public amenities, and a concentration of residences and jobs in proximity to transit stations and commercial businesses. As an additional benefit, the enhanced pedestrian environment will increase casual encounters among neighbors that can contribute to a sense of community. These efforts typically begin with the implementation of major new mass transit investments—often light rail systems that are designed to link central city cores, suburban downtown, and other major activity centers. TOD is possible without new transit, but most metropolitan areas choose to make the transit investment. Bernick and Cervero (1996) suggest that for TOD to succeed a "transit metropolis" must exist, meaning, a sufficient number of TODs having balanced or special uses that are connected and allow for efficient rail travel with bidirectional travel flows.

TOD is derived from the basic concepts of new urbanism: These concepts encourage the usage of several design elements including defined edges; circulation systems functional for pedestrians; public space on prime ground—an important early consideration rather than afterthought made up of leftovers; hierarchy of land uses (cultural centers, commercial, business, residential); mixed land use for working, shopping, learning, worshipping, and playing; and a priority to public space and appropriate building location and a balance between affordable housing and jobs (Farnsworth, 1998). While most proponents of TOD have focused on undeveloped suburban areas for testing and implementing TOD principles, the implications for built-up urban areas are almost untapped.

Applying TOD in Inner-City Neighborhoods

Howland and Dunphy (1996) looked at ways in which TOD can be implemented in inner city neighborhoods. Their study found that TOD principles can be utilized when they play on the strengths of individual communities. This can be achieved by translating TOD principles into the design of transit stations as focal points of their communities, integrating them into community fabric, paying careful attention to pedestrian links, and emphasizing safety. They indicated that, subsequently, transit stations can make a neighborhood look better, enhance the labor force advantages of the area, and support the variety and density of community activities by providing a focal point and broadening the local market area. Howland and Dunphy (1996) state that many TOD principles are consistent with inner-city goals for sustainability. These include encouraging viable neighborhoods, diversity of land uses, mixed-use development, jobs/housing balance, around-the-clock activities for families and youth, and pedestrian-friendly design.

TOD Success

Successful residential projects that use TOD principles are heavily influenced by pre-existing land uses, the alignment of a rail line, and the placement of stations. If local conditions and goals—strong market demand, low-cost available land at attractive sites, and supportive land use policies—are consistent with TOD then rapid development can occur. Thus, TOD is successful when it is achieved with other local development goals. Challenges, however, exist for integrating TOD into existing areas. Existing land use patterns near rail stations can cause limitations leading most importantly to difficulties in assembling large parcels of land pose other obstacles. Municipalities need to have the tools for land assembly through redevelopment zones. Also, available undeveloped land is necessary for TOD.

Although many communities support the principles of TOD, many others fight higher-density housing, especially multifamily dwellings. Surveys show that 95% of Americans prefer single-family homes to multifamily dwellings (Cervero and Bosselmann, 1998). Many people associate noise, overcrowding, urban blight, and stress with high-density areas. This also suggests that negative perceptions of residents of multifamily housing still persist in the United States. It is not clear whether greater value is placed on homeownership and privacy gained through single-family housing that is typical in the United States.

Zoning for TOD

Achieving variety and balance of uses within the TOD is important. The zoning ordinance is the best vehicle to promote diversity of uses and activities as well as design character. Jeer (1994) found that allowable uses and density are necessary to support TOD. TOD areas outside the central business district (CBD) need zoning ordinances that allow for an “urban oasis” around the transit station. Such ordinances must do the following:

- Include a substantial residential component in densities far higher than the average in the community;
- Relax setback and parking requirements;
- Provide density bonuses for public and private amenities; and
- Adopt a site plan and development standards than are more typical for urban center.

Jeer (1994) also suggested that alternative zoning techniques are necessary to achieve TOD. Jeer indicated that an ad hoc approach works better in situations where the TOD plan is parcel-specific in its recommendations by making almost all development proposals within the TOD area adhere to an overlay district (as in Portland) or go through a special exception process specified in the overlay district (as in Fairfax County, Virginia). Additionally, the development of a more generic set of standards and special zoning designations that can be applied through the rezoning process of all nonresidential and mixed-use proposals in the TOD area is important.

Some municipalities have adopted what amounts to multiple codes, with specific provisions for traditional neighborhood development, TODs, and planned unit developments that differ from the general codes (Farnsworth, 1998). It is evident that because many zoning ordinances are based on early 20th century legislation that encouraged the separation of uses, municipalities must embark upon an evaluation of not only the land use regulations but also the development and design review process to reveal the opportunities and barriers for TOD. In many areas current zoning ordinances do not support the pedestrian focused principles necessary for such development.

Baltimore City's Current Zoning Ordinance

Baltimore City is not unlike many municipalities that have antiquated zoning regulations. It's zoning ordinance was created in 1971 after a comprehensive plan was approved. The ordinance has been amended several times since then but requires a major overhaul to support new theories in community development as well as market demand for neighborhood uses.

A review of the zoning ordinances for other cities indicated that TOD is best accommodated when zoning ordinances permit flexibility in uses. TOD proponents suggest that, in order to be successful, TOD must offer a mix of residential and commercial uses. Lessons learned from places like Atlanta, which created districts that promote a mixture of residential and commercial uses, are very important. Atlanta's new Mixed Residential Commercial district is intended to protect and rebuild the commercial districts by "establishing appropriately designed and scaled commercial uses mixed with significant residential uses in a pedestrian-friendly manner."

Review of zoning ordinances and comprehensive plans of other cities that are targeting more pedestrian-friendly development over automobile reliant places shows that a linkage between these two documents is very important. The comprehensive plan provides a vision for future growth of an area while the zoning ordinance indicates how that growth is to be developed through specific bulk regulations.

While these issues are important it must be noted that a combination of factors, inclusion of language in the zoning ordinance to support TOD and public incentives and subsidies to encourage such development, are necessary to create pedestrian-friendly, automobile-reduced environments. Baltimore City is beginning the necessary next step of evaluating and revising its zoning regulations with the expected outcome of promoting such environments.

Potential of TOD Development Along the Proposed Corridor (Analysis of Inventory)

Analysis of the potential of TOD within the study corridor was important for this research effort. Two segments were considered:

- Terminal Hub (Harford at Joppa) Going South to the Hub of Harford at Moravia/Cold Spring From the terminal hub (Harford at Joppa) going south to the hub of Harford at Moravia/Cold Spring, most of the principles of TOD can be implemented. Creating high-density residential development cannot be a short-term goal in this area of stable homeownership. However, the segment of the hub has existing businesses. Hence, the foundation of commercial development within walking distance of the hub is already present. The businesses that currently thrive along Harford from Joppa to Moravia/Cold Spring meet the needs of local residents. Thus, it is presumed that simply changing the streetscape and facades would attract more consumers living outside the local neighborhood who use the light rail to travel to work and urban recreation. TOD is more attainable along this segment because there would be less community opposition since high-density residential development would not be a major goal.

- The Corridor South of Morgan State University The area south of Morgan State University presents opportunities to implement TOD principles at an urban scale. Most of the route is residential with some commercial and community links." This area is generally plagued by poor conditions of the housing stock and high vacancy rates (40%). Despite these indicators of decline, a community organization is involved in revitalization efforts. Therefore, there is a potential market and possible champion for TOD in this area. The current revitalization goals as well as the need for employment opportunities increase the chances of TOD implementation. There are defined edges through neighborhood boundaries recognized by the local government. Many of these boundaries have only a five-block radius; they are not as extensive as the neighborhood boundaries in Northeast Baltimore.

Public Policies to Support TOD

Smart Growth laws in Maryland pursue two principal goals: channeling growth into already developed areas and preserving rural land. The first goal addresses currently developed areas through the following initiatives:

- Smart Growth Areas Act, which creates "priority funding areas," i.e., zones in which development may qualify for state funds.
- The state's cities and towns are automatic priority funding areas.
- Every county government has designated additional areas that meet specific requirements for use, water and sewer service, and residential density.
- Maryland Building Rehabilitation Code.
- The legislature also passed a bill requiring the Department of Planning to draft optional "smart codes" for infill and mixed-use developments.
- Additional new layers in the smart growth legislation include revisions in the brownfields redevelopment program.

In terms of preserving rural land, to date the Rural Legacy program has designated 47,000 acres in 20 of Maryland's 23 counties for protection. The governor's Special Assistant for Smart Growth John Frece (personal communication, February 12, 2002) states that the state's 15-year goal is to preserve 250,000 acres. The Community Legacy program is an urban alternative to this rural focused initiative.

In addition to its historic town centers, Maryland has viable models for smart growth in the several new urbanist projects that predate the smart growth legislation. The greenfield projects, Kentlands, Lakelands, and King Farm, have shown compact neighborhoods to be both aesthetically and financially successful. Hope VI developments such as Pleasant View Gardens and The Terraces in Baltimore set new standards for infill and mixed-income housing. Of the new generation of smart growth projects, the largest and most prominent is the new mixed-use center for Downtown Silver Spring just north of the Washington, D.C., city limits. In its latest report on sprawl, the Sierra Club featured this project as the state's foremost model for combining new employment facilities and residential housing with rehabilitation of historic structures and links to transit. Great hopes are also pinned on Owings Mills Town Center, a transit-oriented, main street development that would replace 46 acres of parking lot adjacent to a Metro line stop in Baltimore County.

TOD Design Guidelines

Calthorpe (1993) recommends that TODs devote at least 20% of the land area to housing. That criterion is also specified in the city of San Diego's (1992) transit-oriented guidelines. According to Calthorpe average residential densities within TODs should be at least 10 dwelling units per acre for neighborhood TODs and at least 15 dwelling units per acre for more centrally located, or urban, TODs. Calthorpe also suggests minimum floor area ratios (FARs) of 0.3 for retail with surface parking and 0.35 for offices without structured parking, but he encourages higher FARs for both types of development. Ways of making higher density projects acceptable include:

- Extensive landscaping;
- Adding parks, civic spaces, and small consumer services in neighborhoods;
- Varying building heights to break the monotony of structures;
- Detailing roof lines and varying building materials;
- Design mid-rise buildings on podiums with tuck-under;
- Below-grade parking; and
- Replacing row apartments connected by exterior breezeways with eight-plex buildings (two-story stacked flats with four ground-level patios and second-level decks).

Neighborhoods oriented toward transit should at a minimum have a mixture of land uses, a commercial center near the train station, prominent public spaces, and a pleasant walking environment (Calthorpe, 1993; Katz, 1993; Audirac and Shermyen, 1994). Cervero (1998) recommends one off-street parking space per unit at transit-base complexes instead of the two normally enforced in the suburbs. Crane contends that the grid pattern—proposed by neotraditional planners and transit-oriented developers—does not necessarily promote pedestrian travel over auto travel. Other community layouts need to be examined.

Herring Run Greenway Master Plan

During fall 2001, graduate Landscape Architecture students developed a Greenway Master Plan for the Herring Run Watershed, which is the watershed for the Harford Road Corridor. Students then designed individual sites within the greenway. As part of their individual site designs, students were to develop "green" pedestrian and bicycle connections to adjacent communities, schools and the proposed Harford Road light rail system.

The light rail station will include a major hub location at Argonne and Hillen Drive where the future Morgan State Hospitality and Hotel Management Complex will be located. To become linked with the greenway, Argonne Drive is landscaped with native species. Paving along this stretch of sidewalk is different from the standard sidewalk to indicate that you are transitioning to a special place—the Herring Run Greenway. Also informational and directional signage is included in this design.

Elsewhere on the proposed line is a stop connection at Argonne and Harford Road to the Herring Run Greenway. Here, the greenway is immediately below the transit stop (under the bridge). The site design includes Americans with Disabilities Act accessibility from street grade to the greenway. Again, native plantings, paving, and signage are proposed to make the connection between the transit stop and the greenway “readable.”

Transportation Hub and Streetscape Designs

Four graduate Landscape Architecture students were hired as research and design assistants to work on this project. As part of the Year 1 research effort, the students completed the inventories and analyses of the designated routes within the northeast corridor. At the end of Year 1, a selection was made of the preferred route that was deemed the route that best promoted community well being, environmental quality, and economic prosperity for all socioeconomic and racial/cultural groups. The Harford Road route was determined to be the preferred alternative. It combines most of the community alternative segments, but is not quite as circuitous and does not adversely impact any suburban neighborhoods.

The great and distinct advantages for using the Harford Road route as a light rail corridor is the ability of this route to serve the numerous intact and thriving neighborhoods and businesses bordering Harford Road. The addition of an efficient transit system along this route provides residents with increased opportunities for employment, services and shopping, and greater access to churches, schools, and cultural centers. The light rail route also benefits those dependent upon mass transit—the elderly, young, and low- to moderate-income residents—by providing them with a cleaner, safer, and more efficient mode of transportation. The neighborhood hubs provide for these community advantages. Based on previous research and experience, the local economy should show a marked improvement with the addition of the new light rail system.

The proposed light rail corridor route has a total of eight station locations with four of these locations being major intermodal hubs. The route begins at the existing Johns Hopkins Metro Station and continues north to terminate temporarily with a loop at the intersection of Harford and Joppa Roads in Carney (the terminus of the earlier streetcar line). The four proposed major intermodal hubs located along this route are: the existing Metro connection at Johns Hopkins Hospital on Broadway; the intersection of Harford Road, North Avenue, and Broadway; the intersection of Hillen Road and Argonne Drive; and the terminus at Harford and Joppa roads in Carney. Four proposed smaller neighborhood hubs also occur along the route and are as follows: Broadway and Gay Street, Harford at Moravia/Cold Spring, Harford at Hamilton, and Harford at Taylor.

Description of Hub Locations

The origin of the new northeast light rail corridor connects with the Metro at the Metro station at Johns Hopkins Hospital. This is the last stop for the current Metro line that runs between Owings Mills and Johns Hopkins.

The next major hub stop is Courthouse Plaza at the intersection of Harford Road, Broadway, and North Avenue. This hub location is to serve as a major connector for the existing east–west MTA bus line. Light rail, buses, pedestrians, and automobiles come together here thus providing a multitude of transit options. There is an existing District Court at the location; the proposed design includes the District Court building as well as the addition of new retail, office space, park space, and parking garages. The third major hub location is at Morgan State

University located at the corner of Hillen Road and Argonne Drive. This hub is to serve the University and the surrounding Northwood community. The location of the hub is at the Northwood Shopping Center site that is slated for redevelopment as Morgan State University's Hospitality and Hotel Management School and University Conference Center. This location would become an activity zone for Morgan students and employees, neighborhood residents, and conference attendees.

The fourth major hub and temporary terminus stop is the Carney Hub located at the corner of Harford and Joppa roads at Carney Town Center. The transportation hub and shopping center support and economically strengthen each other. The Carney Hub at some future time is proposed to serve as a major hub in a larger regional transportation system. The light rail travels in a loop through the Carney Town Center. Buses enter from Joppa Road before taking the ramp underground into Carney Town Center. Automobiles may use the proposed parking garages for shopping or for commuting via light rail or bus to other locations.

The four proposed neighborhood hubs are to serve primarily the surrounding communities and local business and as local transit transfer points.

Hub Designs

Individual hub designs and streetscape improvements were documented in the final project report. When approaching the design of each chosen hub location, several opportunities or constraints arose. We researched, critiqued, and borrowed from transit hub designs from around the world in order to create a thriving design for each of the hub stops. The idea of using themes as an approach to the design process seemed like a logical choice. Many major cities use the idea of local or regional cultural and natural assets as generators of design ideas. For example, Portland, Oregon, highlights its local ecological systems by designing transit hubs that celebrate local wildlife. Portland has also successfully utilized several distinct themes for transit hub stops.

One stop uses punctuation marks as a design theme—the shape of a question mark is used for a bench design.

We decided that it was pertinent that each light rail station be uniquely designed in order to create connections between the surrounding neighborhoods and the new rail line. We chose two main design concepts—Games and Industry—and focused on creating transit hubs that relate to them. Games are a universal pastime, while the industrial theme pertains specifically to Baltimore's history as a city. These two themes were delineated and expanded upon in the detailed hub and streetscape designs.

Baltimore's Industrial History: Revealing the Makings of a City and a People Baltimore's industrial heritage includes such histories as the railroad industry, iron and steel works, brick manufacturing, metal working, and the ship building industry. Baltimore was and continues to be one of the most important ports in America. For over 150 years, Baltimore's industries have provided livelihoods for millions of people and have helped to shape the physical setting of Baltimore as well as the people who have built and inherited this great industrial city.

The design theme that focuses on Baltimore's industrial heritage is a powerful way to enable people to come in touch with the industrial past of their city. Baltimore has historically been a hard working blue collar city. The people and the products that made Baltimore what it is today are celebrated in the design of several light rail hub locations.

Additional local industrial histories are celebrated in the design of other light rail hubs. Baltimore’s brick manufacturing industry is brought to light with the design of a light rail hub utilizing bricks manufactured here in Baltimore. The iron and steel work products that dominated Baltimore’s industry are revealed by utilizing industrial architectural forms in the design of canopies and benching at a light rail hub.

Games Theme A games theme is one option as a design approach to hub locations along Harford Road. This design theme is centered around games and is intended to bring a fun and exciting atmosphere to each hub location. Sub-themes include: bowling, checkers, chess, soccer, baseball, football, and basketball. The design of the paving, lighting, and signage incorporates images of popular games and sports teams. This creates not only an exciting design element for each hub location, but also helps to give each hub an individual and identifiable character. Each light rail stop becomes distinctly memorable to each transit user and the surrounding community.

There are interactive games at each stop such as an oversized checkerboard to play on as you wait for the train to arrive. Here, paving patterns resemble the design of a checkerboard. At other hubs, the lighting design is in the shape of baseballs or basketballs. Sports figures and Baltimore teams are represented at specific hub locations. Statues and plaques of famous sports figures are displayed in order to learn more about their accomplishments. There is a Baltimore Raven’s stop and a Baltimore Orioles stop. The colors of these hub locations reflect the sports teams’ jersey colors and are incorporated into new building façade designs, paving pattern designs, and the design of benches and lighting. Even local little league baseball, football, soccer, and basketball teams are represented at specific hub locations giving the neighborhood children and parents in the local area something to identify with and become excited about.

A games theme brings a unique and memorable identity to the light rail hubs and transit stops and provides endless design possibilities along this new transit route. Because we were focusing on community-based design, it was important to choose a route that has existing neighborhoods working side by side with businesses. Providing for the community’s needs as well as advantages for local business will be a direct outcome of the new Northeast Light Rail Corridor. Neighborhoods need not be underserved by transit needs as they currently are in the Baltimore region. The newly designed Northeast Light Rail Corridor will become a vibrant asset to the city of Baltimore.

CONCLUSIONS

The purpose of the research was to evaluate ways that the existing Baltimore City Metro/light rail system could be improved to be more integrated and to promote community well being, environmental quality, and economic prosperity for all socioeconomic and racial and cultural groups. The research was approached not from the perspective of the availability or feasibility of one location to another in terms of cost and efficiency. Rather, the selection of potential routes was based on the ability of the network to impact a greater number and more diverse socioeconomic groups. The research placed the needs of the community first in hopes of providing better access to jobs and economic opportunities. The objectives were to:

- Evaluate the feasibility of surface (light rail) routes in Baltimore City that would connect existing Metro and light rail lines;

- Analyze neighborhood characteristics (i.e., physical, social, economic) and factors that are associated with the location of the existing transit system; and
- Plan and design a proposed light rail line corridor as a community based model for developing future transit corridors within Baltimore City and elsewhere.

Early in the planning process, the northeast corridor of Baltimore City was selected for study in developing the community-based model for a proposed additional light rail line because such a line would (1) complement the existing northwest light rail line, (2) tie into the terminus of the existing Metro line in Southeast Baltimore, and (3) connect to the newly proposed downtown Baltimore inner loop light rail line that will connect with the existing light rail and Metro lines and the MARC train at Penn Station. If this community-based model were adopted by MTA, any future corridor selections would, by design, be considered components of an integrated, multimodal system for the city. Enhanced system connectivity is an integral component of our community-based approach.

Comparison of Two Planning Processes

Currently the MTA is looking at ways to expand the transit system. According to MTA, the Baltimore Region Rail System Plan Advisory Committee unanimously adopted their recommended rail system plan in March 2002. If completed over the next 20 to 40 years, the plan would add 63 mi of rail in the Baltimore metropolitan area. In recommending priority projects to the MTA, the committee chose an extension of the Green Line between Johns Hopkins Hospital and Morgan State University. A station is proposed at Northwood Shopping Center at Hillen Road and Argonne Drive, within the project area. The green line extension is proposed to be underground until at least North Avenue and then become an above ground line thereafter. MTA selected several priority projects on which to begin planning and environmental review in the Summer 2002. The site at the Northwood Shopping Center was chosen as one of the priority sites.

The following section compares the approach used by MTA to make these recommendations and the process used here for this research project.

MTA Plan

The MTA states that there is a need for a Baltimore Regional Rail System Plan that is a high-quality, high-capacity passenger rail services to multiple destinations throughout the region. The MTA recognizes the existing Metro and light rail lines do not directly connect to one another and they do not form a functional mass transit system. The framework of MTA's new plan will allow the region's residents and leaders to see a long-term vision of how rail lines can work together to serve all of life's activities. The major goals of the plan are to stimulate Smart Growth and economic development in targeted areas throughout the region (MTA, 2002).

The MTA (2002) lists the 10 guiding principles developed by the MTA advisory committee that they will consider when reviewing the draft plan. The Baltimore Region Rail System Plan should:

- Serve corridors with high concentrations of population;
- Serve major employment centers;

- Serve traffic-congested corridors;
- Serve major activity centers such as hospitals, universities, shopping centers, tourist attractions and entertainment centers;
- Support both existing land use and major targeted growth areas;
- Meet the needs of the transit dependent population, and provide benefits to low income and minority communities;
- Optimize the utilization of the existing transit system;
- Be seamless for the transit rider; and
- Provide a transit trip that is as competitive as possible with the automobile with regard to speed and reliability.

Beyond these principles, the MTA proposes to improve the quality of service and expand transit into new markets as part of the Maryland comprehensive transit plan.

Phillips-Edwards Plan

The MTA's list of 10 guiding principles agrees with elements in our planning process. However, our suggested guidelines go much further than MTA's. While we concur that a regional system is vital to the transit health of the Baltimore region, the neighborhood communities along any proposed route are more important, in our view, to the success of an integrated and fully functioning transit system. Our plan proposes that priority be given to serving these neighborhood communities versus regional destinations (i.e., White Marsh Shopping Center, Baltimore-Washington International Airport, Martin State Airport, Columbia Town Center, Arundel Mills Mall). We base this assessment on the fact that Baltimore City is the heart and soul of the metropolitan region and it needs such a community-based system to become once again a truly great neighborhood-based urban complex.

A metro/heavy rail system by its design constraints can only stop at very densely populated areas—whether they are residential, employment or activity-based. Frequent stops are the exception versus the rule with heavy rail. Typically, heavy rail runs underground for most of a route and consequently this does allow for visual and physical connections by riders to commercial districts, residential life, green spaces, etc., along the route. If the rail does surface, the traditional type of track system used often isolates or bisects the corridor and is thus viewed as a community divider.

The intent of proposing the Harford Road Alternative and then designing transit hubs along the line is because it is to serve as a model for selecting and designing potential light rail line corridors within a larger integrated, community-based system. In addition to the MTA principles, the Harford Road Alternative also offers these benefits:

- Enhance and create community character;
- Build upon the intact commercial districts along the route;
- Reach locally underserved low-to-moderate income populations;
- Serve large numbers of existing community-based social and cultural centers, churches, schools, and neighborhood level population centers;
- Promote pedestrian activities along the route, particularly at hub locations;
- Increase and augment commercial development along the route;
- Provide better access to jobs within the city; and

- Minimize physical environmental impacts.

It may be that the optimal solution is a combined regional transit heavy rail network and an interlinking light rail/trolley and bus system. However, the big question we asked ourselves during Year 1: if only a single approach is financially feasible, is it better to build a regional transit system or a local system that serves predominantly Baltimore City residents? We concluded that Baltimore City is where there is the most need—where most persons dependent upon transit reside, where most low-income persons reside, where long-standing institutional and cultural centers exist, where transit was an established way of life until the mid-1950s, where the supporting commercial centers are already in place, where populations of suitable density already reside, etc. Whereas, most people living beyond the beltway have purposefully selected the automobile as their transportation mode of choice. Even in the regional model, transit users would largely enter the rail system via a park-and-ride lot. Residential densities outside the city are not currently conducive to rail transit and walking distances are too great but for a very few potential riders.

The concept of TOD arose to respond to growth outside central city to make a transportation system a viable option. In the TOD model, development follows transit planning or optimally, simultaneously. In fact, outside the CBD, Baltimore City neighborhoods developed in this manner through the expansion of the streetcar system. For the city's current composition, the TOD process is reversed—Baltimore already has the developed infrastructure (its 66 distinct neighborhoods)—what is missing is an effective community-based transit system! And that is what we have proposed here.

RECOMMENDATIONS

This research developed an alternative transportation model that makes community sustainability the focus of the transportation planning process versus availability or feasibility of one location or another in terms of cost and engineering efficiency. Under this model, the overall goal of any transportation system should be to develop an integrated, multimodal transportation system that serves neighboring communities and thus more diverse socioeconomic groups and that is also efficient (level of service), safe, and affordable for all. To achieve this comprehensive goal, the following objectives must be addressed. Baltimore, and cities like it, should plan and design a transit system that:

- Enhances and creates community character.
- Builds upon existing commercial districts along routes.
- Serves first those dependent upon public transit.
- Extends transit to locally underserved low to moderate income populations.
- Provides linkages to existing community-based social and cultural centers, churches, schools, and neighborhood level population centers.
- Promotes pedestrian activities along routes, particularly at hub locations.
- Increases and augments commercial development along route segments.
- Creates for more green space along route segments.
- Provides better access to jobs within the City boundaries.
- Minimizes physical environmental impacts.

- Ensures safety and welfare of riders and non-riders.

While rapid transit or TOD alone is not necessarily the solution to recent challenges to urban life in Baltimore City, the implementation of these objectives may lead to promoting better quality of life for the citizens and visitors to the city.

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"Limited LRT Connections" with the General Railroad System
How Small-Scale, Shared-Use Arrangements Advance U.S. Joint Operations Practices

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A principal conclusion of *TCRP Report 52* is that there is potential in North America for joint light rail–railroad operations, but under limited and controlled circumstances. The question of where these circumstances could exist in the United States that would be similar to Europe and Japan remains difficult to answer. It is argued that U.S. light rail transit agencies, by obtaining approvals and abilities to design, construct, operate, and maintain light rail–freight rail shared-use arrangements on small scales, are North America's counterpart to Europe's extended evolution toward mixed traffic on shared track.

San Francisco's new Third Street light rail extension illustrates this trend. The median running alignment crosses two lightly used freight industry leads. Unique operating, safety, and cost challenges exist at each rail-to-rail crossing. Shared-use arrangements were possible because of low freight volumes and a 3-year negotiated willingness by the Class I railroad to lease the two primary crossings in exchange for maintenance of the freight track and shared liability. The project outcome is a blend of railroad and transit design and operations. This outcome is possible because the transit agency expanded its capability to manage shared assets with both railroad and transit regulatory standards. By building expertise to manage assets shared by the general railroad system, light rail agencies are incrementally advancing U.S. capability to implement more complex shared systems at a future stage.

INTRODUCTION

TCRP Report 52 examines European and Japanese joint operations where incremental integration has achieved acceptable crash avoidance systems for short headway mixed traffic operations. With safety satisfied, integrated controls, common signal systems, regulatory rules, and operating practices are now achieving investments economies with enhanced service opportunities for both modes.

Few U.S. transit agencies are pursuing the major step of joint operations on shared track during normal service hours. This paper explores where several light rail transit (LRT) agencies have undertaken an elementary integration of freight railroad and light rail controls, regulatory rules, and operating practices that is advancing the capability to consider joint operations in the future. This national trend is comprised of both new lines and light rail extensions that must go through, around, or share freight railroad corridors and infrastructure in order for the transit project to go forward.

The core of the thesis is that small scale shared-use programs, such as San Francisco's rail-to-rail crossings, raise substantial portions of the regulatory and technical challenges found in larger, shared track projects with the exception of vehicle compatibility. Vehicle clearances, crash worthiness, compatible controls, and wheel track interface can be seen as a mature stage of mode integration. The examples of small scale arrangements presented here focus on shared track with temporal separation, shared rail crossings, and shared grade crossings. The efforts to address only shared infrastructure can be seen as an initial stage of mode integration in the United States today.

In this context, the relief from the major vehicle issues and costs helps make possible this acquisition by individual LRT transit agencies of railroad design, maintenance, and operating expertise on a manageable scale for all parties involved. This bottom up national development is also largely without the benefit of a coordinated national program that is found in many *TCRP Report 52* examples drawn from Europe and Japan.

As a result, new working relationships are being developed between light rail agencies and their counterparts within railroads, the Federal Railroad Administration (FRA), and state oversight staffs in discussions that merge transit and railroad issues. What is today a somewhat ad hoc trend may take a more explicit national role as agencies, railroads, and oversight authorities increase cross communication and familiarity.

The growing experience base suggests an explicit development strategy by agencies, railroads, and regulators for more ambitious joint operations. Similar to the training and experience qualifications for individuals to be FRA qualified under various 49 CFR Parts (e.g., Parts 213 Track Safety Standards and Part 214 Roadway Worker Protection), one scenario from this thesis is that transit agencies could become FRA qualified for graduated levels of joint operations based on degrees of prior training, experience, and records of safety with small scale, shared arrangements. To give credit to this trend, examples of emerging, small scale shared infrastructure and larger scale joint operations covered by *TCRP Report 52* are compared.

Third Street LRT Project Overview

The San Francisco Municipal Railway (Muni) obtained environmental clearance for the first new surface alignment extension in a decade in 1998 after a 3-year environmental impact review and statement and conceptual engineering program. When completed in 2005-2006, the project will extend the 35-mi light rail system 5.4 mi from just south of the downtown at Caltrain's northern terminus, to the Bayshore Caltrain station at the southern boundary of the city near Candlestick Park.

The at-grade alignment is primarily in a semiexclusive median on Third Street, one of San Francisco's longest north–south streets that runs on its eastern waterfront. Single-cars will operate on 6-min peak headways. Figure 1 shows the Third Street LRT project and the locations of the two rail crossings. Figure 2 shows the Arthur Avenue–Third Street Rail Crossing with proposed signal locations. Table 1 presents the Third Street LRT rail crossing's existing and proposed conditions as well as the extensive features common to the two crossings. Due to these similar features, the Muni submitted to the FRA a Petition for Approval of Shared Use in June 2003 for both crossings in a single petition.

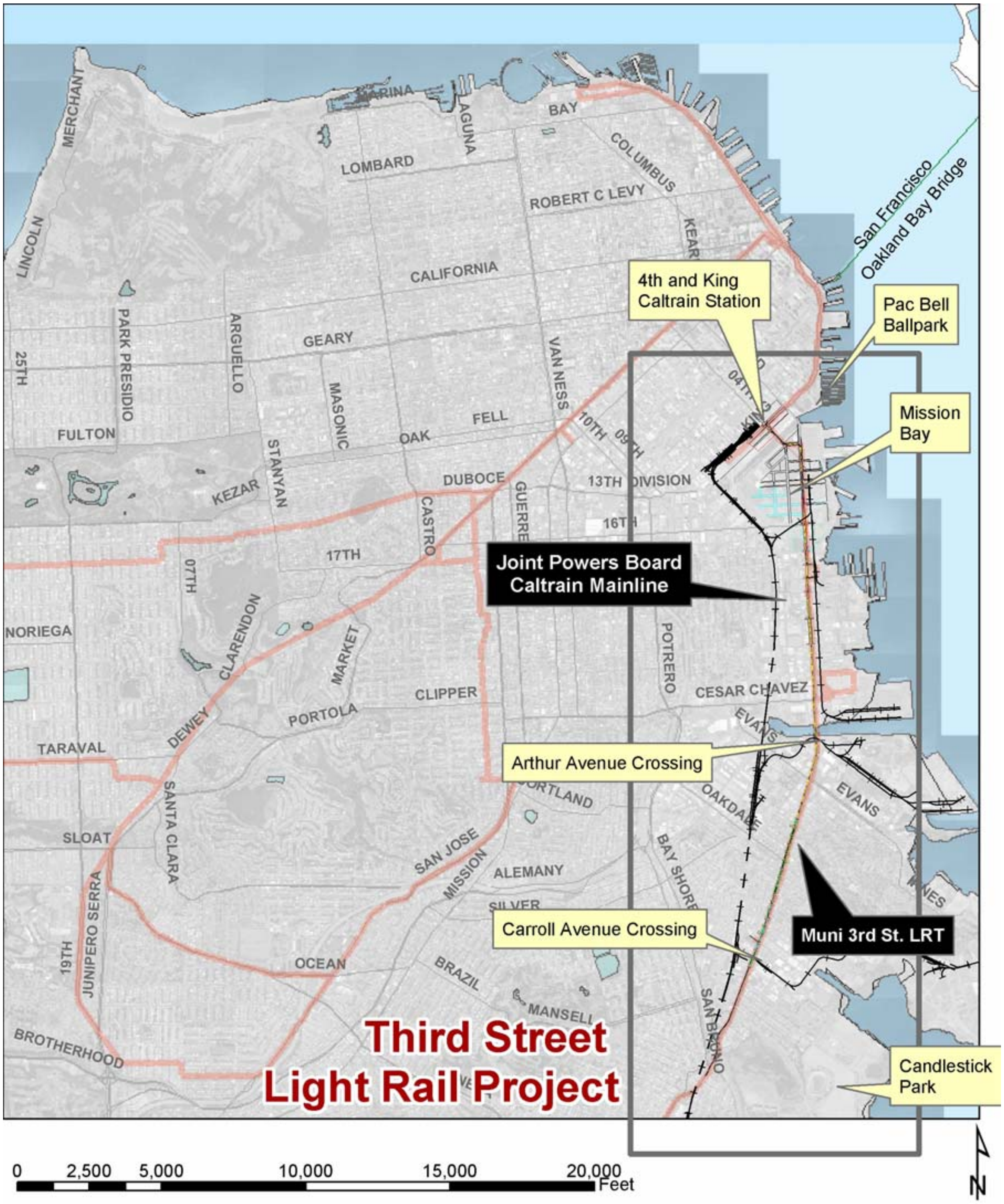

FIGURE 1 Area map of Third Street LRT Project and two Rail Crossings.

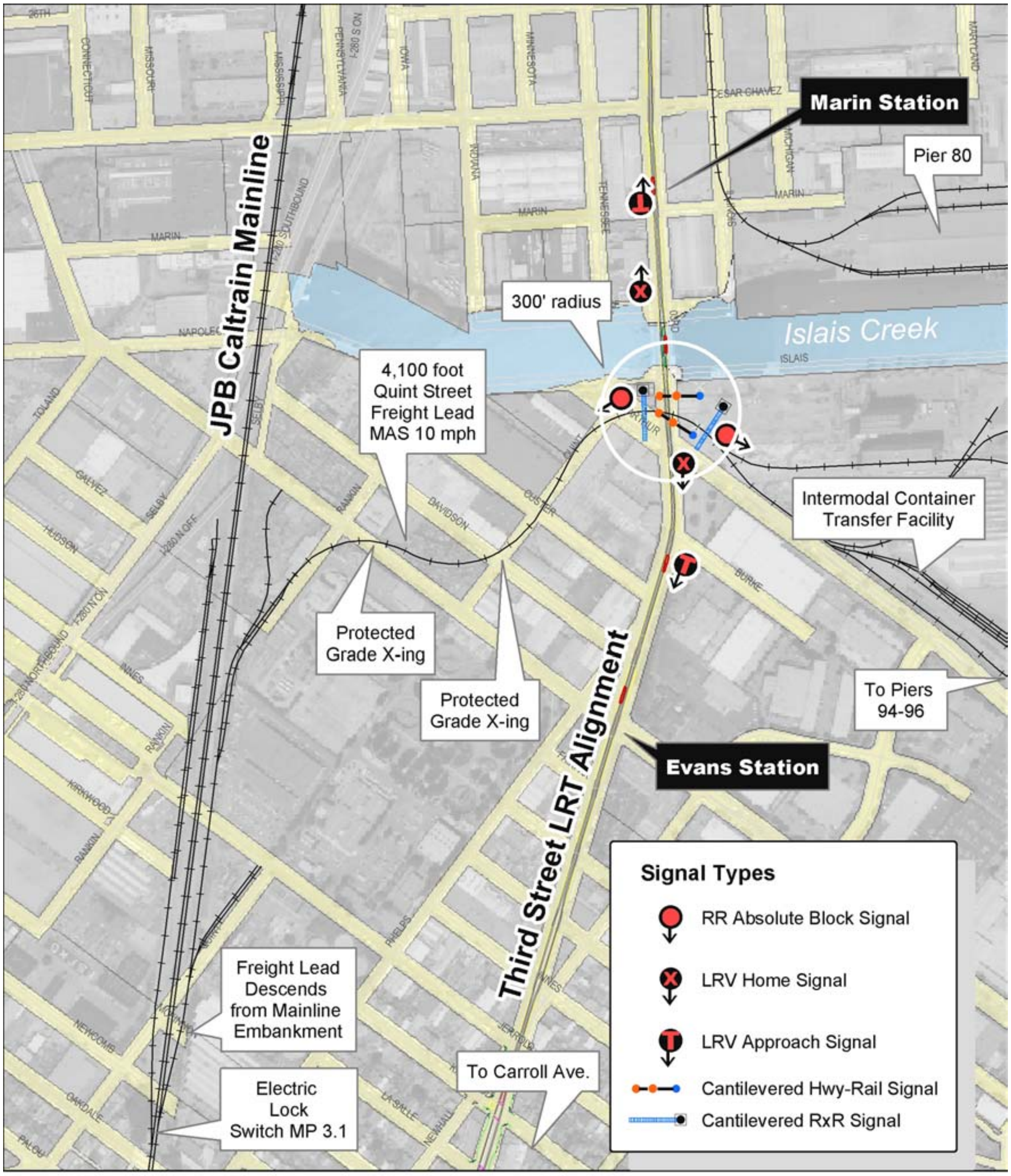

FIGURE 2 Arthur Avenue Rail Crossing at Third Street with interlocking signal locations.

TABLE 1 Third Street LRT Project Rail Crossings—Physical Plant Conditions

Crossings	Existing Conditions	Automatic Interlocking Dimensions From IJ to IJ of Approach Circuits	Track Systems	Signal Systems and Warning Devices	Freight Equipment, Frequencies and Speed In each direction	LRT Equipment, Frequencies and Speed In each direction
1. Arthur Avenue and Third Street LRT TL & TR crosses Quint Street freight lead 80 ft north of Arthur Ave. (at Cargo Way) within existing highway grade crossing **2. Carroll Avenue and Third Street** LRT TL & TR crosses freight lead in center of highway grade crossing	**Existing Traffic Lanes**: 6 **Planned Lanes**: 4 **ADT**: 25,000 **Accidents (Vehicle-Freight Train)**: 0 in prior 6 years (San Francisco Dept. of Parking and Traffic and FRA data through 2001) **Grades**: None **Vehicle -LRT Sight lines**: +300 ft north and south of each crossing down Third Street	• **Railroad:** About 250 feet to east and west of each crossing Occupancy circuits within Third Street spanning diamond east and west • **LRT**: About 600 ft north and south of crossings Occupancy circuits within Third Street spanning diamond north and south	• **Railroad:** 1 Class 2 quality track - yard lead • **LRT:** 2 tracks 2 diamonds in street median Near 90 degree crossings 119 lb rail	• **Railroad:** Cantilever AREMA two aspect Home signals about 140 ft each side of crossing • **LRT:** 2 Way-side LED **Approach** signals with repeaters – 12 in. "T" diameter 1 **Home** signal about 150 to 300 ft each side of crossing LRT and Traffic: LRV **Traffic** signal priority via Vetag RXR Pavement Stencils Cantilever flashers Cross bucks and bells **Pedestrian**: LED Count Down Signals at each crosswalk.	1 GP40 engine and 2-8 cars Arthur Ave: 1 train move in and one move out 3-5 times each week+/- Carroll Ave: 1 train makes one move in and one move out each weekday Operates within the same approximate a.m. time period 9:30 to 11:30 10 mph restricted speed No freight moves currently at night or weekends	1 car LRV train 6-min Peak 10-min Off Peak 150 trains per week day 25 mph restricted speed 20 h of operation per week day 5:00 a.m. to 1:00 a.m.

The geometry and geography of the alignment made grade separations of the rail crossings almost impossible regardless of costs. The railroad that owns the freight leads stated in extensive preliminary contacts that its design, construction, and maintenance resources were committed to higher priorities. Furthermore, the very small scale and benefits of the crossing schemes did not fit the railroad's return-based programs. As a result, the railroad warned, they could not commit to when they would construct any improvements to support the project and would not be bound by private sector standard costs. Finally, potential jurisdictional conflict also loomed between having the railroad's maintenance unions and Muni's separate unions working essentially on common track and signal systems.

After an extensive review of legal and policy alternatives, along with precedents in other cities, Muni elected to approach the railroad headquarters staff directly (bypassing the railroad's local field representatives) and propose a lease agreement that gave responsibility for the crossings to Muni. Muni proposed to rebuild a segment of railroad track and signals at the crossings, to upgrade the crossings and highway warning devices, to undertake the railroad and grade crossing maintenance, and to assume the costs for the major portion of the new risks and insurance. A specific course was developed to use high-level contacts to approach the railroad headquarters senior management. In a positive turn of events, the railroad headquarters staff agreed to consider the proposal and, in the first stage of agreement, stipulated that they wished to see a design standard for a Class 1 Railroad automatic interlocking system.

Railroad Issues

Shared-use arrangements in the United States today are largely led by transit agencies that have purchased a railroad line and the railroad is either an invitee shortline or a willing subordinate in exchange for the payment from the right-of-way purchase. The rapid increase in the number of transit agencies that control freight railroad assets indicates that, armed with sufficient funding during the time Class 1 railroads were shedding branch lines, a major window of opportunity opened. With less funding and options to acquire right of way, San Francisco's rail crossings may represent a possible forerunner of future arrangements where shared assets are leased between equal parties.

However, crediting San Francisco's lease of railroad right of way for use by both parties as a precedent must be qualified by the "limited and controlled circumstances" raised in the conclusion of *TCRP Report 52*. Shipping volumes drive U.S. railroad relationships with all external parties, transit systems included. High-volume freight operations—long trains at any time of the day—produce safety concerns, design criteria, maintenance, and operating agreements that assure control by the railroad, such as Sound Transit's Tacoma Link original agreement with Burlington Northern Santa Fe (BNSF) at Pacific Avenue and Southeastern Pennsylvania's Transportation Authority's (SEPTA's) historical LRT 11 line–CSX Corporation crossing at 6th and Main.

For lower freight volumes, particularly on industrial leads, a major or shortline railroad may consider advantages to ceding control of right of way to a transit agency in exchange for benefits at the project site or within the transit agency's sphere of influence. Building on *TCRP Report 52's* Screening Matrix for Joint Use Feasibility, operating conditions that would appear to be most favorable for railroad and FRA acceptance of a rail crossing shared by light and heavy rail are roughly bounded by the following parameters (*3*):

Condition	Criteria and Operating Parameters
Freight line importance	Should be industrial leads, spurs, or sidings. Mainline triggers FRA's "steep burden."
Speed of freight moves	May need to be less than 15 mph.
Freight train frequency/day	< 4/day between 6:00 a.m. and 8:00 p.m.
Average freight train length	< 15 cars.

SHARED-USE PRACTICE AND PRACTIONERS

Small scale, shared-use arrangements are variations of three types. The most common and largest in scale is shared track with temporal separation. A middle ground of integration complexity is rail-to-rail crossings with a common interlocking. These are relatively rare but are likely to increase in the future. Shared highway–rail grade crossings along parallel light rail and freight rail lines are the most conventional arrangement of shared assets. These types typically are in a combination with one another. San Francisco's rail to rail crossings, in the center of large highway intersections, are also shared grade crossings. Shared track generally includes shared grade crossings and, at a minimum, shared interlockings at the connection points between the railroad and light rail systems. As short hand, these three types are also referred to here as shared track, shared signals, and shared grade crossings. A summary of the transit agency shared arrangements surveyed for this paper follows.

The well known shared track operation with temporal separation in San Diego, California, is now only the first of several similar systems: Santa Clara Valley Transportation Authority (VTA; Moffett Field Drill Track), Utah Transit Authority (UTA) and Maryland Transportation Authority (MTA) also share track with freight rail operations—similarly protected by temporal separation. UTA also includes ones of the first rail-to-rail crossings where two former single track freight lines crossed and one became an LRT alignment. In 2003, Santa Clara, California, expanded its in-house railroad capability with a larger scale program on the Vasona LRT Line that is nearing completion on a right of way purchased by the VTA from a Class 1 Railroad. For the Vasona Line, the transit agency is responsible for maintenance of the freight railroad track including major rail bridge overpasses, maintenance of the several shared highway-rail grade crossings and freight-LRT operations at the interlocking point of connection. This followed the 1988 commitment by Sacramento, California, to undertake maintenance of shared railroad–light rail grade crossings on the lightly used freight railroad single track that parallels the Folsom (largely) double track LRT line as part of Sacramento's purchase agreement with the railroad. Following this trend, San Francisco LRT maintenance forces are training to assume maintenance of their freight rail–light rail crossings and automatic interlockings.

A common thread in these arrangements is that all of the above light rail transit systems are responsible for a portion of the freight track and signal system maintenance within the shared-use arrangements. Most of the transit agencies surveyed evaluated whether to contract out or use in-house maintenance forces. In every case the decision has been to train and use in-house LRT maintenance forces to achieve FRA qualifications and carry out FRA standard practices.

All agencies surveyed with shared track (MTA, UTA, San Diego) use in-house FRA qualified radio communications that at a minimum oversee the check in and check out of freight trains at the interlocking connection to the light rail system. All of the LRT agencies surveyed acquired sufficient training and approvals to address FRA requirements without benefit of an in-house, FRA-compliant commuter rail organization. Indeed, at the time of this paper, UTA was considering the use of its FRA-trained LRT maintenance forces to cover the proposed commuter rail service maintenance needs projected to begin after 2005.

The acquisition of FRA qualified maintenance of track, signal, and grade crossings, as well as limited dispatching represents an important expansion of light rail agency qualifications and credentials—aside from expanded external oversight. The revised LRT system maintenance training programs along with the establishment of specific qualifications, manuals, data collection, record keeping, and supervision practices that are required to maintain shared track, signals, or grade crossings generate new structures and standards within light rail systems. At the center of this change are new relationships with the FRA and state oversight agencies. This process is formally initiated with submittal of an FRA Petition for Approval.

FRA PETITION PROCESS

Shared arrangements such as an at-grade rail crossing operated and maintained by a transit agency and "shared" with a freight railroad may appear too limited to provide useful comparisons to larger issues of mode integration. A core point of this paper is to testify to the parallels between large project joint operations and small scale, shared-use arrangements. Muni's experience is that a FRA petition process involving railroad negotiations and agreements is a major undertaking spanning 3 years from the first formulation of the FRA-railroad crossing specifications in final design through final approval of design by the railroad and subsequent approval of the petition by the FRA. Sound Transit's Tacoma link approval process covered a similar time from initial design in 1999 to approval in 2002. This duration begins to approach larger scale project approvals such as New Jersey. While the 2000 FRA Policy Statement guidance for shared use suggested a "brief" FRA Petition for "limited connections" to the general railroad system such as rail crossings, it is unlikely the processes for small projects will be significantly shorter than large ones until more precedents are established nationally.

Approvals to operate shared rail crossings on Third Street required concurrent effort on three fronts: the railroad, stakeholders, and oversight agencies. Table 2 summarizes the coordination required for San Francisco's shared-use arrangements.

During 2001 and 2002, Muni project staff simultaneously pursued design review, operating plan discussion and real estate lease negotiations with both the railroad's regional and national office staffs. Field inspections and a design review were conducted with track and signal staff from both offices. Presentations were made with shippers who use the industrial leads, the port of San Francisco that is a primary freight and cargo broker, a railroad museum that uses one of the tracks periodically, and Caltrain staff who control all San Francisco freight railroad access on its passenger rail mainline. Periodic briefings and site inspections were held with state oversight staff at the California Public Utilities Commission (CPUC), and regional FRA staff to provide updates and obtain guidance for the breadth and depth of the Petition submittal.

The results of this process at Muni were similar to the other transit agencies that were surveyed. Overall, the process strengthens light rail organizations in three areas: design, maintenance, and operations. A fourth area that is strengthened implicitly is the transit agency's overall transit-railroad system management. The latter is discussed briefly under Risk Management.

TABLE 2 Third Street LRT Project Rail to Rail Crossing Reviews and Approvals

Stakeholders	Review Transaction
Railroad[a]	Railroad Engineering Departments Real Estate Property Lease Insurance and Liability Agreement
Interagency Coordination	Port of San Francisco Local Freight Rail Shippers Caltrain Joint Powers Board Staff Golden Gate Railroad Museum
Internal LRT Project Review	Engineering/Construction Change Order Safety Deptartment/Project Safety Committee Department of Traffic Fire Department and Department of Public Works
Oversight Agencies	FRA Approved Petition and Operating Plan FRA Approved RWP Safety/CM Program FRA Approved Maintenance Program CPUC Overhead Height Clearance Waiver CPUC Approved Crossing Intersection Design CPUC Approved Crossing Application[b] FTA Oversight Review Of Above

[a] Railroad is the Class I Railroad that is the freight shipping service to the San Francisco Peninsula and Port of San Francisco.
[b] CPUC review of application is done in coordination with the FRA regional office.

Design

For the microcosm of shared track contained in a single shared crossing, the primary design criteria are the same as for large scale projects: certain crash avoidance by means of fail-safe controls and practices. The Muni has strong experience with LRT rail-to-rail crossings, interlockings, and automated train control systems. Based on this experience, Muni was immediately prepared to implement the railroad’s design standards for automatic interlockings without manual interface and radio communications and a generally upgraded highway-rail grade crossing. At the end of the design reviews and changes that spanned about 18 months, Muni approved the track and signal design for the freight and light rail systems as well as the operating plans for the crossings.

A key issue for automatic interlocking operations primarily controlled by signal compliance and safe practices is approval by the FRA and state oversight agencies that does not require major enhanced safety devices. Such devices may be inherent to higher risk conditions including mainline, higher frequencies, adjacent active switching and grades in the approaches of the freight alignment. Where necessary, railroads historically use derails at rail crossings tied to the interlocking controller. Derails were required on the BNSF freight line–Tacoma Link crossing due to the grade of the freight track that could have contributed to a run away freight car. Non-mainline railroad tracks with derails previously in place have resulted in derails continuing to be left in place for the point of connection interlocking the remaining freight line and the new LRT lines for VTA and UTA systems.

FRA approval of Muni's approach to use only signals and procedures to achieve crash avoidance is a key measure of the U.S. evolution of small-scale precedents. All such approvals depend in part on the FRA's willingness to recognize the cumulative success of small-scale, FRA-compliant, LRT-freight shared-use arrangements nationally. At the time this paper was submitted, the FRA decision to approve Muni's Petition was expected at the end of November 2003. Construction on the crossings was purposely scheduled to begin in early 2004 in order to achieve CPUC and FRA approvals.

The several revisions made to the initial design as a result of Muni's field inspections and design review improved the dual mode interface:

- The original concept to construct a unique hydraulic liftable overhead contact system mechanism at the crossings to provide historical state mandated clearances of 22 ft above the top of rail cars during freight moves was deleted in favor of pursuing a waiver application before the state oversight authority. After more than a year of review and deliberations, that waiver was granted.
- The location of the railroad approach circuits on each side of the point of connection were extended approximately 50 to 100 ft so that the arrival of a train would trigger the request for a route 200 to 250 ft further from the crossing.
- The interlocking will control the traffic signals at the intersections within the limits of the light rail vehicle (LRV) approach signals north and south of each crossing.
- For the approach intersection signals on the LRT alignment, the corridor integrated LRV-traffic priority system (Vetag) will interface with the interlocking controller to make LRV route requests. The affect is to provide the Vetag system with a vital back up.
- The railroad crossing pavement stencil will be applied to the guideway approach to the intersections as well as the parallel highway lanes.
- A freight rail spur on the northern side of Carroll Avenue, east of Third Street, will be removed to avoid conflict with the freight approach circuits. Flasher signals will be added as warning devices at Carroll Avenue for freight moves across Third Street per CPUC standards.
- LRV dwarf signals will be installed at the approach zones to warn against light rail reverse moves on the opposite track.
- Tactile warning devices will be inserted across the sidewalk path of travel consistent with the Americans with Disabilities Act requirements for freight tack flange width in sidewalks on each side of the rail crossings.

Table 1 shows the considerable physical space and design features in the Third Street interlockings. The freight track is being completely replaced with new rail, ties, insulated joints and signal system for several hundred feet beyond the diamond crossings. The LRT track and signals linked to the interlocking controller reach approximately 1,200 ft. Taken together, the total interlocking track and signal system for both crossings is nearly ⅔ mi if stretched into a linear path. At the most complex of the two crossings, the microprocessor controller is connected to two new AREMA railroad signals, a railroad wayside push button route request box, two sets of cantilevered flashers and bells, four-way vehicular LED traffic signals, pedestrian LED countdown signals, a draw bridge preemption override, a fire station preemption override, four LRT approach signals and two LRV home signals (spanning several blocks) each with repeaters to signalize the near and far side of the three intersections leading to the crossing.

Table 3 shows that across the three types of shared use there is a common set of about a dozen railroad design issues and FRA rules that apply to both shared track and shared crossings where the light rail agency is responsible for the shared assets. A smaller number of issues apply to shared grade crossings.

Maintenance

In interviews with LRT safety and maintenance staff at the five agencies surveyed, every participant credited the presence of FRA rules with strengthening the agency safety mission among employees and management (see contacts at bottom of Table 4).

TABLE 3 LRT-Freight Issues, Design, and Regulations for Three Types of Shared Use

Issues	Shared Track	Shared Crossing	Shared Grade Crossings
Regulatory Approvals			
State Oversight Approved Application	X	X	X
FRA Approved Petition	X	X	Brief Petition
Track, Structures, and Signals			
Design Standards			
Interlockings and Controls	X	X	
Title 49 CFR Rules			
213 Track Safety Standards	X	X	
235 Modification of Signal Systems	X	X	X
236 Signal and Train Control QC	X	X	
Grade Crossings			
Design Standards			
CPUC Interface/Warning Devices	X	X	X
Title 49 CFR Rules			
234 Grade Crossings	X	X	X
Procedures & Operating Practices			
Joint Operating Plan/SSPP	X	X	Brief Reference
Title 49 CFR Rules			
209 FRA Jurisdiction, 211 Waivers	X	X	X
212 State Safety Participation	X	X	X
219 Control Drug and Alcohol	Waiver	Waiver	Waiver
225 Railroad Accidents Reporting	X	X	X
228 Hours of Service	X	X	X
Total Factors	14	14	11

TABLE 4 Transit Agency Railroad Responsibilities and FRA Qualifications for Shared Use

Shared Asset	Transit Agency and Alignment	Maintains Freight Assets	Freight Frequencies	Interlockings: Automatic (A) Manual (M)
SHARED GRADE CROSSINGS/TRACK	**1. Santa Clara VTA** **6 mi side-by-side Vasona freight track ROW; shared grade crossings**	1. Yes, all	1. < 5 trains/week	1. 2 M
	2. San Diego Trolley **15 mi Shared "Mainline" track, signals, grade crossings**	2. Yes, all	2. > 1 train nightly	2. 2 M
	3. Sacramento RTD **7 mi side-by-side Folsom freight ROW and LRT track; shared grade crossings**	3. Yes, grade crossings only	3. < 5 trains/week	3. None
SHARED RAIL CROSSINGS	**4. Municipal Railway** **2 Rail to Rail Crossings - Third Street within highway-rail grade crossings**	4. Yes	4. 5 trains/week	4. 2 A
	5. Sound Transit Tacoma Link **1 Rail Crossing—Tacoma Link and BNSF Lakeview line at Pacific Ave.** ST – BNSF crossing agreement revised as this paper was finalized.	5. NA. LRT staff not involved in FRA qualified work	5. Possible future commuter rail connection.	5. TBD

Sources (unpublished data): Direct interviews, email exchanges, or phone interviews were conducted with a minimum of two staff members at each Transit Agency between July 2002 and July 2003. Primary contacts were as follows:

1. Anthony Bohara, Manager of Track and Civil Engineering, SEPTA. Phone discussion of SEPTA Line 11 rail crossing history and protocols.
2. Fred Byle, Manager of Track and Signal Maintenance, San Diego Trolley, Inc., fbyle@sdti.sdmts.com, (619) 595-4926. Also, Andy L. Goodard, System Safety Administrator, San Diego Trolley, Inc., (619) 595-4986, regarding updating of SSPP and training to meet FRA expectations.
3. Larry Davis, Supervisor of Maintenance, SRTD, (916) 648-8422. Phone discussion regarding Folsom line.
4. Jim Middleton, Rail Safety Supervisor, Santa Clara Valley Transportation Authority, (408) 952-8972, jim.middleton@vta.org - phone and on site visits regarding Moffett Field drill track and Vasona line shared corridor and crossing.
5. Yoav Arkin, Senior Program Director, System Safety and Assurance, Earth Tech, Inc. 7 Saint Paul Street, Suite 900, Baltimore, MD, 21202, (410) 637-1603. Email correspondence regarding Baltimore LRT maintenance with Arkin,who in turn, spoke directly with MTA LRT MOW supervisor, Fletcher Hamilton to verify information.
6. Hamid Qaasim, Program Manager of Safety and Assurance-Link Light Rail, Sound Transit, (206) 398-5129, qaasimh@soundtransit.org. Direct interview at APTA 2002 Rapid Rail Conference in Baltimore and email exchange regarding Tacoma Link rail crossing. Also, Bill Whitbred, at LTK, wwhitbred@ltk.com, consultant to Sound Transit; email correspondence regarding BNSF change of position and the staffing program to meet FRA qualifications for Sounder.

Table 4 shows the FRA compliance and maintenance capability at these transit systems and Muni. At the time of the interviews with Sound Transit staff, the original agreement with BNSF illustrated a railroad's firm ownership interest to protect high train volumes and limit transit agency responsibility for railroad functions. However, it is interesting to note that in 2003 Sound Transit was able to achieve abandonment of the BNSF freight line that crosses the Tacoma Link alignment, and after 3 years of difficult negotiations, FRA approval and construction of the crossing was achieved under the assumption the transit agency would not be responsible for the shared asset.

Four Title 49 CFR Parts provide FRA's national standards that extend most light rail transit agency maintenance practices today to the point of significantly recreating the agency Standard Operating Practices (SOPs):

- Part 213, Track Safety Standards, spells out standards for track maintenance, inspection, and reporting, including qualifications for track inspectors and maintainers and documentation by the agency management to show that maintenance staffs meet their assigned positions. Pending adoption of new American Public Transit Association (APTA) standards, the details of Part 213 represent a level of effort in SOPs not seen at many light rail agencies absent the need to achieve FRA compliance.
- Part 214, Roadway Worker Safety, governs construction and maintenance worker on site safety and procedures to assure protection from collisions or falls from bridgework. From an employee safety perspective, 214 is a comprehensive source of standards (similar to Occupational Safety and Health Administration guidelines) for accident prevention, investigation, and employee safety that otherwise might not always be in place for public transit agency staffs that carry out maintenance duties.
- Part 234, Highway–Rail Grade Crossing Signal System Safety, governs the standards for designing and maintaining grade crossings including prescribed inspections and maintenance by grade crossing system component. For light rail agencies with LRV speeds above 35 mph through highway–rail grade crossings and existing equivalent state oversight requirement, much of Part 234 may already be in place for grade crossing maintenance. Where those conditions have not triggered the comprehensive approach prescribed in Part 234, new, more definitive practices are likely to result from its application.
- Part 236, Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signals, covers the scope expressed in its title. The presence of shared interlockings maintained by a light rail agency introduces a new set of tests and inspections to assure safe operations that are not always present on conventional light rail surface operations.

While APTA is rapidly advancing light rail system standard maintenance practices that parallel those of the FRA, only a small number of APTA or FTA standards are comparable to FRA's tested experience on a national scale, level of detail, and resulting authority as a source of best practices. Examples of rail transit safety standards or practices that are currently equivalent to FRA precedents include System Safety Plan Program documents, glazing for LRVs, and drug and alcohol control of safety critical employees. In the case of the latter, virtually all transit agencies with shared-use arrangements have submitted Petitions for Waivers—and received approval—for Part 219 Drug and Alcohol based on the equivalent sufficiency of the FTA mandated program.

Sources of FRA training used by LRT agencies are commonly a combination of existing employees who are former qualified railroad workers, consultants who provide insights on best practices and technical materials, and FRA and state oversight staff who are sources to classes and field exercises. Training a cadre of most experienced employees first is a common practice, but the vast majority of agencies are training all maintenance employees, from top to bottom, to become FRA qualified as part of their job growth and qualifications. Within this trend there appears to be a concurrent commitment to use FRA standards to achieve a higher level of light rail system performance regardless of the mandates inherent to FRA jurisdiction.

Operations

For transit agencies that control track used for freight moves that are made during a temporal separation, Part 220 (Radio Communications) applies and prescribes the uses, format, and content of radio communications between central control and employees in the field and between employees working in the field together. Part 228 (Hours of Service), which prohibits work beyond 12 h consecutive without 12 h off, applies to the light rail control center dispatchers, supervisors, and signal maintainers. Both of these rules take common LRT agency practices to a more prescribed or exact level than would otherwise have been the norm in many cases.

The experience of Muni parallels most if not all of the light rail agencies reviewed here: Operator training, the Operating Rule Book, management job descriptions, and the System Safety Program Plan have been revised to document commitments to FRA standards and to incorporate the existence of railroad assets within the transit agency's responsibilities.

When the total effort for a light rail agency to institute railroad and FRA standards across the organization is considered, the most important internal impact of the petition process is the ground work the process puts in motion to prepare for the new organizational responsibilities, to conduct detailed training, to carry out start up testing, and then safely operate with confidence.

Risk Management

The FRA Petition process required Muni to conduct a Risk Assessment of the rail crossings to determine if the interlocking plant design and operating rules would achieve FRA standards, such as operations that are equal to or safer than a no-build scenario with no probability of catastrophic collisions. Few FRA rules spell out light rail to general railroad crossing operating standards. In the short history of FRA review of light rail–freight rail crossings, a Petition for Approval of Shared Use is a case by case approval of the controls, operating rules, and practices proposed at the crossings much more than a specific waiver of any FRA rules contained in Title 49 of the Code of Federal Regulations.

The freight railroad and the transit agency's risk management staffs are sources for the transit agency's Risk Assessment. The respective Risk Management staffs are the immediate parties to the railroad–transit agency liability agreements and advisors to the concurrent real estate agreements. The difficulty to integrate railroad operating, safety, liability, and insurance issues with transit agency risk management precedents represent the benefit of achieving small scale, shared arrangements without the steep burden of fully integrating vehicles and operations. In San Francisco's case, a period of becoming conversant and able to translate two technical languages and respective traditions across modes was a prerequisite to LRT–railroad design cooperation. Similarly, considerable effort was required to achieve mutual understanding across modes of liability, probable and perceived risks, and the range of possible protections prior to proceeding with shared risk management agreements.

CONCLUSION

Implementation of limited shared infrastructure by a light rail system and a railroad contains virtually every regulatory and technical requirement found in shared track projects with the exception of vehicle compatibility issues. The first benefit of smaller, manageable shared arrangements is that the absence of vehicle issues makes possible a still considerable level of effort to begin integrating light rail and railroad issues.

New integrated or share arrangements generate a microcosm of intense cross mode cooperation, planning, and engineering that must accommodate a wide range of stakeholders and approvals. Representatives negotiating for the light rail system and railroad will learn about the other's industry practices and issues that are often not always transparent across modes. In addition, many specialized, mode-specific details must be shared and understood across departments within the railroad or light rail organizations before a consensus can be reached for external discussions.

The Third Street LRT project overcame a variety of gaps between the transit agency and the railroad during the 3-year development and negotiation period to submit a petition to the FRA. These mutual interactions across modes, business cultures, rules, terminology, and practices represent the first tier or initial increment of shared use. The growing efforts to integrate technical and institutional light rail and freight rail expertise across the United States are setting the foundation for the next generation of integrated traffic in a shared track world. While no one U.S. light rail system touched on here represents an uniform, industry trend, together they are providing a proving ground effort just as Karlsruhe did at the start of the European trends toward complex arrangements documented in *TCRP Report 52* (*3*).

Finally, the trend of transit agencies to carry out FRA and railroad standards expands the criteria for the FRA to evaluate the ability to manage more extensive U.S. joint use systems of shared track, common signals, and joint timetable operations. The cumulative safety record of FRA approved small scale, shared arrangements may influence the evolution of the FRA's assessment of more complex proposals.

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Safety Criteria for Light Rail Pedestrian Crossings

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Light rail systems introduce certain risks that may not be effectively mitigated through vehicular traffic control conventions. Upon the opening of its Westside MAX light rail extension, TriMet experienced several significant incidents involving pedestrians at crossings. TriMet initiated a process aimed at identifying actions that would eliminate or mitigate causes of such incidents. The criteria and application steps that TriMet developed following review are described.

TriMet commissioned an independent review of its entire light rail system. It also established an internal committee involving engineering, maintenance, operations, safety, marketing and management to evaluate numerous recommendations and to determine an appropriate action plan. Recommendations were implemented, in some cases, on a trial basis. Effects on pedestrian behavior were monitored. The process resulted in TriMet developing "Light Rail Crossing Safety" design criteria for use in the planning, design, and construction of TriMet light rail facilities.

TriMet has applied the criteria to its subsequent light rail extension projects or improvements. Projects include the Airport MAX and Interstate MAX extensions, and improvements to the existing Westside and Banfield alignments. Improvements to the existing system are evaluated by TriMet's newly established "Rail Change Rail Control" committee. The criteria have raised the safety awareness level of those persons who plan, design, construct, and operate the system and resulted in a safer system.

INTRODUCTION

Upon the opening of the Westside MAX extension in 1998 in Portland, Oregon, TriMet experienced several serious incidents involving pedestrians and light rail vehicles (LRVs). The Westside extension added 18 mi to TriMet's system. Ridership nearly doubled to 63,000 daily boardings. The number of at-grade crossings increased approximately two-fold to 159, inclusive of intersections and stations.

The incidents involved risky behaviors including violation of well-marked "No Trespassing" signage in certain instances. While TriMet's system incorporated current standards in the transit industry for operating practices and track crossing designs, TriMet sought to reduce risky behavior around the tracks and particularly at crossings. Accordingly, TriMet initiated an independent review of its entire system for the purpose of identifying enhancements that might reduce risky behavior.

TriMet hired Korve Engineering Inc. to assist in its independent review. TriMet received recommendations based on Korve Engineering's North American light rail research, field evaluation of TriMet's system, and interviews with TriMet safety staff and LRV operators. In addition, TriMet established an internal safety committee to review and take action on recommendations. TriMet's safety committee consisted of representatives from Operations, Maintenance of Way, Systems Engineering, Civil Engineering, and Systems Safety.

Track locations that presented different safety risks were identified for prototype installations of safety treatments. Locations, and the primary safety risks, included

- 28th Avenue in Hillsboro (restricted pedestrian-train line of sight at crossing);
- Baseline/173rd in Beaverton (non-perpendicular traffic crossing of tracks);
- Beaverton Transit Center (high volume train-bus transfer location); and
- 122nd/East Burnside (high volume vehicular and train traffic pedestrian crossing).

Safety treatments included additional signage, swing gates, channeling, detectable warnings, "Stop Here" markings, audible-visual warning devices, and automatic pedestrian gates. Risky behavior was monitored before and after installation of the safety treatments.

While difficult to measure, TriMet concluded that the treatments increased pedestrian safety awareness in certain applications. This led to the development by TriMet of "Light Rail Crossing Safety" criteria. The criteria standardize certain devices and treatments so that they are consistent within the TriMet light rail system. Additionally, the criteria serve as a guide for persons who plan, design, and manage TriMet projects. They supplement, and do not supersede, other applicable rules and regulations.

The primary purpose of this paper is to describe passive and active standards that TriMet has incorporated into its light rail criteria, and guidance in their application. It also identifies key management steps that TriMet has found effective in the mitigation of safety hazards and risks.

BACKGROUND

The TriMet light rail system has been very successful and continues to expand. Since Westside MAX, transit ridership has increased 160% in the corridor. Airport MAX opened in 2001. When Interstate MAX is completed in 2004, TriMet's light rail system will include 45 route miles of track, 64 stations, and 95 vehicles.

Each expansion introduces new elements into the community. The light rail-operating environment includes characteristics that differ from traffic control conventions for roadways and passenger or freight railroad crossings. These include

- LRVs are quiet. TriMet also takes specific measures to reduce LRV wheel-to-rail noise and to mitigate warning sounds at intersections, in response to community concerns.
- LRV crossings through intersections are frequent. The TriMet system accommodates 2- to 5-min headways in each direction.
- Light rail provides an alternative daily transit option and draws large numbers of people toward its stations. Stations are located to encourage transit usage and development.
- Light rail crossings occur in a wide variety of alignment configurations and operating environments. Typical railroad-style, gated crossings are not feasible in certain light rail environments.
- Pedestrian and vehicular incidents at light rail crossings tend to be severe. Incident severity increases as LRV speed increases.

Planning and Design Objectives

TriMet's general approach to planning and design is to eliminate hazards where possible, then mitigate or warn. More specifically, the approach is to

- Eliminate hazards: Hazards to the customers and public shall be identified, evaluated, and eliminated through planning and design where feasible. For example, the number of track crossings should be minimized. Line-of-sight obstructions to oncoming LRVs should be avoided.
- Mitigate unavoidable risks: Where planning and design does not allow for elimination of hazards or unacceptable safety risks, safety treatments that mitigate those risks shall be provided.
- Provide warning devices: Where neither planning, design, nor safety treatments effectively eliminate identified hazards or adequately reduce associated risks, warning devices shall be used to alert persons of the remaining risks and hazards. Warning devices may be passive or active.
- Acceptable level of risk: TriMet systems safety manager shall be consulted to confirm whether an identified risk or hazard that cannot be eliminated or mitigated is acceptable.

Safety Certification

TriMet utilizes a safety certification program to verify that identified safety requirements have been met prior to commencement of revenue service. Certifiable elements checklists are developed for each contract.

RCRC Review of Existing Light Rail Facilities Changes

TriMet has established a Rail Change Review Committee (RCRC) to review and approve all proposed revisions to rail transportation and maintenance policies, procedures, and existing rail system elements. The RCRC consists of members of Operations, Maintenance, Systems Safety, Systems Engineering, and Bus and Rail Transportation. Proposed revisions to the existing system should be supported with a behavior or incident analysis. It should address the risky behavior or incident that has led to the proposed revision, including how and why the proposed passive or active safety treatments will mitigate or eliminate the behavior or incident of concern.

Independent Safety Design Review and Hazard and Risk Analysis

TriMet has incorporated independent review of its designs for pedestrian and vehicular safety into its process for LRT extensions. Independent reviews may be provided by non-project personnel within the agency, by outside experts, or by peer groups. For example, as construction is being completed on Interstate MAX, TriMet is conducting a final, independent hazard and risk analysis. This is in addition to independent review by Korve Engineering during design development. TriMet's Interstate MAX safety committee has been established to discuss and review safety hazard and risk items, consider mitigation options, recommend resolution including changes to the existing design, and document process and follow-through on implementation.

TRIMET STANDARDS

TriMet has established standards for use to mitigate or warn of trackway crossing risks or hazards in the various light rail environments. Application depends upon analysis and review of each location. Standardized treatment is intended to promote the understanding of and compliance with the safety treatments by customers and the public at large.

Passive Safety Treatments

Passive treatments are not activated by approaching trains. A typical at-grade installation is depicted in Figure 1. Passive treatments are listed below.

"Stop Here" Pavement Markings

Figure 2 details Stop Here pavement marking for pedestrian warning. The purpose of this marking is to identify for pedestrians and bicyclists a safe stopping location that is outside the light rail vehicle dynamic envelope.

Generally, the Stop Here markings are not required in city environments because of the slower light rail vehicle operating speeds. Nor are they required at traffic-controlled intersections, at platforms, and at other locations where safe stopping locations are readily identifiable.

Stop Here markings should be considered where:

- LRV design speeds exceed 15 mph in non-city environments, and
- Safe pedestrian stopping location is unclear.

Tactile Warning

Figure 3 details pedestrian tactile warning treatment in pavement adjacent to a trackway crossing. The purpose of the tactile warning is to identify for pedestrians a safe stopping location and safe refuge area that is outside the LRV dynamic envelope.

This standard should be applied:

- In conjunction with "Stop Here" markings, or
- Where detectable warning is required at light rail station platforms and adjacent trackway crossings.

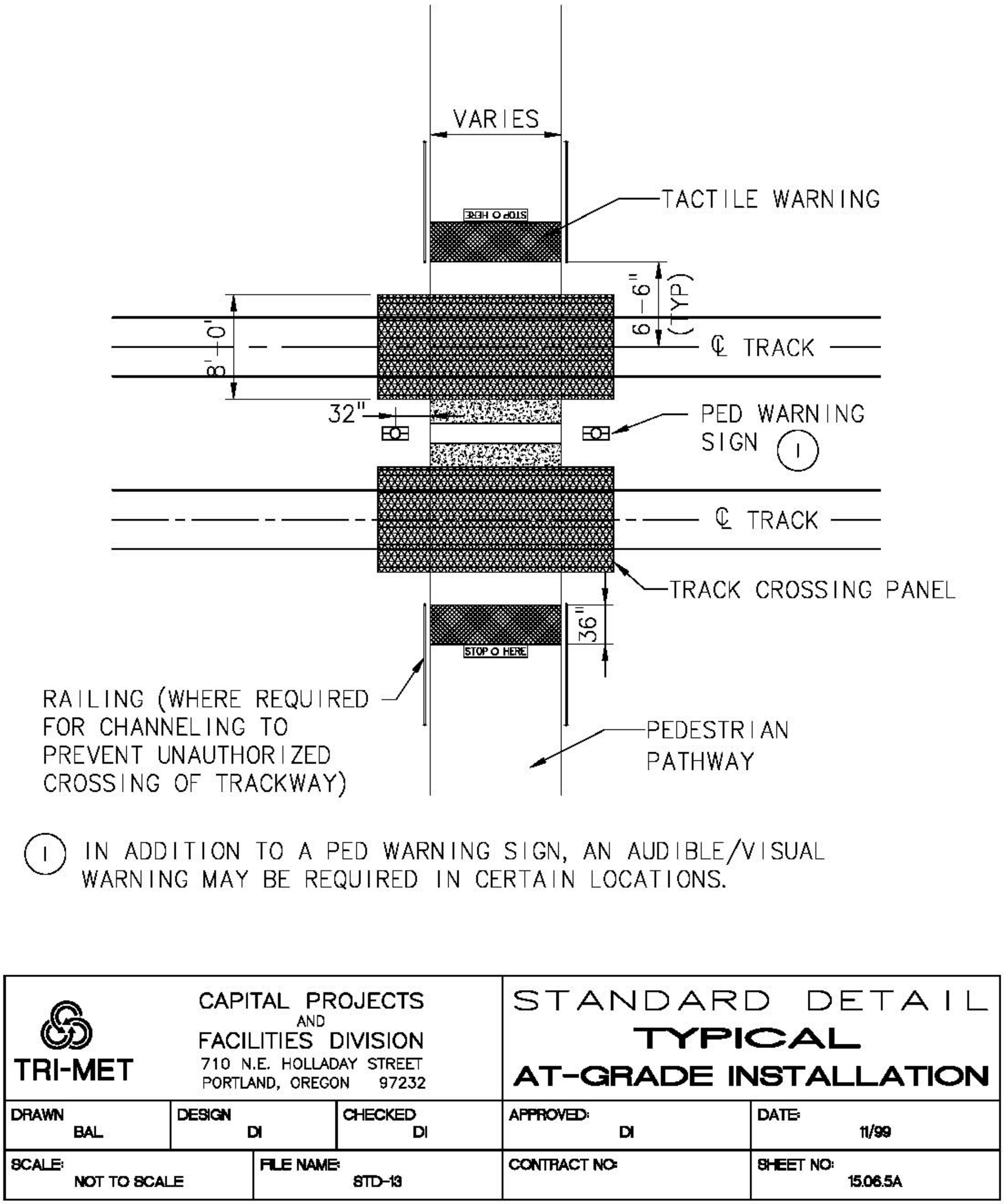


FIGURE 1 Typical at-grade installation.

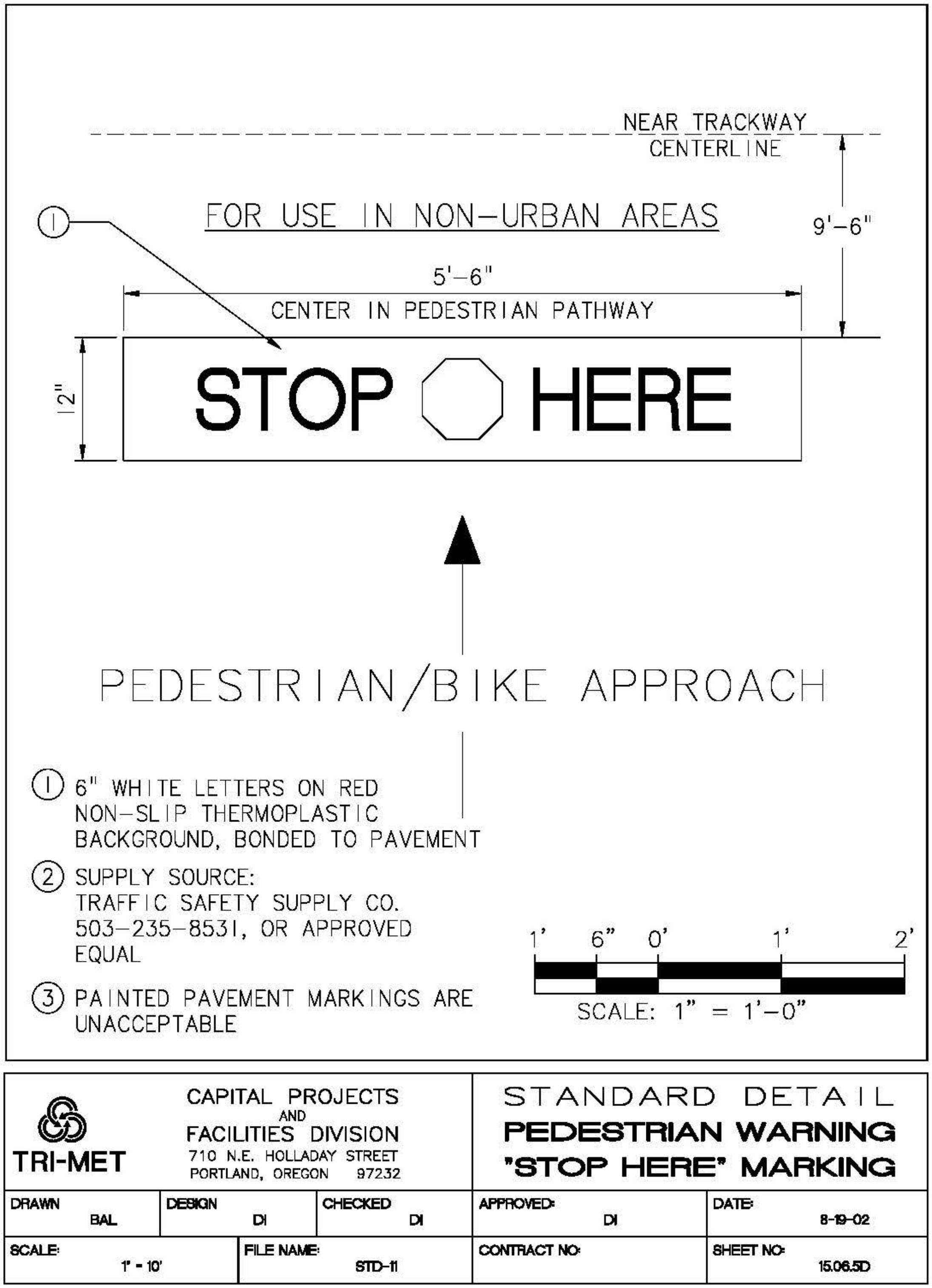


FIGURE 2 Pedestrian warning "Stop Here" marking.

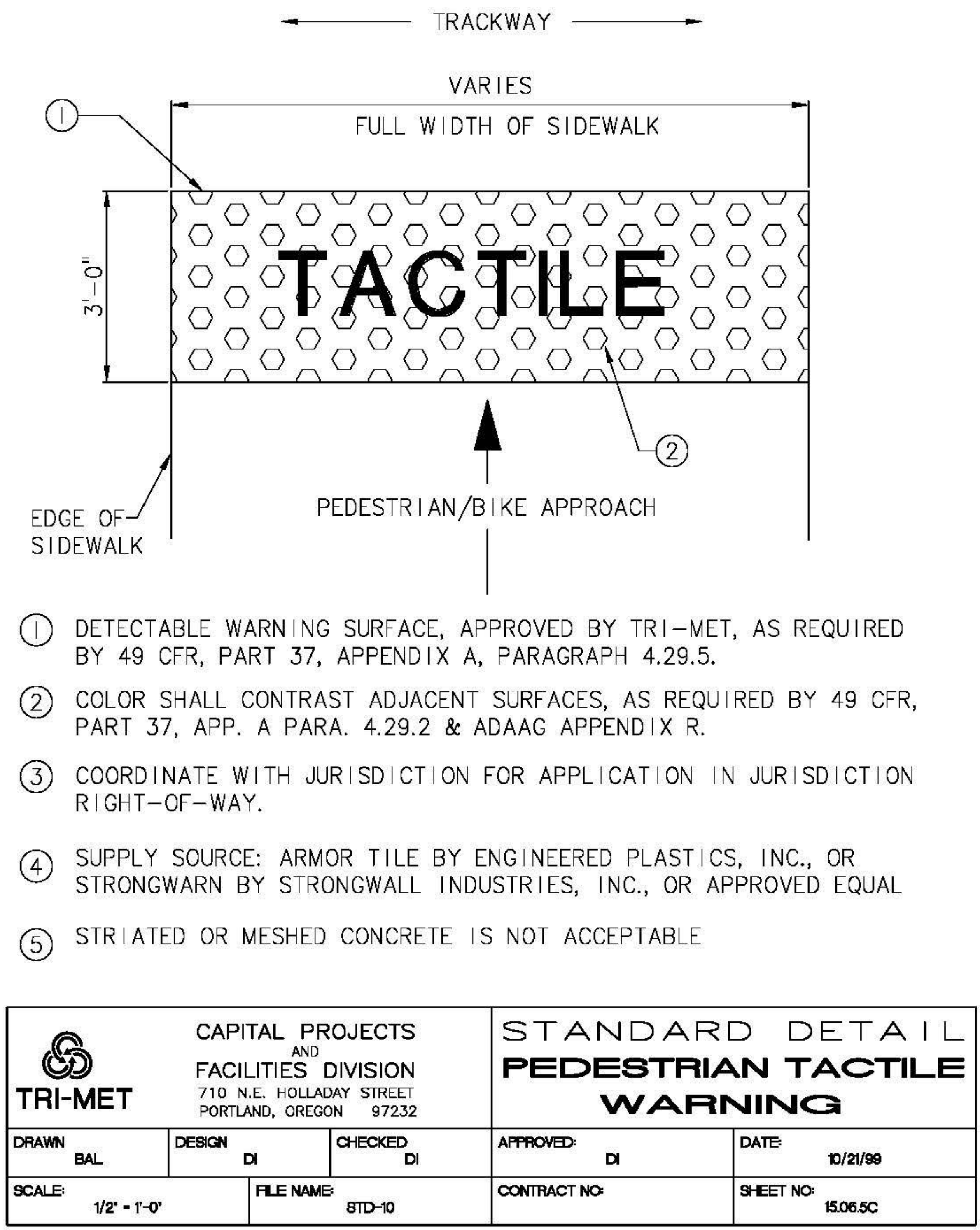


FIGURE 3 Pedestrian tactile warning.

Channeling

Figure 4 details railing that may be used to channel pedestrians or bicyclists. The purpose of the channeling is to create a physical barrier that prevents or discourages persons from taking shortcuts or from crossing the trackway in a risky or unauthorized manner.

Application of channeling depends upon the particular conditions associated with the trackway crossing. It requires custom design for the particular location. Jurisdictional review of the proposed method may be required. In all cases, a channeling method that does not impair sight lines to an approaching train shall be selected.

Channeling should be considered where:

- A high likelihood exists that persons may cross the trackway in an unauthorized manner, particularly if in a hurry, and
- Other elements at the location will be effective in deterring unauthorized crossings.

"Look Both Ways" Signage

Figure 5 details "Look Both Ways" signage. The purpose of the signage is to remind pedestrians and bicyclists as they approach the trackway to look for approaching trains in both directions.

Generally, Look Both Ways signage is not required in city environments because of the slower LRV operating speeds. The signage should be installed at

- Non-city trackway crossing locations where LRV design speeds exceed 15 mph,
- Light rail platforms in ballasted trackway, or
- Mid-block pedestrian crossings.

Swing Gates

Figure 6 details the installation of pedestrian crossing swing gates. The purpose of swing gates is to slow persons who hurriedly approach the trackway. Swing gate operation depends upon the individual. Gate operation is not electrically interconnected into approaching train or vehicular traffic signal systems.

Application of swing gates depends upon the particular conditions associated with the trackway crossing or light rail station. Generally, TriMet prefers barrier free access to its light rail stations.

Swing gates may be appropriate where:

- Pedestrian to train sight lines are restricted;
- A high likelihood exists that persons will hurriedly cross the trackway;
- Channeling or other barriers reasonably prevent persons from bypassing the swing gates; and
- Acceptable provisions for opening the gates by disabled persons can be provided.

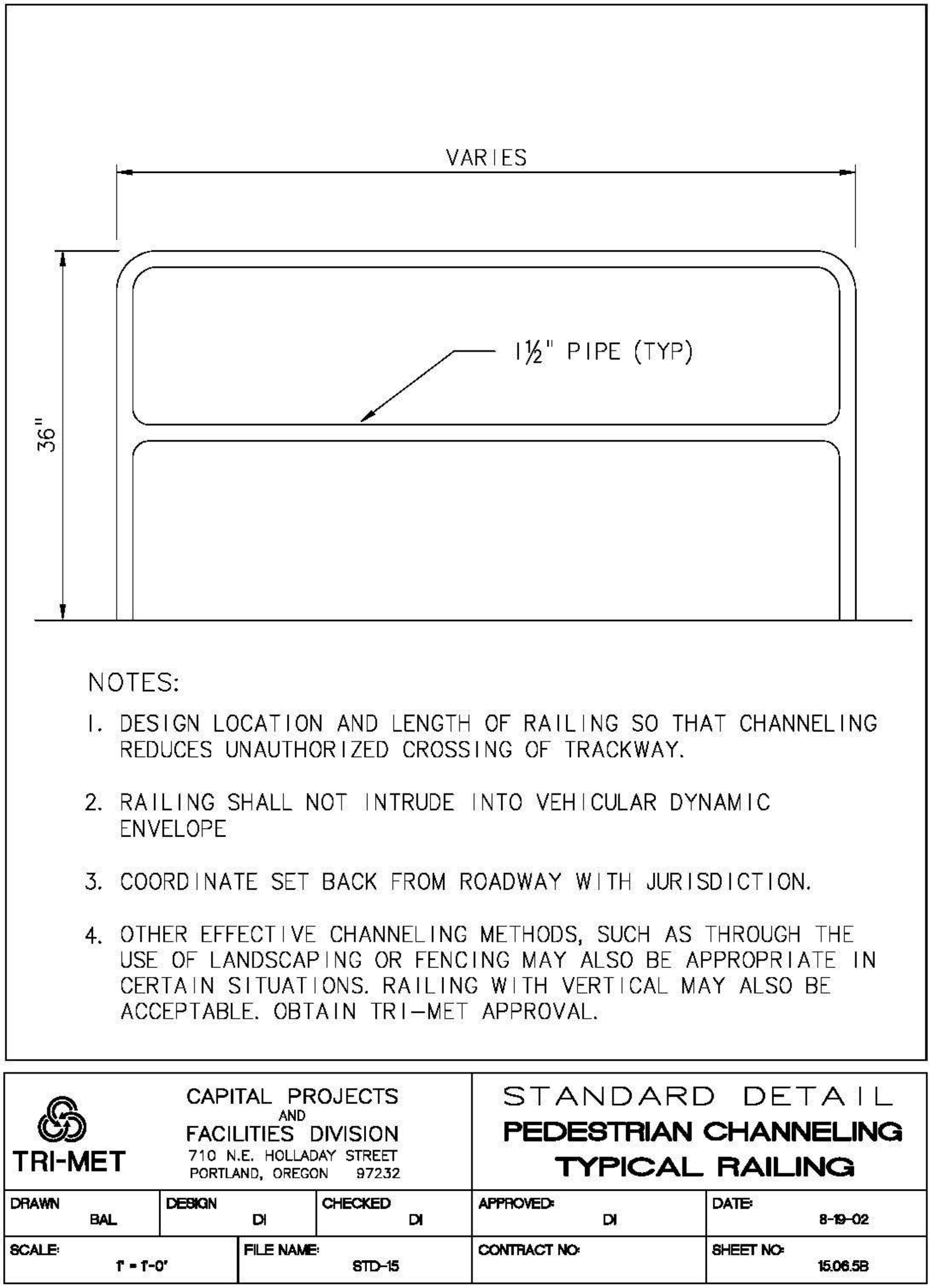


FIGURE 4 Typical railing for pedestrian channeling.

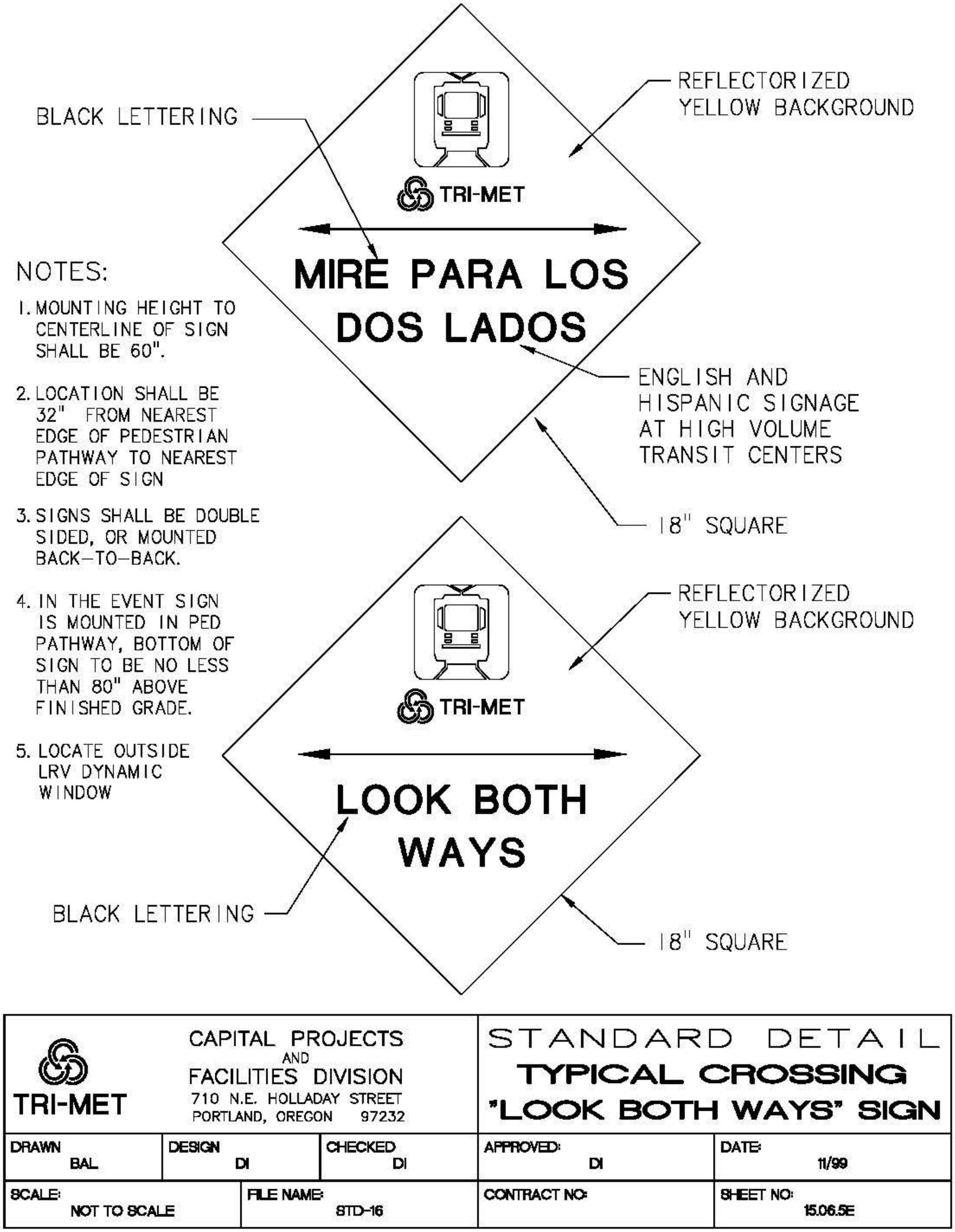
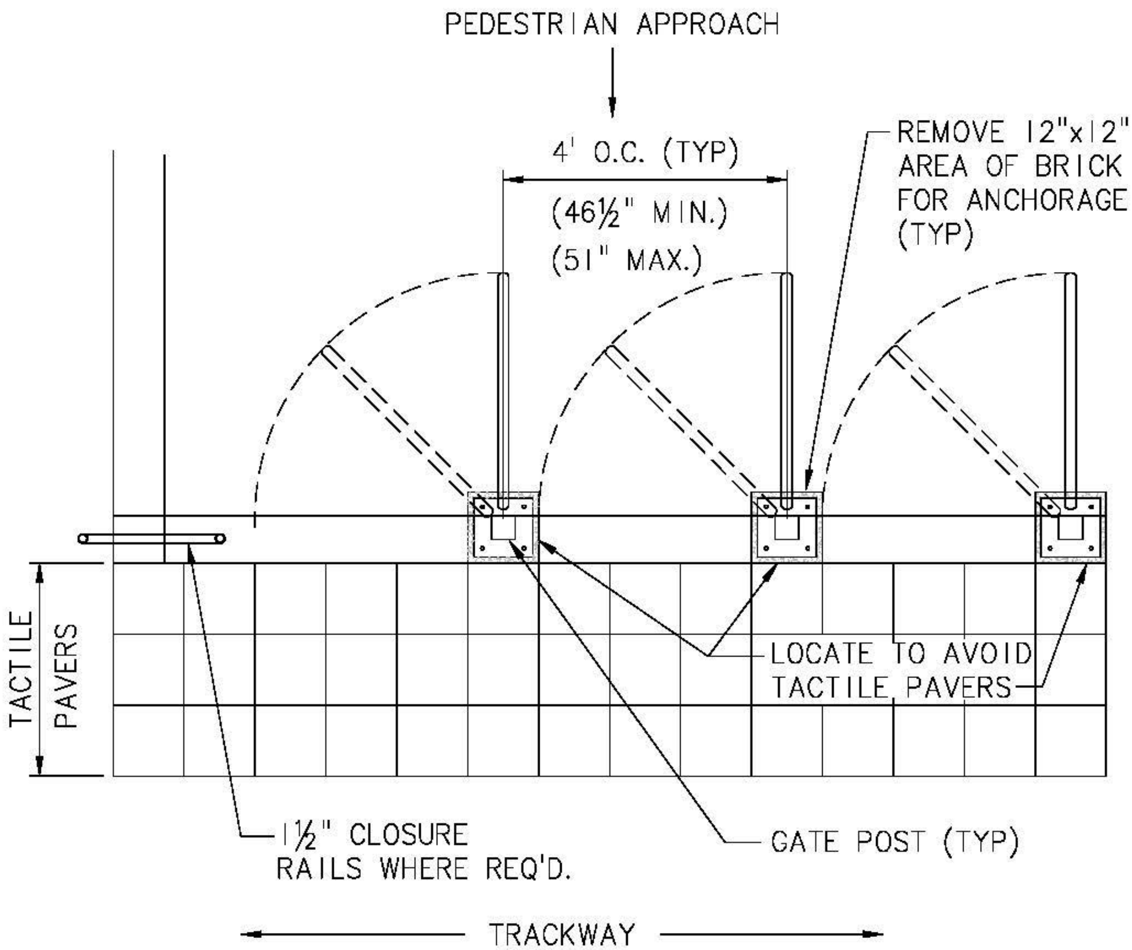


FIGURE 5 Typical crossing "Look Both Ways" sign.



1. GATES SHALL OPEN AWAY FROM TRACKWAY AND RETURN TO THEIR CLOSED POSITION THROUGH SPRING OR GRAVITY OPERATION.
2. AT STATION PLATFORMS, PROVISIONS SHALL BE MADE FOR ADA COMPLIANT PUSHBUTTON OPERATION OF ON SET OF GATES.

TRI-MET	CAPITAL PROJECTS AND FACILITIES DIVISION 710 N.E. HOLLADAY STREET PORTLAND, OREGON 97232		STANDARD DETAIL PEDESTRIAN CROSSING SWING GATE INSTALLATION	
DRAWN BAL	DESIGN DI	CHECKED DI	APPROVED: DI	DATE: 11/12/02
SCALE: NOT TO SCALE	FILE NAME: STD-22		CONTRACT NO:	SHEET NO:

FIGURE 6 Pedestrian crossing swing gate installation.

The disadvantages of swing gates also should be considered prior to proposing their use. Generally, the swing gates have proven effective in slowing access across the trackway. However, swing gates require regular maintenance to ensure proper operation. Additionally, at light rail stations, TriMet requires provisions for push button operation of one set of gates that is compliant with the Americans with Disabilities Act (ADA).

Pedestrian Barriers

Figure 7 details pedestrian barriers. Similar to swing gates, these barriers are intended to slow persons who are hurriedly approaching the trackway. A major advantage of barriers is that there are no operating parts or systems to maintain.

Pedestrian barriers may be appropriate where:

- Pedestrian to train sight lines are restricted;
- A high likelihood exists that persons will hurriedly cross the trackway;
- Channeling or other barriers reasonably prevent persons from bypassing the barriers; or
- Adequate space is available to accommodate their installation.

Pedestrian Z-Crossings

Figure 8 details a pedestrian Z-crossing installation. The purpose of this standard is to promote uniform application and safety features within the TriMet system.

In general, TriMet does not advocate the installation of pedestrian Z-crossings. Z-crossings occur at mid-block locations, rather than at vehicular intersections, and consequently are inherently less safe than traffic-controlled intersection crossings. Nevertheless, circumstances or community desires may result in incorporation of Z-crossings into the planning and design.

Pedestrian Z-crossings should cross the track as closely as possible to perpendicular, or with a slight angle so that a person is oriented facing the nearest, oncoming train direction. Care shall be taken to ensure compliance with ADA standards including path finding.

If a pedestrian Z-crossing is approved by TriMet and the jurisdiction having authority, consideration should be given to the incorporation of active audible or visual warning devices with it, in conjunction with the passive safety treatments. Audible or visual warning devices will require electrical interconnection with traffic signal or light rail signal systems in order to activate the devices. The installation requires careful engineering to ensure safe crossing clear-out time, given the LRV design speed and safe braking distance at each location.

"Do Not Cross Trackway" Signage

At station platforms in tie and ballast trackway, TriMet requires the placement of a warning notice on the vertical edge of the platform opposite customers who await oncoming trains. The warning notice shall read "Do Not Cross Trackway." Easily readable, painted black lettering over a white background may be used.

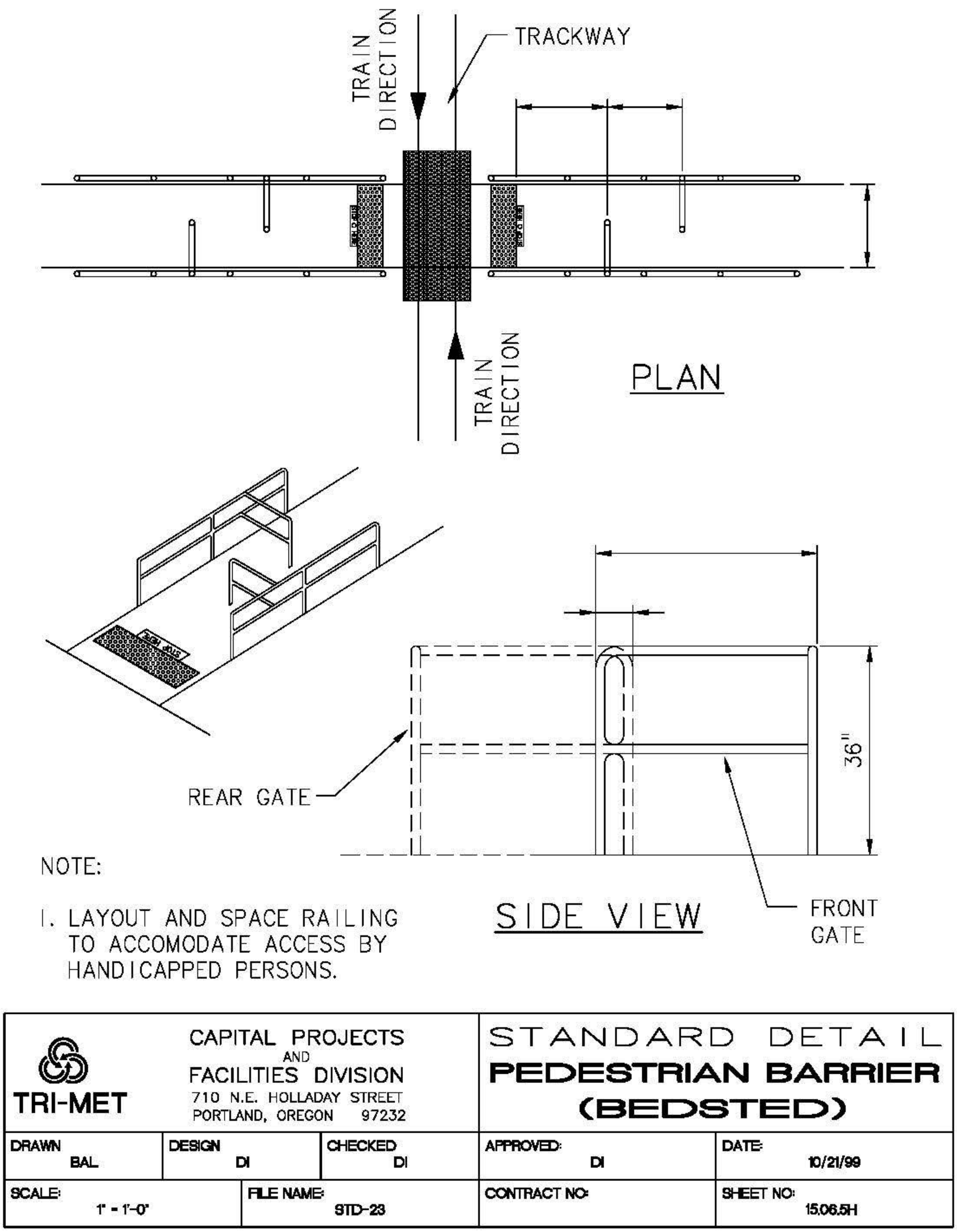


FIGURE 7 Pedestrian barrier.

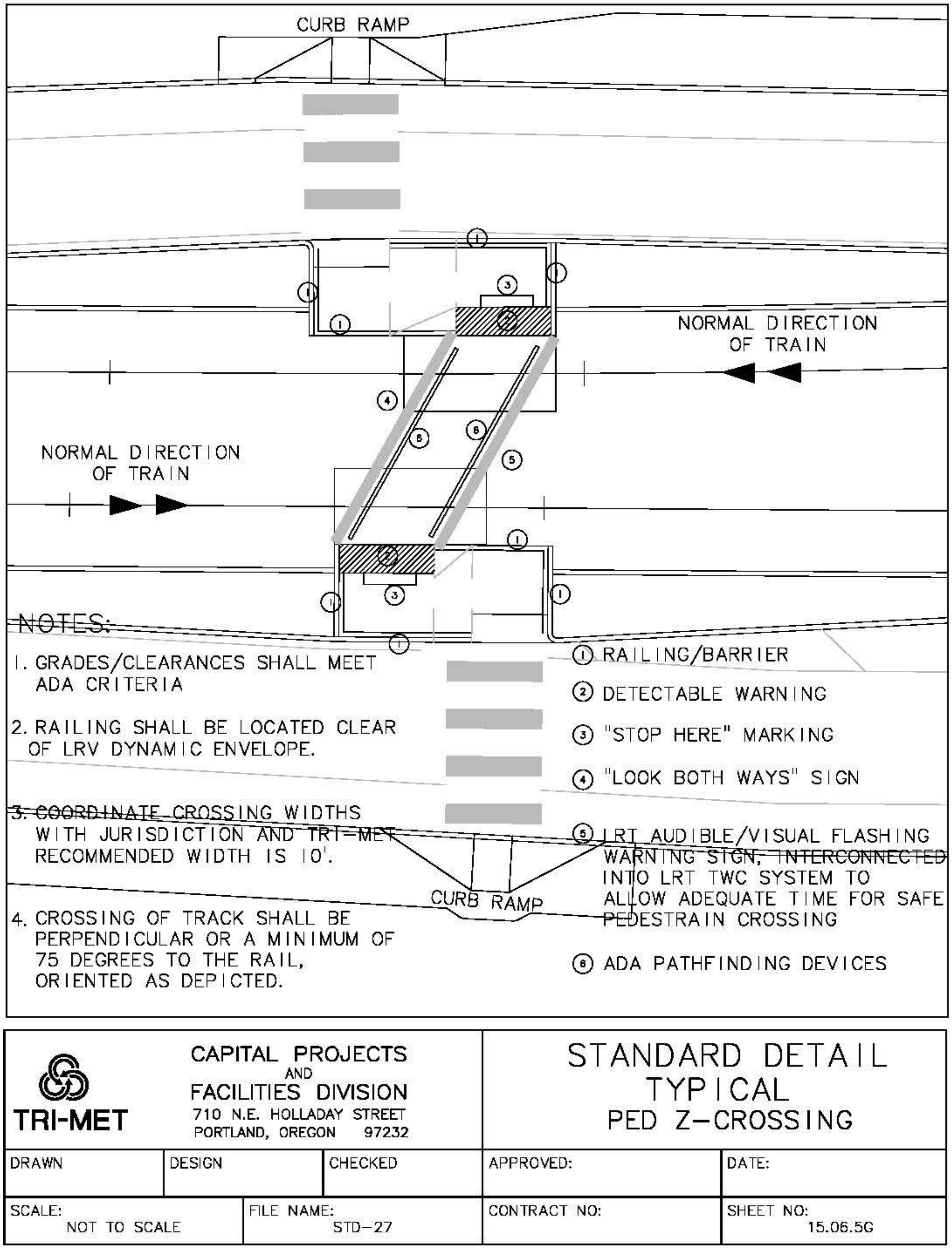


FIGURE 8 Standard detail of typical pedestrian Z-crossing.

Active Safety Treatments

An approaching train automatically activates these devices. These systems may consist of automatic gates, flashing light signals, traffic control signals, warning signs, audible signals, and other active warning devices.

LED Flashing Train Warning Signs

TriMet light rail operations has found that flashing train signs are an effective warning device for both pedestrians and motorists. Figure 9 depicts such a device in a pedestrian application.

To warn motorists of an approaching train at traffic signal controlled intersections, consideration should be given to incorporation of LED flashing train signs on traffic signal mast arms or poles in the following situations:

- Left turns by motorists are permitted across the trackway,
- Cross traffic motorist volumes are high,
- Line of sight obstructions limit motorist ability to see oncoming trains, or
- There is a high volume of slow moving or turning truck traffic across tracks.

TriMet has installed LED flashing signs overhead at several locations for motorists. Examples are 10th and Washington in Hillsboro, 18th and Salmon in downtown Portland, and 82nd and Airport Way. On Interstate MAX, which is currently under construction, the signs have been incorporated into the design at all left turns across the trackway, at cross streets with high volumes of traffic, and at certain obstructed crossings.

At pedestrian crossings at intersections equipped with traffic control signals, pedestrians cross the light rail tracks in response to standard “Walk” and “Don’t Walk” signal indications. Generally, a pedestrian LED flashing sign and audible warning device is not required in the traffic signal controlled environment.

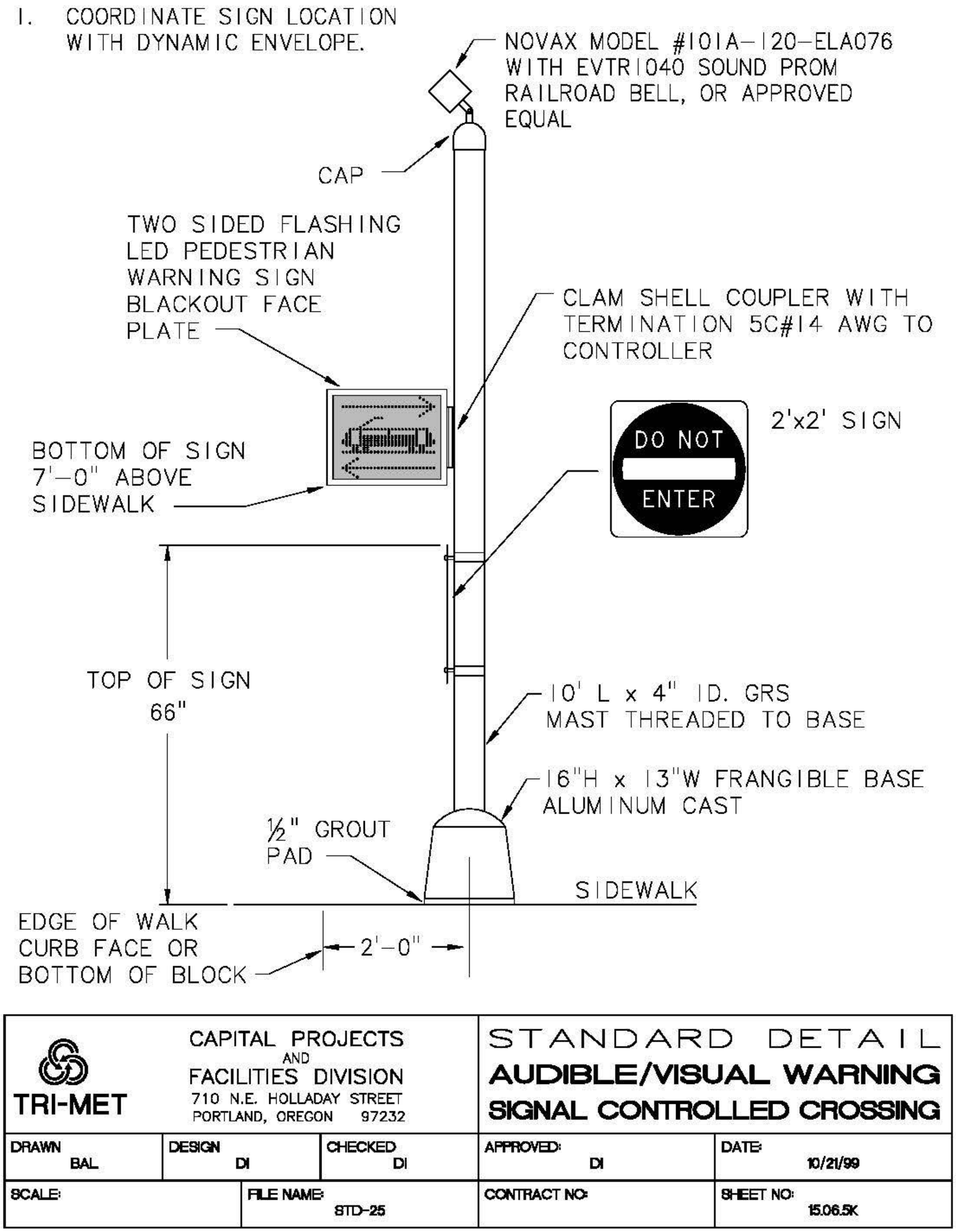


FIGURE 9 Audible or visual warning signal controlled crossing.

The device may be appropriate where:

- LRV design speed at the location exceeds 15 mph,
- The LRV operates in the median of city streets,
- Motor vehicle traffic is discouraged within the trackway and does not normally share the use of the light rail trackway, and
- The pedestrian crossing is an unsignalized mid-block crossing or is at a traffic signal controlled intersection adjacent to a platform.

Pedestrian Flashing Lights and Audible Warning Device in Gated Crossing Controlled Environments

Figure 10 depicts the Pedestrian Flashing Lights and Audible Warning Device that operates when a LRV is approaching in a train signal controlled environment. The purpose of this device is to warn pedestrians against crossing the trackway as trains approach.

This device is used where automatic crossing gates, lights, and bells are provided to warn of an approaching train. This standard should be considered where:

- LRV design speed at the location exceeds 25 mph,
- The LRV operates in a semi-exclusive right-of-way, and
- Sight distance considerations or heavy pedestrian or bicycle activity warrant its use, and
- Oregon Department of Transportation (ODOT) Rail crossing order permits its use.

Automatic Pedestrian Gates

Figure 11 depicts an Automatic Pedestrian Gate installation. The purpose of this device is to prevent or discourage a pedestrian or bicyclist from crossing the trackway when a train is approaching. These gates are electrically interconnected into and activated by the train signal system.

Automatic pedestrian gates should be used only when severe safety hazards or risks, that cannot otherwise be eliminated, exist in the train control signal environment. The circumstances for application of this standard include the following:

- Train speeds exceed 35 mph,
- LRVs are operating in a semi-exclusive right of way,
- Pedestrian-to-train sight distance or visibility is severely limited,
- A safe refuge area between the gates and LRV dynamic envelope can be provided, and ODOT Rail approves use

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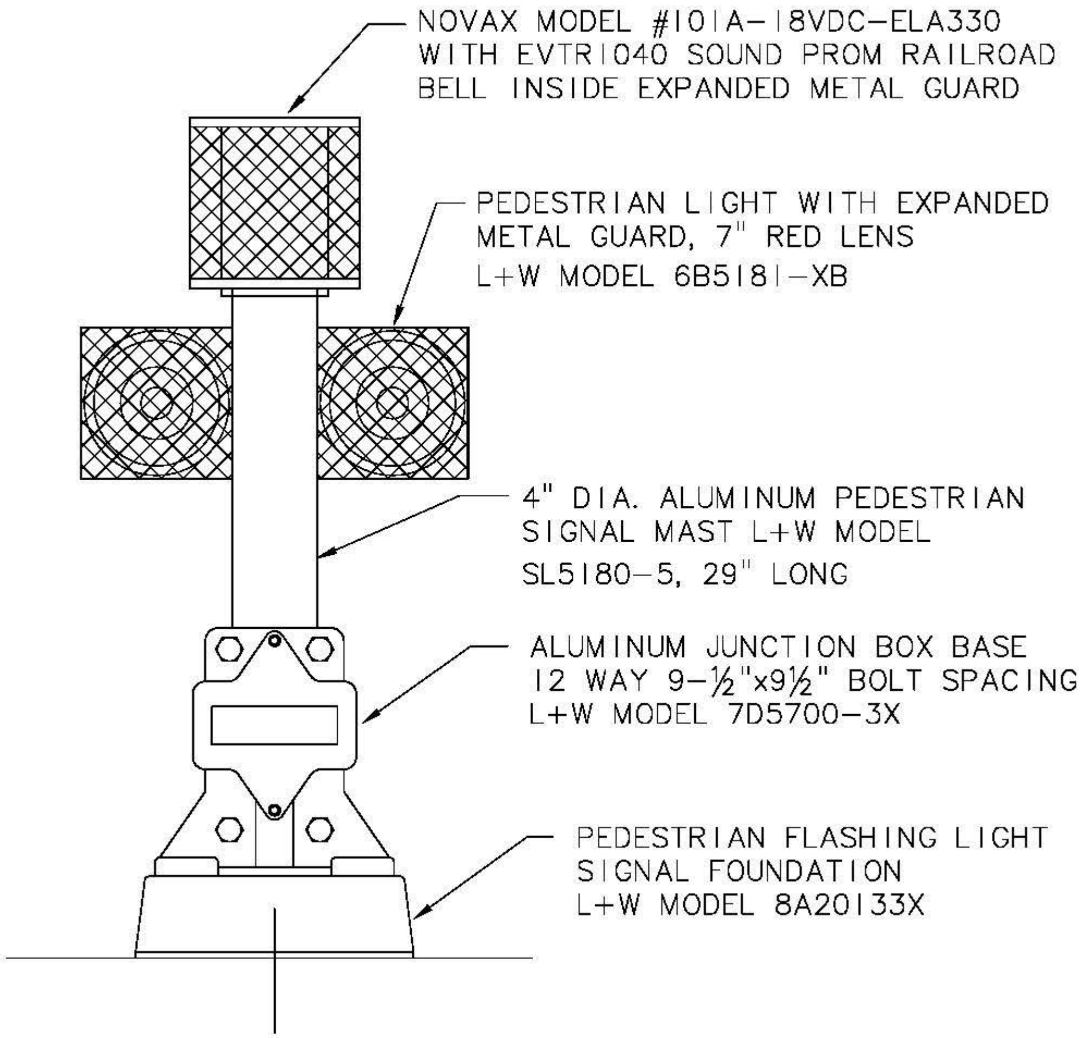
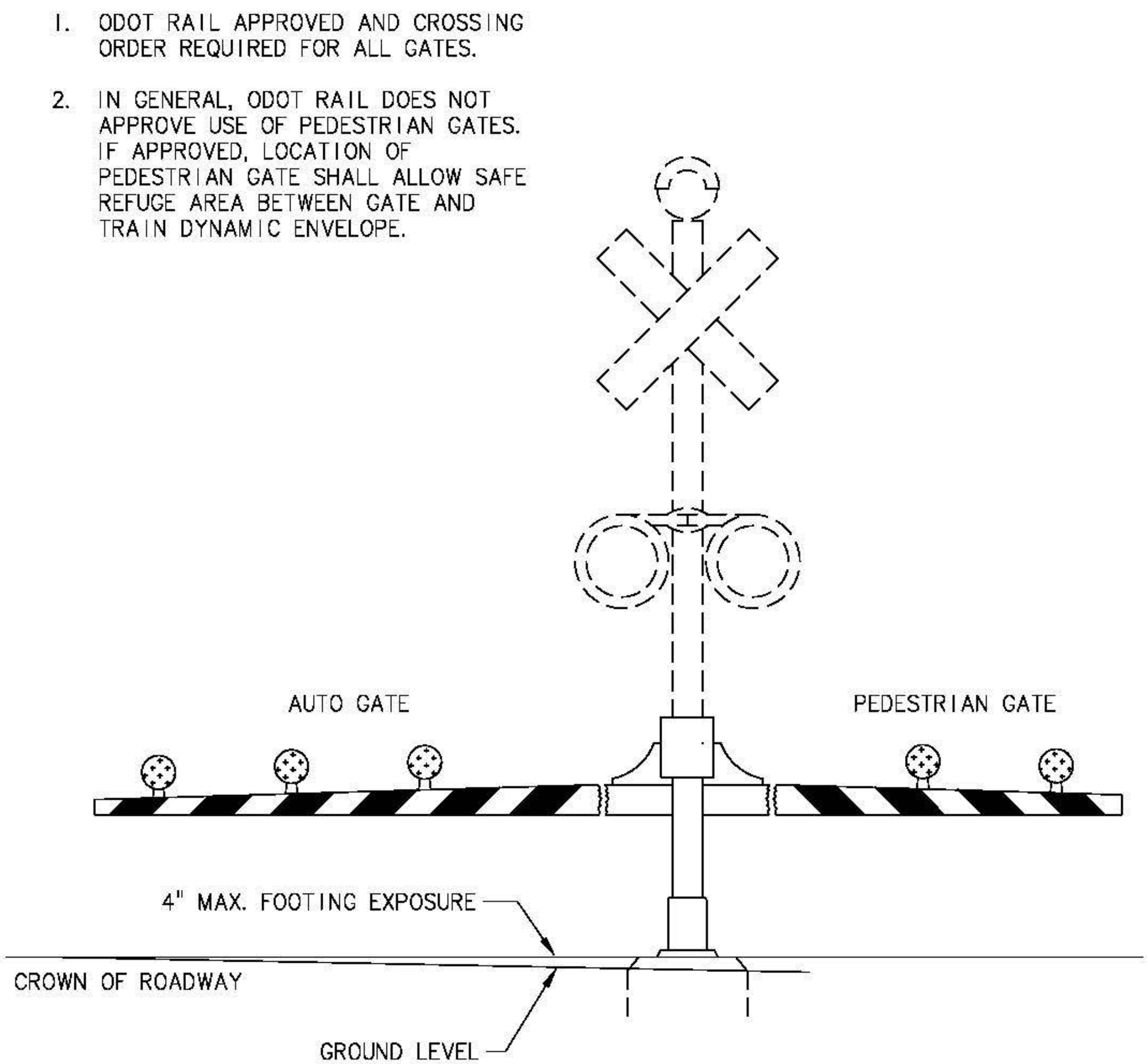


TRI-MET	CAPITAL PROJECTS AND FACILITIES DIVISION 710 N.E. HOLLADAY STREET PORTLAND, OREGON 97232		STANDARD DETAIL AUDIBLE/VISUAL WARNING GATED CROSSING		
DRAWN BAL	DESIGN DI	CHECKED DI	APPROVED: DI	DATE: 10/21/99	
SCALE:	FILE NAME: STD-26		CONTRACT NO:	SHEET NO: 15.06.5L	

FIGURE 10 Audible or visual warning gated crossing.



TRI-MET	CAPITAL PROJECTS AND FACILITIES DIVISION 710 N.E. HOLLADAY STREET PORTLAND, OREGON 97232		STANDARD DETAIL **AUTOMATIC AUTO/PED GATE**	
DRAWN: BAL	DESIGN: DI	CHECKED: DI	APPROVED: DI	DATE: 08/06/01
SCALE:	FILE NAME: STD-28		CONTRACT NO:	SHEET NO: 15.06.5M

FIGURE 11 Automatic automobile or pedestrian gate.

In general, ODOT Rail disapproves of the use of automatic pedestrian gates. An exception may be approved only when extreme circumstances exist and when no other treatments are feasible. TriMet only has one automatic pedestrian gate installation. Its location is at 28th Avenue in Hillsboro. Severely restricted sight distance coupled with train speeds exceeding 35 mph were major considerations in this application. Layout and placement must consider ADA requirements, ensure safe refuge between the gate and train envelope, and comply with the ODOT Rail crossing order.

APPLICATION OF CRITERIA AND STANDARDS

Application of the criteria is dependent upon the operating environment. The exclusivity of use, LRV design speed, line of sight, and other conditions must be considered.

Exclusivity of Use

A semi-exclusive use, light rail-operating environment is a light rail alignment in a separate right of way, or along a street or railroad right of way, where motorists, pedestrians, and bicyclists cross at designated crossings only. An example is Interstate MAX where light rail operates in the median of Interstate Avenue. Along the alignment, traffic signals and crosswalk pavement markings permit pedestrians to cross Interstate Avenue and to access station platforms located in the median.

A mixed-use, light rail-operating environment is a light rail alignment in mixed traffic with motorists, pedestrians, and bicyclists. An example is MAX light rail service in downtown Portland between the Steel Bridge and Jefferson Street, and in downtown Hillsboro between 1st and 10th Avenues.

An exclusive use, light rail-operating environment is a light rail alignment that is grade-separated or by a barrier that prevents intrusion by motorists, pedestrians, and bicyclists. Examples are the Washington Park tunnel, Interstate Max light rail-only structure from Argyle to Delta Park/Vanport station, and segments of Airport MAX. TriMet light rail crossing safety treatments generally are inapplicable, because motor vehicles, pedestrians, and bicycles are prohibited within exclusive right of way.

LRV Design Speed

Application of safety treatments requires consideration of numerous conditions. TriMet's safety committee considered numerous flow charts and approaches in trying to decide how to organize the application of the treatments. TriMet decided to organize application of the criteria around LRV design speed for three primary reasons. First, the committee desired an easily understood starting point so that staff and consultants would apply the criteria as intended. Secondly, TriMet's existing light rail system is easily categorized by design speed and the selected break points. Third, TriMet's experience is that the severity of safety hazards and risks increases with LRV speed.

Table 1 categorizes application treatments based upon the LRV design speed. Design speeds with possible treatments are grouped as follows: 1) 15 mph and less; 2) 35mph and less, but greater than 15 mph; and 3) greater than 35 mph.

TABLE 1 Pedestrian Crossing Application Chart

	LRV DESIGN SPEED		
CROSSING CONDITION	**15 MPH AND LESS**	**16 TO 35 MPH[a]**	**GREATER THAN 35 MPH**
Ordinary, no special conditions	Detectable Warning only	Basic treatment.	Basic treatment; AT
Special Conditions: Treatments listed below are in addition to those above			
Moderate Sight Restriction[b]	----	Channeling; AT; PT gates/barriers	Channeling; AT; PT gates/barriers
Severe Sight Restriction**	----	Channeling; AT; Automatic ped gates	Channeling; AT; Automatic ped gates
High Pedestrian Activity	----	Channeling	Channeling
Extreme pedestrian surges, high pedestrian non-attention or hurried behavior; school zone; transit centers	Basic treatment; Channeling	Channeling; AT; PT gates/barriers	Channeling; AT; PT gates/barriers
Angled crossing or odd geometry; mid-block pedestrian Z-crossings	Basic treatment; Channeling; PT gates/barriers	Channeling; PT gates/barriers; AT	Channeling; PT gates/barriers; AT

NOTES: Basic Treatment: “Stop Here” pavement marking; Detectable warning; “Look Both Ways” signage. Other Passive Treatments: Channeling; PT Swing gates or Pedestrian barriers. Active Treatments (AT): Pedestrian flashing signs/lights and audible warning devices. Other Active Treatments: Automatic pedestrian gates
This chart is intended as a guide only, and not a mandate, as to what treatments should be applied. Perform safety analysis for each location. Apply treatments in a manner consistent with all TriMet design criteria and other governing code and regulatory requirements.
[a]Crossings immediately adjacent to light rail platforms fall into this category.
[b]Eliminate sight restrictions if feasible. Comply with train-person line-of-sight criteria.

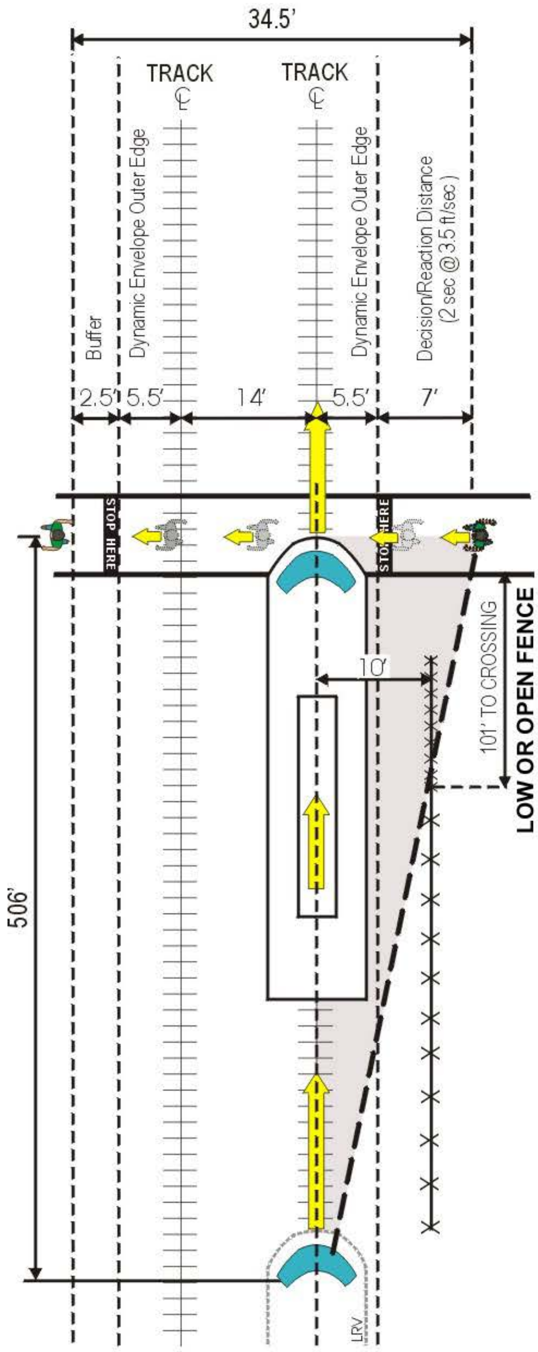
Line-of-Sight Between Persons and Trains

Clear sight lines between persons about to cross the trackway and approaching or leaving trains are important at all locations. TriMet, working with Korve Engineering, developed a pedestrian sight triangle to assist in planning and design. A pedestrian sight triangle may be applied as demonstrated in Figure 12.

On Westside, TriMet encountered several specific line-of-sight obstructions. As a result, TriMet recommends the following:

- Avoid landscaping other than low-growing ground cover in and adjacent to trackway,
- Where sound walls are required for noise mitigation, ensure height does not violate the line-of-sight criteria, and

Figure 4. PEDESTRIAN SIGHT TRIANGLE



CASE: LRV Approaching Crossing at 35 mph

Figure 4 illustrates sight distance required for pedestrian to safely cross two tracks, covering a distance of 34.5 feet

Assumptions:

- Two track configuration
- LRV approaching from left to right on first track
- Time required by pedestrian to travel 34.5 feet, based on 3.5 feet per second walking speed = **9.86 seconds**
- Fence 10 feet from centerline of near track

Minimum Crossing Distance, 34.5 feet, where:

- 7.0 ft is the distance traveled at 3.5 feet per second during decision/reaction period of 2 seconds
- 5.5 ft is the distance from the centerline of the near track to the outer edge of the dynamic envelope of the near track
- 14.0 ft is the distance between the centerlines of the two tracks
- 5.5 ft is the distance from the centerline of the far track to the outer edge of the dynamic envelope of the far track
- 2.5 ft is the width of the buffer/clearance zone beyond the track and dynamic envelope

LRV Braking Distances for Unanticipated Stops

LRV Speed (mph)	LRV Traveled Distance (ft) in 9.86 sec.	Full Service Braking Distance (ft)	Emergency Braking Distance (ft)	Distance of Low or Open Fence
15	217	110	81	43
25	362	244	175	72
35	***506***	***428***	302	***101***
45	651	660	462	130
55	795	942	654	159

Fence Height

Based on distance of 506' covered in 9.86 seconds and 7' reaction time, fence height should not obstruct view 101' from crossing.

Figure NOT TO SCALE

FIGURE 12 Pedestrian sight triangle illustration.

- Avoid placement of buildings or large cabinets on or immediately adjacent to platforms and crossings.

Other Conditions

In addition to exclusivity of use, LRV design speed and line-of-sight between persons and trains, other special considerations may exist. These include

- Degree of sight restriction
- Volume and frequency of pedestrian activity
- Likelihood of pedestrian inattention or hurried behavior
- School zone proximity
- Alignment geometry such as terrain or angled crossing paths.

CONCLUSION

Since Westside MAX, TriMet has applied the criteria to its light rail extension and improvement projects. Projects include Airport MAX and Interstate MAX extensions, and various improvements to the existing Westside and Banfield alignments. The criteria have raised the safety awareness level of those persons who plan, design, construct, and operate the system. Management processes, involving RCRC and project specific safety hazard and risk review teams, encourage independent review and application of the criteria as conditions warrant. The result is a system that is planned, designed, and operated as safely as possible.

Resolving Union Pacific Railroad Intermodal Concerns from TriMet's Interstate MAX LRT Line

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During the final design of Tri-County Metropolitan Transportation District of Oregon's (TriMet's) Interstate MAX project, a LRT station was located at an intersection that serves as the main truck access to the Albina Intermodal Freight Yard of Union Pacific Railroad (UPRR) and to the River Street businesses in the Lower Albina Industrial District. The railroad raised concerns about the impact the station location might have on truck movements on Interstate Avenue at Russell Street, particularly with respect to inadequate signal time and turning radii. In addition, the local businesses were concerned with the cumulative impacts of the LRT project along with the UPRR's own train yard improvements at Russell Street and a proposed City of Portland railroad grade separation project over the UPRR tracks to improve traffic movements from the River Street businesses to Interstate Avenue.

In response to these concerns a traffic model was developed that simulated the intense truck activity along Interstate Avenue within the Lower Albina Industrial district, currently and in the future, which also incorporated the three overlapping projects. Through this detailed, iterative traffic simulation modeling effort, a series of design modifications to the two public projects were made to mitigate the traffic concerns, maintain the UPRR Intermodal Yard entrance, and reinforce the Lower Albina District as an industrial sanctuary with improved access to the River Street businesses.

INTRODUCTION

Tri-County Metropolitan Transportation District of Oregon's (TriMet's) Interstate MAX Project to extend the existing light rail system 7 mi to the north of the Rose Quarter Transit Center dealt with several significant challenges during final design of the $350 million project in 1999. The LRT route traverses the Lower Albina Industrial District, a small industrial sanctuary area, which borders Interstate 5 on the east and the Willamette River on the west (see Figure 1). The district's northern boundary is the UPRR's Albina Manifest and Intermodal Yard, and is narrowed down to the south by Interstate Avenue and Broadway Bridge.

Several businesses in the Lower Albina Industrial District identified concerns with the loss of two traffic lanes on the five lane arterial street paralleling Interstate 5 north towards Vancouver, Washington. One of those businesses, the UPRR, was concerned with the potential for trucks

FIGURE 1 Interstate MAX alignment.

entering UPRR's Intermodal Yard to block light rail traffic on Interstate Avenue, thereby forcing UPRR to relocate the truck entrance to the Yard, or possibly the entire Intermodal Yard itself.

This was complicated by the convergence of two additional multimillion dollar projects within an eight-block section of Interstate Avenue. The UPRR was making modifications to several buildings near the Russell Street intersection along with track improvements to the south. Moreover, at the southern end of the Lower Albina District, an overpass was proposed to alleviate the queuing resulting from train blockages at the five grade crossings of the UPRR tracks south of Russell Street.

Through a detailed traffic modeling effort, a series of design modifications to the light rail project and the Lower Albina Overpass were made to 1) mitigate the concerns of the industrial businesses; 2) maintain the UPRR Intermodal Yard entrance; and 3) reinforce the Lower Albina District as an industrial sanctuary.

The Challenge of Three Overlapping Projects

The challenge to the light rail project was how to accommodate these construction projects together without adversely impacting the businesses in the Lower Albina Industrial District, forcing the relocation of the UPRR Intermodal Yard, and potentially delaying the LRT project.

The first project was privately funded and on its own schedule. UPRR was in the process of relocating its crew change quarters from Brooklyn Yard (5 mi to the south) to Albina Yard near Russell Street in order to improve Amtrak travel times through Brooklyn Yard. In addition, UPRR was designing an upgrade of the track nearest to Interstate Avenue, known as Track 100, as the mainline through track around the perimeter of the Intermodal and Train Manifest Yard to reduce congestion within the Yard and along the approach tracks to the Yard, as shown in Figure 2. Track 100 affords the UPRR a more fluid way to run through trains north to Seattle and east towards Idaho and the Midwest. When UPRR bought the Southern Pacific Railroad in 1996, the I-5 corridor became a far more important route into California and the Pacific Northwest. Trains north and south need to pass through the Albina Yard area, which becomes very slow when switching is required. The run through Track 100 would help increase traffic flows and train speeds.

The second project was partially funded based on a public–private partnership. The UPRR was also under pressure to address the problem of frequent train blockages at the five grade crossings on the approach tracks at the south end of the Yard (see Figure 3). The UPRR was paying heavy monetary fines associated with blockages of grade crossings for longer than 10 min in the Lower Albina District. Several of the businesses that were blocked by train activity had time sensitive materials, such as freshly mixed concrete, leaving the district for delivery. Businesses west of the railroad tracks were being cut off from Interstate Avenue when those grade crossings were blocked by normal switching activities associated with the UPRR yard, and these events led to an effort by the City of Portland, the Lower Albina Industrial District, UPRR, and Oregon Department of Transportation Rail Safety Division to develop an overpass plan. By 1999, a type, size, and location study had identified that the optimal location for the new

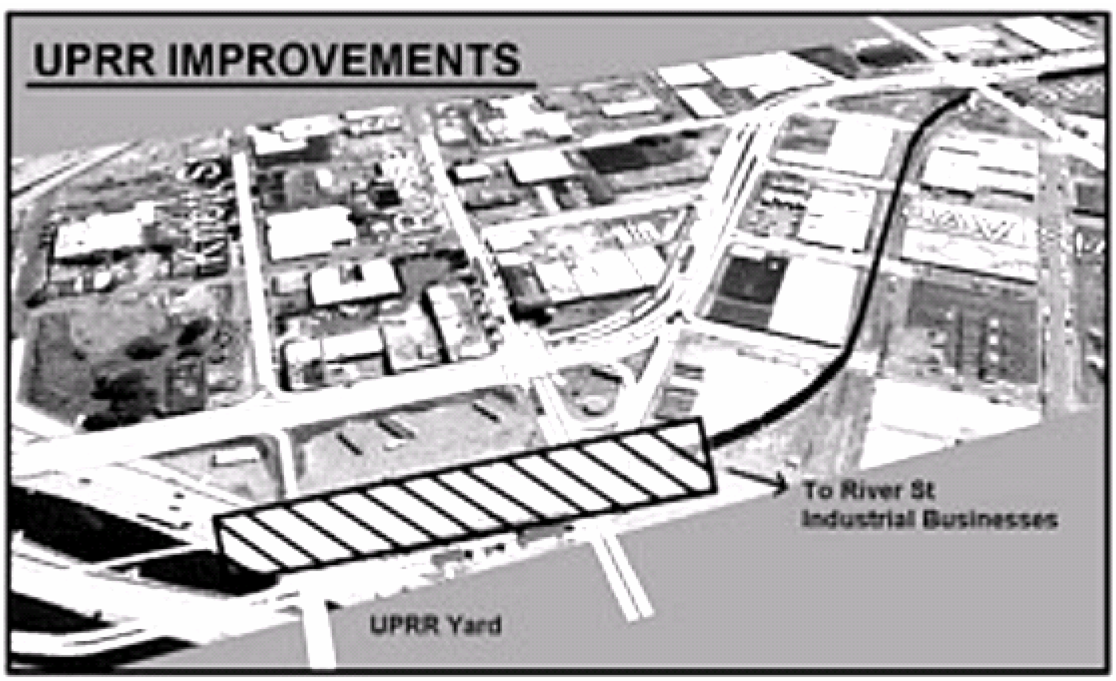

FIGURE 2 Union Pacific railroad improvements to Track 100.

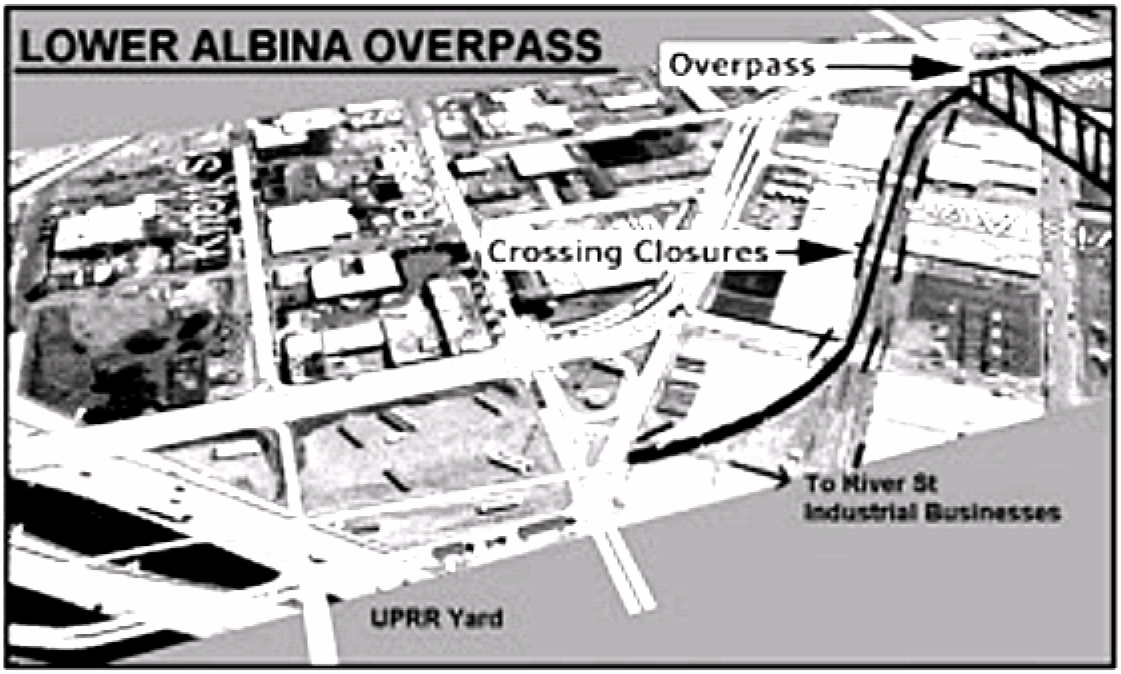

FIGURE 3 Lower Albina Overpass improvements.

overpass was at the south end of the district connecting into the existing intersection of Interstate Avenue with Tillamook Street. The businesses and users of the streets benefiting from the overpass were below the thresholds for full public funding of a major grade separation project within the city. As a result, a technical solution had been identified, the Lower Albina Overpass, but the project was only partially funded. As it stood, the estimated cost was $14 million. Although the city had secured federal highway funds and state crossing safety funds, had dedicated Transportation System Development Funds, and received a significant commitment of funding from UPRR, the project had identified a serious shortfall. A Local Improvement District (LID) had been discussed in the Lower Albina neighborhood, but the neighborhood was not willing to fill the entire gap with an LID. In addition, with the Interstate MAX Light Rail project starting up, time was becoming critical. TriMet's desire was to have the Overpass project completed before Interstate MAX construction began in order to avoid costly construction conflicts.

With TriMet's goal of building two tracks of LRT in the middle of Interstate Avenue and replacing the five-lane arterial with a two lane, two track cross-section, the businesses that were already affected by the UPRR train blockages raised additional concerns with the loss of truck capacity on Interstate Avenue. In addition, a key element in serving the Lower Albina area and Emanuel Hospital east of Interstate Avenue along Russell Street was locating a light rail station at the corner of Russell Street and Interstate Avenue, where several restaurants on the east side of the street were thriving (see Figure 4). The location of the station at the entrance to the Intermodal Yard increased UPRR staff concerns about the potential conflicts between pedestrians accessing the station and the wide turning movements of trucks exiting the Yard at Russell Street, as well as raising the question of who would get signal priority after the LRT

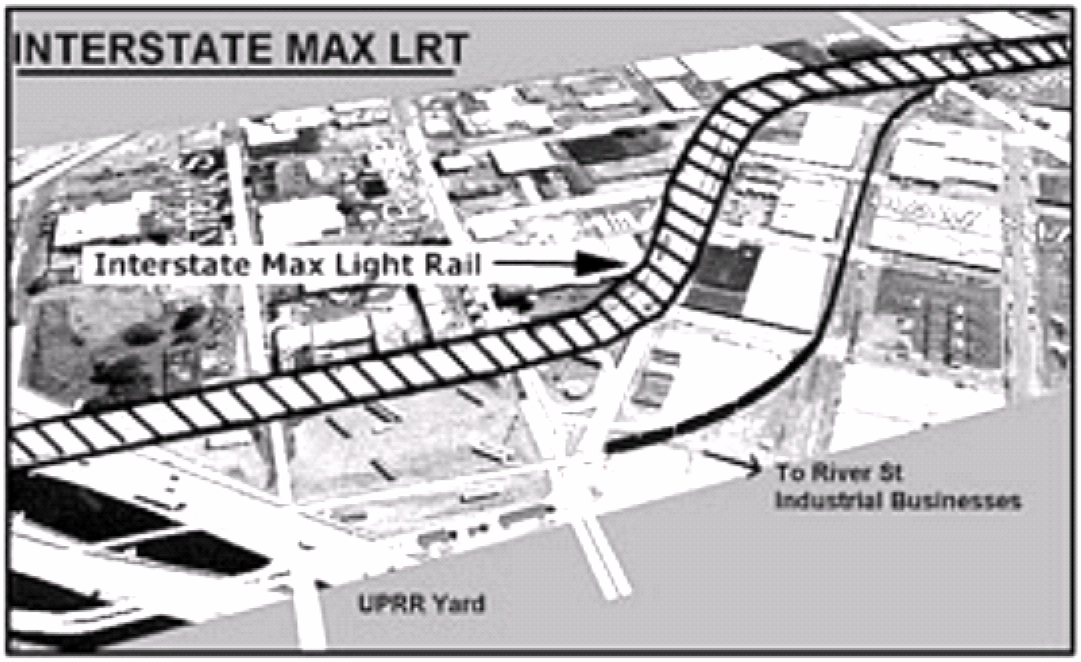

FIGURE 4 Interstate MAX alignment through Lower Albina.

trains. In addition, with the increase in UPRR train traffic on Track 100, the Intermodal Yard staff were concerned with UPRR being fined for trucks queuing up on Interstate Avenue due to a Track 100 train blockage and the trucks blocking vehicular and LRT traffic on Interstate Avenue. Along with the traffic issues was the potential for gentrification of the area around the Russell Street station, which was owned by UPRR on the west side of Interstate and used as truck and container storage for the Intermodal Yard. Both of these issues caused UPRR to raise the concern that the Intermodal facility was being incrementally pushed out of the Russell Street area and potentially displaced by the Interstate MAX project. UPRR started looking at alternative Intermodal sites with price tags in the range of more than $20 million for relocation.

Multimodal Modeling

As part of the preliminary engineering for the Interstate MAX project, TriMet had developed a standard multimodal traffic simulation model using computer modeling to visually represent how the street network would work with the predicted traffic volumes after the light rail line was built. The model incorporated the LRT traffic, and all classes of roadway traffic (i.e., 5% trucks, 1% buses, 94% automobile) along Interstate Avenue. The model did not assign additional truck movements from any of the side streets, such as Russell Street, as shown in Figure 5. In reviewing this analysis, the businesses in the Lower Albina District and UPRR raised concerns that the model did not reflect either the existing or future traffic since the truck movements were not typical of what they experienced daily on Interstate Avenue.

Based on these concerns, TriMet and the City of Portland revised their methodology to address the gaps identified by the business community. Additional traffic counts were collected along the side streets to expand the traffic model. The methods used are summarized in Table 1.

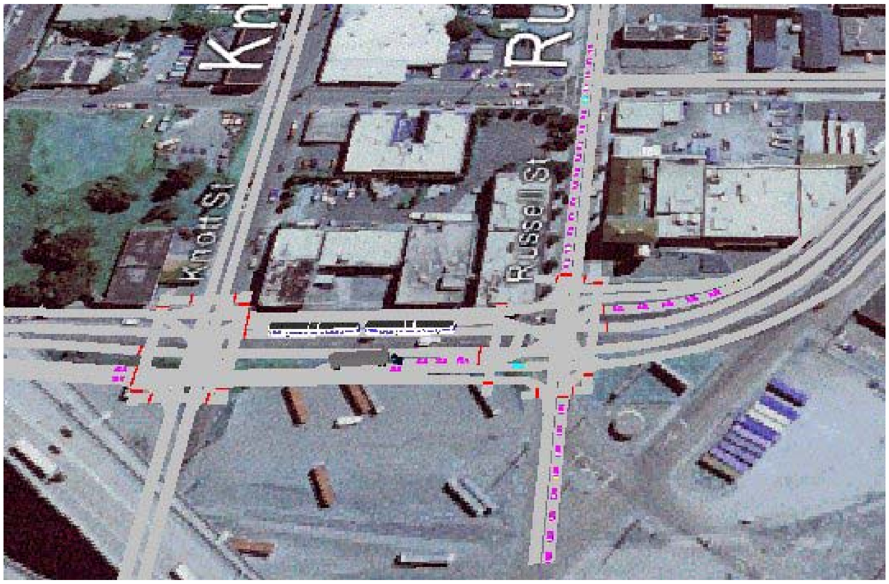

FIGURE 5 Initial traffic simulation model of Interstate Avenue at Russell Street. LRT vehicles are shown in white, buses in blue, trucks in gray, and passenger cars in pink. No train is shown on Track 100 or trucks on Russell Street.

TABLE 1 Lower Albina Truck Data Collections Methods

Method	**Data Collected**
Automatic Traffic Recorder	• General traffic pattern • Peak day • Peak hour • Heavy use streets (eg., Lewis and Knott)
Business Surveys	• Peak days and seasons • Picture during peak season by firm: number of trucks/time of day/truck type/direction • Seasonal growth (% increase over current for peak condition) • 5-year growth (% increase to use in future year forecasts)
Video Turning Counts	• Truck turning counts at intersections for peak hours • Speed and other operational characteristics of study area trucks • Movement conflicts (operational issues) • Direction and number of trucks • Train and truck interactions
Train Counts	• Average blockage delay at Knott, Russell, and Randolph Streets • Types of train movements • Future growth of train movements

The next step involved the compilation of a detailed truck survey from the businesses located along Interstate Avenue within the District. The business survey found that 85% of the trucks were entering and exiting the west side of Interstate Avenue at Russell Street, near the UPRR yard entrance. Half of the truck traffic accessing via Russell Street was associated with the Intermodal Yard, with the other half accessing the River Street businesses; such as the two concrete plants or the sand and gravel company. Truck movements were classified by direction arriving and exiting, time of day, day of week, seasonal peaks, and into 11 vehicle types running the gamut from semis and Western Doubles to concrete mixer trucks. One of the major elements to come out of the business survey information was that the peak truck traffic leaves the River Street area in the a.m. peak and returns evenly throughout the day.

For the truck traffic destined for the UPRR Intermodal Yard, data from the Automatic Traffic Recorders (hose counts) was correlated with vehicle counts from video taping of the major intersections entering the Yard, including Russell Street. The vehicle movements were tracked by direction arriving and exiting, time of day, day of week, seasonal peaks, and into 7 vehicle types running the gamut from doubles to vans and cars. Since UPRR was concerned that the LRT station at Russell Street would limit the throughput capacity of the existing Intermodal Yard, the truck data was converted into typical intermodal freight data, such as the gate count where UPRR takes custody of the trailers or containers. This gate count data correlated with the video counts once the containers that were rejected by the gate and the internal movements within the UPRR yard between storage lots were accounted for. One of the major elements to come out of the UPRR information was that the peak truck traffic accesses the Intermodal Yard at midday rather than an a.m. or p.m. peak. There is also a distinct increase in truck traffic accessing the Intermodal Yard on Mondays and Thursdays corresponding to intermodal train movements between Portland and Los Angeles.

The final element was to identify UPRR train movements affecting truck traffic movements within the district. One of the major elements controlling the function of the Russell Street intersection was the frequency and length of grade crossing blockages from UPRR trains. As part of the effort to quantify the types of blockages and predict future blockages, the frequency of and types of train movements on UPRR’s tracks were monitored. Train counts were collected for Tracks 100, 101, 102, and 528 (the locomotive engine repair shop lead) over several days. Data was collected by track with identification by direction of train, number of locomotives, type and length of train, time of day, day of week, grade crossings blocked, amount of time crossing blocked, length of traffic queue on either side of blockage, type of movement (switching, through movement, locomotive move, etc.). This information was then used to predict the increase in train movements on Track 100 from UPRR improvements as they might affect traffic queuing on Interstate Avenue from Russell Street for the Intermodal Yard.

From this data collection, the simulation model was revised to reflect the increase in truck movements in the a.m. and midday peaks, along with the interaction of the trucks queued up at Russell Street for the trains using Track 100. The traffic patterns in the simulation model were revised to shift all traffic accessing the businesses between the railroad tracks and the river to the proposed new overcrossing. It was also revised to incorporate pedestrian movements at signalized intersections, as they would access the LRT station and bus stops. The truck modes were expanded to reflect the concrete mixer trucks with their short wheel base along with the semis, doubles, and dump trucks accessing the River Street businesses. Truck types accessing the Intermodal Yard included single container trucks such as the typical WB 40 or WB 67 trucks. Also included were local delivery vans such as UPS deliveries. The resulting traffic model, as shown in Figure 6, reflected the experience of the businesses within the Lower Albina District and clarified the interactions of the LRT vehicles with the truck movements.

Findings

Once the simulation model incorporated a more accurate representation of typical truck movements and time of day truck peaks, the process of identifying the LRT impacts and developing mitigation measures began. The modeling demonstrated that the Lower Albina Overpass reduces the turning movements at the Russell Street intersection by 50%. It also showed that LRT train movements have little to no effect on truck queuing on Interstate Avenue, even with signal priority. The model also showed, however, that the pedestrian movements to the Russell Street Station competed with the trucks making left turns to exit the Intermodal Yard, limiting the number of trucks exiting the Yard per signal cycle. The extended traffic queuing on Interstate Avenue at Russell Street occurs only when a UPRR train blocks Track 100, as shown in Figure 7. Further iterations on the modeling identified that a single lane southbound, right turn into UPRR at Russell Street. may result in up to 20 blockages of Interstate Avenue annually for 3-5 min.

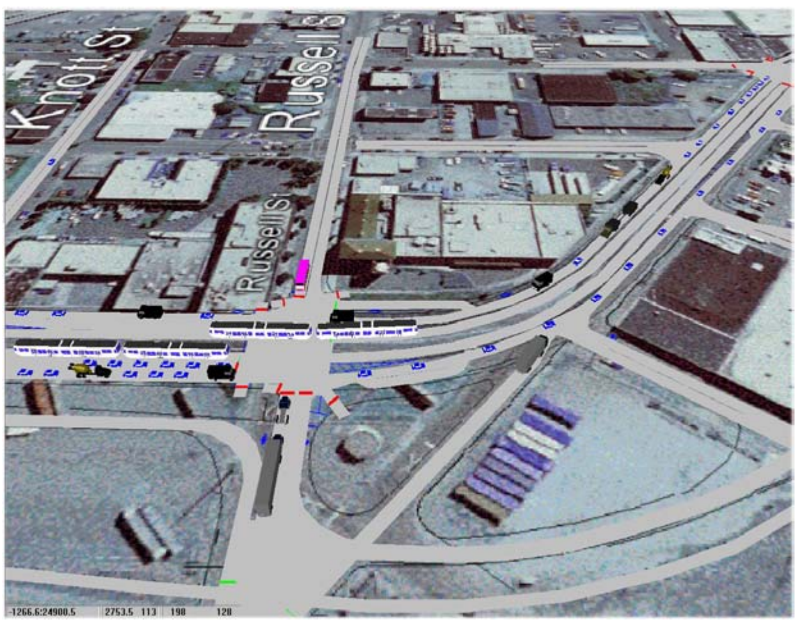

FIGURE 6 Revised traffic simulation model during typical traffic cycle with LRT priority. The gray trucks and pink buses are queued up at Russell Street for the LRT trains, and passenger cars are shown in blue intermixed with a higher number of trucks in the through traffic movements on Interstate Avenue.

FIGURE 7 Revised traffic simulation model at midday with Train 100 event. UPRR train blocks the Russell and Knott Street accesses, resulting in truck queuing on Interstate Avenue.

Project Modifications

Based on the impacts identified in the revised traffic simulation model, the following modifications were made to the Interstate MAX Light Rail Project:

1. The LRT station was shifted 3 blocks south to Albina Street and away from the Russell Street intersection. This separated the pedestrian and bus movements from the intermodal truck turning movements, addressing the UPRR concerns about the traffic congestion associated with the LRT station. The station shift also reduced the perceived land use pressure to redevelop the UPRR's Intermodal Yard parking lots next to Interstate Avenue to housing or other mixed use to support transit.
2. A dedicated double right turn lane to Russell Street westbound was constructed to optimize the truck queuing space on Interstate Avenue associated with grade crossing blockages from UPRR train movements. This additional queuing space minimizes the potential for UPRR Freight operations to adversely affect automobile or LRT train traffic on the rebuilt Interstate Avenue by increasing the right turn storage space. The double right turn was incorporated into the critical path as one of the first elements to be built as part of the construction traffic mitigation for the Interstate MAX project.
3. The Russell Street traffic signal was reprogrammed to accommodate long truck queues for the left turn movement exiting the Intermodal Yard onto Interstate Avenue.
4. Since the traffic model only worked if the Lower Albina Overpass removed half the truck traffic from the Russell Street intersection, the LRT project's critical path was revised to incorporate the Lower Albina Overpass as construction traffic mitigation.

Funding Challenges

Early funding discussions had included a small funding contribution from the LRT project to the Overpass project for accommodating changes in the bridge design to better function with light rail on Interstate Avenue. As a result of the traffic analysis, however, TriMet increased its contribution helping to fill the gap. A LID was then formed, incorporating the properties in the Lower Albina district west of Interstate Avenue including UPRR, and the City of Portland increased its contribution. The funding gap was nearly closed but time had advanced and the City no longer had time to build the bridge before light rail construction began. At this point the City and TriMet conferred, and as a result the City asked TriMet to construct the bridge with their LRT contractor, with the City and TriMet jointly managing its construction, thus reducing costs through efficiencies and eliminating the inevitable conflict of two independently hired contractors attempting to build simultaneously in a very compact neighborhood.

CONCLUSION

Through a detailed, iterative traffic simulation modeling effort, a series of design modifications to the two public projects were made to mitigate the traffic concerns, maintain the UPRR Intermodal Yard entrance, and reinforce the Lower Albina District as an industrial sanctuary.

The combined computer modeling of the three overlapping projects allowed the technical discussions to focus on the pertinent traffic issues. The visual medium of the modeling software provided all parties with a compelling image of the complex, overlapping patterns. This allowed a clearer understanding of what impacts were associated with the light rail project versus freight rail. The cumulative risk analysis for freight blockages identified in the modeling allowed appropriate managing of risk for each project.

This allowed for the merger of the two public projects, which reduced the cost of the combined projects by narrowing the scope of the LRT project and minimizing the impacts to the UPRR Yard and access points. The resulting projects maintained the UPRR's competitive access to I-5 and surrounding street network from Interstate Avenue at Russell Street and the Swan Island area. The visual medium of the modeling allowed the City and UPRR to gain confidence in approving closure of grade crossings and reduction in traffic lanes crucial to the two projects. Finally, acknowledging the Interstate MAX project's dependency on Lower Albina Overcrossing for traffic mitigation allowed the funding reallocation to be adjusted, enabling the bridge to be constructed and traffic congestion to be relieved.

ACKNOWLEDGMENTS

The Interstate MAX Project Team included TriMet, Parametrix, Parsons Brinkerhoff, HDR Engineering, Inc., and Innovative Transportation Concepts (VISSIM Modeling). The Lower Albina Project involved the City of Portland, CH2M-Hill, Union Pacific Railroad, HNTB, and the Oregon Department of Transportation. Union Pacific Railroad improvements were coordinated by Union Pacific Railroad, the City of Portland, and the Rail Division of the Oregon Department of Transportation.

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Shared-Use Corridors
Survey of Current Practice and Recommendations for the Future

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The paper addresses current practice in shared use of rail corridors. For this purpose the paper reviews an inventory of such corridors performed recently for the Federal Railroad Administration. Design elements related to the design and construction of light rail transit (LRT) systems in joint use corridors, currently operating or under construction, are discussed. Design elements examined in existing and under construction joint use systems include grade separation, intrusion fences, crash walls, retaining walls, grade crossings, and drainage facilities. Recommendations for future action in regard to design and operation are developed based on the findings of the survey of the current practice. To assist the LRT designer with new projects, examples from existing LRT systems operating in shared corridors or such systems under construction is provided. The authors hope that this paper might serve as the first step in developing official design criteria and standards governing transportation corridors shared by LRT and freight railroad operations.

INTRODUCTION

In the last 20 years the light rail transit (LRT) systems, previously known as trolley operators, have been reintroduced in urban areas of increasing population density. Such urban areas have utilized highways and roadways to their full existing traffic capacity and adding lanes is either unfeasible or of lower cost-effectiveness from regional transportation and transit planning. The LRT, utilizing a few light rail vehicle (LRV) cars used for each trip, is also suitable for low-volume operations. It has provided an emerging mass transit means that have been reintroduced with a regional development vision of meeting future transit demands, to supplement and replace existing means of transportation and to revitalize declining existing urban centers.

The flexibility of the LRT of mixing with traffic on city streets, while also achieving relatively high speeds, enable it to take advantage of existing rail corridors and relatively lower costs. The number of transit project systems constructed in either abandoned or active freight rail corridors in the United States has increased in the last two decades. As this paper is being written, several transit systems within freight–LRT shared corridors are in construction or in various stages of planning and design. This trend is anticipated to increase due to the opportunities and advantages associated with the use of freight corridors in relation to land use category, available right-of-way (ROW), and economic benefits in light of dense urbanization in areas needing mass transit, existing zoning designations, and the rising land costs.

With all the advantages that the shared-use corridors offer to the transit authorities in developing LRT systems, the use of existing freight corridors for mass transit impose challenges. Most of the freight corridors were designed and constructed for transporting goods and materials. Also, the design and construction took place many years ago under old freight rail standards and not mass transit. The character of the area in which the freight rail was extended in swamps, flood plain or just the lowest area in the town receiving drainage that became the last tier of development after the freight rail was constructed and started operations. Grade crossings of local and major roadways were constructed after the rail was in place and some existed prior to the construction of the rail. However, the urban development condition in those days and frequency of freight rail operations have changed to densely populated areas with heavily traveled grade crossings. The mass transit now being developed needs to be designed under modern mass transit standards for project life of tens of years.

The Federal Railroad Administration (FRA) has a legal responsibility for the development and enforcement of safety regulations for the United States railroad industry while the development of the LRT project is usually sponsored by another federal agency, by the Federal Transit Administration (FTA). In a few cases, track is shared, and FRA regulations apply. However, in many locations, LRT share a common transportation corridor, or ROW, with freight trains. When track is shared, passenger-carrying vehicles must meet stringent safety requirements or freight and passenger operations must be time-separated. Regulations established jointly by the FTA and FRA and published in the Federal Register were reviewed (*1*). The existing regulations are general in nature. There are no specific design requirements. However, in practice, freight and passenger-carrying vehicles must meet stringent requirements, even when the LRT track and the freight railroad are as close together as two tracks on a double-track railroad. FRA defined these operations as “common corridors” when rail transit and railroad tracks are less than 200 ft apart, track center to track center. FRA regulations define adjacent tracks (shared ROW) where tracks are 25 ft or less center to center, while shared corridor relate to freight tracks and transit tracks, such as LRT, separated by more than 25 ft, but less than 200 ft, center to center.

The following sections were prepared based on findings obtained from a census of numerous existing shared corridors (*2*). These findings include spacing between track centers, use of structures such as fences crash walls or retaining walls for safety, shared minor facilities such as rail to rail crossings at grade or shared grade crossing protection, operating practices (including type of train control) such as spacing between the freight and transit tracks, time separation and operating speeds and traffic control practices. The following sections also cover design elements related to grade separation, fencing, crash walls or retaining walls, embankment profile and drainage and flooding protection. The design elements and recommendations for future design and operation have been developed based on the findings of survey of current practices and design experience related to LRT operating systems, systems and systems under various design phases.

DEFINITION OF SHARED-USE CORRIDORS

The FRA has a statutory obligation to promulgate safety regulations for the "general rail network"—the approximately 150,000 route mi of standard-gauge track in the United States used by both passenger and freight trains.

Operators of rail public transit services, other than commuter rail that uses the general railroad network, come under state rather than federal regulation. Passenger-carrying equipment does not need to meet the same standards set by the FRA for passenger cars and locomotives operating on the general railroad network. Neither does FRA regulate operating practices, signal systems, track design, or track maintenance.

Transit systems are regulated by states, unless the transit operation actually shares track with an FRA-regulated operator (in which case FRA regulations apply). But what if a rail public transit operator shares a transportation corridor with FRA-regulated passenger or freight service? These are "shared-use rail corridors", and at present there are no standards or regulations applicable to such operations.

In a recently issued report, FRA defined three types of shared-use rail corridors (*3*):

1. Shared track, in which heavy or LRT vehicles operate on the same tracks used by freight trains. FRA regulations govern this type of operation, in which time separation (no simultaneous operation) is required in most cases.
2. Shared ROW. In this case the transit vehicles run on separate tracks, but track centers are less than 25 ft (that is, separation between the centerline of the freight track and the centerline of the passenger track is less than 25 ft). FRA requires railway maintenance workers to observe specific safety precautions when multiple main tracks are adjacent.
3. Shared corridor. Transit and freight operators share a transportation corridor, but tracks are separated by at least 25 ft and no more than 200 ft. FRA believes that intrusion by derailed freight or transit cars onto a parallel railroad track is unlikely beyond 200 ft.

In addition, FRA defines "shared minor facilities". These are:

- Rail/highway crossings where transit line and general railroad system share crossing protection;
- Level crossings (diamonds) between transit tracks and general railroad system tracks; and
- Shared movable bridges.

The focus of this paper is on shared ROWs and shared corridors, with shared minor facilities requiring some consideration during the design of the light rail facilities. Although the focus of this paper is light rail, it also addresses heavy rail design issues in shared corridors for considering additional data that are of interest to light rail in such environment. Table 1 summarizes the route mileage of shared-use rail corridors in the United States.

TABLE 1 Shared-Use Rail Corridor Mileage: Current and Planned

Type of Operation	Shared ROW	Shared Corridor	Total
Current Operations			
Light Rail	66.7	12.0	78.7
Heavy Rail	63.3	80.6	143.9
Planned or Under Construction			
Light Rail	71.5	1.2	72.7
Heavy Rail	17.0	--	17.0
TOTAL	218.5	93.8	312.3

Note: "Planned" is limited to those projects where construction is underway or FFGAs have been reached with FTA

EXISTING SHARED-USE CORRIDORS

As Table 1 shows, at present there is about twice as much heavy rail trackage as light rail trackage in shared-use rail corridors. The majority of the heavy rail trackage, however, is classed as "shared corridor" (more than 25 ft from the nearest freight track, center to center), while the light rail trackage is mostly "shared ROW" (less than 25 ft, center to center, between tracks). Also, substantial light rail mileage is planned or now under construction on shared ROW. In the near future, the light rail mileage on shared ROW will come very close to the total mileage of heavy rail in common corridors (the majority of it more than 25 ft from active freight or passenger tracks).

The reason for this is clear. As interest in mass transit has grown in the past decade, planners have discovered that existing rail corridors can be good locations for construction of new light or heavy rail transit systems. Rail corridors tend to run through commercial and industrial areas with few or no permanent residents (and thus no one to object to a new rail facility). As freight railroads have reduced their fixed plant, tracks have been removed. This means that there is often room on the existing ROW for a single- or double-track rail transit line. However, since freight rail lines generally are not grade-separated, it is easiest to use existing rail ROWs for light rail operations, which do not generally require grade separation.

By contrast, heavy rail facilities require grade separations, and this often means either elevated structures or tunnels are needed. While grade separations do reduce the risk of accidents involving transit vehicles and freight or passenger trains on adjacent rail lines, they are also costly.

A recent survey of shared-use rail corridors by FRA revealed a number of common design practices. The objective of the survey was to identify all current transit operators, and all those with Full Funding Grant Agreements (FFGAs) from the FTA for proposed new construction, with lines that:

- Share track (covered by existing FRA regulations),
- Share ROWs with freight or commuter railroads,
- Share corridors with freight or commuter railroads, and

- Had connections or grade crossings with active freight or commuter lines.

The survey identified a total of 30 rail systems that had either shared track, shared ROW, or a shared corridor with the general railroad system. Several of the systems surveyed are in the midst of expansions of service. In several instances, major projects will add shared track, ROW, or corridors. Information on planned expansions has been limited to those for which funding has been identified, or where construction is actually underway. Table 2 shows agencies with shared ROW or shared corridor operations.

Note that Port Authority Trans-Hudson (PATH) rail operations are not shown in Table 2. The Hudson & Manhattan Railroad (H&M; predecessor to PATH) ran its first trains in 1908. Although it was a rapid transit railroad, the fact that it was an interstate operation and connected with (and shared trackage with) the general railroad system resulted in its being classified as an “interurban railroad” by the Interstate Commerce Commission (ICC), and therefore subject to ICC regulation. Railroad labor unions represented H&M employees, and trains were operated in accordance with standard railroad operating rules.

When the FRA was created in 1966, the railroad safety regulation was transferred from the ICC and FRA acquired regulatory responsibility for what was now PATH (owned and operated by the Port Authority of New York and New Jersey). Since PATH is already under FRA regulation, it was not included in the survey of common use rail corridors.

In general, transit systems sharing transportation corridors with freight railroads have good communication with the railroads and have established emergency notification procedures in the event of an incident on either the freight railroad or the transit system. Some transit systems have policies of placing fencing between the transit tracks and the railroad, to prevent maintenance workers or passengers from inadvertently wandering onto the freight ROW.

In locations where the transit and freight operators share rail–highway crossing protection, a high degree of cooperation is necessary. In San Diego, which has both shared trackage and shared ROW, San Diego Trolley (SDT) employees maintain crossing equipment on the east side of the shared ROW, while North County Transit District (NCTD) employees maintain equipment on the west side. Because NCTD commuter trains fall under FRA regulation, and freight trains also use the tracks, all SDT maintainers are trained in FRA standards and practices, and inspection of the equipment is carried out in accordance with FRA rules. In fact, all SDT track and maintenance personnel are FRA compliant due to the large amount of SDT trackage shared with freight trains.

As might be expected, there is a wide variation in traffic density and operating speed of the rail lines sharing corridors with transit lines. Rail lines in these corridors range all the way from infrequently used branch lines or industrial tracks with 10 mph speed limits to heavily-used mainlines with much higher operating speeds. Whatever the operating situation, however, all transit operators interviewed noted that encroachments had been rare.

In a few cases, transit lines are adjacent to rail lines used principally, or solely, for commuter rail service. This is true at one location in Chicago, where the Purple Line from Howard Street to Evanston (heavy rail) parallels a former Chicago & Northwestern Railroad main line that carries Metra commuter trains and no regular freight traffic, and also in Boston,

TABLE 2 Transit Systems with Common Corridor Operations (Existing)

City	Operating Agency	Route Mileage			Shared Minor Facility (type)	Notes
		Shared Track	Shared ROW	Shared Corridor		
Atlanta	Metropolitan Atlanta Regional Transit Authority	--	--	25.0	None	Three separate line segments. Track spacing varies; all track is fenced.
Baltimore	Maryland Mass Transit Administration	10.9		7.2	Track connection, diamond, grade crossing protection	Shared corridor with CSX Hanover Sub, heavy rail. Track spacing all > 25 ft. Light rail, shared track North Avenue to Timonium.
Boston	Metropolitan Boston Transportation Authority	--	21.6	--	None	Two segments of shared ROW on Orange Line; one on Red Line. See text.
Camden, NJ	Port Authority Transit Corp. (PATCO)	--	5.5	--	None	Track spacing almost all < 25 ft. No fencing. 5.3 mi shared w/NJT; 0.2 mi. with CSAO.
Chicago	Chicago Transit Authority	--	11.9	3.4	None	Purple and Blue Lines, track centers > 25 ft. Others < 25 ft. All fenced.
Cleveland	Greater Cleveland Regional Transportation Authority	--	14.3	1.0	Diamond crossings (two)	Red Line, shared ROW. Unfenced. Light rail: shared corridor.
Dallas	Dallas Area Rapid Transit	--	4.2	0.9	Track connection, grade crossing protection	Track at Dallas Union Station > 25 ft. Planned: 28.4 mi shared ROW.
Denver	Regional Transportation District	--	11.8	--	Grade crossing protection	10th and Osage to Littleton/Mineral, shared ROW. Track spacing > 17 ft.
Jersey City	NJT -- Hudson/Bergen LRT	--	4.2	--	None	Track centers vary. Generally < 25 ft.
Los Angeles	Los Angeles County Metropolitan Transportation Authority	--	15.9	1.6	Diamond crossing, grade crossing protection, Blue Line	Green Line: 1.6 mi shared corridor, mostly elevated structure on RR ROW. Blue Line on shared ROW; fenced
Memphis	Memphis Area Transit Authority	--	2.0	--	Diamond crossing, grade crossing protection	Historic trolley operation. Shared ROW with CN industrial track. Trolley on exclusive track parallel to freight track.

continued

TABLE 2 (*continued*) **Transit Systems with Common Corridor Operations (Existing)**

City	Operating Agency	Route Mileage			Shared Minor Facility (type)	Notes
		Shared Track	Shared ROW	Shared Corridor		
New York	New York City Transit	0.3	--	3.3	Track connections	Two shared corridors; short segment of shared track with subsidiary South Brooklyn RR. Track connections at 38th Street and Linden yards.
Oakland, CA	Bay Area Rapid Transit	--	--	18.6	None	Three segments. Planned 17 mi extension to San Jose will share rail corridor
Philadelphia	SEPTA light rail	--	--	--	Diamond crossing	Diamond in street, protected by standard highway crossing warning devices
Portland	Metropolitan Area Express	--	8.5	--	Lift bridge	Steel Bridge shared with UP; double-deck lift span with railroad underneath
Portland	Portland City Streetcar	--	--	--	Diamond crossing	BNSF spur may be out of service; no signal protection
Sacramento	Regional Transportation Dist.	--	6.9	3.0	None	16.5 mi shared ROW under construction or planned; 20 ft track centers standard
St. Louis	Bi-State Development Agency	--	3.5	--	Diamond crossing; track connection, grade crossing protection	1.9 mi adjacent to UP; 1.6 mi adjacent to industrial track owned by Bi-State
Salt Lake City	TRAX	12.0	--	--	Diamond cr., two track connections; 33 grade crossings	Shared track with UP; no shared ROW or corridors
San Diego	SDT	31.1	--	5.7	Track connections	Shared track on two lines; shared corridor on Old Town/Mission Valley line.
San Francisco	SF Municipal Railway	--	--	--	Four diamonds	Third Street Line (under construction)
San Jose	Valley Transportation Authority	2.1	1.5	--	Track connection	Shared ROW with Caltrain; shared track, see text. Planned shared ROW, 6.8 mi
San Pedro	Port of Los Angeles	1.5	--	--	Track connection	Shared track with Pacific Harbor Line (temporal separation)

continued

TABLE 2 (*continued*) **Transit Systems with Common Corridor Operations (Existing)**

City	Operating Agency	Route Mileage			Shared Minor Facility (type)	Notes
		Shared Track	Shared ROW	Shared Corridor		
Scranton	Lackawanna County	4.0	--	--	Track connection	Shared track with Delaware Lackawanna Railroad (temporal separation)
Seattle	Waterfront streetcar	--	0.5	--	None	Shared ROW Bell Street to Broad, BNSF
Tacoma	Downtown trolley	--	--	--	Diamond crossing	Crossing of BNSF Lakeview Sub; see text
Tampa	Downtown trolley	--	--	--	Diamond crossing	Crossing with CSX, protected by flagmen
Washington, D.C.	Washington Metropolitan Area Transportation Authority	--	10.0	22.1	None	All track in common corridors fenced, with intrusion detectors.
TOTALS		62.1	124.6	91.8		

where the Red Line to South Braintree (also heavy rail) is closely paralleled by a single track carrying only commuter trains from South Station to Plymouth and Middleboro. Clearly, the risk of derailments, shifted loads, and intrusion is less on these lines than on busy freight main lines.

In virtually every common corridor, there are protocols for contacting the freight operator if a problem occurs on the transit line. The reverse is also true. In most cases, the freight railroad has special instructions or timetable notices to crews that, in the event of an undesired emergency (UDE) brake application, or if a derailment or shifted load is suspected, they are to notify the dispatcher and inspect their train. Dispatchers are also instructed to alert the light or heavy rail operator if a crew experienced a UDE or some other difficulty.

There is a wide variation in construction standards for transit lines in shared-use corridors. In some locations, transit tracks are spaced only 12 or 13 ft, center to center from the closest freight track, without fencing of any kind, giving the appearance of a multiple-track rail line. In some new construction such as the “south line” in Sacramento, the design standard is a 20-ft center-to-center spacing. Light rail lines are likely to be spaced closer to freight tracks than heavy rail lines. The one exception to this is Cleveland, where the grade-separated heavy rail shares unfenced ROW and structures with adjacent grade-separated freight trackage. Cleveland, however, is unusual in that the Red Line uses overhead catenary. Other heavy rail lines employ third rail, and the ROW is fully fenced. Where shared ROW exists, generally the transit tracks are separated from freight trackage at least by fences, and sometimes by differences in elevation or “crash walls” (concrete barriers).

In a number of locations, a heavy rail line on an elevated structure follows an existing, at-grade freight railroad ROW. The San Francisco Bay Area Rapid Transit (BART) line from Oakland to Fremont, for example, is adjacent to the former Western Pacific Railroad main line (now used only for industrial switching) for most of the distance from Oakland to Fremont. It is at the same grade as the freight line only briefly, at Hayward (where the BART maintenance shop is located). The aerial structure for the Green Line in Los Angeles follows the alignment of the BNSF Harbor Subdivision from El Segundo to the southwest end of the line. In Atlanta, several branches of the Metropolitan Atlanta Regional Transit Authority (MARTA) system follow freight lines, but are sometimes grade separated and often at a considerable distance from the freight trackage (50 ft or more). MARTA trackage is fully fenced.

Grade separations provide a fairly high level of safety for the transit operator. A catastrophic high-speed freight derailment might damage or even destroy one or more of the supporting columns of an elevated structure, but such derailments are statistically unlikely.

DESIGN ELEMENTS OF SHARED-USE CORRIDORS

The design of LRT systems, and joint operations of LRV and freight trains in shared-use corridors is driven primarily by safety concerns, particularly the safety of passengers, whether directly or indirectly. The safety concerns have resulted in physical separation of freight from light rail in some existing operating systems and systems under design and construction. The following paragraphs provide a review of several design elements considered lately for planning and design of LRT projects in shared-use corridors.

Time Separation

Time separation of CSXT freight operations and NJ Transit's South Jersey LRT System (SJLRTS) was incorporated in the design of the SJLRTS. This design will require freight operations by CSXT during the late night hours while the SJLRTS operations are paused only to resume commuter services in the early morning while the freight operations are paused. Time separation actually provides very safe and efficient use of LRT and freight sharing the same tracks and rail system. At present, the FRA requires time separation of freight and LRT operations, although FRA has indicated its willingness to consider some type of advanced signal system that could provide positive separation.

Distance Separation

Distance separation such as more than 25 ft between freight track and LRT track centerlines is normally desired by the FRA. In many corridors, existing freight ROWs do not provide room for such a distance. Track centers in some shared-use rail corridors are as close as 13 ft, without fencing between tracks. At present, there are no regulations that require operation of either freight or LRT trains at lower speeds in this situation. Future design guidelines might require reduced speed on close track centers because of the potential of impact related to exceeding the distances allowed by the design dynamic envelope, primarily as a result of a potential derailment. The design of adequate separation distance should be an acceptable safe balance among several parameters of which operating speed may be a major parameter. Other measures considered lately in design of shared corridors include intrusion fences, crash walls, retaining walls and grade separation.

Intrusion Fence

Intrusion fence is a fence or other structure designed to detect an intrusion of the LRT clearance envelope by derailing, or derailed freight rolling stock; by large a defective appurtenances such as freight car doors; or by a significantly shifted load such as an improperly secured container on flat car container or trailer on flat cars. Such requirement was made by the FRA in connection with a proposed Hudson–Bergen LRT (HBLRT) extension side by side with existing CSXT and NYS&W freight tracks. Intrusion fences alone were required by the FRA for the proposed extension of the HBLRT project where the LRT and a NYS&W siding are both on embankments with a distance of 33 ft between their track centers. Due to low operating track speed, the FRA has not required any crash walls between NYS&W's and the LRT tracks.

Grade Separation

Grade separation is provided in shared corridors when the proposed LRT tracks need to cross a railroad yard, when there are many roadway grade crossings and when the existing corridor is inundated by riverline and tidal flows. The grade separation normally elevates the LRT tracks since the safety standards for the mass transit operations require more stringent safety measures and adherence. Also, the light rail operations require lower design load than freight operations. Grade separation has been achieved by elevating and supporting the LRT tracks on embankment, piers or on fill placed between retaining walls, depending on the function the grade separation is intended to serve.

Crash Walls

Crash walls have been required by the FRA for the protection of piers designed for the proposed grade separated HBLRT extension crossing the North Bergen CSXT yard, a multimodal railroad yard. The FRA requires the crash wall to protect the piers from a potentially derailing freight train. The crash wall height is required to be either 6-ft or 12-ft high, depending upon the centerline distance between the nearest freight track and each pier, as per American Railway Engineering and Maintenance-of-Way Association (AREMA) Standards Part 2, Section C-2.1.5. While indicating that the National Transportation Safety Board found no clear break point in the distribution of the distance traveled from the centerline of the track by derailed equipment, AREMA suggests to retain the 25 ft minimum distance within which collision protection is required. Yet AREMA recognizes that “the distance traveled by equipment in derailment is related to the speed of the train, the weight of the equipment, whether the side slopes tend to restrain or distribute the equipment and the alignment of the track. In cases where these factors would cause the equipment to travel farther than normal in a derailment, the required distance shall be increased.” AREMA adds that other structures not mentioned in the standards may still require crash wall protection. However, the FRA required intrusion walls, in addition to crash walls, in cases where both the LRT and the CSXT tracks are on embankments with a vertical distance difference of less than 6 ft. This FRA required a crash wall on one side of the proposed LRT tracks, where CSXT operate s a live track with speeds that exceed 25 miles per hour (mph), even though the distance between the CSXT and LRT track centerlines would be 34 ft. On the other side of the LRT tracks, where NYS&W siding tracks exist on a distance of 33 ft between track centerlines, the FRA required an intrusion fence only. Apparently, the FRA requirements are less stringent in regard to sidings where travel speeds are relatively low. The FRA indicated that the where retaining walls were designed and on a vertical distance of 5 ft between the freight track and the LRT track, the retaining wall can be designed and built as a crash wall with an intrusion fence in addition.

Retaining Walls

Retaining walls are used to support higher tracks on contained fill to reduce the width of an otherwise used embankment. As such, the retaining walls act to grade separate the LRT tracks from the freight track by elevating former above the latter. Since such design result in significant construction costs, alternative studies should provide comparisons with cost to acquire adjacent property for providing sufficient distance between the track centerlines for the acceptable safety. It is likely that in high population density areas where an LRT system is planned, the real estate cost is relatively high. For the HBLRT extension project, the FRA required retaining walls to be built as crash walls with intrusion fencing between the LRT and CSXT track, even though the centerlines distance would be 34 ft. However, on the other side of the LRT tracks, where NYS&W siding is located on a distance of 17 ft from the LRT’s track centerline, the FRA required an intrusion fence only.

Grade Crossings and Traffic Impacts

Grade crossings and traffic impacts are a significant issue from the point of view of the community. Obviously, the local traffic issues at the grade crossing are not of the FRA concern as long as the rail and traffic signals are designed and operating according to FRA's standards. Often when an LRT alignment is planned to share an existing railroad corridor crossed by local roads at grade, a traffic issue is being introduced, since it is designed to operate in a higher frequency (as high as 6 minutes headways) and higher speed (as high as 45 mph) than the freight train operate. In some areas where a new LRT line is planned for construction, the railroad operates on a frequency of one train to two trains per day and on an average speed of 10 mph. The impact on traffic is more pronounced where the grade crossing roads are equipped with automatic gates and every time a freight train or an LRT train that pass by activate the controller, the gate operate in a cycle of descent prior to the LRV or train crossing, staying down during the time the train enters the grade crossing and it ascent after the LRV or the train clears the grade crossing. It is understandable that an LRT operation under a frequent timetable or headways of 6 to 12 min with automatic gates at the grade crossings result in impact on currently occurring traffic queues. For example, a period of at least 30 s "warning time" that elapses between the time when the flashers are activated and the time when the train enters the crossing. The Manual on Uniform Traffic Control Devices (MUTCD) mandates a 20-s minimum but some states such as New Jersey require providing 30 s. The 12-s gate descent takes place during this period and thus it does not exacerbate the negative effect of the warning. A period, usually in a range of 7 to 15 s, elapses between the time when the train enters and the time when the train enters and the time it vacates the crossing. The duration of this period varies according to the street width, train length and average speed of the train while it is occupying the crossing. In addition, an 8-s period that elapses between the times that the gates begin and complete their ascent should be considered.

Drainage Facilities

Drainage facilities in shared-use corridor need to be addressed in the design of new LRT lines in old freight rail corridors. Experience with at least three LRT projects in freight rail corridors indicates that in some areas the freight rail tracks were originally constructed in wetlands and floodplains. In some cases, the freight rail was constructed on top of past streams located in low topography and that had been filled with the introduction of other means of transport such as trains, automobiles and trucks and for urban development. An example is the Hoboken Creek that was filled between Paterson Plank Road and 16th Street in the City of Hoboken, New Jersey for the construction of the Jersey Junction Railroad and adjacent urban development (*3*). Hoboken Creek flooded by runoff originated at the top of the Palisades and tidal rise in the Hudson River. Both flooding sources required the design of special drainage structures to protect the newly constructed HBLRT. Inherently, such stream reaches were subject to inundation resulting from runoff flowing down gradient to the low areas. When they were filled or relocated by the railroad, the water channels were filled with soil up to the bank, usually to the levels equivalent to the frequently occurring tidal levels, while neglecting the runoff conditions and inundation that occurred from the rainstorms. The freight railroad operators appeared to avoid drainage facilities design, either because of the relatively low frequency of train- trips or because of the nature of the transport that is freight. The low trip frequency result in a lower risk or probability of being inundated and damaged, while freight affected by flooding normally has carried liability limited to the value merchandise hauled which has been likely to be covered by insurance. Mass transit systems such as LRT operate very frequently, 6 to 12 min headways are not unusual in densely populated areas. In areas where inundation result from flash flooding, there is a high probability that the LRT system would be affected by storm events, while the risk of flooding to less frequently operating freight trains is significantly lower. Furthermore, the potential impact of flooding on passengers transported by the LRT is not comparable to the lower risk of damage and liability to freight. In addition, it should be remembered that commuters are customers would be repeat riders, if the transit system is safe and reliable. In the same juncture, it is clear that safety and damage concerns of flooding on freight systems are significantly different and less in potential impact. Therefore, protection of LRT systems in shared-use corridors by providing drainage facilities is an issue that should not be ignored keeping in mind the number of passengers who may be affected by flooding.

Like earthquakes, flooding occurring during extreme storms such as the design storm event is unpredictable but may result in significant damage and impact to commuters. All LRT projects, including projects located within shared-use corridors, need to be designed and constructed with drainage systems that adhere to federal and/or state standards, despite the inherent differences in LRT versus freight. Even though some modern elements have been introduced in the drainage design standards of freight rail operators, such standards have not been implemented along many miles of freight rail corridors operated solely for freight. Therefore, one of the significant challenges in design of modern and safe LRT systems in shared-use corridors is folded within the existing freight rail ROW. The existing freight facilities and shared operations make the task of designing an LRT for future operations of tens of years with today’s standards to be not an easy task. An example of a project where such challenge has been tackled is the HBLRT where facilities have been designed consistent with modern criteria and with effective drainage systems.

RECOMMENDATIONS FOR FUTURE DESIGN AND OPERATIONS

No much has been documented for shared-use corridors in technical manuals, design handbooks or regulatory issues. Even though there are many operating transit systems in existing freight rail ROW. The “Catalog of Common Use Rail Corridors” by Randy Resor, prepared for the FRA in 2003, is the first step in a needed process of preparing an inventory of existing shared-use corridors and operations of transit and freight trains, preparation of technical research for facilities design for side-by-side safe operations of both mass transit and freight trains, develop research and standards for maintenance of freight tracks for minimizing derailment probability, develop research for operations of shared-use corridors and roadway crossings of tracks and develop design criteria.

Inventory and Compilation of Existing Data

Again, the “Catalog of Common Use Rail Corridors” is the first step. There are additional data that need to be collected for research. Records for the inspections of the freight tracks and trains, records for maintenance of tracks and other equipment (including trains, signals and switches), records of accidents (particularly derailments) need to be collected. All the collected data and records need to be reviewed and prepared for research.

Technical Research for Safe Facilities and Joint Operations

The wealth of data from successfully operating can be also used as the basis for developing design charts, tables or directives. The basic parameters that influence the design, construction and simultaneous operations of freight and LRT within the same corridors are the distances between the centerline of tracks, vertical distances between the tracks, speeds of operations, alert systems, protective structures and other options of separation such as grade crossings. Other parameters may provide a guide for probability of derailment that can be considered in future design.

A review of the existing operating systems indicates that there are shared-use corridors where the distance between the centerline of the freight track and the mass transit track is 13 ft without fencing. Example can be found in New Orleans Public Belt's ROW where the regional transportation authority operates the Riverfront Line that includes a streetcar (not a light rail). However, the speed limit of the freight railroad is 15 mph in the downtown area adjacent to the Riverfront Line. The economic advantages of avoiding construction of crash walls and fences, where possible, would be great over the years to come with the extent planned new light rail in shared-use corridors. While the practice and a wealth of data have existed for many years for the shared-use corridors operating under various track centerlines, operational speeds of both LRT and freight trains, vertical distances and protection structures, no official research has been performed to develop design relationships among these parameters and other parameters such as probability of derailment, cost of construction of intrusion walls, crash walls, retaining walls, and grade separation. Basic relationships needed are primarily among the following parameters: centerlines distances, operational speeds of both LRT, trips frequency and probability of derailment, whether expressed graphically, in a tabular format or in text, would provide more insight for review of the existing agency regulations and potential update of the agency requirements in regard to shared-use corridors.

Research for Maintenance of Facilities and Derailment Probabilities

Existing records collected for the maintenance of existing freight tracks, accidents and derailments need to be reviewed and used for understanding of maintenance and operational safety requirements in shared-use corridors. Particular emphasis should be placed on studying the probability of derailment occurrences under various operational speeds and facility condition, dynamics of derailments and impacts. Also, understanding of inspection and maintenance frequency and operation speeds required to avoid or minimize probability of derailment is very important for developing standards for maintenance for safe operations. Here the FRA can provide data. FRA requires most freight trackage to be inspected either once or twice per week, and maintains the Railroad Accident/Incident Reporting System, to which railroads must report all derailments, collision, and other accidents exceeding a specified cost and all injuries to persons

Research for Joint Corridor Operations and Roadway-Track Grade Crossings

Is indicated above, roadway crossings of shared-use corridors require research and development of signal systems that operate such as to replace the automated gates that stops the automobile traffic when trains approach the grade crossings. The objective is to reduce potential traffic delays that may result from the descent and ascent of automatic gates for crossing trains. Thinking on how to reduce such traffic delays has indicated that the potential replacement of the automatic gates system with a Constant Warning Time. This method is particularly applicable to freight rail operations. However, further research and development is needed.

Design of Drainage Facilities

Design of drainage for shared-use corridors, like traffic issues related to existing roadway-tracks grade crossings, has to consider factors originating outside of the ROW, while considering the existing freight facilities and proposed shared use. Some rail operators, such as Conrail, developed their own drainage design for freight operations. Currently, drainage design standards for new LRT projects in shared-use corridors are being prepared expressly for each project. Research is needed to identify the current drainage design practice of freight and the characteristics of existing drainage systems, to determine the risks and probability factors considered for joint use of existing corridors.

Development of Design Criteria

As stated before, there are no published unified design criteria for the design and construction of LRT systems in freight rail corridors. New LRT systems have been planned and designed based on discussions with the FRA and FTA for each specific proposed system in relationship to the existing freight ROW. The data available from the numerous shared-use corridors and the suggested research in the above sections can be used as a basis for developing a general standard document or guidelines acceptable by both agencies. Unified design criteria endorsed by both the FRA and FTA would bridge potential differences between the two uses of the shared-use corridors and would provide the planner and the engineer with the tool for planning and design of facilities and operations based on research.

SUMMARY AND CONCLUSIONS

LRT system use of existing freight corridors is anticipated to continue to grow due to the shortage of available mass transit ROWs in densely populated areas. While such corridors present a clear economic and land use advantages, they also present concerns and challenges. The challenges relate to safety concerns and consideration of existing facilities that were constructed tens of years ago under old design criteria, relatively sparse land development in the adjacent municipalities and the high frequency (6- to 12-min headways) usage of the corridors by new LRT systems as compared to relatively infrequent freight train operations.

The inventory prepared by the FRA is a first step additional data and collection of operation and maintenance records, equipment and facilities inspection records, derailment and accident records will be needed to serve as a basis formulation of design standards. It is recommended that the additional data and records and additional technical researching and design criteria be used in a joint effort by FRA and FTA to develop design manuals.

Research of investment in upgraded maintenance of facilities and potential reduction in probability/risk of derailment and accidents in comparison to investment in structures as crush walls is recommended for examining the potential replacement structural measures with safety achieved in well maintained systems. Research related to effective operations of roadway-track grade crossings and effective drainage design.

This paper is intended to be used as the first step in research and development and preparation of design manual and design criteria of LRT facilities and joint operations of LRT and freight with safety, as a center issue in mind.

Design manuals for joint-use corridors should address the following criteria:

- Track Spacing;
- Fencing;
- Vertical Separation;
- Crash Walls;
- Operation Speeds; and
- Drainage.

REFERENCES

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DISCLAIMER

References to the Hudson–Bergen Light Rail Transit system in the paper do not necessarily reflect the opinions of NJ Transit, FRA, or the railroads companies.

CRITIQUES:
HOW ARE WE DOING?

Ridership Trends of New Start Rail Projects

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This paper reports on the ridership trends of new start light rail transit (LRT) projects implemented in the last two decades. These systems are colloquially referred to "new start" systems. The purpose of the research presented here is to look at the process of maturation of these systems in terms of ridership trends. Each system's ridership is examined, and system extent in terms of route miles and service miles also are examined. The research attempts to discern the impact of service expansion associated with the system synergies that might result from increased accessibility, through the review of ridership changes as LRT systems grow in contrast to service supply.

This review of the National Transit Database data indicates that ridership trends for new start LRT projects matured relatively quickly, with subsequent growth driven by system extent and service levels. The initial rapid maturation is partially attributable to the high levels of attention light rail lines receive when they are under development and implemented, as well as the inherent physical presence that LRT provides for transit. It is interesting to note that the LRT systems, even the more mature systems, are a modest share of the urban area's total transit service, with the most successful systems providing approximately 30% of total regional transit trips. LRT investments may be very important to a community by stimulating attention and investment in public transit. LRT implementation has helped several communities expand public transit use; however, it has not resulted in dramatic changes in the role that public transit plays in regional mobility in the respective communities. While LRT is playing an important role in expanding opportunities for transit use, even LRT system development is a lengthy process with no assurance of substantial increases in transit ridership.

INTRODUCTION

During the past two decades, several urban areas have invested in light rail transit systems (LRT) with the expectation that these systems would attract substantial ridership and hence, contribute to meeting the mobility needs of the community. The debate continues as to what extent new transit developments can impact positively on the balance between private vehicles versus transit trip-making levels. Available statistics indicate that, during the latter half of the 1990s, overall transit ridership grew by 21%, with the largest increase in the growth attributed to rail passengers (Pucher 2002). During this same period, a number of LRT projects were implemented, building on earlier new start LRT developments since 1980. Both National Transit Data (NTD) and National Household Travel Survey (NHTS) data indicate that a growing share of all transit trips are on rail systems including light rail, commuter rail and heavy rail (Polzin 2003). Analysis of the ridership trends of these new start LRT systems can help to provide a richer understanding of the role that LRT systems are having. In addition, by looking at how ridership levels change as systems mature, it may be possible to shed some light on the impacts LRT systems will have as they reach maturity.

The analysis attempts to shed light on the extent to which systems show maturation in terms of ridership growth over the near term as awareness of the system grows, and over the longer term as might be a result of changing demographics, changes in mode choice of travelers, or increased transit accessibility as the overall transit system expands. The research attempts to discern the impact of service expansion associated with the system synergies that might result from increased accessibility, through the review of ridership changes as LRT systems grow in contrast to service supply.

The scope of this paper will be to analyze LRT systems constructed during the period 1980 to 2001. These systems are colloquially referred to "new start" systems. Exploration of transit data as contained in the NTD is the primary method of analysis and was supplemented by literature searches and exchanges of information with transportation experts in the transit data field. Due to the available data, the analysis is restricted to reviewing LRT ridership and region wide bus and total ridership. These data sources do not allow corridor specific analyses of ridership changes and system impacts. One would expect corridor level impacts to be more significant due to the more limited geography.

LIGHT RAIL SYSTEMS: AN OVERVIEW

LRT can be defined as "a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways or, occasionally, in streets, and to board and discharge passengers at track or car-floor level" (Transportation Research Board 1989). An alternative and possibly later definition, illustrating how LRTs have increasingly shared the road space with other road users, defines LRT as "rail cars with motive capability, usually driven by electric power taken from overhead lines, configured for passenger traffic and usually operating on non-exclusive rights of way" (APTA 2002). LRT as a term has primarily been used to define light rail systems constructed after 1970; before that year, the terms streetcar, trolley, or tram often were used.

According to the 2001 NTD, there were 24 LRT systems in operation in the United States. Of these 24 systems, 17 (or 70%) were "new start" projects, i.e. constructed during or after 1980. Key characteristics of these 24 systems are presented in Table 1. The last column in Table 1 indicates the first year of NTD availability with respect to LRT systems being studied. Differences in the actual start year of the LRT system, when compared to the first year of data supplied may be due to calendar versus fiscal year accounting policies of the respective systems.

Table 1 also includes the 17 new start LRT systems. The LRT systems of Seattle, Memphis and Kenosha (Wisconsin), though new start projects, are also heritage/vintage "trolley" systems that function differently from true LRT systems. Therefore, these three systems have not been included in the analysis that follows.

TABLE 1 LRT Systems as of December 2001 (listed according to service start year)

NTD ID	Operator/Company Name	Location	Service Start	Total Miles Track	# Stations	New Start	NTD Yr Start
6032	Regional Transit Authority of Orleans and Jefferson	New Orleans	1835	13.7	9	No	na
1003	Massachusetts Bay Transportation Authority	Boston	1889	77.5	78	No	na
3019	Southeastern Pennsylvania Transportation Authority	Philadelphia	1905	171	64	No	na
9015	San Francisco Municipal Railway	San Francisco	1912	73.3	11	No	na
5015	Greater Cleveland Regional Transit Authority	Cleveland	1920	33.0	34	No	na
3022	Port Authority of Allegheny County	Pittsburgh	1964	44.8	13	No	na
5119	Detroit Department of Transport	Detroit	1976	1.60	8	No	na
2080	New Jersey Transit Corporation (Consolidated)*[a]	Newark	1980	8.3	11	Yes	1981
9054	San Diego Trolley, Inc.*	San Diego	1981	96.6	49	Yes	1982
1	Municipality of Metropolitan Seattle	Seattle	1982	2.1	9	Yes	1983
2004	Niagara Frontier Transit Metro System, Inc.*	Buffalo	1985	14.1	14	Yes	1986
8	Tri-County Metropolitan Transportation District of Oregon*	Portland	1986	71.9	47	Yes	1987
9013	Santa Clara County Transit District*	San Jose	1987	58.9	49	Yes	1988
9019	Sacramento Regional Transit District*	Sacramento	1987	39.4	29	Yes	1987
6015	Island Transit	Galveston	1988	4.90	3	Yes	1988
9154	Los Angeles County Transportation*	Los Angeles	1990	85.7	36	Yes	1991
3034	Maryland State DOT Mass Transit Administration*	Baltimore	1992	50.9	32	Yes	1992
4003	Memphis Area Transit Authority	Memphis	1993	6.1	28	Yes	1993
7006	Bi-State Development Agency*	St. Louis	1993	73.5	26	Yes	1994
8006	Regional Transportation District*	Denver	1994	28.5	20	Yes	1994
6056	Dallas Area Rapid Transit*	Dallas	1996	53.0	22	Yes	1996
8001	Utah Transit Authority*	Salt Lake City	1999	34.2	20	Yes	1999
2080	New Jersey Transit Corporation (Consolidated)*	Newark	2000	20.2	15	Yes	1999
5003	Kenosha Transit	Kenosha (WI)	2000	1.9	1	Yes	2000
Total				**1065.1**	**628**		

* LRT systems analyzed in this paper (14 of the 17 new starts)
[a] Date of operation by the current authority
Source: APTA and NTD

RIDERSHIP

Ultimately, the fundamental benefit of a transit investment is dramatically dependent on its role in providing mobility. Energy savings, air quality contributions, congestion relief, offsetting roadway infrastructure needs, etc., all require the transit services to be utilized by travelers for these benefits to be captured. While the economic impact of construction will occur regardless of the system's subsequent success, even the land use influencing power of LRTs ultimately will be dependent on the system servicing a meaningful role in providing mobility. Thus, understanding the ridership response to LRT implementation is critical to understanding the contributions of the investments. The fundamental premise in LRT development is that the service will play a meaningful role in transporting passengers; therefore, they are typically developed in areas with proven transit market conditions. Similarly, one anticipates additional land development near the LRT investments creating additional demand and, as the overall rail system and accompanying bus system expands in the community over time, one anticipates additional ridership as the geographic coverage and temporal availability of transit improves.

To what extent do the ridership data for new start LRT systems confirm these predictions of increased transit usage? The analysis presented in the following discussion seeks to shed light on this question.

Light Rail Transit Ridership Statistics

Figure 1 presents ridership statistics for 13 LRT systems in the United States. These ridership statistics have been standardized across systems by showing the ridership plotted versus the number of years each system has been in service. It is evident from Figure 1 that three LRT systems (all in U.S. west coast states) approximated or surpassed 25 million/year ridership levels. These 3 LRT systems, which operate in Los Angeles, San Diego and Portland, are distinctly noticeable in that all but two of the other LRT systems (St. Louis and Buffalo) have experienced annual ridership levels in excess of 10 million/year during any 12 month period of their operational lifetime.

Figure 2 presents the overall ridership trends of all new LRT systems (both the 17 new start and those in service pre-1980). Since the mid 1980s, total LRT ridership has grown steadily, spiking in 1994 at 284 million trips and reaching 336 million trips in 2001. New start LRT ridership has had a continuous upward trend in ridership since 1980. This may be partly due to any dips or stabilization of ridership levels in a system being counterbalanced by the opening of another system or extension elsewhere. The 164 million riders who used new start LRT systems in 2001, represented approximately 50% of all unlinked trips made on all LRT systems in the United States. When total LRT ridership is compared to total transit ridership for the year 2001, it comprises 3.5% of all trips made (total transit ridership approximated 9.65 billion unlinked trips per APTA). On average, between the years 1990 to 2001, the new start program has produced 254,000 trips annually per track mile and 454,000 trips annually per new station.

Figure 2 presents year-over-year growth rates for both new start and mature systems. The pronounced peaks and troughs in growth rates experienced during the 1980s and mid 1990s, seem to have stabilized somewhat during the late 1990s. Table 2 presents compound growth rates for the LRT systems from service commencement to the year 2001.

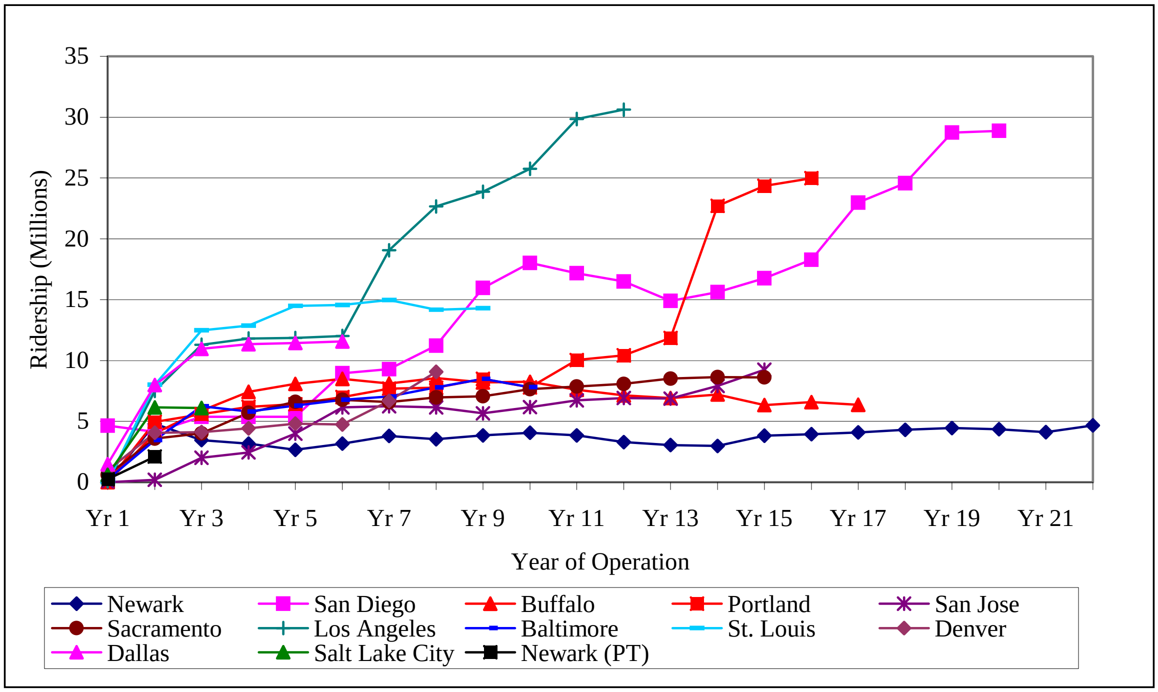

FIGURE 1 New Start LRT ridership trends. (Year 1 represents year of service commencement and, in some cases, NTD is not available for this year.) (Source: APTA and NTD.)

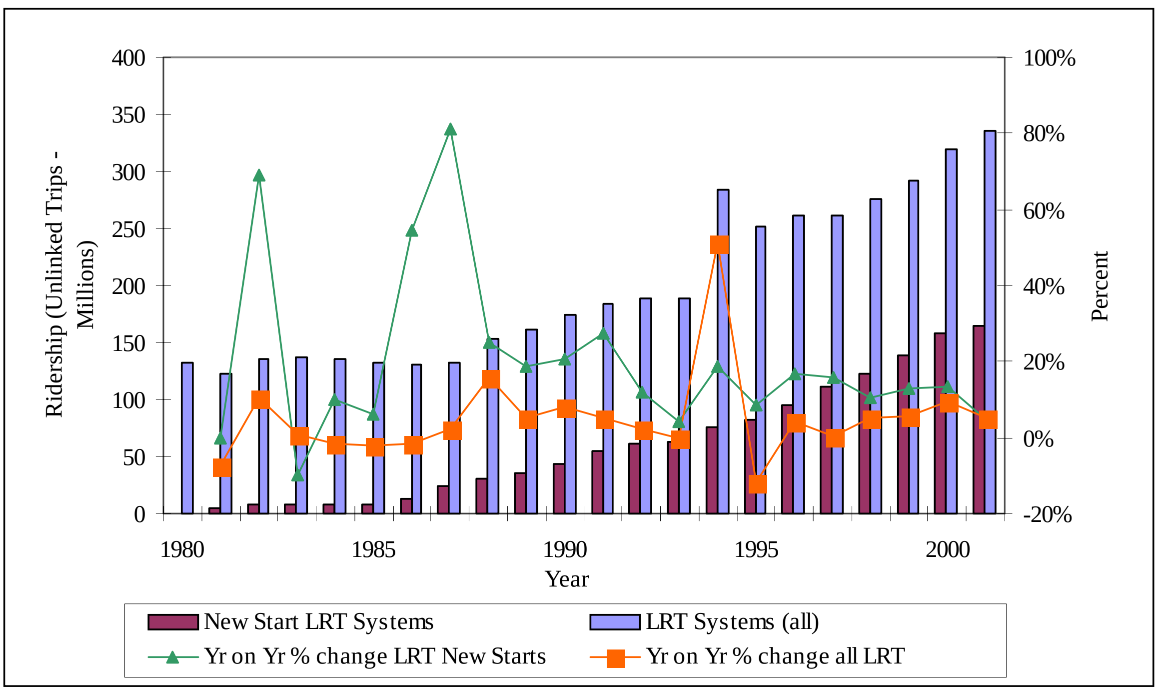

FIGURE 2 New Start LRT versus all LRT ridership trends. (Source: APTA and NTD.)

TABLE 2 LRT Compound Rate of Ridership Change (service start year to 2001)

NTD ID	Operator/Company Name	Service Start	Data Year Start	Number of Years	Annual Growth Rate (Data Year Start 12/31 to 12/31/2001)	Rank
8006	Regional Transportation District (Denver)	1994	1995	6	14.4%	1
9013	Santa Clara County Transit District	1987	1989	12	13.6%	2
8	Tri-County Metropolitan Transportation District of Oregon (Portland)	1986	1988	13	12.2%	3
9154	Los Angeles County Transportation	1990	1992	9	11.7%	4
9054	San Diego Trolley, Inc.	1982	1983	18	11.4%	5
3034	Maryland State DOT Mass Transit Administration (Baltimore)	1992	1993	8	10.7%	6
6056	Dallas Area Rapid Transit	1996	1997	4	9.8%	7
9019	Sacramento Regional Transit District	1987	1988	13	7.0%	8
7006	Bi-State Development Agency (St. Louis)	1993	1995	6	2.3%	9
2080	New Jersey Transit Corporation (Consolidated) (Newark)	1980	1982	19	1.6%	10
2004	Niagara Frontier Transit Metro System, Inc. (Buffalo)	1985	1987	14	0.6%	11
8001	Utah Transit Authority	1999	2000	1	-0.8%	12

Note: Data start year disregards NTD first-year data for each respective system. Part-year operations, novelty attraction, aggressive marketing efforts, and other ridership initiatives in the introductory years of a new LRT service may produce misleading first year ridership levels.

The data presented in Table 2 illustrate the challenge of correlating growth rates to operational length of time (i.e., growth rates decline as operational time increases) as an indication of system maturity. This observation is alluded to in the data, in that there is an equal dispersion of “older” (i.e., systems in operation >10 years) and “younger” (i.e., systems in operation <10 years) new start LRT systems, in the top 6 and bottom 6 rank positions, respectively. The high compound growth rates as experienced by LRT systems in Denver, San Jose and Portland, may be due partly to the continued ability to attract riders, manifested through recent network expansion. All top three systems in Table 2 have extended their LRT networks within the last 4 years, positively impacting their total ridership levels.

Figure 3 presents the rolling three-year average ridership levels for 11 LRT systems. Each of these 11 systems show positive growth trends through the first four years of operation (the exception being Newark). Further analysis of Figure 3 indicates that of the six new start LRT systems that have been in operation for 10 years or more, operational year 7 generally marks the point at which one or more systems experienced their first decrease in ridership growth. Nevertheless, it would be premature to conclude that after operational year 7 new start LRT ridership growth should stabilize.

As an indication of systemwide ridership levels before and after new start LRT introduction, Figure 4 presents data for 8 selected systems. These graphics give an indication of the significance of the LRT system as part of the overall public transportation plan, through sustaining or increasing overall transit ridership in each of the cities respectively.

SYSTEM EXTENT

In this section, LRT system extent will be looked at in terms of route miles and service miles. Obviously, the extent of route and service miles will affect ridership.

Directional Route Miles

Figure 5 illustrates directional route miles for 15 new start LRT systems. The second half of the 1990s saw a significant expansion of many LRT systems, over that of the first half (9 new start LRT systems expanded during the period 1995–2000, versus 3 during the period 1990–1994). This expansion during the latter half of the 1990s coincided with the dispersion of ISTEA 21 funds, which, in turn, stimulated significant transit infrastructure enhancements and contributed to the subsequent increases in transit ridership in the United States. At the end of 1990, new start LRT directional route miles approximated 146, with 107 stations (i.e., for LRT systems introduced during and post 1980); this increased to 299 mi with 227 stations at the end of 1995 (105% and 112% increases, respectively) and to 616 mi and 370 stations in 2001 (106% and 63% increases, respectively, from 1995). These changes are presented in Figure 6.

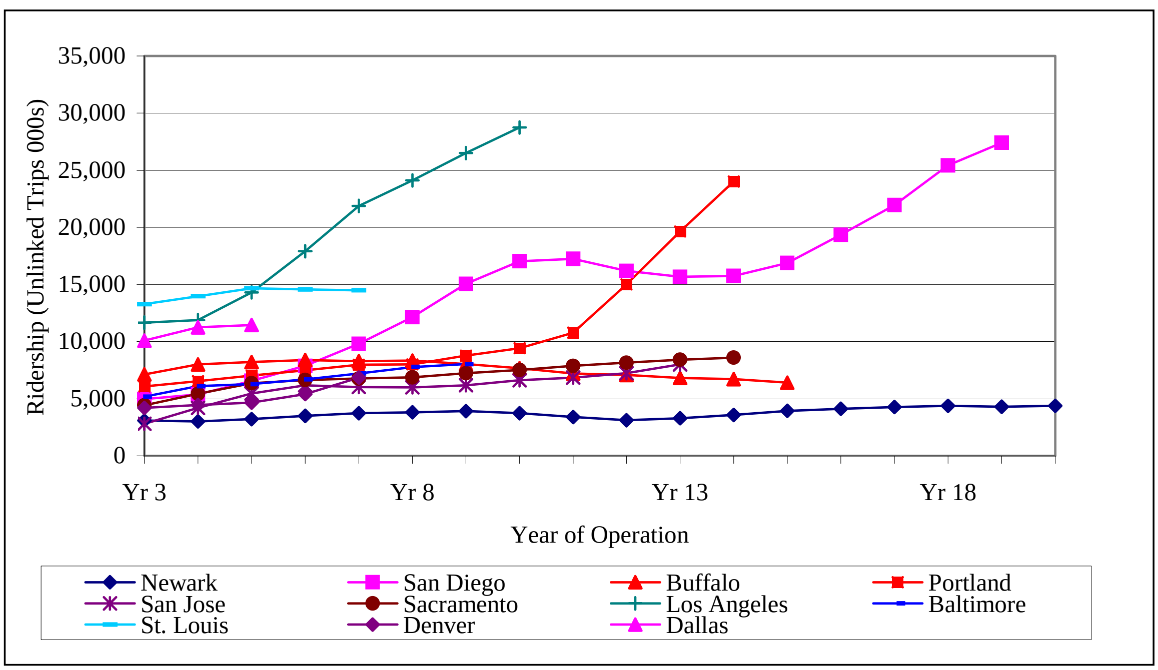

FIGURE 3 LRT: Rolling 3-Year Average Ridership.
(Note: Operational start year = data start year (as in Table 2) = Year 1)

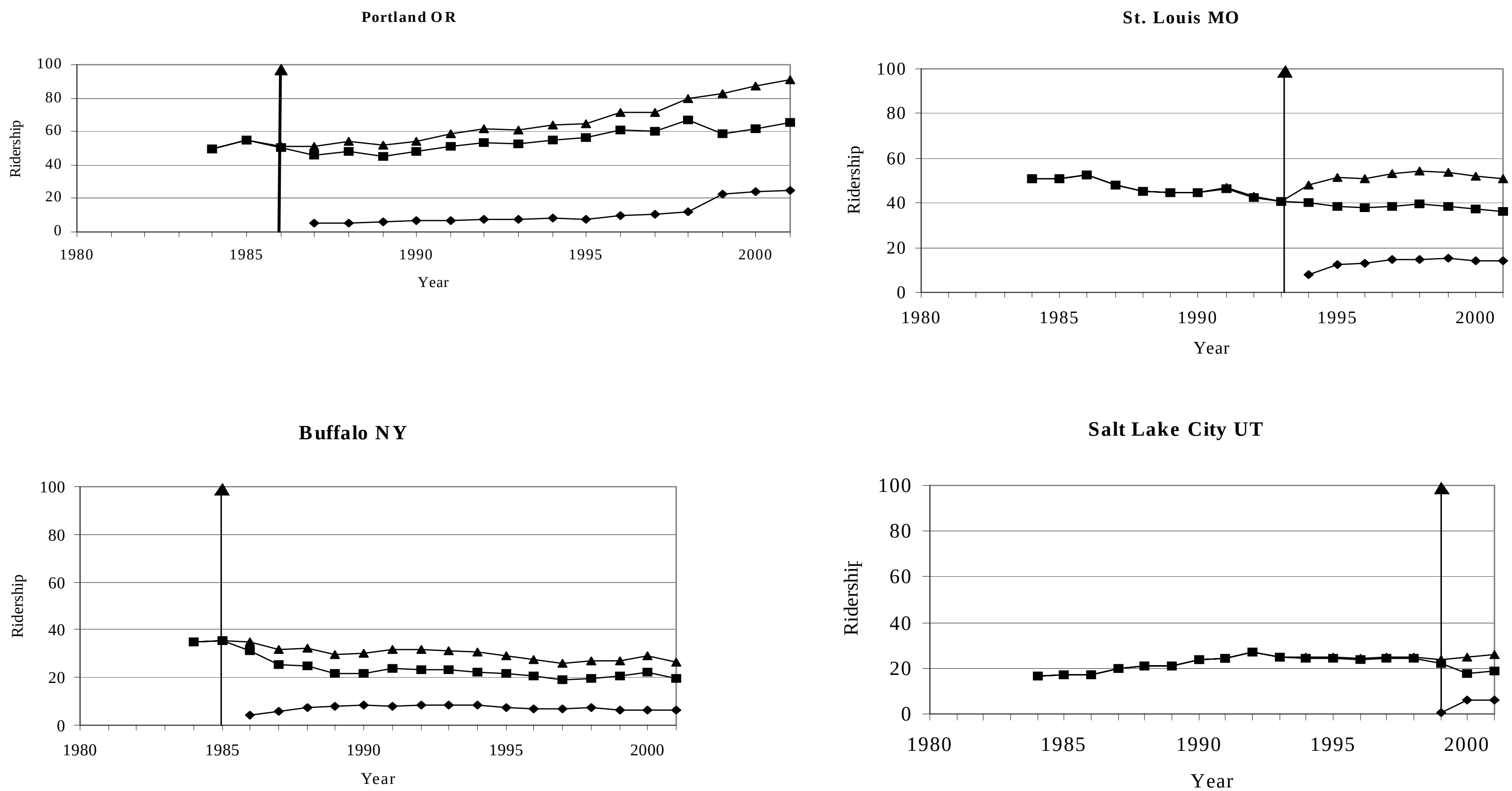

FIGURE 4 (Part 1) Transit ridership trends (in millions) of a selection of metro areas.
(Note: Up arrow represents year of introduction of LRT.)
Key = ♦ Light Rail, ■ Metro Bus, ▲ Systemwide
(Source: NTD.)

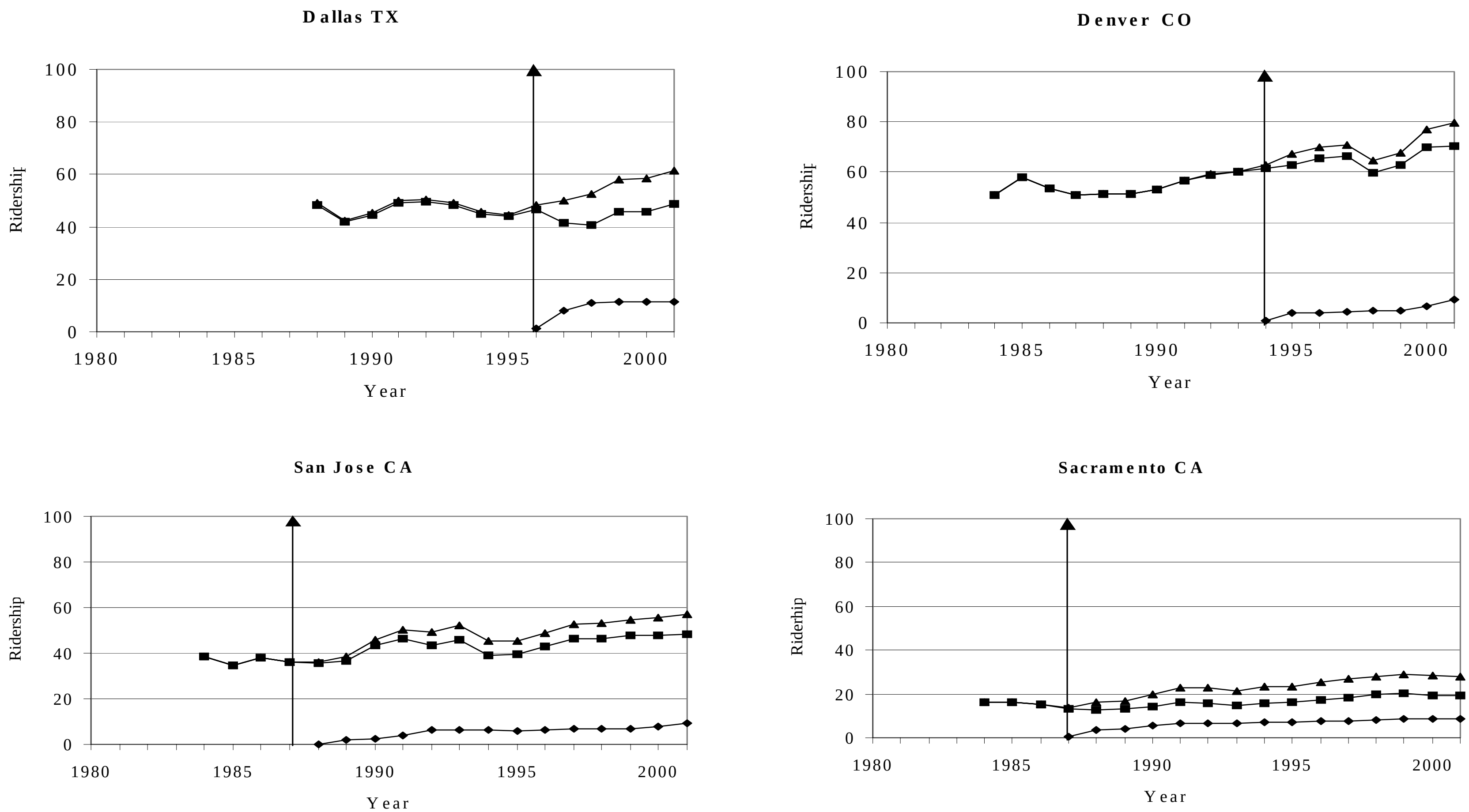

FIGURE 4 (Part 2) Transit Ridership Trends (in millions) of a selection of metro areas.
(Note: Up arrow represents year of introduction of LRT.)
Key = ♦ Light Rail, ■ Metro Bus, ▲ Systemwide
(Source: NTD.)

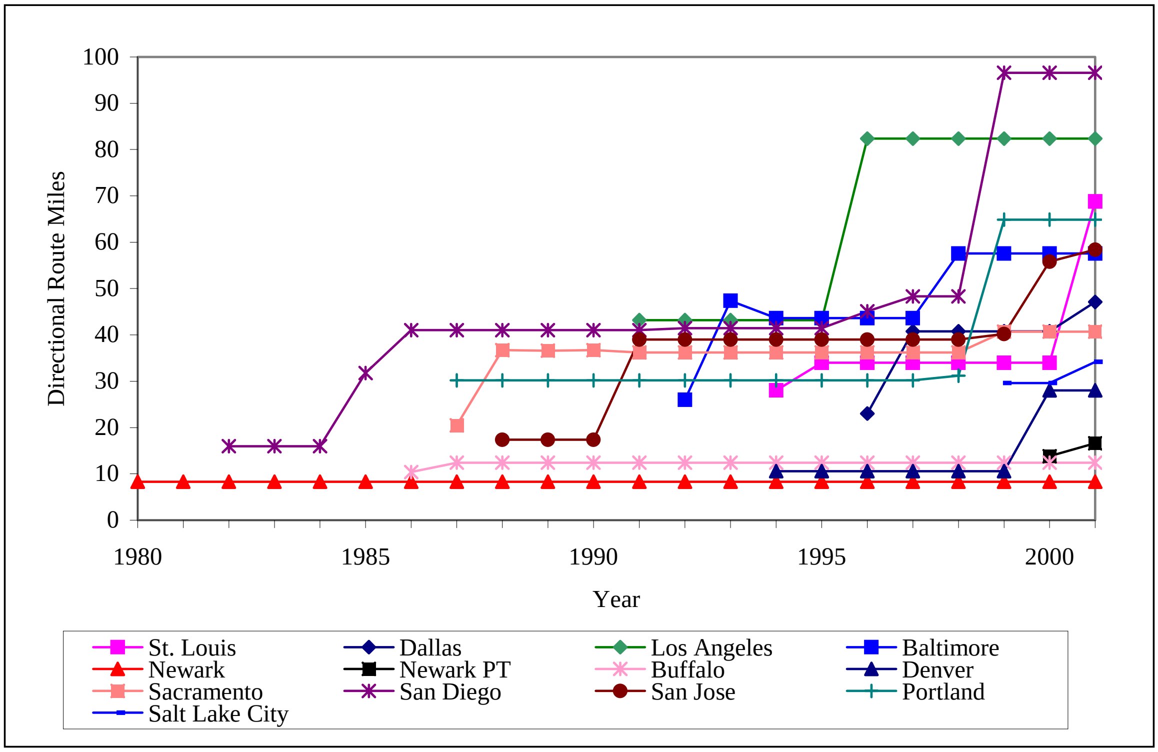

FIGURE 5 LRT directional route miles. (Source: NTD.)

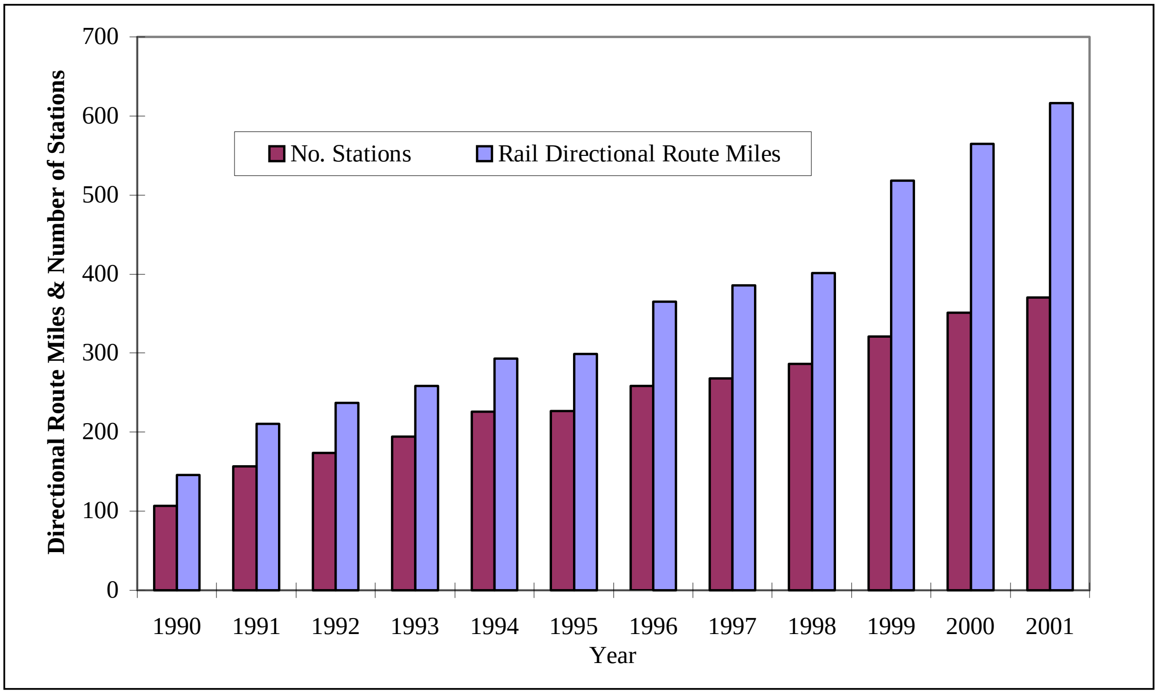

FIGURE 6 New Start LRT total directional route miles and stations. (Source: NTD.)

Passengers per directional route mile has been taken to be a better measure of the intensiveness of the use of a transit system. Thus, maturation of such systems may be evidenced from a tapering-off of total ridership levels per directional route mile. Theoretically, from new start LRT service inception, ridership per directional route mile increases to a certain level as awareness of the system grows; thus, subsequent growth should be at a rate that reflects the extent of population growth in the market area and changes in mode share. Even for fully-developed areas that are not growing, this might mean some relocation of population that needs or wants to use the LRT system who choose locations in proximity to the system over time as home and employment relocation opportunities are presented. Figure 7 illustrates intensity of ridership use of new start LRT riders per directional route mile.

In Figure 7 it is evident that Niagara Frontier Transit Metro system (Buffalo) has had consistently high ridership levels per directional route mile from its early years of operation when compared to the other LRT systems. This is, no doubt, attributable to its short length and downtown focus. Sharp changes (either upward or downwards) in ridership per directional route are often due to changes in the system extent, either in LRT system itself, or in other competing modes. Take for example, the sharp fall in San Diego's system between the operating years 17–18. This coincided with the expansion by 100% of the length of the LRT system. Ridership per directional route mile rises again in year 20, and may continue to rise as the expanded system becomes established. In general, accounting for route miles produces a ridership plot with a more stable ridership trend as systems expand. The route mile expansion explains a significant share of the growth in ridership. In aggregate, ridership increased by 110% whereas route miles increased by 100% between the 3rd year after system start up and the most recent year. Thus, ridership increases were able to slightly outpace line mileage expansion.

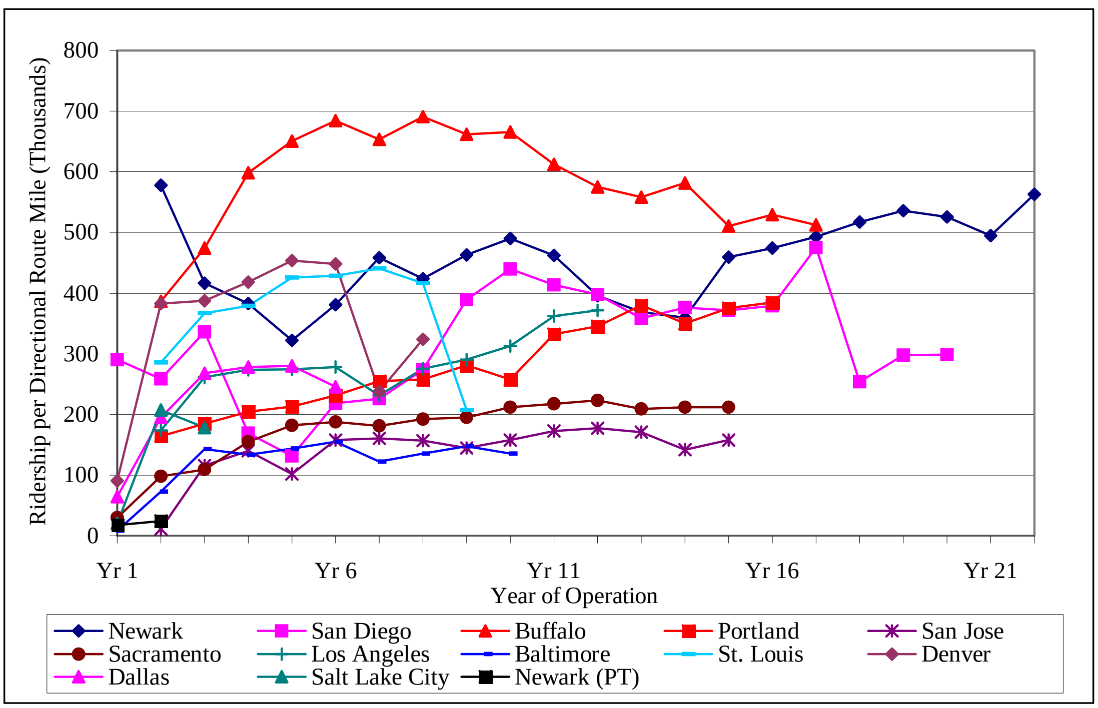

FIGURE 7 LRT ridership per directional route mile.
[Note: Year of service introduction = operational year 1 (see Table 2). Source: NTD.]

There are two possibly contradictory phenomenon of interest in system expansion. Presumably, the expansion of the system allows greater accessibility, which should increase the probability of users in proximity to the system choosing it more as a larger share of their total travel needs would now be accessible via the system. This presumes the expansion offers a more convenient or faster alternative than the preexisting prospect of a possible combination of LRT/bus trip. Also, with more stations, a larger market should be within walking distance for access or egress from the system. On the other hand, an urban area typically will place its initial segment in the strongest market location, often the best transit corridor serving the central business district. The second segment opened would presumably be in the second best location; thus, excluding the prospect of synergistic effects, one might expect the overall system performance (ridership per route mile) to decline with system expansion. One might make similar arguments regarding new start geographic expansion by presuming LRT investments occur in the cities with the strongest markets and, over time, systems are being added in more modest markets. That assumption would presume resource allocation decisions are made from a national optimizing perspective rather than through complex local, state, and national political processes.

Interpretation of Figure 7 also has to include recognition that a host of other factors influence ridership trends, including the strength of the economy, land use/development trends in the vicinity of the system, the condition of the competing auto system (particularly the prospect that parallel major facilities are undergoing changes), fare levels, network effects, and service levels among others. In addition, as the system ages, one might expect that the physical condition and perhaps the system reliability may not be up to the same levels as in the early years of operation.

Ridership levels also may be influenced by the extent to which the LRT system is integrated in and supported by the bus system serving the community. In general, the trends in Figure 7 suggest that the levels of use per route mile in subsequent years are remaining at or above the initial levels. Thus, one might surmise that, for the existing LRT cities, there were additional corridors or extensions that offered comparable LRT market opportunity beyond the initial segment. Given that most systems are located in urban areas with several hundred miles of freeways and hundreds or thousands of miles of major arterials, it is not surprising that the modest extensions that are affordable for various cities offer equally promising performance.

In Figure 7, it should also be noted that there is a significant variation in the absolute performance between the various systems.

Table 3 presents data showing directional route mileage changes for a selection of LRT systems and the corresponding changes in ridership.

Of the 9 new start LRT systems presented in Table 3, 19 individual instances of directional route mile changes (expansions or contractions) took place after operational year 3, (years 1–2 and 2–3 are not considered). The LRT system operating in San Diego had the highest number of system expansions (6). The most common operational period for route mile expansion, according to the data, was during operational years 6–7. This period dovetails with the previous argument that initial ridership maturity may be achieved after operational year 4 (i.e., years 5, 6, 7 etc).

Figure 8 graphically presents the data in Table 3. A cursory observation of Figure 8 indicates a modest relationship between the percentage change in directional route miles and ridership, (i.e., expanding the route miles in a LRT system by X% will not necessarily result in a corresponding change in ridership by Y%). A regression analysis of the relationship between system expansion and ridership (using data in Table 3) results in a low R^2 value (0.26), confirming the weak relationship.

TABLE 3 Percentage Change in Directional Route Mileage and Corresponding Change in Ridership

System	Period	Operational year of change	Directional mile change (%)	Ridership change (%)
St. Louis	2000–2001	8–9	102.35	–4.62
Dallas	2000–2001	5–6	15.44	1.98
Los Angeles	1995–1996	6–7	90.74	158.34
Baltimore	1997–1998	6–7	32.11	–47.82
Denver	1999–2000	6–7	164.15	88.91
Sacramento	1989–1990	3–4	10.90	140.63
San Diego	1984–1985	3–4	503.75	598.19
San Jose	1990–1991	4–5	235.63	360.08
Portland	1997–1998	12–13	114.90	148.57

Note: 1. Year of service introduction = Operational Year 1 (see Table 2)
2. Part-year operations, novelty attraction, aggressive marketing efforts, and other ridership initiatives in the introductory years of a new LRT service may produce inflated first and second year ridership levels. Thus, expansion in years 1 - 2 or 2 - 3 have been omitted.

Source: NTD

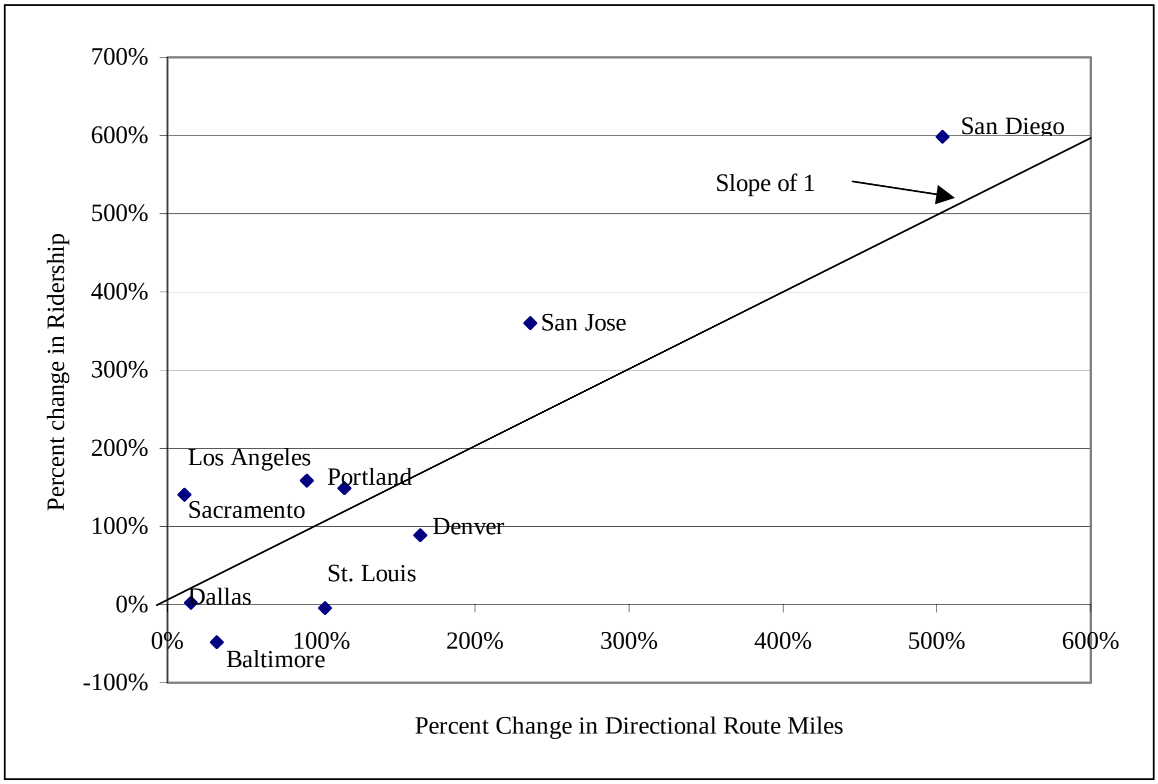

FIGURE 8 Change in LRT directional route mile versus change in ridership. (Source: NTD.)

Other data, such as elasticities for transit service supply, suggests that marginal increases in service will result in proportionately lower average productivity. The elasticity for transit service expansion has historically been less than one with, for example, a 100% increase in service producing perhaps a 65% increase in ridership (TCRP 2000). Of the five new start systems that had route mile expansions of 100% or more (San Diego, St. Louis, Portland, San Jose, and Denver), Portland, San Jose, and San Diego had corresponding ridership increases greater than their respective changes in directional route miles.

Figure 9 illustrates annual average trip length of new start LRT riders. The extent of urban sprawl and the penetration of the transit system into the suburban areas may result in long trip lengths. The LRT systems operating in the California cities of Los Angeles and San Diego may be evidence of this. These systems, in most years of their operation, have consistently experienced high trip lengths when compared to other new start LRT systems analyzed. In making this assessment, one needs to exclude trip lengths in year one, as the novelty aspects of system use may still be in force (note for example year 1 trip lengths in Salt Lake City and Baltimore). Low average trip lengths may be due to LRT systems of short system length or those that serve dense urban areas with a correspondingly high density of stations. Examples of the latter are in Newark and Baltimore, which have 1 station per ¾ and 1 mi, respectively. It is intriguing to the authors that there was not greater evidence of increasing trip length over time as systems expand.

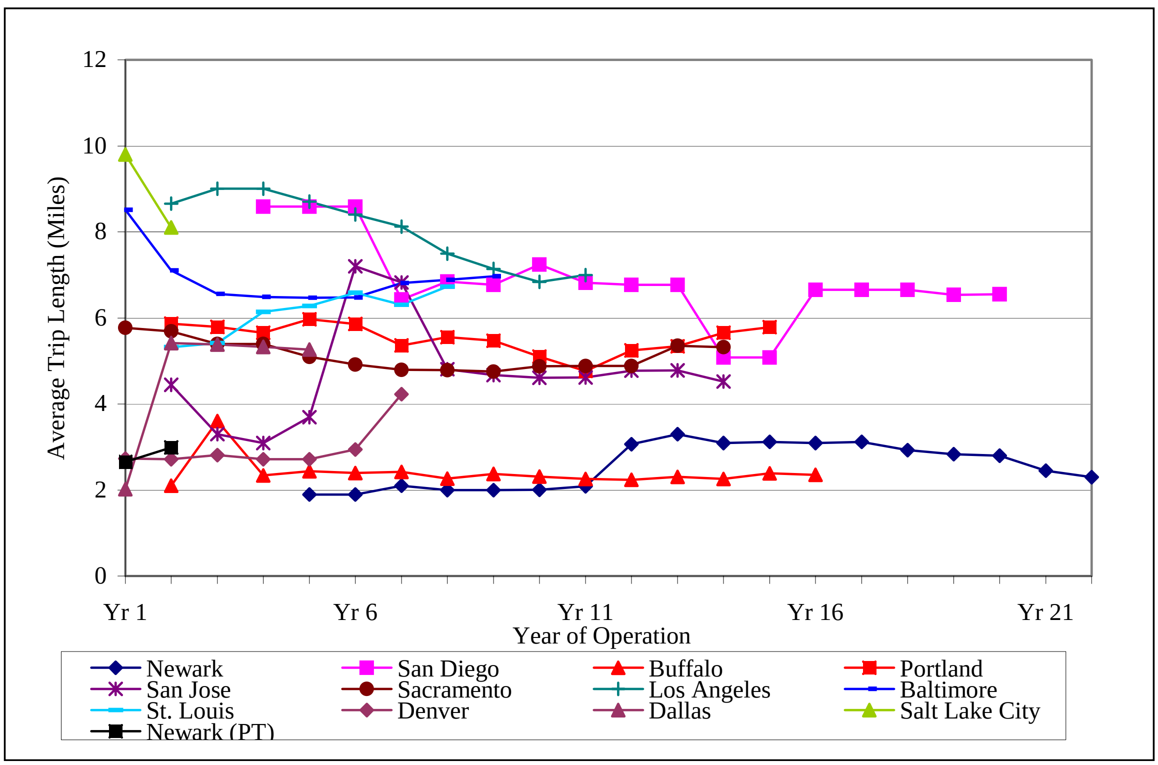

FIGURE 9 New Start LRT annual average trip length. [Note: Year of service introduction = Operational Year 1 (see Table 2). Source: NTD.]

Figure 10 graphically presents ridership per 1,000 population in a selection of cities. LRT systems operating in the cities of Portland and San Diego stand out due to their consistently high levels of ridership per 1,000 population. In the case of Portland, high ridership levels per 1,000 population are due to the city's widely acknowledged transit-friendly land use development. Along with transit-friendly development policies, private corporations can also encourage transit ridership by providing incentives in the form of annual passes. Intel Corporation in Portland has offered its employees an annual travel pass for the Tri-Met system.

Figure 11 graphically presents new start LRT ridership as a percentage of overall systemwide ridership. These data suggest that, while LRT has grown to be a significant share of travel in several markets, the public transportation system for LRT cities continues to be reliant on multiple public transit modes, most notably bus based services.

Figure 12 shows the relationship between passenger miles served per directional route mile. This comparison is partially to determine if system expansion provided benefits in terms of more passenger miles of service (not just trips), as this might be expected in cases where system expansion consists of line extensions. This situation might result in cases where a shorter initial line has substantial ridership boarding at a terminal station from distant points accessing the stations via either bus or park-and-ride modes such that the extension might enable a larger share of the individual's total trip to be on the rail segment but not necessarily increase the number of trips. This should show up as an increase in the number of passenger miles per route mile.

Figure 12 also indicates that, for the majority of new start LRT systems, passenger miles per directional route mile increased during the early years of service operation. This result supports the hypothesis made in the previous paragraph, where trip lengths may increase

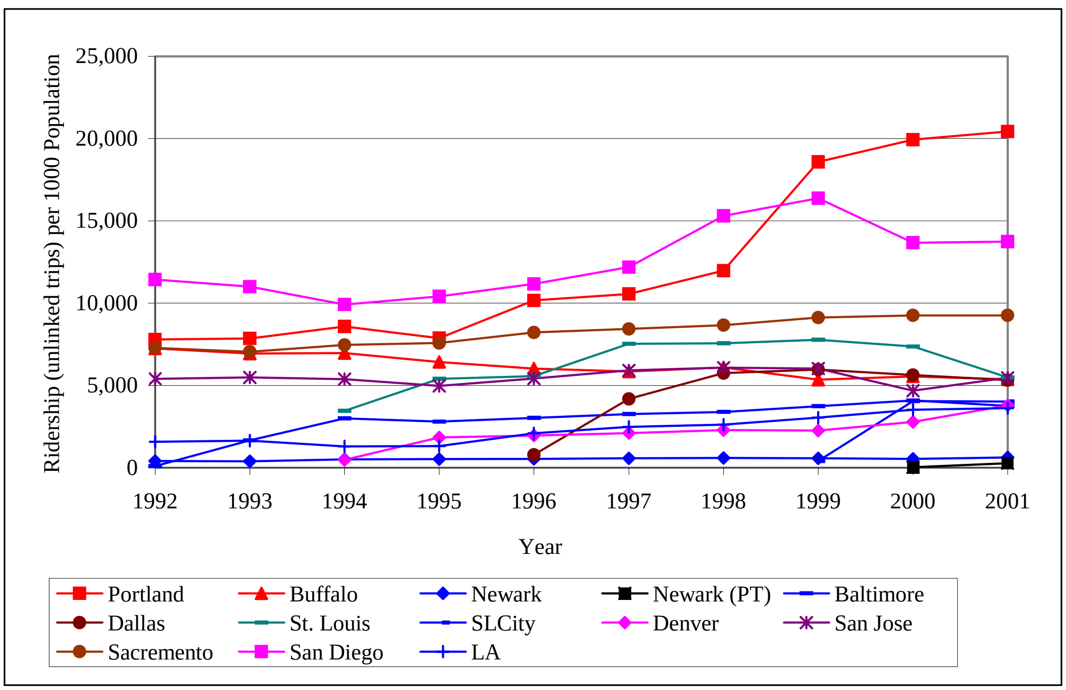

FIGURE 10 Unlinked New Start LRT trips per capita. (Source: NTD.)

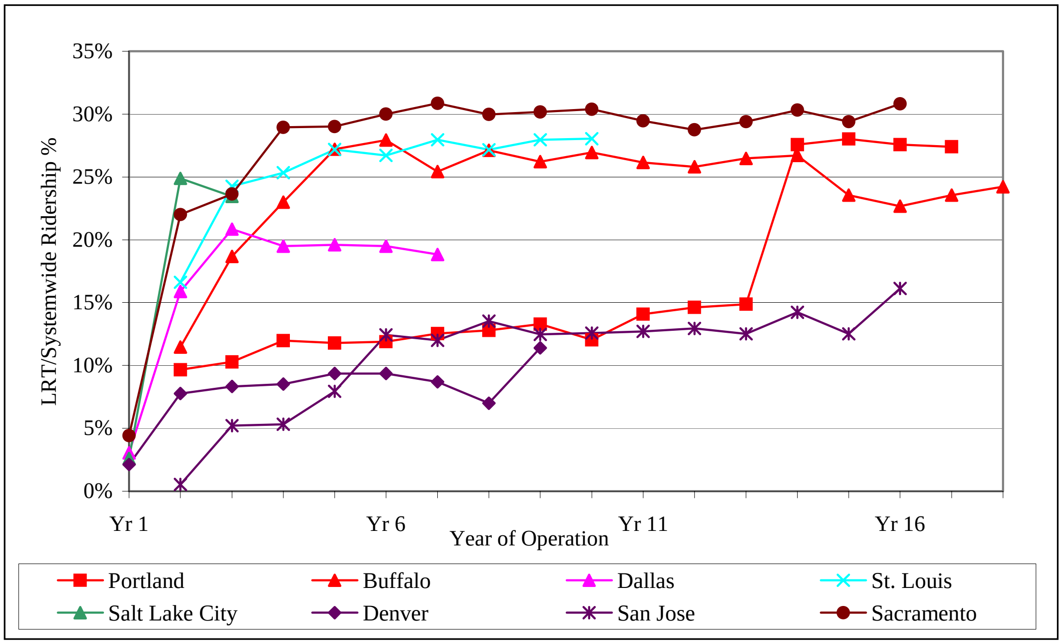

FIGURE 11 New Start LRT annual ridership percent of systemwide ridership. [Note: Year of service introduction = Operational Year 1 (see Table 2). Source: NTD.]

independently of the number of trips. Despite these early year increases, sharp, positive changes in directional route miles after the initial year, often result in corresponding sharp falls in passenger service miles per directional route mile. Note, for example, the sharp fall during operational years 17–18 in passenger service miles per directional route mile for San Diego; this corresponded to a 100% increase in directional route miles (see Table 3). Nevertheless, the LRT system in Portland seems to be the exception where positive changes in directional route miles have not resulted in correspondingly steep negative changes in passenger miles per directional route miles.

Figure 13 shows the relationship between passenger miles served per passenger car revenue miles of service. Passenger miles traveled per revenue mile of service is the best single measure of transportation productivity of a transit investment.

As indicated in Figure 13, a total of 4 new start LRT systems have achieved more than 30 passenger mi for every vehicle revenue mile traveled. Again, three of these systems, namely: Los Angeles, Portland, and San Diego, are located on the West Coast; the fourth system is in St. Louis. While these load factors are modest in comparison to airline load factors, they are not dissimilar to autos where the average occupancy is approximately 1.6 compared to a nominal average capacity of 4-5 persons. Maintaining high occupancies in light of directional and temporal fluctuations in demand is an important challenge for LRT systems. In absolute terms, the productivity levels are modest in terms of the typical LRT vehicle capacity, and the trends indicate relatively stable productivity trends for most systems. In an era of scarce resources, it would be advantageous if the LRT systems were able to show improved productivity over time to evidence both careful management and traveler and land use response to the presence of systems.

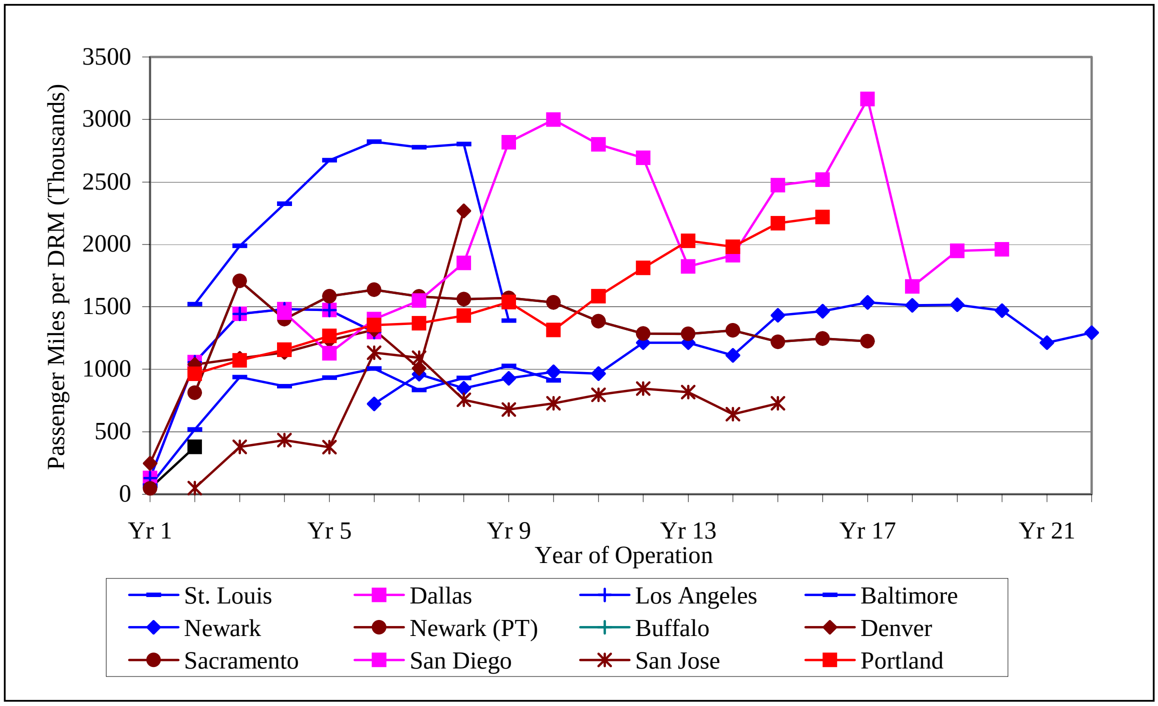

FIGURE 12 New Start LRT passenger miles served per directional route mile. (Source: NTD.)

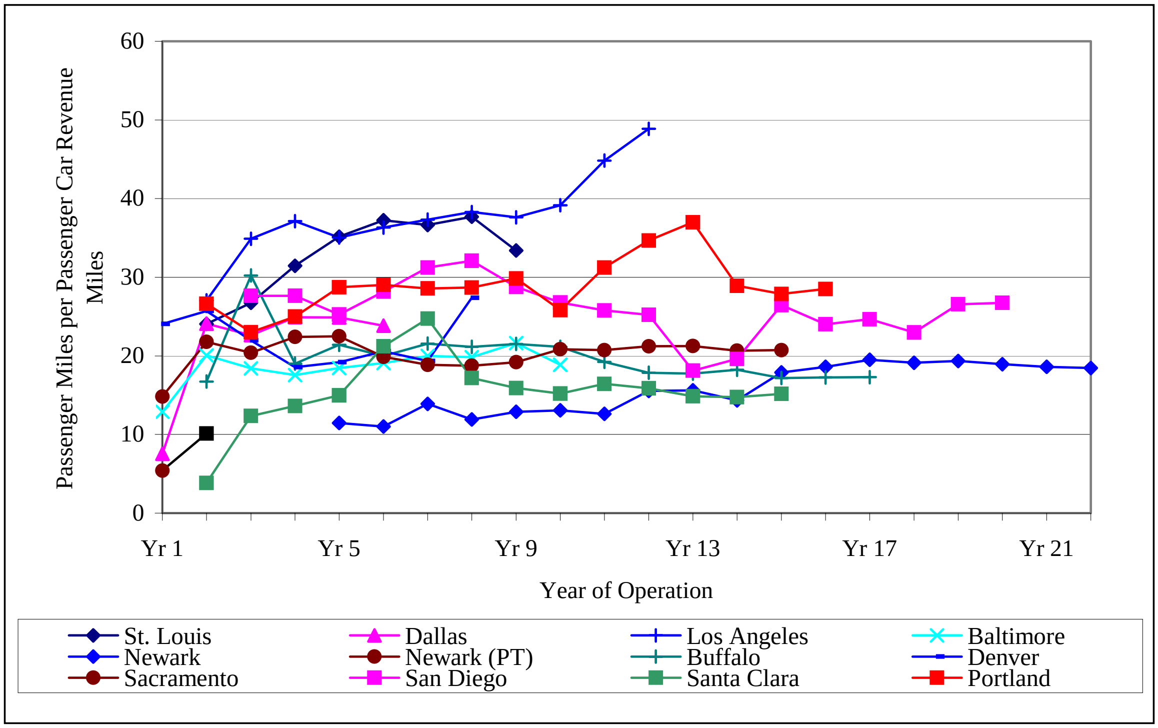

FIGURE 13 Passenger miles served per passenger car revenue miles of service. (Source: NTD.)

CONCLUSIONS

Reviews of NTD data indicate that ridership trends for new start LRT projects matured relatively quickly, with subsequent growth driven by system extent and service levels. The initial rapid maturation is no doubt partially attributable to the high profile light rail lines receive when they are under development and implemented. Unlike bus services, where it may take a while for the public to understand where they serve. The physical presence of the LRT system, particularly when it is new and unique in a community, makes it easy to understand. As most systems start with a single line and at best have a very simple network of lines, the general public can quickly understand the service areas for LRT whereas the more complicated bus system is more difficult to understand. Thus, bus service planning often presumes routes require up to 2–4 years to mature.

Beyond an initial maturation that might be associated with customer awareness of the services, one would also hope to see steady ridership growth related to both a relocation of the population that had an interest in LRT to locations near the system, and growth of population and activities near the stations as land use started to respond to the presence of rail. These trends would be longer-term trends and more difficult to discern, particularly if other factors such as changing economic and demographic conditions, changes in service cost or quality, or other factors come into play.

The route coverage elasticities presented in Figure 7 suggest that system expansion, shown in terms of route miles, is generally as productive as the initial line investment. This is perhaps a result of a combination of factors from the natural growth of population and ridership over times offsetting any tendency for subsequent lines to be built in successively less promising locations. There is no compelling evidence that the synergy of having a larger rail system offsets the disadvantages of implementation in successively less promising corridors. This may be partially explained by the fact that the existing bus services have already captured the synergistic effects of more comprehensive service coverage. More detailed context-specific analysis would be required to develop a richer understanding of these phenomena

The review of data also provided some additional observations that may be of use to those involved in planning new systems. It is particularly interesting to note that the LRT systems, even the more mature systems, are a modest share of the urban area's total transit service, with the most successful systems providing approximately 30% of total regional transit trips. This situation as well as the data in Figure 4 indicate that, while the LRT investment may be very important to a community, the current history of LRT implementation has not resulted in dramatic increases in the transportation role that public transit plays in their respective communities. In light of the relatively modest extent of a system that any single urban area can afford to implement in a decade, one would not expect 10 to 30 mi of rail line to dramatically impact overall mobility in an area that most probably has thousands of miles of roadways and hundreds of miles of freeways.

LRT systems appear to mature quite quickly initially, then show modest increases in ridership unless expanded. The expansions can produce larger increases in ridership, with these increases generally enabling proportional growth of ridership. Finally, Figure 13 indicates that LRT systems have not generally been able to show steady growth in productivity over time. This can be attributed to a variety of factors, including the prospect that the service supply is appropriately managed from the beginning, to the reality that many mode choice considerations such as auto availability and cost, and overall transit system service supply, may be impacting productivity trends. Again, closer context-specific analysis would be required to more clearly analyze this issue. While LRT is playing an important role in expanding transit use, even LRT system development has not made transit ridership expansion easy.

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Portland Streetcar
A Two-Year Report Card

GARY COOPER
City of Portland

THOMAS B. FURMANIAK
LTK Engineering Services

The Portland Streetcar in the city of Portland, Oregon, is the first modern streetcar line built in North America in the past fifty years. The 7.7-km (4.8-mi) single track streetcar loop was constructed in a short, 2-year time frame and at a very modest cost. In adhering to the theme of simplicity, the entire project, including five streetcar vehicles manufactured in the Czech Republic, cost approximately $54.6 million, or about $7.1 million per track-kilometer ($11.4 million per track-mile). The concept of the service is single cars operating in mixed traffic on city streets, with stops every two or three blocks.

Service was inaugurated on July 20, 2001. In the 2 years since, Streetcar has enjoyed a steady growth in ridership and popularity. This report provides a summary description of the line. It presents ridership and service reliability statistics for the first 2 years of service, including the experience of operation in city traffic with high pedestrian activity. It also describes some of the design features which needed to be revisited based on observations, operating experience, and passenger feedback.

Overall, the streetcar line has been extremely well-received, and the positive experience of the first 2 years of operation is lending credence to the city's efforts to expand the line to other areas close to downtown Portland. It has also become a model that many other municipalities, large and small, have come to see in order to gauge possible application in their own communities.

INTRODUCTION

The Portland Streetcar story was first reported to colleagues of APTA and TRB at the 8th Joint Light Rail Conference in Dallas, Texas, in November 2000 (*1*). At that time, the streetcar line was still under construction and the vehicles still at the manufacturing plant. The line opened 8 months later on July 20, 2001. Since then, this project has gained notoriety and publicity, and is helping to spark streetcar planning in cities of all sizes around the country. A brief overview of the project will be provided, as well as reports on the experience of operating the line during its first 2 years of service.

PROJECT OVERVIEW

The streetcar line consists of a 3.8-km (2.4-mi) route extending from the campus of Portland State University south of downtown Portland to NW 23rd Avenue at Legacy Good Samaritan Hospital in the close-in northwest section of the city. It is actually a 7.7-km (4.8-mi), single-track loop running with the direction of street traffic on one-way couplets a block or two apart for nearly the entirety of the route, as shown in Figure 1.

For the most part, the tracks are situated in the right travel lane, and streetcars run in mixed traffic, with parallel parking preserved along the right curb.

The streetcar line crosses TriMet's MAX line, which itself operates on parallel one-way streets, at four intersections. Two of these are particularly complicated because they occur at TriMet's downtown storage and turnaround loop, the ladder tracks for which extend across the streetcar tracks. A third intersection has a nonrevenue track connecting the streetcar with the light rail system.

There are 32 streetcar stops on the loop and a storage yard and inspection and light maintenance facility located where the line crosses underneath the elevated Interstate 405 freeway.

FACILITIES

Right of Way and Track

All track is situated in the right driving lane with one exception where the existence of a large water main required a shift to the opposite side of the street. The track structure consists primarily of RI 52 girder rail encased in a rubber boot for stray current isolation and embedded in a 300 mm (12 in.) deep, 2.5 m (8.2 ft) wide concrete slab. The track gauge is 1430 mm ±3 mm (8.3 in. ±0.1 in.), slightly narrower than the standard 1435-mm (4-ft, 8.5-in.) gauge to provide for better wheel and rail wear. The shallow track slab was chosen to minimize interference with underground utilities, and thus to avoid the associated time and expense of relocating them. Done mostly in three-to-four block segments, each taking three to 4 weeks to install, the track construction was done with a minimum of disruption to adjacent residences and businesses.

Stops

Keeping with the theme of simplicity, streetcar stops consist of extensions of the sidewalk approximately 2.4 m (~8 ft.) out into the parking lane at the near-side end of the block. These "platforms" transition from whatever the sidewalk elevations are at the specific sites to 240 mm (9.5 in.) along the trackway edge at the accessible doorway of the streetcar and tapering to 150 mm (6 in.) at the leading edge of the platform. The lower height at this location enables buses with wheelchair lifts which cannot accommodate a curb height higher than this to use the platform. The horizontal gap between the streetcar and the platforms is 50 mm (2 in.), which can be spanned by extendable bridge plates on the streetcars to accommodate passengers using mobility aids.

The platforms begin approximately 4.5 m (15 ft) back from the intersection to allow space for pedestrian crosswalks, including curb cuts. They are about 13.5 m (45 ft) long, which is

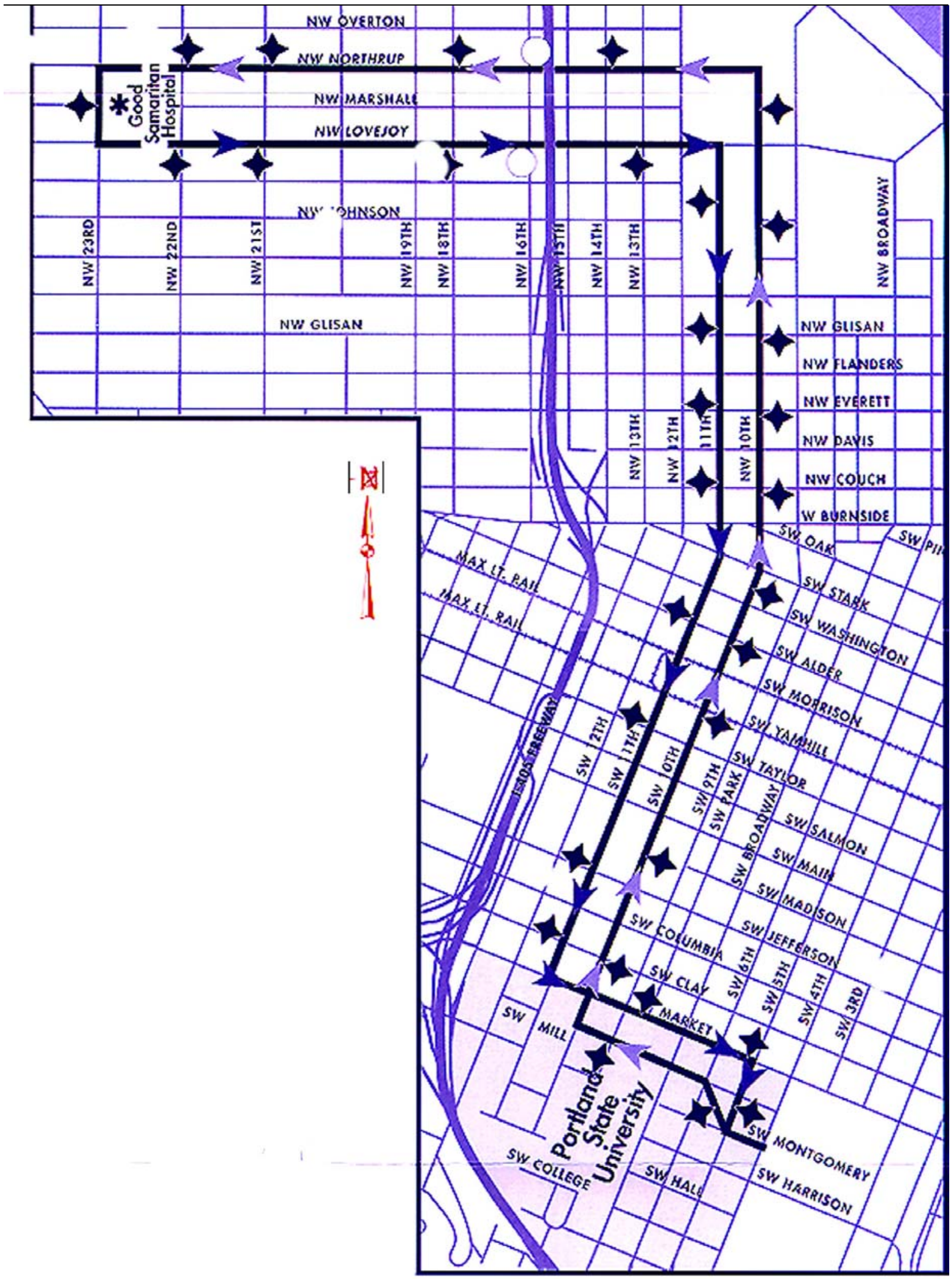


FIGURE 1 Portland Streetcar route map.

less than the 20 m (66 ft) length of the streetcar, but sufficient to serve all doors on the car. This effectively eliminates only three existing parking spaces at these locations.

Platforms are outfitted with only a modest shelter, leaning rails, transit signage, and a trash receptacle. Illumination is from existing street lighting. A Nextbus LED arrival time sign display was later retrofitted to 24 of the stops where power supply was readily available.

Yard and Shop

The functions at the yard and shop complex include vehicle storage, cleaning, inspection, running repairs, materials storage, and operations and maintenance staff accommodations. Heavy repairs and any major bodywork are contracted off-site.

The facility includes three parallel tracks for exterior vehicle storage for up to 10 cars, with space for two additional tracks in the future, and a 700 m^2 (7,500 ft^2) shop building. Two of the three tracks pass through the building, providing one car position on each track. Both positions have pits, one of which is also equipped with work platforms and an overhead crane to reach roof-mounted equipment. Portable jacks are used for lifting cars.

SYSTEMS

Vehicles

The city of Portland initially purchased five cars from Inekon/Skoda of the Czech Republic, a partnership of a project management and engineering firm and one of the country’s largest and diversified manufacturers of industrial products. These cars were off-the-shelf versions of their Astra streetcar being produced for several Czech cities and modified for this project as a bi-directional streetcar.

As illustrated in Figure 2, the streetcars for Portland are 20 m (66 ft) long, 2.46 m (8 ft) wide, double-ended, and double-sided. With split articulation the cars have three distinct compartments: two end sections with floors 780 mm (31 in) above top of rail and a center section, suspended between the articulated joints, with a low floor 350 mm (14 in) above the top of rail. The low floor section represents approximately 60% of the total floor area of the car.

There are three entryways on each side of the car: a 700 mm (28 in) wide single panel door opening opposite the operator’s position, with two steps of approximately 215 mm (8.5 in) up into the high floor area, and two double panel door openings 1,300 mm (51 in) wide in the low floor center section allowing level entry. One center door on each side is equipped with a movable bridge plate to accommodate wheelchairs and passengers who otherwise need assistance to traverse the gap at platforms. Similar to the front door area, there are two steps in the interior at each articulation connecting the center low floor section with the high floor end sections.

The cars have 29 seats and space for 127 standees at a density of 6/m^2. The latter includes two positions in each car which are designated for wheelchairs, bicycles, strollers, and the like. The cars are air-conditioned.

The streetcars do not have conventional couplers. Rather, folding towbars are housed behind removable panels and can be used to pull disabled streetcars.

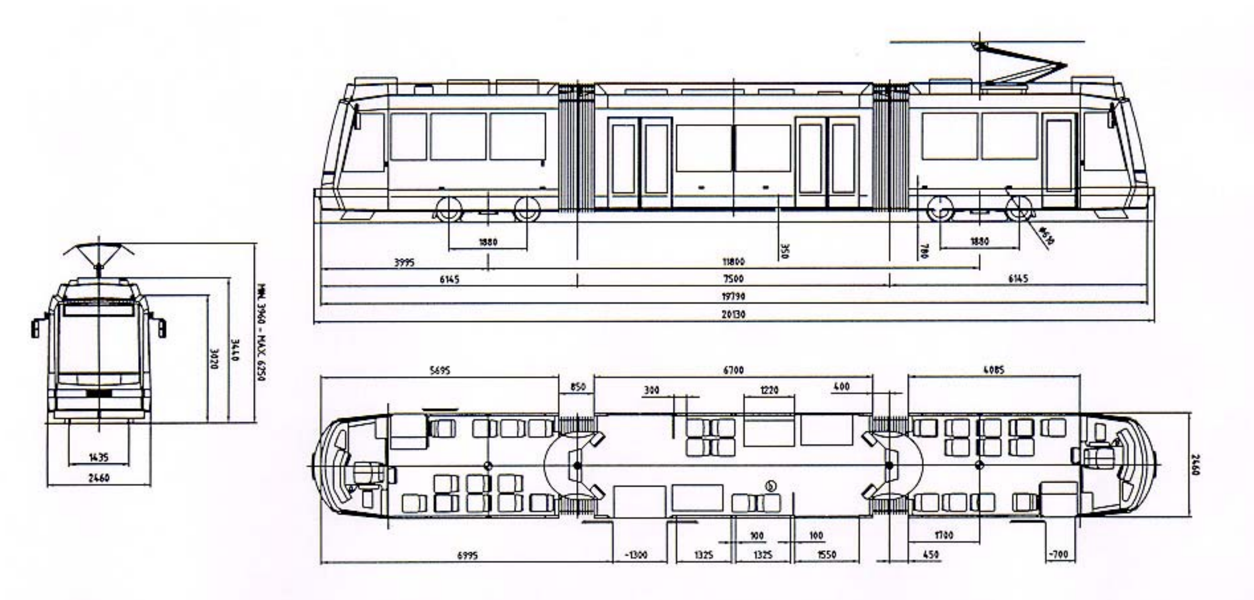


FIGURE 2 Portland Streetcar general arrangement. (Source: Inekon/Skoda.)

Propulsion is supplied by inverters feeding the AC traction motors that drive each axle. Rated at 85 kW each, these motors support acceleration rates of 1.3 m/s^2 (3.0 mphps) and a maximum speed of 70 kph (42 mph). Braking is provided in three steps: dynamic braking, friction braking through hydraulically applied disc brakes, and track brakes for emergency stopping. Additionally the track brakes are used in spin and slide control.

Power for heating, ventilation, and air conditioning (HVAC), lighting, and other auxiliaries is provided by two IBGT inverters producing a 3-phase, 400 Vac 50 Hz supply, typical in Europe.

Most of the equipment (propulsion controls, inverters, static converter, resistor grids, and HVAC) is mounted on the roof of the center section, while the pantograph is positioned over the truck center of one end of the car.

Each car sports a unique paint scheme, and there are no exterior advertisements save a tasteful logo identifying the current sponsor of the car. The interiors are bright and welcoming through a combination of large windows, lighting, and the patterns and colors selected for the various interior appointments.

Modifications from the off-the-shelf design included conversion to a double-sided, double-ended car, structural modifications to improve crashworthiness, dual versus single inverters, interior materials satisfying National Fire Protection Association 130 smoke and toxicity requirements, signage compliant with the Americans with Disabilities Act (ADA), and other features.

Power Supply

The concept of the traction power system design was to provide numerous small substations so as to limit the need for either unsightly overhead feeder or expensive underground conduit installation. Power is distributed to the streetcars at a nominal 750 Vdc from six substations, which are each rated at 300 kW, and spaced at 800-m (2,600-ft) intervals on average. The substations receive power at 480 Vac, three phase, from the local utilities, and are housed in available spaces along the line. Installations include prefabricated stand-alone housings, under-sidewalk vaults, and a city-owned parking garage.

Streetcars take power from an overhead system comprised of simple, fixed trolley. With a single track in each street, most overhead wire is suspended from side poles with cantilever arms. In several areas, span wires anchored to adjacent buildings are used.

Signals and Train-to-Wayside Communications

Since the streetcar is running in mixed traffic and subject to rules of the road, there is no signal protection on the line. The only exceptions are the crossings with MAX. At these locations, simple interlocking circuits have been installed to protect against the circumstance of two trains trying to occupy a crossing at the same time. Clearance to proceed is processed on a first-come, first-serve basis and indicated by a rail traffic signal head.

Where streetcar movements conflict with the normal flow of traffic, train-to-wayside communications (TWC) is used to preempt traffic signals. The TWC system is compatible with that used on TriMet's MAX service.

Communications

Communication with the operations office is provided through hand-held radios compatible with the city of Portland's 800 MHz system. There is no central control per se; however, supervisors can observe streetcar location through a standard web link to the NextBus system provider, the same display which is available online to the general public.

Fare Collection

The fare structure, fare collection means, and ticket stock is integrated with TriMet's proof-of-payment system. TriMet tickets and passes are valid on the streetcar, in addition to those sold by the streetcar service itself. However, since about two-thirds of the streetcar line is located within TriMet's downtown free-fare zone, Fareless Square, and the remainder in TriMet's Zone 1, fare collection is not as intense an activity as might normally be expected. There are no ticket vending machines at streetcar stops. Rather, there is a simple, coin-only ticket vending machine installed on each car that dispenses single-fare tickets which, like TriMet's, are valid for 1.75 hours of use. A companion bill acceptor has recently been added. Canceling machines are also located onboard to validate TriMet tickets. A ticket purchased on the streetcar is also honored on TriMet trains and buses within Zones 1 and 2, but a streetcar-only annual pass currently sold for $75 is not.

OPERATIONS

Streetcars operate 18 h/day Monday through Thursday, 19 h on Friday and Saturday, and 16 h on Sunday. Headways are 12 to15 min during the peak and midday, and 20 min in early morning and during late evening hours.

Service is operated by single cars operating in mixed traffic. While the maximum speed capability of the cars is 70 kph (42 mph), they are speed-limited to not exceed 48 kph (30 mph), which is deemed adequate for the mixed traffic operation and passenger stops every few blocks. Even for regular roadway traffic, most of the traffic signals in downtown Portland are timed for about 24 kph (15 mph) in a free-flow situation. The one-way trip time is 28 min, deriving an average speed of about 8 kph (5 mph).

The streetcar system is operated and maintained under a city of Portland contract with Portland Streetcar Inc. (PSI), the private, non-profit organization which oversaw its design and construction. PSI, in turn, contracts with TriMet for operators, mechanics, and operations supervision. In all, the lean staff numbers only 25 positions fielded by the three organizations as listed in Table 1.

RIDERSHIP

During the planning stages, the streetcar service was expected to attract an average of 3,000 passengers per weekday. The actual experience has exceeded expectations. At first, there was very high ridership due to the novelty of the line, especially on weekends. Over the first several months, this settled down to a pattern whereby the average weekday ridership was 4,000 passengers, with 3,750 on Saturdays and 3,100 on Sundays. A significant portion of the weekday ridership occurred off-peak, both midday and in the evening. That has changed as the practicality of using the service during peak periods, such as for work and school trips, has evolved, growing to about 4,820 riders per weekday; whereas Saturday and Sunday patronage has leveled off. Figure 3 shows the monthly ridership trends over the past 2 years.

OPERATING EXPERIENCE

While not without its challenges, the operation of the streetcar line has gone quite smoothly since its inception. How well the streetcar fared in its mixed traffic operating environment, its interface with TriMet, passenger acceptance, and equipment reliability is described below.

TABLE 1 Portland Streetcar Staffing

Position		Organization
Chief Operating Officer*	1	PSI
Project Manager*	1	City of Portland
Operations Manager	1	City of Portland
Superintendents	3	TriMet
Operators	14	TriMet
Maintenance Managers	2	City of Portland
Mechanics	2	TriMet
Car Cleaners	1	City of Portland
Total	25	

*Part time

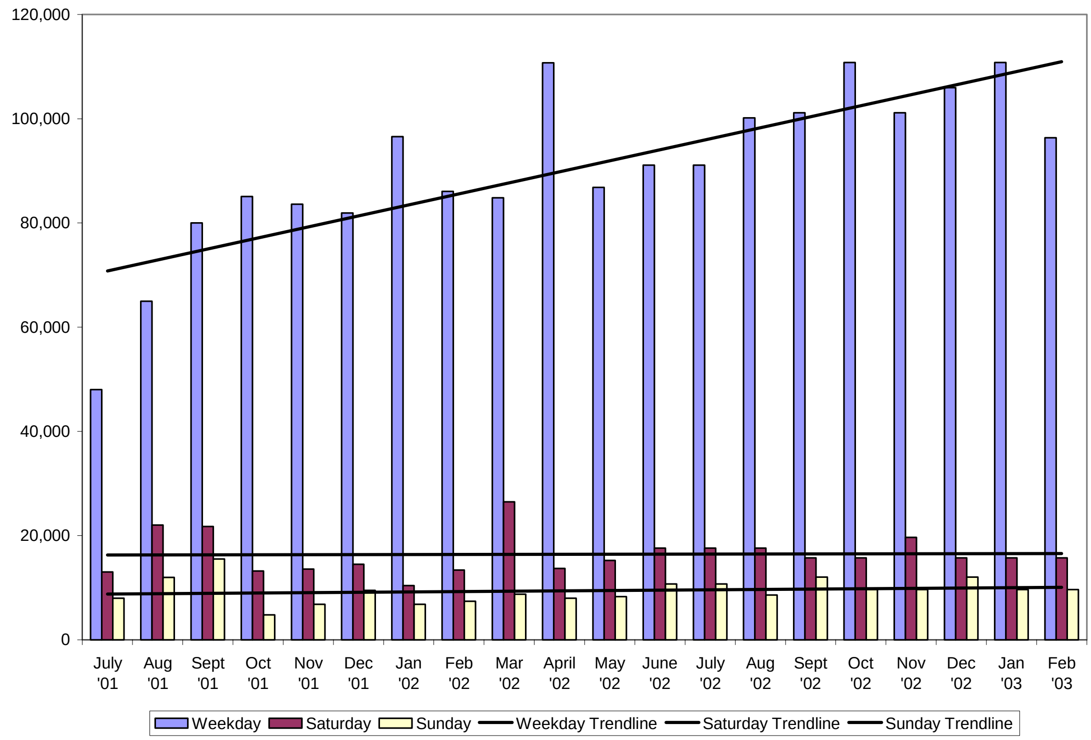


FIGURE 3 Portland Streetcar monthly ridership.

Operating Environment

The streetcar line operates in mixed traffic for the majority of its alignment. This suggests risks to traffic flow, and the potential for vehicle and pedestrian accidents.

An initial concern was that the streetcars would delay the flow of automobiles and trucks along its path as it halted at car stops. This has not materialized to any extent because the traffic signal progression for Portland's one-way streets is timed for about 24 kph (15 mph). While a streetcar making a stop may affect the flow of traffic behind it, drivers have grown aware of the potential and stay in the parallel running lane. Usually, the impact is only one light cycle at that one stop, and does not accumulate as the streetcar proceeds down the track because it, too, can catch the "green wave" for a few blocks. Sometimes it is the other way around; the traffic stopped at a light at near side stops precludes the streetcar from getting to the stop until the light has turned green and the traffic has cleared that location. In either case, the delay has not been significant enough to raise any major complaints from the driving public. Similarly, the scheduled travel time for the streetcar has not changed substantially from that originally assumed when the service was planned, with a round trip requiring about 56 min around the 7.7-km (4.8-mi) loop.

As with any nonexclusive rail system, there is exposure to conflicts with automobiles and pedestrians. Over the first 2 years of service there were 18 minor accidents, all of which involved autos turning in front of the streetcars. There have been three major accidents, one which involved a Jeep Cherokee that ran a red light in the late evening and literally knocked the streetcar about 8 m (25 ft) off the tracks. No major injuries were sustained by passengers in any of these accidents. Also, there have been no accidents involving pedestrians crossing in front of the streetcars.

The overall low record of incidents may be attributed to several factors: the education of the driving and walking public prior to start of service; the acquired familiarity with the streetcar after service was inaugurated; the distinctive appearance of the streetcars; the relatively low speed of operation; and the attention and alertness of the operators to running in the Portland urban traffic and pedestrian environment.

Another aspect of operating concern was conflict with parked vehicles overhanging the traffic lanes. Prior to start of service, the city relocated truck loading zones to adjacent streets and informed delivery companies of the need to respect streetcar clearances. While trucks, particularly those of parcel delivery companies, still stop along the trackway, one can observe their drivers folding in side mirrors as soon as they park.

Interface with TriMet

The streetcar line crosses TriMet tracks at four locations, its one-way couplet of tracks on 10th and 11th Avenues crossing TriMet's one-way couplet on Morrison and Yamhill Streets. These crossings are interlocked, with clearance given on a first-come, first-serve basis. This has been more onerous on streetcar operation than on TriMet in that TriMet's frequency on each track is about 5 to 8 min, whereas the streetcar frequency is 12 to 15 min. It is further exacerbated when a TriMet Airport train (Red Line) is completing its trip to downtown and terminating at TriMet's turnback loop at 11th Avenue because TriMet holds that train at its 10th Avenue station until the operator can confirm that all passengers have disembarked. Streetcar delays can be as much as 5 min at these crossings, especially the southbound run at 11th and Morrison.

There is no imminent solution for this problem area, and the respective operating agencies and the streetcar passengers have accepted this reality. Some relief will come when TriMet extends its Airport Red Line service to Beaverton west of downtown, eliminating the need for a long dwell on Morrison Street.

Equipment Reliability

The streetcars selected for Portland were based on the Inekon/Skoda Astra streetcar recently introduced in operation in the city of Plzen in the Czech Republic. Therefore, there was some degree of comfort in being able to study the design and manufacture and witness the operation of these cars. However, the changes that were implemented for the Portland variant, namely adding a second cab and a dual inverter-based propulsion system, warranted a battery of static, dynamic, and reliability demonstration tests on the first completed vehicle. For the latter in particular, the vehicle was run in non-revenue service late night on the streetcar network in Plzen and experienced an unprecedented 2,415 km (1,500 mi) of operation without a failure on the first attempt to achieve this reliability requirement. This was the harbinger of the noteworthy reliability these cars have demonstrated in Portland.

The traditional statistic for expressing car reliability is mean distance between failures. However, this measure is somewhat meaningless for a service that has a small fleet and runs at low speeds and low frequencies on a short loop. Indeed, the streetcars average about 24,135 km (15,500 mi) and 3,000 h of service per year. Rather than just focus on equipment, the city of Portland records all incidents which lead to an interruption of service. This includes equipment failures, power outages, traffic incidents, police and emergency vehicle actions, no operator, passenger situations, and the like, with no differentiation among them, giving a statistic of service reliability rather than equipment reliability. Figure 4 charts the experience over the first 2 years. Based on this information, some form of service disruption has occurred on average every 347 mi, or about every other day; however, the overall impact has been small, with the streetcar operating at over 99% of scheduled service consistently.

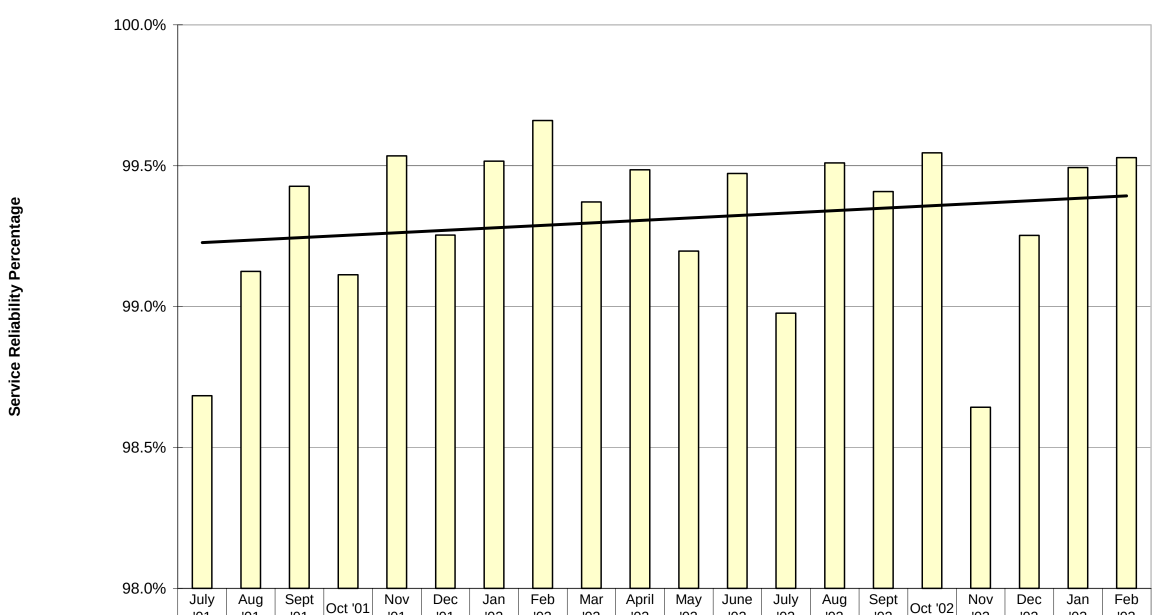
While the statistics do not measure equipment failures directly, PSI records failures and follow-up maintenance actions as a normal course of business. The largest number of unscheduled maintenance tasks has been with the door system. These have been primarily related to keeping doors adjusted properly. With 32 platforms, the doors average 288 cycles per side during a full 18-h service day

DESIGN ISSUES

As with any project of this nature there are always items for which hindsight dictates a different design. These were relatively few, being mostly features on the streetcars which relate to passenger interface with fare collection and ADA accommodations.

Fare Collection

The ticket vending machines were purchased for the streetcars through the vehicle procurement contract. The rationale was that there was not a domestic product available which could provide the needed functions (at least not without development costs), the quantity was small (five originally), and the vehicle manufacturer had a source of supply of proven equipment.



	July '01	Aug '01	Sept '01	Oct '01	Nov '01	Dec '01	Jan '02	Feb '02	Mar '02	April '02	May '02	June '02	July '02	Aug '02	Sept '02	Oct '02	Nov '02	Dec '02	Jan '03	Feb '03
Percentage	99.28	99.59	99.80	99.58	99.87	99.68	99.86	99.96	99.76	99.84	99.64	99.83	99.48	99.86	99.79	99.88	99.25	99.68	99.85	99.87
Hours of Loss Service	5.33	7.60	3.46	6.84	2.05	5.79	2.33	0.62	4.11	2.72	6.33	2.97	9.61	2.57	3.67	2.12	12.94	5.73	2.78	2.09
Hours of Service	739	1843	1719.5	1626.3	1629.3	1797.4	1680.1	1644.4	1713.3	1702.1	1749.6	1754.6	1861	1800.3	1712	1798.5	1725.2	1774.3	1800.5	1611

FIGURE 4 Portland Streetcar service reliability.

Unfortunately, these were coin-only machines. A bill acceptor was envisioned but there was insufficient time before start of service in mid-2001 to develop the recognition hardware and software for U.S. banknotes. The lack of a bill acceptor was immediately evident as numerous passengers, who were accustomed to using bills in TriMet vending machines and bus fareboxes, were observed attempting to buy tickets with bills. Fare revenue was lost because they had no means to purchase a ticket, yet they were already onboard completing their trip. This was remedied after the first year with the acquisition of a bill validator which could interface with the ticket vending machine.

ADA Accommodations

The off-the-shelf configuration of the streetcars found in the Czech Republic included a wheelchair ramp at one of the two double-width door positions in the center section to the car. For the Portland car, in which doors were installed on both sides, a second ramp of like design was included in the diagonally opposing doorway. Provisions were added to the interior of the car which included a parking area for wheelchairs and accessible tape strips for stop request. Accessible buttons for ramp deployment were already part of the original design. Interior seating layouts were sized and configured to assure the prescribed clearances for the movement of wheelchairs, including the possibility that a wheelchair-bound passenger might enter the car on one side and exit the other. In addition, an internal stop announcement sign was installed at each end of the car above the operator’s cab door with two opposing display signs in the center section.

Several issues arose as the wheelchair-bound passengers began using the service. Two involved the ramp. First, several car stops were constructed slightly out of tolerance such that, when deployed, the wheelchair ramps exceeded the ADA-specified slope of 1-to-6 at 50% passenger load. For some wheelchairs, such as those with small diameter soft rubber lead tires, negotiating the transition from the platform to the ramp was difficult. PSI has corrected platform elevations at the ramp position to bring ramp slopes within tolerance. Second, the ramp is 254 mm (10 in.) narrower than the 1,300 mm wide (51 in.) car door opening. Unless their chairs are centered on the door opening, passengers can enter or exit the car and risk one wheel missing the ramp. As an interim step, PSI has installed warning signs and floor striping delineating the side limits of the ramp to emphasize the need to enter and exit cars in the center of the doorway. PSI is working with the car builder to replace the existing ramp with one that extends the width of the door opening, as well as being longer.

Another issue is the interior message display. Complaints have been that the sign lettering is not large enough to read. PSI is currently investigating this.

On the facilities side, there were several lessons learned in addition to the car stop elevation tolerances noted above. One involved the poles selected for the overhead contact system. While slender tubular steel poles were specified, a decision was made to select thin-wall galvanized poles at a significant reduction in price. The result was some poles of extremely large diameters failed to achieve the required strength. This use of these poles ceased after the initial supply was depleted. The extension through the Portland State University campus at the current southern end of the line, which was an add-on to the construction contract, has the originally specified poles. These will be the standard for future extensions.

Another facility issue is storage space at the maintenance site. To the credit of the frugal stewardship under which the system was designed, the maintenance and storage yard was creatively placed under an elevated freeway, and woven around the structural columns supporting that roadway. The parcel dictated the installation. In practice, insufficient covered and secure storage was allotted for the materials accumulated on the project. This includes extra components and parts for vehicles and spare equipment for the infrastructure of the line such as poles, waiting shelters, and the like. PSI is installing used shipping containers to handle this overflow material.

Public Acceptance

Portland has embraced the streetcar line in various ways. In addition to achieving the ridership growth noted in Figure 3, the streetcar line continues to serve as an important element of the city's plans to strengthen existing neighborhoods, create new ones, and reduce dependence on automobile travel. Anecdotally, new housing and commercial developments along its path are thriving in what is an otherwise lackluster local economy; people are making lifestyle choices in which the streetcar is one of their choices for travel, including their work and school trips; and they are reducing use of their automobiles. Likewise, existing businesses along the line and new business locating there are advertising their proximity to it.

Transit-Oriented Development

The streetcar line has been a catalyst for development. Initially, this was focused on the Pearl District, an urban renewal area of former railroad yards and abandoned warehouses near the middle of the line and now the scene of explosive housing growth and neighborhood development. However, there have been numerous buildings and land parcels elsewhere along the line which have capitalized on the line's popularity. Through the first quarter of 2003, more than 40 new construction or renovation projects valued at over $1 billion have been started along the line, with more on the drawing board.

FUTURE EXPANSION

Even before the initial segment of the streetcar line opened, the city was studying its expansion. Next is the extension of the line from the Portland State University campus 1 km (0.6 mi) eastward to the Willamette River to RiverPlace, an area of housing, restaurants, shops, offices which is somewhat remote from the downtown. This $14.6 million extension is under design. Construction should begin in the latter part of 2004 and be completed for a mid-2005 opening. Two streetcars were purchased for this extension 2 years ago as an option to the contract under which the first five streetcars were acquired.

A second phase of this extension is planned to go southward another 1 km (0.6 mi) from RiverPlace to the North Macadam Urban Renewal District, a large plot of brown fields and industrial land along the river south of downtown. This area is targeted to accommodate expansion of the Oregon Health Sciences University (OHSU), whose main campus is in the nearby hills, along with complementary businesses and new housing. In all, 10,000 new jobs and 5,000 new dwelling units are anticipated. The streetcar line will intersect with a new aerial tram which will be built to link this area with OHSU's hillside campus.

Interest is also growing to carry the streetcar line over the Willamette River to the east side of Portland. Local eastside businesses have been in the forefront of an initiative to create a large streetcar loop which would connect them with the downtown on the west side. A number of proposals are being considered, including how far the loop would extend eastward and which bridges the streetcar would use.

Further on the horizon is a plan to extend the streetcar line south from the North Macadam Renewal District to Lake Oswego, a distance of about 11.2 km (7 mi). This extension would use the right of way of the Willamette Shore Trolley, an old interurban line on which vintage equipment is operated by the Oregon Electric Railway Historic Society as a tourist attraction. The right of way was purchased from the Southern Pacific Railroad, which abandoned the line in 1984, to preserve it for future transit use. Title to it is being held by the city of Portland on behalf of several local government entities.

CONCLUSION

By all accounts, the Portland Streetcar has performed well during its first 2 years of operation. Ridership started strong and continues to grow, currently averaging 4,800 riders on weekdays with no change in level of service since its inception; the equipment is performing very reliably; and minor shortcomings of the initial installation have been, or will soon be, addressed. Operation in mixed traffic has also worked well. While minor accidents have occurred, the streetcar has blended well with its traffic environment and vice versa. Moreover, the streetcar has successfully connected neighborhoods and complemented, if not catalyzed, growth in urban renewal areas. The success of the streetcar to date has reinforced the city of Portland's efforts and the public's interest to extend it to other locations close to downtown.

REFERENCE

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Peak-Period Service Supply Versus Observed Passenger Utilization for Rapid Bus and Rapid Rail Modes
Issues and Implications

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Data from U.S. and Canadian rapid bus and rapid rail systems demonstrate a strong and consistently positive relationship between transit service supply and consumption during peak periods. Rail modes attract greater utilized capacity per unit of offered capacity during peak period than bus modes, and this aspect of consumer choice may be quantified by regression analysis. Data and observations fail to support alternative hypotheses to a consistent and observable consumer preference for rail. Observed consumer behavior suggests that peak service consumption may be determined from supply within a fairly broad demand range. The linear regression models might therefore be useful for supply-side verification of ridership forecasts. Peak consumption levels assumed by some previous studies were unrealistically high. Cost per passenger for various bus and rail projects were therefore higher, and ridership lower, than predicted during planning. Some potential consumers will choose not to ride if peak period service is inadequate, leading to increased costs per passenger. Crowding often discourages patronage in markets where consumers have competitive alternatives to public transit service. This occurs at crowding levels significantly below the capacity figures used by transit planners. These findings have important implications for planning and cost analysis, particularly when bus and rail modes are compared. A stronger case for rail transit might be made than some previous studies have found, but bus modes have significant advantages in certain situations.

INTRODUCTION

Urban planners seeking effective, affordable alternatives to more highways and more automobiles must determine whether bus rapid transit (BRT) or rail rapid transit (RRT) provides superior performance and lower costs, and whether either mode will attract enough passengers to justify the investment. The findings in this paper stem from the relationship among travel demand, service supply, and service consumption. Consumption (ridership) requires both travel demand and service supply. Supply, of course, does not "cause" consumption but "permits" it. Supply-side analysis seeks to determine service–supply levels appropriate for predicted consumption levels, and considers what mode and other project aspects can best fulfill ridership projections and other objectives. Such analysis can shed much light on appropriate modal choice and effectiveness, based upon empirical data about the travel decisions consumers actually make.

Investigation and quantification of the relationship between peak-period service supply and consumption for existing United States and Canadian BRT and RRT systems was the authors' primary goal. They began with the fundamental postulate of supply-side analysis: transit service consumption requires both travel demand and service supply; therefore, various supply and consumption levels may be compared against a "background" of demand in various travel markets. In other words, various determinants of demand are postulated to exist, in combinations and at levels sufficient to produce—in concert with service supply—transit service consumption, or ridership. With reference to peak-period, peak-direction ridership carried past the maximum-load point, the relationship between supply and consumption may be expressed as follows: service supply [vehicles per hour per direction, (vhd)], multiplied by vehicle occupancy [passengers per vehicle, (p/v)] equals service consumption [passengers per hour per direction (phd)].

Maximum peak service levels for BRT and RRT are typically established by operating practices and site-specific constraints; limitations on train length and vehicle fleet size are characteristic of some U.S. light rail lines opened from the mid-1980s. This parameter could be determined from available published information. Some published data for peak-hour passenger volumes was available, but not for all corridors and systems, and not always with information regarding corresponding service supply (vhd). The importance of peak vehicle occupancy (PVO; the average number of passengers carried by each vehicle during the busiest hour, in the busier direction, past the maximum-load point) was obvious, but available data did not permit systematic analysis.[1]

The authors did not anticipate that PVO would differ significantly from rated vehicle capacity, roughly 150 passengers per 90-ft (27-m) articulated railcar. However, PVO observed at the beginning of research, in Portland, Oregon, on December 6, 1991, fell dramatically lower to roughly 100 p/v. Data from onboard surveys conducted by the operator confirmed this result. Data and observations from other North American cities established that, in the United States and Canada, PVO levels as high as 150 p/v have been recorded only in the most densely populated and congested metropolitan areas, and then only in the busiest corridors. Adjusting for differences in vehicle size, the authors found that the maximum utilized capacity level for RRT was a PVO between four and five passengers per meter of vehicle length, or 100 to 120 passengers aboard a typical articulated light rail transit (LRT) railcar. This finding was remarkably consistent in spite of the wide range of demand characteristics in various corridors and cities.

The authors also did not anticipate that peak-hour utilized-capacity levels would differ significantly between BRT and RRT modes. However, PVO for BRT services proved to be consistently less, slightly below three passengers per meter of vehicle length. This, the principal finding of this paper, reflects observed consumer behavior that cannot be argued away, and suggests a significant consumer preference for rail transit, at least during peak travel times.

Regression analysis demonstrated a strong correlation between peak-period service supply and observed consumption, based on empirical data from existing U.S. and Canadian BRT and RRT systems. Supply does not "cause" consumption but the correlation permits reasonable predictions of peak service consumption from peak service supply within a fairly broad range of demand. This relationship provides a potentially useful tool for analysis and verification of ridership forecasts.

Consumption may be constrained by inadequate service supply, as suggested by the following observations: (1) the number of peak-period passengers per meter of transit vehicle length is remarkably consistent for various recent BRT and RRT, and (2) significant consumption increases have followed supply increases during peak periods.

The finding that rail modes consistently attract higher levels of utilized capacity per unit of offered capacity during peak periods has important implications for cost analysis, particularly when comparing bus and rail alternatives. In many locations, a stronger case for rail might exist than some previous studies have found. However, bus modes retain significant advantages in some situations, particularly in travel corridors with lower demand or where there are opportunities for phased introduction of unconnected shorter, less costly route segments.

Peak consumption levels assumed by many previous studies are often unrealistically high with respect to service levels stated or assumed. As a result, actual costs per passenger may prove higher, and ridership lower, than predicted during early planning. If peak service supply is not adequate for projected demand, patronage will not reach predicted levels. This will lead to higher costs per passenger than predicted. Peak-period crowding will discourage additional patronage in markets where consumers have competitive alternatives to public transit service, and this will occur at crowding levels significantly below the “capacity” figures often assumed by planners and vehicle designers.

Results are specific to the United States and Canada, but the analytical framework itself need not be limited to this area. The paper is organized into three sections, the first of which presents a regression analysis of modal capacity. The second section outlines differences between BRT and RRT peak vehicle occupancy levels that suggest a consumer preference for the latter, together with related analytical issues. The third section presents our conclusions.

Regression Analysis of Modal Capacity

The regression analysis presented in Tables 1–3 used post-1990 data for busway, transitway, and high occupancy vehicle (HOV) services, and 1994–2000 data for RRT. Data were separated into BRT, LRT, and heavy rail transit (HRT) categories. The four most crowded and congested U.S. and Canadian metropolitan centers—Boston, Montréal, New York, and Toronto—were excluded. Buffalo’s hybrid RRT line in New York, in many respects an HRT facility adapted for central business district (CBD) surface operation, had an atypically low level of consumption per unit of service, suggesting a “background” of demand substantially different from other LRT corridors. In Dallas, Texas, the northward corridor had an atypically low level of service consumption per unit of peak-period service. This reflected a great increase in peak-period service to reduce overcrowding, permitted by delivery of additional vehicles a few months prior to data collection (the line has since been extended). Both were excluded from the analysis.

Ottawa data were excluded owing to (*1*) discrepancies among published data, and (2) incompatibility with published data from other BRT and RRT facilities. These factors led the authors to suspect that published data for Ottawa represent flows rather than volumes. Actual hourly volumes might be in the range of 3,500 to 5,000 phd, or 45% to 70% lower than published maximum figures[2].

Parkinson and Fisher (*1*) suggest passengers per meter of vehicle length (p/m) as the standard for vehicle occupancy, to place all systems and modes on an equal footing. Accordingly, service-supply data were converted from vhd to meters of vehicle length per hour (mhd).

The analysis demonstrates a strong correlation between peak-period service consumption and service supply, and also provides least-squares regression models for supply-side analysis of modal capacity. These models explain 80% to 96% of the variation in peak-period service consumption, suggesting a strong relationship.

The authors used *t*-tests to address the possibility of random chance; all regression coefficients (and all intercept terms except that for BRT) were found significantly different from zero (5% level). Results for the regression coefficients were very highly significant (0.1% level). In addition, the three regression coefficients were found to be significantly different from each other (5% level).

Using the BRT and LRT regression models to predict supply levels commensurate with given consumption levels, a peak-period volume of 3,000 phd is correlated with an LRT service supply equivalent to 34 vhd given 23-m (75-ft) vehicles. The BRT service supply is equivalent to 86 standard buses or 58 articulated buses per hour. Implied peak vehicle occupancies are 88 p/v for LRT, 35 p/v for standard buses, and 52 p/v for articulated buses. The BRT service-supply level is 36% higher than for LRT at the same consumption level. This comes as no surprise given the differences in PVO characteristic of each mode. The HRT service level associated with a peak-period volume of 3,000 phd is 6% greater than for LRT, a difference that is probably not significant.

The authors sought to avoid problems related to uncertainty and bias by excluding certain data, presented in Tables 1–3, from the regression models. Inclusion of authors' personal observations and authors' estimates in Tables 1 (BRT) and 3 (HRT) would not result in significant changes in the regression coefficients. For the LRT regression model, inclusion of observations and estimates for Baltimore, Maryland, Salt Lake City, Utah, and St. Louis, Missouri (Table 2) would produce a significantly different, and smaller, regression coefficient (3.83) and a weaker relationship (R^2 = .74). However, inclusion of these observations and estimates, together with those for Philadelphia, Pennsylvania and San Francisco (p.m.), would result in a significantly different, and greater, regression coefficient (4.44) and a stronger relationship (R^2 = .89). The implication in the latter case is that the peak-period BRT service level would need to be up to 50% greater than LRT for a given consumption level. It is true that the Philadelphia and San Francisco networks do not resemble the "typical" suburb-to-downtown LRT facilities opened in the United States and Canada over the past two decades; however, these results indicate a need for additional research.

Model Development, Interpretation, and Significance

It is important to understand that the regression models presented in Tables 1–3 are not the product of "revealed preference" or "revealed choice" consumer surveys, but of direct observation of consumer behavior—"observed choice." Therefore, certain issues of statistical validity that are characteristic of preference and choice surveys do not apply. For example, a preference survey asking respondents to choose among one's own auto, a red bus and a blue bus[3] might lead to biased results, for the otherwise-identical transit options are not likely to attract identical shares of respondents. However, researchers able to demonstrate through direct observation that red buses do attract larger numbers of consumers than blue buses, all else equal, face the challenge of explaining why this behavior occurs. With reference to the consumer behavior documented herein, the models in Tables 1–3 are a tentative first step towards this goal.

TABLE 1 Regression Analysis of Modal Capacity—BRT

City and Corridor		Year	Peak Service Consumption phd	Peak Service Supply		Peak Vehicle Occupancy	
				vhd	mhd	p/v	p/m
Houston	I-10 (Katy) Transitway	1990	1,820	45	548	40	3.3
" "	I-45N (North) Transitway	1990	2,810	76	926	37	3.0
" "	I-45S (Gulf) Transitway	1990	840	26	320	32	2.6
" "	US 290 (Northwest) Transitway	1990	600	17	209	35	2.9
Los Angeles	El Monte Transitway	post-1995	2,750	70	857	39	3.2
Pittsburgh	East Busway, Negley, p.m.	2000	4,002	102	1,399a	39	2.8 a
" "	South Busway, South Hills Junction, p.m.	2000	1,858	57	695	33	2.7
" "	I-279 HOV	1997	783	20	245	39	3.2
San Diego	I-15	1990	350	14	171	25	2.0
Seattle	I-5, a.m.	post-1995	2,750	70	1,067b	39	2.6 b
" "	SR-520, a.m.	1990	3,140	56	855 b	56	3.7 b
" "	I-90	1990	1,250	34	515 b	37	2.4 b
Vancouver	Lions Gate Bridge	1990	1,080	27	329	40	3.3
Washington	Shirley Highway Transitway	1996	4,500	140	1,714	32	2.6
" "	I-66	post-1995	2,920	85	1,027	34	2.8
Los Angeles	Harbor Transitway	a. 2000	300	22	268	14	a. 1.1
Miami	South Dade Busway, a.m.	a. 2000	(bus) 460	13	158	35	a. 2.9
			(van) 140	6	36	23	3.8
			(total) 600				3.1
New York	Lincoln Tunnel XBL	b. 1998	34,796	1,003	12,227	35	b. 2.8
Seattle	Tunnel, International District, s.b.	a. 2000	2,500	54	988	47	a. 2.6
" "	Tunnel, Convention Place, n.b.	a. 2000	2,600	48	879	54	a. 3.0

Notes: Peak service supply in vehicles per hour per direction (vhd) converted to meters of vehicle length per hour per direction (mhd) assuming vehicle lengths of 40 ft (12.19 m) and 60 ft (18.29 m) for standard and articulated buses, respectively.
[a] based on composite vehicle length of 13.715 m, assuming 25% articulated vehicles.
[b] based on composite vehicle length of 15.24 m, assuming 50% articulated vehicles.

Los Angeles (Harbor Transitway), Miami, and Seattle (downtown transit tunnel) data are based on authors' personal observations, were included for information only and were not used in the Ordinary Least Squares (OLS) regression model.

New York data included for information only and were not used in the OLS regression model. Ottawa data excluded as incompatible with data from other cities (see text Section 1).

OLS Regression Model (*t*-statistics in parentheses):

$$\underset{}{\text{PSCBRT}} = \underset{(0.758)}{103.91} + \underset{(17.022)}{2.75}\text{PSS} \qquad R^2 = .96$$

PSC: Peak Service Consumption, passengers per hour per direction (phd).
PSS: Peak Service Supply, meters of vehicle length per hour per direction (mhd).

The model above is based on the 15 BRT corridors in the first group above. Corridors are unweighted in the model calculations.

Data sources for Tables 1–3: Levinson and St. Jacques (*2*), Parkinson and Fisher (*1*), Tennyson (*3*), Turnbull and Hanks (*4*), and Buffalo, Calgary, Cleveland, Denver, Los Angeles, Miami, Pittsburgh, Portland, Sacramento, St. Louis, and San Jose operator staff members who kindly responded to the authors' requests for information.

TABLE 2 Regression Analysis of Modal Capacity—LRT

City and Corridor		Year	Peak Service Consumption phd	Peak Service Supply		Peak Vehicle Occupancy	
				vhd	mhd	p/v	p/m
Calgary	South Line	2000	4,660	39	1,064	119	4.4
“ “	Northwest Line	2000	3,650	36	982	101	3.7
“ “	Northeast Line	2000	4,550	36	982	126	4.6
Cleveland	Blue/Green (Shaker Heights)	2000	1,200	20	470	60	2.6
Dallas	LRT, southbound, Union Station, a.m.	2000	1,900	28	800	68	2.4
Denver	LRT, northbound, 10th/Osage, a.m.	2002	2,400	31	756	77	3.1
Edmonton	Northeast LRT	1994	3,219	36	866	89	3.7
Los Angeles	Blue Line	2001	2,618	22	599	119	4.4
“ “	Green Line	2001	1,112	8	218	139	5.1
Newark	City Subway	1994	1,769	30	421	59	4.2
Pittsburgh	LRT, Station Square, p.m.	2000	2,448	24	614	102	4.0
Portland	Eastside MAX, a.m.	1999	2,375	22	584	108	4.0
“ “	Westside MAX, a.m.	1999	2,380	18	478	132	4.9
Sacramento	LRT east	1997	1,727	16	368	108	4.7
“ “	LRT north	1997	1,600	16	368	100	4.3
San Diego	South Line LRT, a.m.	1999-2000	2,015	24	552	84	3.7
“ “	East Line LRT, a.m.	1999-2000	1,174	14	322	84	3.7
San Jose	LRT south	1997	1,327	14	380	95	3.5
Baltimore	Central LRT - north, p.m.	a. 2000	650	10	286	65	a. 2.3
“ “	Central LRT - south, p.m.	a. 2000	920	14	400	66	a. 2.3
Boston	Green Line	b. 1994	10,000	90	1,958	111	b. 5.1
Buffalo	LRRT	c. 1997	1,240	25	510	50	c. 2.4
Dallas	LRT, northbound Mockingbird, a.m.	c. 2000	1,385	27	771	51	c. 1.8
Philadelphia	Subway–Surface LRT	d. 1994	4,100	60	914	68	d. 4.5
St. Louis	MetroLink	e. 1996	2,000	18	491	110	e. 4.0
Salt Lake City	TRAX, Ballpark, a.m.	a. 2000	1,400	17	391	82	a. 3.6
San Francisco	Muni Metro, Van Ness, a.m.	a. 1999	3,870	43	953	90	a. 4.1
“ “	Muni Metro, Van Ness, p.m.	a. 1999	6,100	60	1,330	102	a. 4.6

Notes: Peak service supply in vhd converted to meters of mhd using vehicle lengths reported by Parkinson and Fisher (*1*).

Based on authors’ personal observations, included for information only; and were not used in the OLS regression model.

Boston data included for information only and were not used in the OLS regression model.

Excluded from OLS regression model as an outlier (see text Section 2F).

Authors’ estimate, assuming service frequencies as shown in public timetables. Included for information only; excluded from the OLS regression model.

Authors’ estimate, assuming 8% PTS for the busier (eastward) segment of the line, 2-car trains and service frequency as shown in public timetable. Included for information only; excluded from the OLS regression model. Streetcar operations using historic vehicles (e.g. Memphis, New Orleans, San Francisco F Line, Seattle Waterfront Streetcar) were excluded from this tabulation.

OLS Regression Model (*t*-statistics in parentheses):

PSCLRT = 36.62 + 3.83PSS R^2 = .81
(0.124) (8.395)

The model above is based on the 18 LRT corridors in the first group above. Corridors are unweighted in the model calculations.

TABLE 3 Regression Analysis of Modal Capacity—HRT

City and Corridor		Year	Peak Service Consumption phd	Peak Service Supply		Peak Vehicle Occupancy	
				vhd	mhd	p/v	p/m
Atlanta	East–West	1994	2,986	60	1,380	50	2.2
" "	North–South	1994	5,093	58	1,334	88	3.8
Chicago	Dearborn Street Subway	1994	9,376	112	1,651	83	5.6
Cleveland	Rapid (Red Line)	2000	1,200	20	436	60	2.8
Los Angeles	Red Line	2001	3,400	60	1,380	57	2.5
Miami	Metrorail, Vizcaya, a.m.	1998	3,854	52	1,184	74	3.3
Philadelphia	Lindenwold Line	1995	5,650	90	1,829	63	3.1
San Francisco	Transbay Tube, a.m.	1999	16,700	180	3,863	93	4.3
" "	Mission St. Subway, a.m.	1995	8,069	130	2,789	62	2.9
Vancouver	Skytrain	1994	6,932	100	1,232	69	5.6
Washington	Blue/Orange, eastbound, Rosslyn, a.m.	2000	15,800	140	3,286	113	4.8
" "	Blue/Orange, eastbound, L'Enfant Plaza, p.m.	2000	10,400	106	2,488	100	4.3
" "	Red, southbound, Dupont Circle, a.m.	2000	12,300	120	2,816	103	4.4
" "	Red, southbound, Union Station, a.m.	2000	11,800	120	2,816	98	4.2
" "	Green, southbound, Mt. Vernon Square, a.m.	2000	4,200	40	939	105	4.3
" "	Green/Yellow, northbound, L'Enfant Plaza, a.m.	2000	8,100	80	1,878	101	4.3
Baltimore	Metro, State Center, a.m.	a. 2000	4,200	108	2,213	39	a. 1.9
Chicago	Brown (Ravenswood)	b. 1994	7,051	97	1,507	73	b. 4.7
" "	Green (Lake / South)	b. 1994	2,952	42	653	70	b. 4.5
" "	Orange (Midway)	b. 1994	4,287	66	1,026	65	b. 4.2
" "	Purple (Evanston)	b. 1994	3,479	42	659	82	b. 5.3
" "	Red (Howard / Dan Ryan)	b. 1994	11,533	120	1,865	96	b. 6.2
Philadelphia	Broad St., northbound, Girard, p.m.	a. 2000	4,200	108	2,213	39	a. 1.9
" "	Market St., eastbound, 15th St., a.m.	a. 2000	5,500	96	1,600	57	a. 3.4
San Francisco	s.b. from Ashby, a.m.	c. 1995	4,400	70	1,502	63	c. 2.9
" "	s.b. from Rockridge, a.m.	c. 1995	7.627	81	1,738	94	c. 4.4
" "	n.b. to Lake Merritt, a.m.	c. 1995	6,413	86	1,846	75	c. 3.5

Notes: Peak service supply in vhdconverted to mhd using vehicle lengths reported by Parkinson and Fisher (*1*).

a. Based on authors' personal observations, included for information only; and were not used in the OLS regression model.

b. Authors' estimate, assuming service frequencies as shown in public timetables. Included for information only; excluded from the OLS regression model.

c. BART volumes into downtown Oakland are shown for information only, and were not used in the OLS regression model since the lines to Concord, Fremont, and Richmond form branches of the transbay "corridor."

Boston, Montréal, New York, and Toronto were excluded from this tabulation.
OLS Regression Model (*t*-statistics in parentheses):

PSCHRT = -928.80 + 4.50PSS $\quad R^2 = .86$
(-0.896) (9.376)

The model above is based on the 16 HRT corridors in the first group above. Corridors are unweighted in the model calculations.

The models establish strong and statistically valid correlation between peak-period service supply and consumption. This correlation does not imply causation. On the other hand, it is the consumers who decide what levels of consumption will be observed. To overlook the important role of service supply in shaping consumer choice is to deny the obvious: transit service supply "permits" consumption, and given levels of consumption will therefore not occur without adequate supply.

The authors, based on the principle of parsimony, chose to include only service supply as the determinant of consumption in the regression models. Other factors certainly influence the outcome, but their influence is much less clear. For example, schedule (commercial) speed may influence the consumer choices that determine PVO. However, data are not available to permit quantification of the likely relationship between passenger speed, relative to that provided by autos in individual corridors, and PVO. It is also possible that factors apparently extraneous may influence the outcome. For example, overall vehicle length and height do not influence available floor space per meter of vehicle length, but might influence consumer choice and therefore PVO. Once again, data are not available; additional research is clearly indicated.

The authors did not include demand factors (e.g. corridor population, population density, CBD employment, CBD parking supply and cost) in the regression models, for this is not appropriate for supply-side analysis. Such analysis is conducted against a background of demand factors (those that "cause" consumption) that are postulated to remain constant as other factors are changed. Inclusion of demand factors as controls is therefore not appropriate. Statistical validity is, however, not compromised unless changes in supply or other "non-demand" factors also cause changes in demand factors, thereby introducing bias. In other words, such bias would occur as the result of "induced" (or "suppressed") demand—in the literal sense. Data are not available to establish whether this occurred in the various BRT and LRT corridors in Tables 1–3. (The authors advocate strict adherence to the definitions of demand, supply, and consumption; induced consumption is not at all synonymous with induced demand.)

Strictly speaking, the models presented herein cannot predict the responses of consumers to changes in service supply. This fact comes as no surprise, because such prediction requires consideration of demand factors, which are not incorporated into supply-side models. It should be obvious that, if service supply could be increased without limit, consumption would eventually reach the theoretical maximum established by demand factors. The authors address this matter at greater length in a separate paper (http://209.233.41.114/documents/modechoice/WP02-04%20Modal%20Capacity.pdf).

However, from the supply-side perspective, observed consumer behavior makes it possible to determine peak-period consumption levels associated with a given supply level, and to do so within a rather broad range of demand factors. Supply-side analysis cannot replace demand-side analysis, of course, but provides useful verification of demand forecasts. The fact that peak service changes in Portland and Los Angeles were soon followed by consumption changes consistent with the regression model (Table 2) illustrates 1) the strength of the correlation, and 2) the existence of demand previously unserved.

Rail Versus Bus Peak Vehicle Occupancy: A Matter of Consumer Preference?

Observed consumer behavior—differences between BRT and RRT peak vehicle occupancy—implies that RRT generates greater consumption per unit of peak-period service, all else equal. This behavior suggests that for a given consumption level, roughly 35% more service would have to be supplied by a BRT alternative. This consumer behavior is not explained by the following:

- Differences in vehicle size or interior configuration. However, the average railcar is not 30% to 50% wider than the average bus, and does not have 30% to 50% more net floor space per unit of vehicle length. This is true in particular of LRT vehicles. Available facts do not support this hypothesis.
- Differences in service characteristics. U.S. and Canadian BRT operations are dominated by freeway and HOV express-bus services, where vehicles operate without stopping between suburban neighborhoods or park and ride lots and CBD destinations. Lower PVO might be an inherent characteristic of such service, owing to the lack of intermediate stops where shorter-distance riders willing to travel as standees might board. However, this is not apparent in Pittsburgh and Ottawa, where local routes serving intermediate stops share facilities with express routes that pass through intermediate stations. On-site observations do not support this hypothesis.
- Lower demand in BRT corridors. However, to give just one example, PVO is lower through the Lincoln Tunnel between New York City and New Jersey than on several recent LRT systems, but Lincoln Tunnel peak volumes (phd) are much higher. Available data do not support this hypothesis.
- Calibration of supply to demand by operators. Observed PVO levels may be established, in effect, by transit agency decisions tailoring supply to demand. If this is true, then it would also introduce bias to the regression models presented above: higher PVO for RRT would lead to results suggesting that consumers respond to RRT service changes in greater numbers than actually occurs. However, this hypothesis is extremely difficult to support. Various operators have widely different loading standard, and the authors do not know of a single instance where these were established with consumer input. The hypothesis begs the questions of how operators are able to maintain such consistent PVO levels nonetheless—and why consumers tolerate (or why operators subject them to) higher levels of peak-period crowding aboard RRT vehicles.

Service effectiveness is also an issue. In Los Angeles, El Monte Transitway buses supplied 66% more service during the busiest hour (mhd) than the LRT Blue Line, but carried just 8% more peak-hour traffic (phd) (Tables 1–3). The operator charged premium fares for BRT services (based on freeway or transitway distance) but not for LRT or HRT.[4] Pittsburgh's East Busway supplied 2.3 times as much peak-hour service (mhd) than the light-rail system, and carried nearly twice as much peak-hour traffic. These examples do not support careful calibration of supply to demand.

Underlying assumptions do not stand up to critical analysis. The hypothesis implies that operators have the ability to serve all existing demand, and that unserved demand therefore does not exist. However, various RRT facilities opened from the early 1980s could not accommodate peak-period volumes of the size implied by preconstruction ridership forecasts. The principal constraint was vehicle fleet size, although limitations on train length and service frequency are characteristic of LRT facilities (*5*). Unserved demand has been demonstrated in two cases, and probably exists in others.

In sum, on-site observations and available data fail to support this hypothesis.

- Lack of service-supply capacity of recent LRT systems relative to BRT facilities. Service constraints, imposed in the majority of cases by vehicle fleet size, may explain why most LRT lines carry consistently higher PVO than BRT. However, in the two cases cited above (Los Angeles and Pittsburgh), LRT peak service levels (vhd) were at the practical maxima, while PVOs are high enough to suggest the existence of unserved demand. The PVO disparity between LRT and BRT persists in corridors with a wide range of demand characteristics, and over a very wide range of peak volumes: 1,000–10,000 phd for LRT, and 400–32,000 phd for BRT. Available data fail to support this hypothesis.
- Disutility created by the need to change between vehicles. The “transfer penalty” suggested by consumer surveys should manifest itself in terms of PVO: express bus services offering one-seat transportation between suburban residences and CBD destinations should have higher vehicle-occupancy levels than line-haul services requiring transfers, all else equal. Comparison between modal PVO levels reveals exactly the opposite pattern, and comparisons within the BRT mode are inconclusive.[5] Disutility from transfers is offset apparently by increased service frequency on busy portions of trunk or feeder networks, those providing high connectivity between large numbers of origins and destinations in particular. High transfer rates are characteristic of such systems, including the most successful transit operators in the U.S. and Canada (e.g., San Francisco, Toronto). On-site observations and available data fail to support this hypothesis.

The PVO differences suggest an observable consumer preference for RRT over BRT with reference to peak-period travel. Some consumers may find that seated travel is equally acceptable aboard either mode, but that standing travel is less acceptable aboard BRT. Such consumers would be willing to ride RRT even if not certain of obtaining a seat, but would be willing to ride BRT only if seats could be obtained. Others may prefer seated travel aboard railcars to seated travel aboard buses, and would therefore be more likely to ride RRT than BRT. Still others may prefer seated travel aboard buses to seated travel aboard railcars, and would therefore be more likely to ride BRT than RRT.

Most previous studies of consumer choice found no special attractiveness for RRT (*6*, *7*), but did not focus on peak-period markets. Consumers in a single corridor market are rarely able to choose between equivalent BRT and RRT services, so direct comparison to determine relative consumer attractiveness would be difficult. Few fixed-guideway corridors are closely similar, and BRT facilities are scarce in the U.S. and Canada.

Different user perceptions may lead to greater attractiveness of RRT per se over BRT. More plausibly, characteristics typical of each mode (8, 9) might lead to different user perceptions of BRT and RRT service; in other words, the two may not be perfect substitutes. For example, users may perceive RRT as offering a smoother ride, less discomfort owing to less-frequent starts and stops, and greater reliability of service. This in turn might lead to greater willingness among prospective customers to travel aboard railcars as standing passengers—which may be inferred from available data, and has been recognized by Seattle planners.

Capacity estimates for mixed LRT and bus operation in the Seattle CBD transit tunnel are based on different loading standards for each mode. The LRT standard of 137 p/v is based on observed PVO in Portland, and implies 4.7–5.0 p/m given the planned vehicle length (90–95 ft). The bus standard of 46 p/v, or 2.5 p/m, reflects actual experience in Seattle. The operator has found that planning for an overall average PVO of 80% of seating capacity usually results in periodic overloads, requiring some passengers to stand. The operator has also found that regularly exceeding this PVO level results in a large number of complaints. It has concluded that a PVO greater than 80% of seating capacity may discourage ridership on bus services using the CBD tunnel (*10*).

Vuchic (*9*) states that RRT provides a higher quality of service than BRT and thus attracts greater ridership. Tennyson (*8*) concluded that RRT would attract 34% to 43% more passengers given equivalent service conditions. Peak vehicle occupancies for RRT are 30% to 50% greater than for BRT. This, together with results of the regression analysis presented in Tables 1–3, appears to confirm Tennyson's prediction, at least for peak-period travel markets.

Martinelli (*11*) states that "there are fewer passengers per vehicle for busways," but refers clearly to differences in vehicle size and seating capacity, not observed PVO. He also states, "The capacity of busways is far more flexible and often can be used more efficiently than that of light rail." Once again, this refers clearly to theoretical (roadway) capacity, not to achievable utilized capacity.

Although additional research is needed to identify and quantify the underlying cause or causes, greater peak-period vehicle occupancy for RRT is well supported by available data. The authors emphasize that such research will need to give paramount importance to consumer behavior, perceptions and attitudes rather than the researchers' perspectives. Vuchic et al. (*12*) state that the "image" of a transit system is derived from operating conditions rather than vehicle type: that is, bus services in mixed traffic present a much different image than high-speed BRT services on exclusive rights-of-way. But public input received by Louisville, Kentucky, planners is rather different, summarized by a consultant as follows: "If this [project] is going to cost hundreds of millions of dollars, I'd rather be riding a train" (*13*). Kain (*14*) states that an "inflexible" system such as LRT, requiring "virtually all" users to transfer from other transit services or autos, cannot be strongly attractive. But observations from Los Angeles and Pittsburgh, where LRT peak vehicle occupancies were substantially greater than for BRT services (Tables 1–3), fail to support this hypothesis. (As noted above, Los Angeles charged higher fares for most BRT services, but Pittsburgh did not.)

It is striking that three recent study documents regarding BRT are silent on the PVO issue (15– 17). The PVO issue will certainly influence the results of FTA's current "Bus Rapid Transit Demonstration Program."

The difference between observed PVO for BRT and RRT has important implications for cost analysis. If a BRT alternative had to provide a peak-period service supply 30% to 40% greater than LRT in a given corridor, operating and certain capital costs for BRT would have to be adjusted upward. Labor productivity, for example, is an important issue. Given equivalent operating speeds, LRT with self-service fare collection and one-person operation of trains can achieve greater peak-period labor productivity than BRT, by factors in the range of 6:1 to 11:1. This advantage would be narrowed if an equivalent BRT service achieved higher speed, and of course it is only part of the comparison; vehicle and guideway maintenance labor and the overall capital costs must be included in the analysis.

Does Unserved Demand Exist?

If no U.S. or Canadian BRT or RRT corridor has unserved demand, then positive changes in service levels would not produce positive changes in consumption. If so, then PVO levels would simply decrease with each increment of additional service, with no net increase in ridership. But this conclusion is difficult to support. Data from several LRT systems imply high PVO, and service levels at or near practical (site-specific) maxima. This suggests that, at least in some cities and corridors, unserved demand does still exist. Examples include

- Portland: A September 1998 service increase was followed by a large ridership increase. Weekday vehicle-trips were increased by 31%, from 388 to 510. Weekday services (train-trips) were increased by 19%, from 213 to 255. Eastside Line ridership at October 1998 was 37,200 passengers per weekday (p/w), up by 34% from the October 1996 level of 27,700 p/w. An expanded vehicle fleet permitted a peak-period service increase from 17 to 22 vhd, or 29%. This was accompanied by a 17.5% peak-hour ridership increase, from 2,100 to 2,500 phd. The majority of the weekday ridership growth occurred outside of the peak-period, peak-direction travel market. This may reflect "reverse direction" travel by passengers riding through from the new Westside Line, which opened in September 1998, to employment centers east of the CBD.
- Los Angeles: University of Southern California researchers counted 24,100 boardings in June 1991. Two months later, the operator counted 32,587 boardings. Moore (*18*) labels the latter an "outlier" and implicitly questions its veracity. However, peak service frequency was increased from 10 min to 7.5 min prior to the second count. A 33% service-supply increase, during the hours when roughly 50% of weekday transit ridership occurs in the United States, is a very significant change and corresponds well to the 35% increase in reported boardings. The explanation offered by Moore (*18*), reduction of parallel bus service, was much too small to account for this.[6]

Peak Service Supply and Peak Vehicle Occupancy: Theory Versus Practice

Previous modal comparisons and planning studies often assumed different, usually higher, service-supply and vehicle-occupancy levels from those observed in actual operation. Results are therefore biased in a manner that does not reflect actual experience.

Observed PVO in most metropolitan areas is much less than vehicle capacity usually assumed by planners. This comes as no surprise. Transit vehicle capacity ratings typically reflect arbitrary standards of floor space per passenger, and are highly inconsistent between operators. The authors have not found any cases where loading standards were based on the wishes of consumers, demonstrated consumer choice, or feedback from surveys of potential passengers or focus groups.

Observed PVO reflects a complex relationship among several demand and supply factors. It is also an important indicator of consumer choice, and reflects willingness to travel as a standing passenger and willingness to tolerate existing levels of crowding aboard transit vehicles (whether standing or seated). Ancillary effects of high crowding levels also influence this choice: increased loading and unloading (dwell) times, irregular intervals between vehicles and lack of space onboard. PVO levels off at the point where, on average, prospective passengers choose to travel at a different time or by a different mode.

It is now clear that U.S. and Canadian consumers will not accept the PVO standards used for many planning studies during the 1970s and 1980s. This is demonstrated by the stabilization of observed PVO at similar levels in corridors having a wide range of demand characteristics (Table 1–3). In Portland, operator staff members have concluded that Portland transit passengers will not accept LRT vehicle occupancies greater than 135 p/v (4.9 p/m), except for special events. Prior to construction, LRT planners estimated the capacity of each 90-ft vehicle at 166 passengers (6.1 p/m) based on 76 seated passengers and four standees per square meter. This loading standard was based on (West) German experience (*19*).

Levinson and St. Jacques (*2*) present “suggested bus passenger service volumes for planning purposes” of 7,500-10,125 phd, requiring 81-135 vhd. These figures, which imply 75-96 p/v and 6.1-7.9 p/m, are unrealistically high. The authors have found only one case since the crush-loading years of World War II where published data support an observed PVO exceeding 4.8 p/m for any U.S. or Canadian bus service. This is 5.6 p/m for bus services on Hillside Avenue, Queens, New York City, circa 1962 (*20*).

Boyd et al. (*21*) postulated 576 vhd to provide a “capacity” of 31,600 phd, implying PVO of 50 p/v. The supply level is nearly 300% greater than the maximum yet offered on any U.S. or Canadian BRT facility other than the Lincoln Tunnel with its unique CBD terminal.[7] Biehler (*22*) assumed PVO levels of 200 p/v for LRT and 100 p/v for articulated buses, well above those suggested by empirical data. Meyer et al. (*23*) postulated 79 seats per railcar, 50 seats per bus, and service levels sufficient to provide seats for all passengers.[8] The “no-standee” model underestimates peak vehicle occupancy, for RRT in particular, and therefore overestimates supply levels necessary to attract and move given traffic volumes. The capacity of a two-lane busway, based on observed highway-lane capacity, was projected at 480 vhd. This would require extraordinary preferential-lane measures involving multiple CBD streets or a large off-street terminal. RRT capacity figures, 320-720 vhd depending on line and terminal configuration, were based on theoretical maxima calculated by Lang and Soberman (*24*), and were not compared with actual operating experience. Much has been published in the nearly four decades since this pioneering study, but more recent studies do not include peak service supply and PVO details.

Rubin and Moore (*25*) overestimate peak service supply and peak vehicle occupancy in egregious fashion for the El Monte Transitway in Los Angeles. The postulated theoretical maximum of 194,400 phd was based on 1) three-section double-articulated buses as used in Curitiba, Brazil; 2) peak service supply of 720 vhd; and 3) PVO of 270 p/v, or 11 p/m. The service supply level is entirely unrealistic without a large off-street terminal, the PVO level far exceeds those observed in the U.S. and Canada, and the estimated peak volume far exceeds levels achieved in actual service, anywhere.

Performance evaluations of existing U.S. fixed-guideway facilities seldom consider supply issues, focusing exclusively on demand parameters and demand analysis. This curious and consistent oversight is difficult to explain; only a few examples can be cited here. Hamer (*26*) wrote before most projects he considered had been completed. But Webber (*27*) considered only the BART system, and was certainly aware of the large peak-capacity shortfall. Hall (*28*) could have analyzed the impact of service-supply levels on BART ridership over the initial six years of operation. But neither addressed service-supply issues.

The critical role of peak service supply in increasing transit use and attracting patronage from private autos has also been ignored. For example, Hensher (*29*) states that the failure to attract significant new patronage to RRT over the past two decades is due largely to lack of disincentives to automobile use. But San Francisco planners recognized 40 years ago that diversion of RRT patronage from automobiles would not occur uniformly throughout the day, but would instead be concentrated into peak commute hours (*30*). Large-scale diversion of auto trips to public transit is not likely unless existing and planned systems provide levels of peak-period comfort acceptable to consumers and provide this comfort on a scale large enough to accommodate a significant share of consumers who now use private autos.

Other Analytical Issues

The consumer behavior described above suggests that a much stronger case for rail transit in the United States and Canada may be made than some previous studies have found. The first comprehensive analysis, by Meyer et al. (*23*), could draw on current experience with high traffic volumes in only one city, New York, and, for historically high traffic, on wartime conditions that restricted automobile use. LRT systems were few and BRT an early experiment. This led to overestimates of achievable capacity for BRT, especially for high (hypothetical) traffic volumes, and underestimates of BRT costs relative to RRT. Overestimation of practical maximum capacity leads to underestimation of capital and operating costs for a given traffic volume, and to overstatement of the cost difference between modes. Meyer et al. placed the economic break-even point, the traffic level at which RRT has a total cost advantage, at a very high traffic level—50,000 phd, well above the modal capacities implied by empirical data from the United States and Canada. Pickrell (*31*) placed the BRT/HRT break-even point far above the levels that have ever been achieved, anywhere, over a single lane or track—200,000–340,000 phd for a 10-mi corridor, depending on HRT capital cost.

Various planning studies for specific corridors contain unrealistic assumptions regarding supply parameters and the demand-supply-consumption relationship. Examples include

- Adelaide (Australia), Northeast Busway: estimated maximum capacity (*32*) implied that tripling of peak service supply (from 60 to 180 vhd) would produce a 39% increase in PVO (from 72 to 100 p/v). This is unlikely without substantial increases in demand factors (e.g., population and employment levels, road congestion, and fuel and CBD parking costs). With PVO at the (then-) current level, the corresponding maximum volume (about 13,000 phd) would fall nearly 28% short of the estimate.
- Los Angeles: examples below illustrate chronic overestimation of 1) PVO, and 2) off-peak and reverse-direction ridership relative to peak-period, peak-direction traffic.
- Blue Line LRT: Parsons Brinckerhoff/Kaiser Engineers (*33*) assumed 175 p/v (6.4 p/m) to estimate peak capacity. Weekday ridership and maximum peak volume were forecast at 54,702 p/w and 2,668 phd, respectively.
- Eastside HRT (later planned as LRT): Los Angeles County Metropolitan Transportation Authority (*34*) used “normal” and “maximum” PVO of 169 p/v (7.4 p/m) and 301 p/v (13.2 p/m) respectively. Weekday ridership and maximum peak volume were forecast at 65,902 p/w and 4,000 phd, respectively.
- Harbor Transitway BRT: peak capacity estimates assumed 66 p/v (5.4 p/m) for standard and 96 p/v(5.2 p/m) for articulated buses, respectively (*35*). Implied peak-hour service supply and passenger volumes were 80-125 vhd and 5,000–12,000 phd. These figures far exceed the peak service levels, PVO, and passenger volumes carried to date (Table 1). Anticipated PVO levels were 79% to 86% higher than observed on the El Monte Transitway, and anticipated peak volumes were two to five times greater than carried by the El Monte facility (Table 1).
- Red Line HRT: in 1983, system capacity was estimated initially at 30,600 phd, based on 170 p/v (7.4 p/m) (*36*). Weekday ridership and maximum peak volume were forecast at 376,375 p/w and 30,000 phd, respectively. Such assumptions were carried forward throughout the planning process.
- New Jersey, Hudson-Bergen LRT: New Jersey Transit (*37*) forecast a maximum of 8,247 phd during the a.m. peak, carried aboard 30 vhd. This implied 275 p/v [9.8 p/m, given the

92-ft (28-m) vehicle length]. These PVO figures imply crowding levels higher than reported anywhere in North America, except on the busiest HRT lines in México City, Montréal, and New York.

- Ottawa: PVO (capacity) levels of 54 p/v for standard buses, 102 p/v for articulated buses, and 117 p/v for LRT vehicles were assumed during alternatives analysis (*14*). This overstated BRT net capacity by roughly 50% (or more, given PVO observed on-site: 30–38 p/v; 2.3–2.9 p/m). The analysis 1) underestimated BRT service supply corresponding to given consumption levels; 2) underestimated BRT operating cost and certain capital costs; and 3) overestimated BRT performance relative to LRT. These problems appear insignificant compared to nontechnical and political factors which influenced the mode choice (*38*). However, the designed maximum of 15,000 phd would require 300-500 vhd, rather than 200 vhd as stated prior to construction (absent measures to increase peak-period demand for transit services; e.g., higher parking or fuel costs, leading to higher peak-period utilized-capacity levels). This appears impractical with the current CBD distribution facilities.
- Pittsburgh: a capacity analysis assumed 80 p/v for standard buses and a service supply ranging between 90–150 vhd, resulting in capacity figures of 7,200–12,000 phd (*39*). The PVO figure is nearly twice that observed on Pittsburgh's busways, and observed peak volumes are 40% to 60% lower than projected.
- San Diego: San Diego Transit Corporation (*40*) proposed a BRT alternative to LRT, and projected a corridor ridership increase from 15,000 to 64,000 p/w over 20 years (to 1995). But the distribution of ridership between peak and non-peak hours was assumed to remain fixed as ridership quadrupled. Moore (*18*) made similar assumptions. Such predictions conflict with actual experience, results produced by modal-split models, and common logic. The increased ridership generated by BRT or RRT, at least during initial operation, occurs as an increased share of travel in the dominant market—CBD work trips—is attracted by the new, faster service.
- Seattle: the maximum capacity of CBD transit tunnel, as implied by the parameters used currently by the operator, is 5,750 phd, based on 125 vhd and PVO equal to 80% of vehicle seating capacity. The operator states that the 125 vhd figure is based on "more than ten years of experience with operating the only all bus tunnel with on-line passenger stations in the world" (*10*). 125 vhd is nearly 80% greater than the maximum service level that has yet been operated.

Niles et al. (*41*) and DMJM+Harris (*42*) estimate maximum tunnel capacity at 13,455 phd, assuming 65 seats per vehicle, full seated loads, and 200 vhd. The associated service supply is nearly three times greater than that yet operated. These analyses also estimate a maximum capacity of 15,950 phd, assuming 110 p/v (6.0 p/m) and 145 vhd. PVO and service-supply figures are double the current levels. Rubin and Moore (1997) state a "theoretical" peak-hour capacity of 18,000 phd, based on 145 vhd. This implies 124 p/v (6.8 p/m), roughly three times greater than PVO carried currently by tunnel services.

Seattle's plan for mixed bus and LRT operation in its CBD transit tunnel include a maximum service level of 60 bus vhd, 10 LRT thd, and 4-car trains. Six buses would be scheduled to operate in "platoons" during the 6-min interval between trains. The feasibility of mixed operation has been demonstrated in Essen, Germany, but with much less than 60 bus/h/d. The planned bus and LRT service levels may prove impractical when operated over the same guideway. Another issue, which has not been addressed, is that safety standards for each mode are not identical. Road vehicles, including Seattle tunnel buses, typically operate beyond the safety limit (i.e., the safe stopping distance from the maximum permitted speed is less than the minimum spacing between vehicles), but RRT systems worldwide do not permit this.

CONCLUSIONS

The principal finding of this paper is the consumer behavior described and analyzed above. The principal conclusion that follows is that supply of transit service is a critical factor governing ridership and effective capacity in the U.S. and Canadian environment, where most consumers have alternatives and are not forced to travel under “crush-load” conditions. Effective RRT capacity, as established by consumer choice, is an average vehicle occupancy between four and five passengers per meter of vehicle length, corresponding to 100–120 passengers in a typical articulated LRT railcar. BRT peak-hour vehicle occupancy is consistently less, slightly below three passengers per meter of vehicle length. These are averages during the peak hour as vehicles traveling in the peak direction past the busiest point on their route. If service supply is not adequate to meet potential demand under these conditions, some potential customers will decide not to ride. In Los Angeles and Portland, LRT capacity increases attracted additional customers, indicating the previous existence of unserved demand. There are other, perhaps many, systems where similar results could be obtained.

Service consumption arises from consumer decisions shaped by interactions between travel demand and service supply factors. It is therefore clear that consumption parameters such as PVO must be influenced by population density, CBD employment and other demand parameters. But quantification of such relationships would require, in the words of Cervero and Landis (*43*), “a far richer, more comprehensive and more dynamic data base . . . than we, or anyone else to date, had available.”

For this paper, the authors addressed demand in aggregate fashion, in the manner of supply-side analysis: postulating the existence of various demand parameters, in magnitudes and combinations sufficient to generate the predicted consumption levels—in concert with various service-supply levels. Additional research, better data, and improved methodology should eventually permit disaggregate analysis of various demand factors with supply and consumption parameters, and extension of this analysis to off-peak and weekend service periods. Compilation and publication of nationwide data regarding peak service supply and consumption for U.S. fixed-guideway facilities, of the quality available for countries such as Japan, by an agency (such as the Federal Transit Administration) would expedite such research.

Overly optimistic demand forecasts would lead inexorably to ridership shortfalls, but veracity of demand analysis cannot be determined through observation of consumption levels alone. Supply parameters must also be addressed.

In conclusion, the authors believe there is a crucial relationship among travel demand and service supply parameters, which must be recognized as a key factor determining transit service consumption. It is hoped that additional research will provide a more comprehensive picture of these interactions and their impact upon consumer choice.

NOTES

1. The authors discuss a number of issues related to supply-side analysis, including service-supply and vehicle-occupancy parameters, in a separate paper, “Rapid Bus and Rapid Rail: Peak Period Service Supply vs. Observed Passenger Utilization,” available online at http://209.233.41.114/documents/modechoice/WP02-04%20Modal%20Capacity.pdf . Data related to peak-period BRT and RRT service supply and consumption for various North American cities, compiled by the authors, is available online at http://209.233.41.114/ documents/transitsupply/ MG02-01%20Bus-Rail%20Peak%20Loads.pdf .
2. The maximum hourly volumes observed by the authors range from 3,400 to 4,700 phd. The authors have provided additional information at http://209.233.41.114/documents/ modechoice/WP02-04%20Modal%20Capacity.pdf .
3. This example is adapted from lecture material presented by Fred L. Mannering, Professor and Head, School of Civil Engineering, Purdue University.
4. The operator, seeking to reduce overcrowding on peak-period LRT Blue Line trains, eliminated the express surcharge on Harbor Transitway services as a promotion from November 2000 to January 2001. Ridership increased by about 10% (to 2,700–2,800 per weekday), and most new passengers continued to use Harbor Transitway services following the end of the promotion.
5. The Ottawa transit network operates in trunk-feeder configuration during most of the day, shifting to the one-seat pattern during weekday peak periods. The peak-period transfer rate should therefore be less than during other times. However, supporting data are not available.
6. Two freeway express bus routes, 456 and 457, carried about 2,700 p/w, less than three percent of pre-rail corridor ridership (101,000 p/w at FY 1990). Line 456 ridership fell by more than 45% (to 1,300 p/w) after rail service began. This line was discontinued in June 1991, after the USC count of June 1991 but before the operator’s August count. Line 457, when discontinued early in 1995, averaged 90 p/w, down from 300 p/w at FY 1990. Large-scale forced abstraction of ridership from parallel bus routes to rail is not supported by operator statistics and public timetables, which show little evidence of peak service-supply reductions (40-60 vhd) commensurate with the rail peak volume (2,400 phd, at 1994).
7. Boyd et al. (1973) estimated a peak capacity of 144 vhd per CBD street, and stipulated four parallel CBD streets for their hypothetical BRT service.
8. Enforcing a “seat for everyone” rule on most existing U.S. fixed-guideway facilities would require controls on boarding during peak periods. Consumers who derive greater utility from traveling as standing passengers aboard the first available vehicle rather than from waiting for a seat—and those who prefer to stand even when seats are available—would view such controls as unjustified marketplace interference.

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Light Rail and Urban Mobility
Is Light Rail Transit Justifying Its Investment?

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Many critics of mass transit argue that mass transit investment, and rail investment in particular—especially in light rail transit (LRT)—are not justified. It is frequently argued that mass transit ridership is so small as to be irrelevant to urban mobility; that transit ridership is in steady decline; that the share of urban trips by mass transit is decreasing; and that major transit investments, such as those in LRT, have not had an impact on these trends or on traffic congestion. Recently, critics have referred to U.S. Census journey-to-work survey data in an effort to dismiss seemingly impressive reported increases in transit ridership in North America. While it is possible that transit work trips might have declined despite a rise in overall ridership, claims of an absolute decline in public transportation work trips between 1990–2000 contrast with reported increases in nationwide ridership. They also appear to be based in part on excessive reliance on the competency and precision of census survey data, which may have methodological weaknesses.

Journey-to-work survey data may be useful in suggesting broad trends in work travel mode choice or "market share;" but they do not appear reliable for the precise numerical analysis and conclusions interpolated by such critics. Furthermore, such use of these data fails to account for such factors as the effects of urban sprawl, fostering automobile dependency; the fact that much of this sprawl-type growth is typically outside the transit service area; and the fact that roadway development in almost all cases has significantly outstripped rail transit development. In addition, of the 12 big-city transit systems that apparently gained or maintained "market share" of work trips (according to census data) between 1990 and 2000, 9 are cities with major rail transit, and most operate LRT systems. Anecdotal case studies of LRT in Dallas, Texas, Portland, Oregon, and Denver, Colorado, suggest that ridership expansion, productivity (passenger-mileage) improvement, and reductions in unit operating costs may provide some justification of LRT investment in those cities. Furthermore, performance of Denver's LRT provides at least anecdotal evidence that LRT may provide significant mobility improvement in a specific corridor.

INTRODUCTION

Pro-automobile critics of mass transit have long argued that mass transit investment, and rail investment in particular—especially investment in light rail transit (LRT)—are not justified. Such critics frequently argue that mass-transit ridership is so small as to be irrelevant to urban mobility; that transit ridership is in steady decline; that the share of urban trips by mass transit is decreasing; and that major transit investments, particularly LRT, have not had an impact on these trends or on traffic congestion.

Certainly, increasing ridership and improving urban mobility have been important goals motivating investment in LRT and other quality transit projects. However, there have been a number of other goals (and criteria for judging these investments) as well—for example, urban planning goals, such as improving urban livability and encouraging transit-oriented development.

Improving the cost-effectiveness and economic productivity of public transport has also been an objective. Particularly in the face of soaring bus transit operating costs, some agencies have hoped that LRT investment would help raise productivity and reduce unit operating costs, while contributing to the expansion of service area ridership.

Although the somewhat complex and multifaceted issue of urban planning goals is beyond the scope of this study, other criteria will be addressed. These include ridership, service productivity, unit operating cost trends, and (in one case) impact on mobility congestion. While some aggregate consistent national data will be examined, this study will mainly focus on several individual LRT systems which have been particular targets of criticism by rail opponents. Although anecdotal, these cases will perhaps provide some indication of whether LRT investment has fulfilled at least some of its original justification expectations.

NATIONAL RIDERSHIP GROWTH

Seemingly impressive increases in transit ridership in both the United States and Canada have helped refute some critics' portrayal of U.S. mass transit in decline. According to data from the American Public Transportation Association (APTA), U.S. public transit ridership has been experiencing the longest sustained growth in the nation's history. Since 1995, ridership has grown by 20%. Public transportation carried more than 9 billion trips in 1999, representing the highest level of ridership in nearly 40 years; 2001 was the fifth year in a row that transit ridership grew faster than highway use. Americans made a record 9.5 billion trips on mass transit in 2001, 2% more than in 2000. Highway use grew only one percent. All major modes of public transportation have reported more riders. Particularly significant is the fact that public transportation ridership has been rising at a faster rate than automobile use and even domestic air travel (*1*).

Furthermore, transit ridership growth appears to reflect greater public use of transit, and not simply more boardings due to more transfers. This is indicated by the substantial increase of 15.9% in transit passenger-mileage from 1990 to 2000 (which would not be increased merely by more transfers). Moreover, most of this increase is attributed to rail transit. Of the major transit modes, passenger-mileage increased as follows:

- Motor bus—260 million or 1.2%
- Regional (commuter) rail—2.32 billion or 32.8%
- Rail rapid transit—2.369 billion or 20.6%
- LRT—785 million or 137.5%

Rail transit thus accounted for approximately 84% of all major transit mode passenger-mile growth in this period. Furthermore, rail outpaced motor bus growth by over 21 times, and LRT growth alone outpaced bus by more than three times (*2*).

SUCCESS MEANS FAILURE?

Despite what would appear to most people to be a clear record of success in reversing a long-term trend of decline and attracting automobile travelers back to transit, public transportation has remained a target for disparagement by many opponents. Prominent rail transit critic Wendell Cox, for example, dismissed APTA's ridership growth figures in a widely published diatribe tailored for several individual cities (mainly those operating or considering LRT), and containing much the same language:

> At the national level, a recurring theme has been that ridership has reached a 40-year record … So it was to have been expected that when the results of the 2000 U.S. Census were announced, a large increase would be shown in the number of people using transit to get to work. The news is out, and there is a record—a record low. Not in the 40-year history of Census journey-to-work information have fewer people used transit to get to work. As a result, transit's work-trip market share is also at a record low and is probably at the lowest rate since before the streetcar was invented in the 1880s. Now, just 4.7 percent of people use transit to get to work. (*3*)

Likewise, Linda Seebach, in an article in the Denver-area *Rocky Mountain News*, argues that "despite the subsidies lavished on it, and a modest growth in ridership, mass transit is steadily losing ground to automobile travel, which is growing much faster" (*4*).

These and similar critics have seized upon year-2000 U.S. Census journey-to-work survey data as the mainstay of an argument primarily aimed at curbing the growing interest in the installation of new LRT systems and expansion of those that exist. These data are mainly used to argue that transit's share of work trips, both absolutely and proportionately, has declined. But how reliable and accurate are these data when applied as a gauge of public transit performance? An analysis of the same census data indicates there are problems applying these data to measure transit ridership trends.

Census journey-to-work data can be interpreted to roughly indicate market share or modal split for work trips within a given metropolitan statistical area (MSA), central city, or in some cases, service area (although the latter, as one might expect, is quite hard to correlate with census data in many cases). In this sense, the data can be properly used as a rough indicator or bellwether, particularly in suggesting trends in travel mode choice or market share.

CENSUS SURVEY WEAKNESSES

However, it is important to note that these data do not seem comparable to conventional transit ridership and modal-split data, such as are gathered in regional analyses. They are derived from a totally different methodology, with a significantly different degree of reliability and competency. Furthermore, Census choices are not tailored to what exists in any individual area, but are uniform for all urban areas nationwide—putting forth the possibility of erroneous choices by respondents.

One should note that it is possible for total transit use and even mode share to increase while work trip mode share declines, and in fact there are factors that may even promote this. For example, several LRT systems are expanding service in off-peak periods and focusing on destinations other than key employment centers (e.g., airports, entertainment venues, and stadiums). Many systems note unexpectedly high ridership on weekends, suggesting substantial ridership growth for non-work trip purposes.

Nevertheless, one must also recognize important weaknesses and fallacies in the census methodology—weaknesses that may contribute to serious data discrepancies vis-à-vis industry-reported ridership and regional transportation data. These disparities are particularly critical when one attempts to compare similar census survey data for 1990 versus 2000, and to draw sweeping conclusions from the results—a common practice of many mass transit critics. (One must, however, acknowledge that transit agency ridership data are not universally regarded as beyond reproach; boarding counts by some agencies have been criticized, and the Los Angeles County Metropolitan Transportation Authority recently revised its previous counting methodology.)

These discrepancies suggest what may be fundamental limitations of the census survey data. One can obtain some gauge of the reliability of these data when one considers that, in the 1990 census journey-to-work survey, some 298 work commuters in the Houston-Galveston Consolidated MSA were reported to be using "subway or elevated" public transportation as their primary means to get to work. Of course, there is no subway-elevated system in the Houston-Galveston area. Another 157 were reported to use "streetcar or trolley car"—an extremely dubious item of information, since the only "streetcar" in the region is the diesel-powered vintage unit that carries tourists around central Galveston and hardly can be described to function as a work commuter system (*5*). These are relatively small discrepancies out of a total of more than 1.6 million work journeys reported, but they do signal the possibility of important methodological flaws and data inaccuracies, especially when analyzed (as critics have done) down to just a few thousand work trips.

The Houston–Galveston metro area census data are not unique in reporting patently erroneous mode-choice responses—similar discrepancies can be found in other major cities without any form of rail transit. Furthermore, another indication of possible confusion or misinterpretation of the census survey questionnaire by respondents is the sizable "other means" response given. These various issues are revealed in the sampling of 1990 census data from a number of MSAs, shown in Table 1, which reports various numbers of individuals in a sampling of major urban areas who supposedly used "subway or elevated" or "streetcar or

TABLE 1 Commuter Mode Choices Extrapolated from Year 1990 Census Responses

MSA	Streetcar/Trolleycar	Subway/Elevated	Other Means
Austin, TX	26	6	2,382
El Paso, TX	60	9	2,132
San Antonio, TX	36	0	4,260
Houston–Galveston, TX	157	298	13,772
Denver–Boulder, CO	87	112	5,183
Las Vegas, NV	29	17	4,166
Salt Lake City, UT	74	52	2,432
Louisville, KY	112	12	2,292
Norfolk, VA	36	137	8,030
Richmond, VA	15	107	3,093
Kansas City, MO	93	46	4,687
Minneapolis–St. Paul, MN	163	114	5,047
Phoenix, AZ	65	75	7,383

trolley car" for their work commutes (*5*). None of these areas had subway/elevated or corridor-service streetcar/trolley car systems in 1990. Also, the number of "other means" responses is significant with respect to the relatively small numbers of public transportation commuter losses calculated by critics for some of these areas.

Of course, it is unknown whether any of these "other means" commuters could legitimately be reassigned to a public transportation mode. The presence of these large unassigned values, however, certainly calls into question the reliability of these census data as a competent basis for inferring losses (or gains) amounting to a few hundred or a few thousand public transportation commuters

In a regional transportation survey, such as an origin-destination survey, most of these erroneous issues would be avoided, since nonexistent modes would not be an option. Results might not be 100% accurate, but they would be considerably closer to reality, and would focus on relevant issues such as how many different modes were used for each link in the previous day's trips, the purpose of these trips, possibly the perceived time involved, and so forth.

In contrast, the census survey lacks this sensitivity. Its data weaknesses can be seen in the case of Ft. Worth, Texas, which *did* have a light rail subway-surface system in 1990 which was carrying thousands of daily riders, including several thousand to work in downtown Ft. Worth. Yet the 1990 census journey-to-work survey data report only 15 city residents using "streetcar or trolley car" for their work trip and only 9 using "subway or elevated" public transportation (*6*). Thus, for this case, the census data would seem to "disappear" thousands of work commuters using the Tandy LRT subway in operation at that time.

These discrepancies probably reflect additional fundamental problems of the census survey data: first, the survey is based on individual respondents' own subjective assessment of what various household members used as their "primary" mode for commuting to work. For each household member, the census form asked, "How did this person usually get to work LAST WEEK? If this person usually used more than one method of transportation during the trip, mark the box of the one used for most of the distance" (*7*).

POSSIBLE SOURCES OF CENSUS SURVEY ERROR

Unlike regional transportation and origin-destination surveys, the census journey-to-work survey appears to have a major weakness in accounting for mode choice in multimodal commute trips. This methodological weakness would seem to be particularly disadvantageous to park-and-ride (P&R) users (and one should note that the Ft. Worth LRT subway was an entirely P&R service). From the respondent's point of view, a household member gets in a car and drives to work. If that person parks the car and gets on public transit, that second mode might "disappear," from the perspective of the survey respondent. This problem is compounded if the questionnaire is completed by, say, a spouse and not the actual commuter (she or he sees the worker leave by car each morning). This may be a problem affecting census survey responses in regard to *all* transit systems with significant P&R services.

Second, there is the problem of serious sampling error. The census journey-to-work survey queries only a relatively small sample of the population (about 1 in 6 households) (*8*). Sampling errors can become significant when sample data are extrapolated to areawide cumulative numbers—particularly when issues of just a few thousand residents' work-trip mode are being raised within an area's total population of millions. For example, using the Census

Bureau's recommended methodology for estimating standard error (*8*), one can calculate that, say, for an urban population of 2,000,000, with 40,000 residents estimated (from survey data) to use transit for their work trips, the standard error expected from sampling is more than 3,100.

Another problem arises when transit critics use census journey-to-work survey data to bolster allegations about transit ridership for a given transit system, serving a specific urban area. The survey data which are cited typically are based on samples of residents only *within* the given transit service area. But hundreds or even thousands of riders from outside the service area (and even the urbanized area) may use the system. In the case of Dallas Area Rapid Transit (DART), for example, many passengers appear to come from outlying areas, outside the service area, to use the regional system's transit services, particularly via P&R facilities (*9*). These commuters would not register in a tabulation of census survey data limited to service-area residents.

While this would not necessarily affect the mode-share issue, this may help explain some of the apparent discrepancy between census-extrapolated numbers of work commuters and actual inferred work ridership experienced by the given transit system. Furthermore, as noted above, the census method (i.e., focusing only on just one leg of a multimodal trip) would seem to do a particular disservice to P&R ridership—a strong component of public transit ridership growth, especially for many newer and expanding systems.

DROP IN WORK TRIPS? DALLAS CASE

While the census journey-to-work survey may, with reasonable accuracy, suggest *trends* in the *proportion* of metro area workers who use transit for their work commute, serious problems arise with claims of a decline in the absolute *number* of work commuters, such as Cox's assertion (above) that "Not in the 40-year history of Census journey-to-work information have fewer people used transit to get to work." In other words, the gross numbers of reported commuters (which are derived by extrapolation from sample data) are much less reliable and meaningful than the broad indications of relative modal share ("market share") of work travel.

Cox's claim that "fewer people" have been using transit for work trips apparently is based on Census totals of *estimated* numbers of individuals who made their work trips by public transit, according to survey data from 1990 and 2000. These estimates show a drop of about 1,900 people (out of more than 128 million) making their work trips by public transport over the decade. However, with a standard sampling error of more than 5,400 involved with these figures, making assertions as to any ostensible change in terms of numbers of public transport users seems rather dubious.

Cox, however, applies the same methodology in offering urbanized area census survey data to argue that there has been an absolute decline in the number of work commuters by transit in the service area of the DART system—supposedly, in Cox's view, a further demonstration of the utter irrelevance of LRT and Dallas's regional (commuter) rail service:

> Perhaps the most surprising result was in Dallas, which opened three light rail lines and a commuter rail line in the 1990s. The local transit-media complex has produced an unending litany of success stories. But in at least one measure, success eluded them—3,100 fewer workers commuted on transit in 2000 than in 1990. (*3*)

Cox's claims appear to be contradicted by more solid and verifiable ridership data. DART has substantially *gained*, not lost, ridership since implementing rail transit (LRT) in mid-1996. This can be seen in the increase in ridership between 1990 (42.5 million boardings) and 2000 (58.3 million). During this same period, total system passenger-miles increased from 175.5 million to 249.3 million—a rise of 73.8 million, or 42%, indicating an *actual* increase in public usage of DART (and fulfilling one of the basic goals of establishing DART and its rail services) (*10*, *11*).

The impact of DART's LRT service can be seen since its launch in mid-1996, as weekday boardings for DART (directly operated and contracted services) increased from 212,414 in 1996 to 232,325 in 2000 (an increase of more than 9%). For LRT alone, ridership went from about 16,700 a day to 37,700 a day. As for total boardings on an annual basis, DART ridership increased from 57,328,559 in 1996 to 58,342,845 in 2000 (an increase of about 2%). For LRT, the increase was from 1,481,603 boardings to 11,433,508 (*10*, *12*).

For this same period, an examination of passenger-miles (p-m) again reveals an actual increase in usage of DART, with growth from 186.5 million in 1996 to 249.3 million in 2000—a net increase of 62.8 million p-m. Of this, LRT grew from 3.0 million in 1996 to 60.2 million in 2000—a growth of 57.2 million. In other words, LRT accounts for 91% of DART's total p-m growth in this period when both bus and rail service were offered (*10*, *12*). These results hardly corroborate the picture of dismal failure publicized by rail critics like Cox; on the contrary, they suggest that LRT has been fulfilling at least some of its original objectives with eminent success.

Likewise, there has been apparent success in fulfilling the economic goal of reducing unit operating costs, as measured in costs per p-m. Prior to LRT, Dallas transit managers were seeing a staggering increase in operating cost per p-m. For example, as passenger-mileage plunged from 258.8 million in 1981 to 175.5 million in 1990, unit operating costs grew more than four-fold, from $0.21/p-m to $0.93/p-m (all costs in constant 2000 dollars) (*11*, *13*).

The advent of LRT has reversed those trends. Not only have p-m increased since 1990, but the systemwide unit operating cost has been lowered by 19%, to $0.75/p-m (*10*, *11*).

Regarding the remaining issue of public transit market share, or the modal split of work trips, the jury still seems out. There are no readily available data, with acceptable accuracy, specifically for the DART service area. Currently aggregated census journey-to-work survey data do not focus specifically on DART's service area and, as discussed above, are not a fully reliable survey of individual mobility behavior. As detailed above, DART ridership actually increased substantially in the period in question, suggesting that many more people living in Dallas turned to transit. A major portion of this ridership undoubtedly consisted of work trips; however, trip purpose is not routinely queried in ridership counts.

It is also important to consider that many of the new passengers attracted to DART (and to other systems which have installed LRT or have otherwise been aggressively pursuing improvements in transit services) appear to have been attracted for nonwork trips. Cox implicitly dismisses these as not significant to the problem of traffic congestion, but the case can be made that many trips to school and for other nonwork purposes (e.g., late-afternoon trips after shopping) may well contribute to traffic congestion. Likewise, evening and weekend recreational events may be major generators of traffic congestion, and LRT has shown a useful capability to handle large crowds and contribute significantly to mobility congestion relief during such events.

In any case, Cox's claim of an absolute decline in work commuters on DART between 1990 and 2000 appears to suffer from the methodological fallacies previously pointed out, such as a faulty and excessive reliance on the accuracy of census journey-to-work survey data, with their numerous anomalies, and a failure to allow for possible sampling-error distortions in the extrapolation of survey data to areawide totals. It is also worth noting that, in Dallas County alone, there were more than 9,300 of the rather dubious "other means" commuters extrapolated from the 2000 census survey responses (*6*). These issues, however, are notoriously difficult to explain to the public.

ROADWAY GROWTH AND SPRAWL

As in many U.S. cities, the share (percentage) of work trips in the Dallas area made by transit may have decreased somewhat over the 10-year period between censuses. Because of the dependency on automobile transportation, especially in the continually expanding lower-density suburban areas that are mostly outside the DART service area, overall personal trips by private car may have increased faster than DART's transit development program has been able to respond to mobility needs, particularly the need for suburb-to-suburb travel.

This relates to another issue impacting work trip market share and the competition between mobility choices offered by public transport versus those offered by private motor vehicles. Cox implies that DART's opening of "three light rail lines and a commuter rail line" in the 1990s was basically a failure since DART's overall transit ridership failed to keep up with areawide motor vehicle traffic growth (*3*).

Indeed, DART did install approximately 20 mi of light rail and about 15 mi of regional (commuter) rail in 1996 (which did not see full operation until 1997, after 70% of the decade had already passed). Yet, it must be noted that, in contrast, the area's roadway system had been expanded continuously throughout this period many times more vigorously. Between 1990 and 2000, the urbanized area's freeways were extended by 575 lane miles, and the entire roadway system by 1,000 centerline miles. Moreover, the entire urbanized area grew in size, expanding by 325 square miles (*14*). Clearly, the intensive pace of growth of facilities for private automobiles vastly outpaced the growth of rail transit service, and continued to foster even greater dependency on automobiles for travel in increasingly suburban-sprawl-type areas difficult to virtually impossible to adequately serve with public transit.

DART planners and decision makers, like many among public transit agencies, apparently believe that providing LRT and other versatile and higher-quality mobility choices will help meet the increasing needs of regional and intrasuburban travel in the future, thus increasing the percentage of regional work trips by transit. Such transit innovations and expansion, integrated with better approaches in land-use patterns, such as transit-oriented development, are believed to have potential for reducing the need for unnecessary trips and providing more opportunities for work travelers to choose mobility alternatives to the automobile, such as transit. Indeed, since its rail lines opened, DART's annual boardings have grown by over a fourth, from 59 million (1997, the first full year of operation) to 75 million (in 2001) (*12, 10*).

ATTACK ON SMART GROWTH AND LRT IN PORTLAND

Among new LRT systems such as DART's, some transit critics, in their campaign to disparage efforts to develop higher-quality transit and combat suburban sprawl, have found Portland an especially compelling target because of its highly publicized LRT system and Smart Growth policies (e.g., its Urban Growth Boundary program). In the commentary previously cited, Wendell Cox further argues:

> Portland, Ore[gon], has built not only two new light rail lines but has embarked on smart-growth strategies to limit sprawl and to not expand highways. All of this was to attract people out of their cars. Yet today more people than ever drive alone to work in Portland, and transit's market share is lower than before the rail system was built. (*3*)

To advance his portrayal of Portland's MAX LRT as a failure, Cox reverts *two* decades to cite the 1980 "market share" figure (before LRT), which was 9.5%. This enables him to show the change between 1980 and 2000 as a *negative* figure and thus disparage what was actually a significant transit improvement (the installation of MAX in 1986) which effectively *reversed* Portland's previous trend of transit decline (declining boardings and passenger-miles on Tri-Met, the transit agency). Indeed, since the opening of MAX, both indicators have increased significantly; between 1990 and 2000, total transit boardings have increased 68%, and passenger-miles 80% (*10*, *11*). Between 1990 and 1997 alone (even before opening the Westside line), transit ridership in the Portland metropolitan area grew 20% faster than the growth in vehicle miles traveled (VMT), 43% faster than the growth in transit service provided, and 40% faster than the growth in population (*15*). Ridership growth, which actually outpaced growth in both population and VMT, would seem to be a laudable achievement for any large metro area.

Cox, unfortunately, ignores in his essay above a comparison of the census data for 1990 and 2000 for the three-county TriMet service area in Portland—which he, however, tabulates on his own website, Publicpurpose.com. These data indicate that the journey-to-work "market share" actually *increased* from 6.3% to 7.6% over the 10-year period—a *gain* of more than 20%.

Curiously, it is of interest to note that Portland was not alone among large metro areas in *not* exhibiting a decline in "market share" among residents in the census journey-to-work survey. Indeed, of the 12 major-city transit systems that actually gained or maintained "market share" of work trips between 1990 and 2000, nine of them are cities with major rail transit (New York, Los Angeles, San Francisco, Boston, San Diego, Denver, Portland, Sacramento, and Salt Lake City), and all except New York City have LRT systems (New York, too, if considered as the New York–New Jersey urbanized area, encompassing LRT in Newark and Hudson-Bergen). The specific percentage changes in the estimated proportion of workers using transit ("market share") for selected cities with LRT are listed in the accompanying table (Table 2). Whether these trends tend to suggest that rail transit has any impact on area-wide transit usage, merits further investigation.

TABLE 2 Percentage Change in Proportion of Residents Using Transit for Work Journeys, 1990-2000

Urbanized Area	Change in Transit Share
Denver	2.1%
Los Angeles	2.2%
Portland	20.6%
Sacramento	13.3%
Salt Lake City	0%
San Diego	2.7%
San Francisco–San Jose	2.0%

One should also note that, as in the case of Dallas, Portland saw a pace of highway expansion between 1990 and 2000 that far outstripped rail transit development. During this period, only 18 mi of LRT route (the Westside MAX extension) were added. In contrast, freeways increased by 95 lane-miles and the overall roadway system by more than 1,200 centerline miles (*14*). Under these conditions—and the many more billions of investment dollars poured into Portland-area roadway expansion—it is hardly surprising that private automobile travel has grown enormously despite Portland's transit investments and Smart Growth policies.

Nevertheless, as noted above, Portland's transit system has experienced significant gains in key performance indicators. This extends to economic performance, which, before the advent of LRT, was troubling to TriMet management and planners. Between 1981 and 1983, for example, the all-bus system operating cost per passenger-mile increased (in constant 2000 U.S. dollars) from \$0.56 to \$0.64. However, by 1990, with MAX in operation for 4 years, helping increase productivity and reduce unit operating costs, the system average had dropped to \$0.59, and by 2000 to \$0.57 (*10*, *11*, *13*, *16*). In this respect, at least, MAX seems to be fulfilling expectations and possibly justifying its investment.

LRT'S IMPACT ON MOBILITY CONGESTION

Along with claims that mass-transit ridership is in steady decline (as supposedly evidenced by an apparent decrease in the share of urban work trips by mass transit in some urban areas), some transit critics also argue that mass-transit ridership is so small as to be irrelevant to urban mobility; and that major transit investments, such as investments in LRT, have not had an impact on traffic congestion. In a paper for the Heritage Foundation, for example, Cox argues that "the false promise of 'congestion relief' is the calling card rail proponents have used to seduce voters into paying higher taxes" (*17*). In an online commentary on the Planetizen.com website, Cox elaborates his attack on Portland's transportation and urban development policies, arguing that, because of Smart Growth and investment in modest transit improvements instead of even more highways, "Portland's highway congestion has become the worst of any metropolitan area of its size" (*18*) .

This latter assertion, however, is quite dubious. If, as a measure of congestion, one uses the Travel Rate Index of the Texas Transportation Institute's 2002 Mobility Study (*14*), then Portland (1.22) is topped by other "large" category cities like Ft. Lauderdale, Florida (1.24), Las Vegas, Nevada (1.23), Phoenix, Arizona (1.25), and Seattle, Washington (1.25).

But another question is raised: Is it really valid to brandish roadway congestion as a measure of the effectiveness of mass transit expansion and Smart Growth policies? The basic argument for both programs is that roadways are inherently *prone* to congestion. Mass transit and Smart Growth are posed as *alternatives* to congestion, not as remedies for it—for example, more as means to *maintain* mobility in the face of increasing congestion rather than as means to dispel gridlock. It is quite arguable that, as roadway congestion increases, mass transit—especially LRT and other fixed-guideway, segregated modes—becomes increasingly attractive and *gains* ridership. Conversely, reduced congestion probably correlates somewhat with lower transit ridership.

DENVER'S LRT AND MOBILITY CONGESTION RELIEF

The basic argument of these LRT opponents—that LRT does not reduce travel congestion, and therefore mass transit funds should be diverted into roadway construction—is captured by the following excerpt from a paper published by the virulently anti-transit Independence Institute, based in Denver, directed at an effort to forestall further extensions of Denver's LRT system:

> No Reductions in Traffic Congestion. The light rail extension will only carry 1,400 passengers per hour. A single freeway lane carries more than 2,000 vehicles per hour at capacity! … Simply put, if Congress wants to solve traffic congestion, it should build more roads—not light rail. (*19*)

In regard to these claims, data provided by Denver's Regional Transportation District (RTD), relating to the impact of Denver's new Southwest LRT line on travel congestion in one of the line's major corridors, may serve as a productive rejoinder. This information yields at least anecdotal insight into how well-deployed LRT can have a significant impact—not necessarily on *traffic* congestion, but on *travel* congestion—and can contribute to improving mobility in an affected transportation corridor (*20*).

Santa Fe Drive Corridor

The Denver data, collected by RTD in the fall of 2000, focus on traffic flow on a section of Denver's Santa Fe Drive (north of Mississippi), a signalized, 6-lane major arterial paralleled by the Southwest LRT line to Littleton on a separate, exclusive railroad right of way. The segment of roadway covered by the corridor study is 3 lanes wide, eventually narrowing to 2 lanes.

The Southwest LRT line runs in a separate, exclusive alignment along an existing railroad right of way, through industrial areas, and past residential developments which range from lower-density urban housing to suburban housing. In the peak hour during the RTD study period, 8 trains/h at 6 two-car trains and 2 three-car trains were running along this alignment—a total of 18 cars/h.

Total bus ridership in the Santa Fe Drive corridor was roughly 2,000 passengers per day before the Southwest LRT line opened. Since the Southwest Line opened in July 2000, LRT replaced bus service in the corridor, with bus feeder service interfacing with the LRT at stations. In October 2000, covered by the period of the RTD study, LRT ridership averaged over 13,000 riders per day.

Nearly a Third of Passenger Traffic by LRT

According to data from the Colorado Department of Transportation, peak-hour, peak-direction roadway traffic volume on the section of Santa Fe included in the RTD study was approximately 4,500 motor vehicles. RTD does not now run buses on this segment. However, approximately 7% of this traffic consists of freight vehicles. Thus the automobile count was about 4,180 vehicles. With average auto occupancy of 1.2 persons per car (*20*), the number of persons travelling by automobile can be calculated at approximately 5,020.

RTD tabulated the number of peak-hour, peak-direction LRT passengers at 2,000 to 2,500 at the time of the study. It can be calculated, therefore, that total peak-hour, peak-direction person-movement in the corridor ranged between 7,020 and 7,520. Of this, the percentage (modal split) traveling by LRT ranged between 28.5% and 33.2%—a significant proportion of total passenger traffic (see Figure 1).

Another way of assessing this impact is to consider that, if these riders chose to make their trip by automobile instead, they would further congest these 3 lanes of Santa Fe Drive with between 1,670 and 2,080 additional automobiles during the peak hour. Thus, LRT can be said to provide a significant amount of "congestion relief" in this case. (Of course, some of these riders might choose to carpool or take a bus, but that would still put them back in the congested traffic stream.)

Goal: Relieve *Mobility* Congestion

As previously noted, some LRT critics consistently try to pose "reduction" of roadway traffic as a basic measuring stick for the "success" of LRT—a measure it will inevitably fail to meet. In reality, by raising (unachievable) expectations of significant traffic congestion reduction from LRT and other major transit projects, opponents of transit and LRT exploit a common fallacy and misconception: that any single transportation facility, roadway or transit, can ever truly "reduce" traffic congestion. It is almost universally recognized, even among highway planners, and throughout the transportation planning profession, that roadway traffic congestion is a fundamental fact of life. Basically, it continues to grow with population expansion and the proliferation of motor vehicles. Acceptance of some degree of congestion is actually incorporated into the basic design of urban roadways (*21*).

For these reasons, bona fide congestion relief provided by LRT and other major transit services cannot be expected to take the form of significant reductions in road traffic. Instead, relief is far more likely to take the form illustrated in Denver: *diversion* of significant traffic growth into high-quality transit service in specific corridors.

It is inappropriate to try to assess congestion relief by the measure of whether or not existing roadway congestion simply evaporates. Indeed, traffic congestion never just "evaporates." The traffic lanes on Santa Fe Drive are probably as crowded as ever (particularly because of ongoing population and traffic growth throughout the metro area). What LRT does is open up, in effect, a new traffic artery along which people can move past the existing congestion. Moreover, unlike the capacity-increasing effects of a freeway, the result with LRT is that all those private motor vehicles are totally off the road, out of the traffic stream, and out of the competition for scarce parking spaces. Perhaps the realistic goal of major transit improvements like LRT, therefore, is to improve overall mobility, not necessarily to reduce roadway traffic congestion.

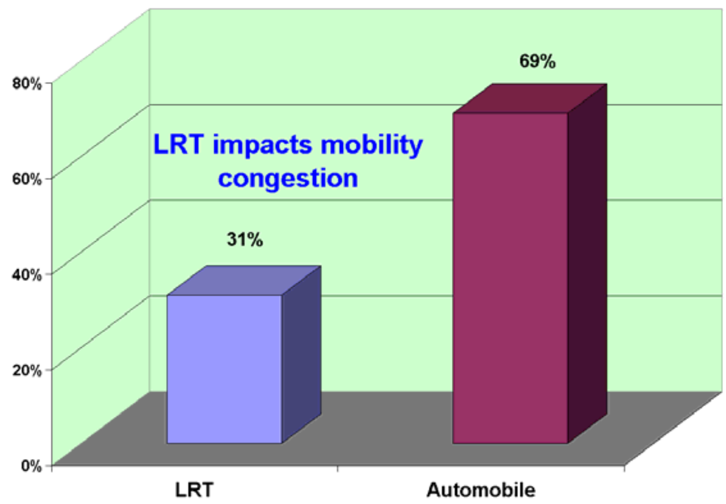

FIGURE 1 Average proportion of LRT versus automobile passenger peak directional traffic in Denver's Santa Fe Drive corridor.

Lessons for Other Cities

In sum, these data suggest that LRT in Denver's Santa Fe corridor at peak hour in the peak direction is carrying between 28% and 33% of the total passenger traffic flow. In other words, without the LRT line (or other segregated or exclusive-alignment transit) in service, one can infer that approximately 30% of corridor passenger traffic would be added to the roadway traffic congestion. This appears to demonstrate that LRT does have a significant impact on mobility in this corridor.

These results have significance for other communities evaluating LRT and similar transit-based mobility improvements. The public might well consider whether they would rather have an additional significant percentage of motorists on crowded streets, contesting for scarce space, or on board LRT or other high-quality transit. Expanding the roadway arterial to accommodate this extra traffic in Denver's case would mean adding from 2 to 6 more lanes to Santa Fe Drive (depending on whether reversible peak-hour or all-day lanes would be added). Undoubtedly, this would be a rather expensive proposition, with very costly inner-city right of way acquisition as well as construction. On top of this must be added the extra costs and spatial requirements for additional parking spaces for thousands more cars.

Denver's Success in Ridership and Economic Productivity

Denver's LRT seems to have demonstrated success in additional ways. Like Portland and many other cities, prior to the installation of LRT in 1994 Denver's public transit seemed a system in decline. Between 1981 and 1990, annual boardings dropped by over 3 million, or about 6%, and passenger-miles plunged by 26%. Financial performance was especially troubling, as the all-bus system operating cost per passenger-mile skyrocketed from $0.48 to $0.71, or 48% (all constant 2000 $) (*10*, *11*, *13*).

RTD's LRT operation has apparently helped reverse these trends. Year-2000 boardings soared 49% over the 1990 level, and 40% above that of 1981. Likewise, year-2000 passenger-miles surged 82% over 1990 and 35% over 1981. In terms of unit operating cost, year-2000 operating costs per passenger-mile dropped 20% compared with 1990, reversing the previous upward trend. All in all, it would appear that, by these indicators at least, Denver's LRT also has possibly been justifying its investment (*10*, *11*, *13*).

CONCLUSIONS

Reported increases in transit ridership in North America are not refuted by census journey-to-work survey data, but discrepancies present problems. Census data are not comparable to transit ridership and modal-split data, such as are gathered in regional analyses. A totally different methodology is used in the census survey, and its mobility-related data appear somewhat less reliable. The precision of census data for tabulations of a few thousand commuters' mode choices thus seems questionable. This stems in part from the subjective nature of the responses, and bears little relationship to actual ridership counts experienced by transit service providers. Claims by critics of an absolute decline in mass transit work trips between 1990 and 2000 appear to be based on a methodological fallacy—particularly a faulty analysis of census journey-to-work survey data which ignores sampling error, survey methodological flaws, and other problems.

The census work-journey survey data appear useful for assessing broad trends, and do suggest that, in many urban areas, the proportion of residents using mass transit for their work trips (the work trip "market share") has declined slightly—certainly, a troubling issue for American transit industry professionals and decision makers. In many cases, however, use of such data fails to note (1) the effects of urban sprawl, necessitating more and more automobile dependency; (2) the fact that much of this sprawl-type growth is typically outside the transit service area; and (3) the fact that roadway development in almost all cases has outstripped rail transit development by hundreds of times. Interestingly, of the 12 major-city transit systems that actually gained or maintained estimated market share of work trips between 1990 and 2000, 9 of them are cities with major rail transit, and most operate LRT systems.

History and experience suggest that there will be highway congestion no matter how much highway capacity is increased or mass transit is expanded. Some highway-promoting critics of rail transit attempt to make the sole value of an LRT investment hinge on the extent to which it "reduces" roadway congestion. Since it can never do this, it therefore will always fail by this measure. Such a measure must be discarded. What LRT and other mass transit improvements on segregated, reserved, or exclusive alignments do is provide additional mobility *alternatives* to traffic congestion. Improving mobility is the issue, not eliminating roadway traffic congestion. This, LRT has demonstrated, it can do.

Anecdotal case studies of LRT in Dallas, Portland, and Denver suggest that ridership expansion, productivity (passenger-mileage) improvement, and reductions in unit operating costs may provide some justification of LRT investment in those cities. As demonstrated anecdotally in a specific corridor in Denver, LRT can have a very real impact on travel congestion. This anecdotal evidence suggests that many new (and established) LRT systems may likewise be justifying their investment, in terms of achieving similar performance goals and enhancing mobility in specific corridors. Research efforts similar to those of Denver's RTD, aimed at assessing the relative traffic-volume impacts of LRT versus private motor vehicles in specific corridors, would be helpful in determining this and perhaps providing evidence to the public that their investment in LRT and other major transit improvements is indeed paying off.

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CIVIL DESIGN

Design and Construction of the Weehawken Tunnel and Bergenline Avenue Station for the Hudson–Bergen Light Rail Transit System

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The existing 9.5 mi (15.2 km) long Hudson–Bergen Light Rail Transit System in Northern New Jersey is being expanded. This 6-mi (9.5-km) expansion includes 4,100 ft (1,250 m) through an existing railroad tunnel. The Weehawken Tunnel was built in 1881-1883 by the New York West Shore and Buffalo Railroad (NYWS&B) to provide a rail connection from west of the Palisades Ridge to the Hudson River Waterfront in Weehawken, N.J.

The engineering task was to provide an LRT alignment within the rock tunnel along with a mid-tunnel LRT station. The station is located approximately 160 ft (49 m) beneath the cities of Weehawken, West New York, Union City, and North Bergen Township. The existing tunnel needed to be enlarged by blasting methods to accommodate the two-track light rail trackway and station platform.

This paper discusses the building of the original tunnel; the engineering design relative to the new tunnel configuration and mid-tunnel station; and the construction work done to date.

INTRODUCTION

The Hudson–Bergen Light Rail Transit System (HBLR) Project is a 30-mi (48.1-km) and 37-station light rail system in the state of New Jersey (Figure 1). The project is located in the Hudson–Bergen transportation corridor, which is a vital artery to the economic and social well being of New Jersey and the adjacent New York metropolitan area. The project is being built in phases. The 9.5-mi (15.2-km) Minimum Operable Segment (MOS)-1 is in operation. The 6-mi (9.6-km) MOS-2 is currently under construction. The 13-mi (20.8-km) MOS-3 is being planned at this time. The light rail transit (LRT) alignment runs along the westside waterfront of the Hudson River, overlooking Manhattan, New York, from the southern tip of Bayonne to Bergen County. The LRT alignment serves surrounding communities, which include Bayonne, Jersey City, Hoboken, Weehawken, Union City, West New York, North Bergen Township, and the southern communities of Bergen County.

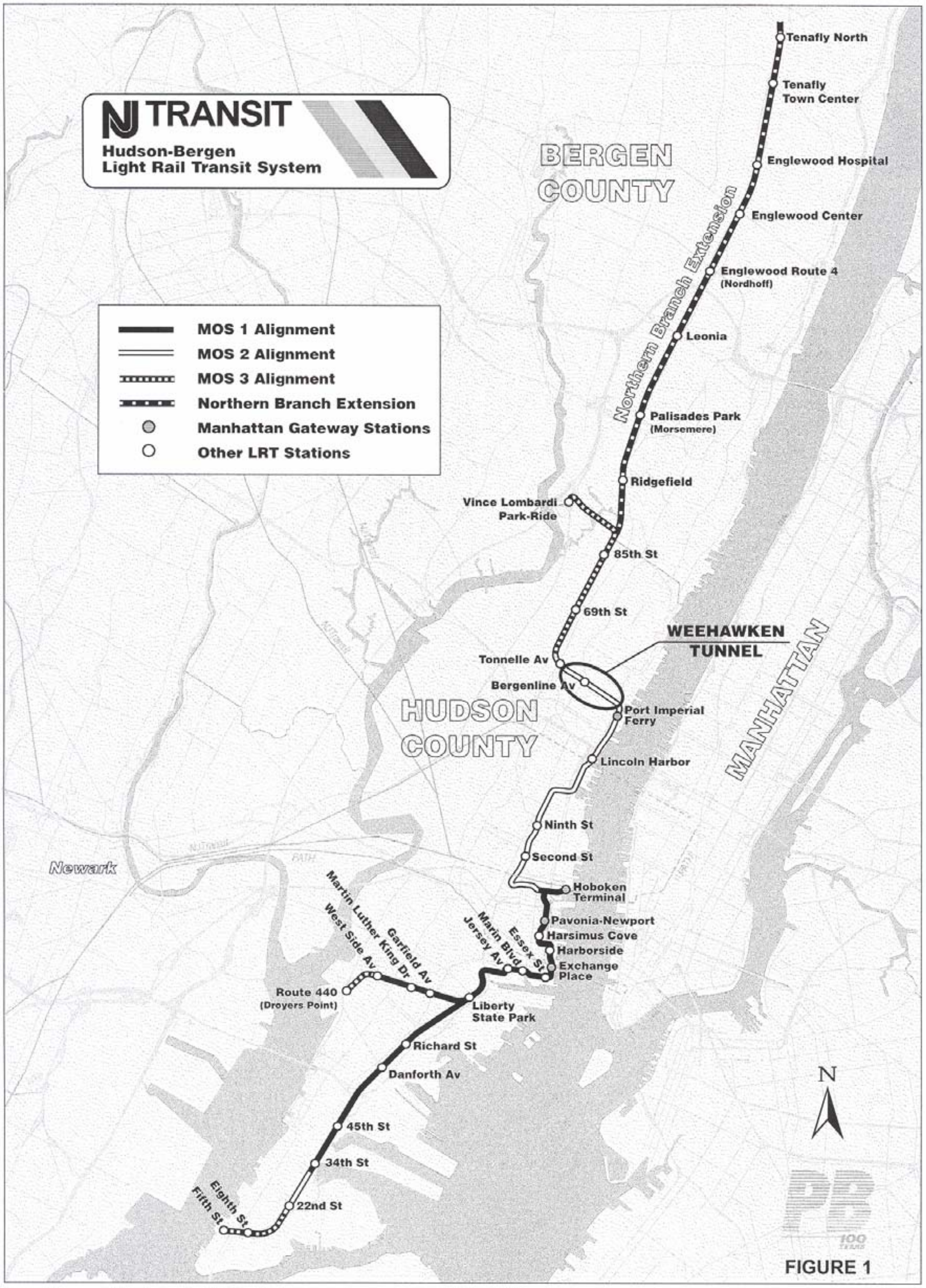

FIGURE 1 The Hudson–Bergen Light Rail Transit System.

A portion of the MOS-2 runs through an old 4,100 ft (1,250-m) long freight rail tunnel in Weehawken. The Weehawken Tunnel was originally built by the New York West Shore and Buffalo Railroad (NYWS&B) from 1881-1883 to provide a rail connection from west of the Palisades to the Hudson River waterfront where the NYWS&B had constructed the Weehawken Terminal, a freight and passenger terminal. It was designed and constructed under the supervision of NYWS&B Chief Engineer Walter Katte. The tunnel passes through the Palisades Sill, a steep prominent east-facing ridge along the west shore of the Hudson River.

Tunnel Construction

The original Weehawken Tunnel extended 4,014 ft (1,223 m) from its western portal in North Bergen Township, Hudson County, New Jersey, to its eastern portal near the Hudson River in the township of Weehawken, Hudson County, New Jersey (Figure 2). The tunnel extends beneath 48th Street in Weehawken, Union City, and West New York.

The original tunnel had a semi-elliptical arched roof with nearly vertical walls and was constructed for two tracks with a 13-ft (4-m) centerline distance. The majority of the tunnel was constructed in the rock of the Palisades Diabase. For approximately three-quarters of its length, the tunnel was unlined and the natural rock exposed. Eight sections of the tunnel, varying in length from 18 ft (55 m) to 357 ft (109 m), were lined with brick masonry. Excavation was conducted simultaneously from each end of the tunnel and in both directions from five construction shafts. Explosives were used to loosen the rock and workers loaded the debris onto rail cars, which were then hoisted to the surface through shafts, and removed by locomotive via a temporary rail line. An average of 450 men, working two shifts of 12 h, completed the tunnel in 2 years. The size of the existing tunnel was 27 ft (8.2 m) wide by 21 ft (6.4 m) high, or 19 ft (5.8 m) from the top of rail to the center of the roof arch.

Weehawken Terminal

The NYWS&B had grand designs for Weehawken Terminal, however, only the passenger terminal was completed, and one or two of the large piers originally planned were actually built. By 1884, the New York Ontario and Western Railway, partner of the NYWS&B, had declared bankruptcy, burdening the NYWS&B's already strained finances. In 1885, following the intervention of J. Pierpont Morgan, the NYWS&B was sold at foreclosure to the New York Central Railroad (NYC). It was immediately re-organized as the West Shore Railroad Company and became known as the West Shore or River Division. Within a few years, the NYC completed the Weehawken Freight Terminal complex according to original NYWS&B plans. This included: a dozen piers, two grain elevators, passenger, ferry, and freight terminals, locomotive roundhouse and turntable, railroad and marine repair shops, and an icehouse, all serving 12 freight piers that occupied over a mile of Hudson River waterfront. With its completion, the Weehawken Terminal became the NYC's major freight export facility in New York harbor.

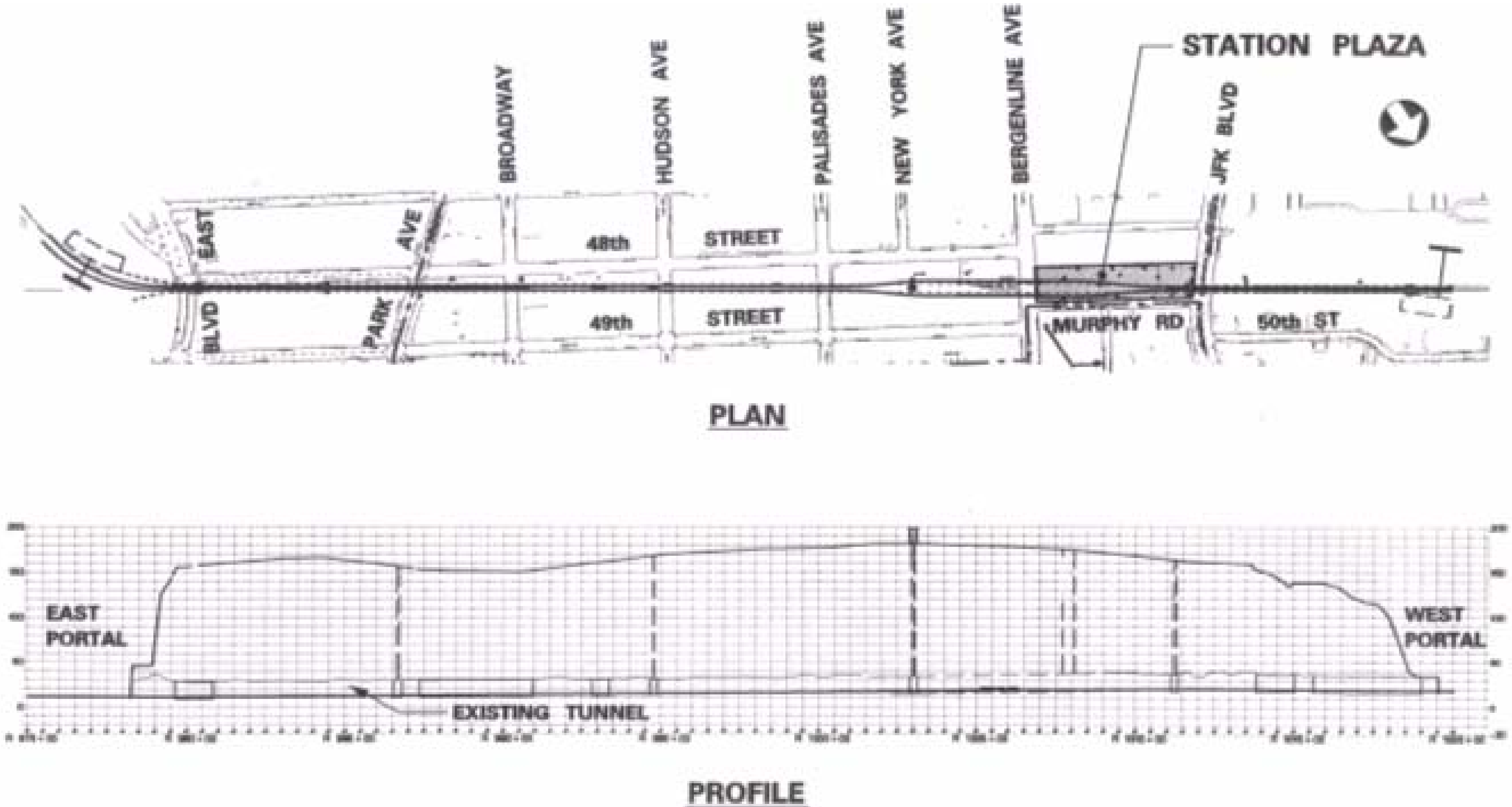

FIGURE 2 The original Weehawken Tunnel extended 4,014 ft (1,223 m) from its western portal in North Bergen Township, Hudson County, New Jersey, to its eastern portal near the Hudson River in the township of Weehawken, Hudson County, New Jersey.

West Shore Railroad

The West Shore Railroad promoted suburban development along its route, and farmland was transformed into middle-class housing developments. However, rider ship declined almost immediately following the opening of the George Washington Bridge in 1931. Then in 1937, the Lincoln Tunnel provided a second automobile route almost parallel to the West Shore's Weehawken 42nd Street ferry crossing. Finally, the Tappan Zee Bridge and the New York State Thruway were constructed in the 1950s, and by 1959 all passenger service on the West Shore Railroad was abandoned.

Public Service Electric & Gas Company

In late 1980s Public Service Electric & Gas (PSE&G) constructed two high voltage transmission power duct banks (230 kV) at the tunnel invert on either side of the railroad track, hugging the tunnel walls.

The Tunnel's Rebirth

In the 1980s, NJ Transit planned to implement the northern portion of the HBLR utilizing the tunnel. Working with its design consultant, Parsons Brinckerhoff Quade & Douglas, Inc., (PB) and the railroads, it was agreed that freight service could be shifted west to the Conrail Northern Branch Line to allow for construction of NJ Transit's HBLR Transit System.

The portion of the HBLR through the Weehawken Tunnel is known as Design Unit N30. The Design Unit includes approximately 4,300 ft (1,311 m) of LRT alignment and, a deep rock station cavern (Bergenline Avenue Station) and a 160-ft (49-m) vertical shaft for the connection with the surface bus station. The Bergenline Avenue Station will be one of the most frequently used stations on the entire system. During the peak commuter hour, a total of 1,900 persons will enter or leave the station. Contributing to this rider-ship is the large population within a walking distance, significant retail and businesses, and numerous bus routes.

PB developed the tunnel and station design for NJ Transit. A Joint Venture of Frontier-Kemper Constructors, Inc., J. F. Shea Construction, Beton and Monierbau Gesellschaft M.B.H. (FKSB) is the tunnel contractor under subcontract to the HBLR Design Built Operate Maintain (DBOM) Contractor, Twenty-First Century Rail Corporation (TFC). Construction started in Spring 2002 and is scheduled to be complete in Spring 2005.

ENGINEERING

The engineering task for Design Unit N30 consists of providing engineering design for a 4,300 ft (1,311 m) of LRT at-grade alignment of which 4,100 ft (1,250 m) is inside the existing Weehawken Tunnel, a mid-tunnel LRT station – Bergenline Avenue Station, and a NJ Transit bus plaza and station entrance at the surface located at the northwest corner of Bergenline Avenue and 49th Street.

The majority of the existing tunnel is unlined and the highly irregular rock surface is exposed. The linings are composed of brick arches and ashlar stone masonry sidewalls. Brick-lined zones are present either at rock zones of poor rock quality or at construction shafts. The construction shafts, spaced about 800 ft (244 m) on centers, are believed to have been sunk at five locations during the original tunnel construction. The existing brick linings conceal four out of five originally constructed shafts. One shaft remained open and it provided natural ventilation to the tunnel.

The geometrical requirements of the tunnel cross-sections were established taking into consideration the dynamic clearance envelope of the light rail vehicle; system and catenary clearances; construction tolerances; a maintenance walkway; presence of the existing utility duct banks and need for their uninterrupted service in all phases of construction; requirements of minimizing the excavation quantities; and the tunnel ventilation requirements. Different “modified horse-shoe” shaped cross-sections were identified for the unlined sections and fully lined sections of the tunnel.

ALIGNMENT

The LRT alignment for Design Unit N30 begins approximately 400 ft (120 m) south of the existing east portal structure of the Weehawken Tunnel. The alignment approaches the tunnel on a horizontal curve with a radius of approximately 350 ft (107 m) with a 33-mph (53 kmph) civil design speed. Track spacing reduces to 12 ft (3.7 m) on centers through this curve as the alignment enters the Tunnel. The cross section outside the Tunnel consists of Ballast Track with variable centers.

The cross section through the east tunnel segment, consists of direct fixation track, at 12 ft (3.7 m) centers, with a 36-in. (0.9 m) wide maintenance walkway located on the right (north) side of the track way. In the event of an emergency inside the tunnel the entire width between the rails of each track could be used as an emergency walkway, as it is a smooth surface of the direct fixation track work.

The second segment of the tunnel alignment includes the transition areas from running tunnel to the station, and the station area itself. As the alignment approaches the station from the east, the alignment transitions from 12-ft (3.7 m) track centers to the 49-ft (15 m) track centers required for the center platform station. The transition is attained through pairs of reverse curves meeting at a point of reverse spiral. The point of reverse spiral configuration was utilized to minimize the amount of rock excavation required for the station area.

At the west end of the station the track way centerline spacing transitions from 49 ft (15 m) to 12 ft (3.7 m) through pairs of reverse curves which are similar to those on the east side of the station. Direct fixation track construction is utilized throughout this area.

The final segment of tunnel alignment extends from the west transition area to the west tunnel portal. The cross section in this area is the same as those in the east segment of the tunnel. The N30 alignment ends approximately 50 ft (15.2 m) beyond the west portal.

BERGENLINE AVENUE STATION

Station Configuration

Bergenline Avenue Station is a center platform station located below grade with access at Bergenline Avenue and 49th Street. At the street level, a plaza is designed to provide a waiting area, a bus pick-up/drop-off, and an access to the station. A shaft 37 ft (11.3 m) in diameter provides access to the platform. The shaft contains three elevators, access stairs and the ventilation ducts.

At the bottom of the shaft, at platform level, is an elevator lobby. The elevator lobby was sized to accommodate peak level patronage. The elevators were sized to completely transfer the patronage of one peak period train from the platform level to the surface prior to arrival of the next peak period train. The elevator cabs have a capacity of 5,000 lb (2,268 kg) with a maximum load of 33 passengers. The cabs will run at 700 ft (213 m) per minute. The doors will be 4 ft, 6 in. wide, (1.4 m) allowing easy transfer of passengers on and off the elevators. With openings at both ends of the elevator cab, the cabs will load from one side and exit from the other, for peak passenger transfer efficiency. The elevator lobby at the platform level will be provided with closure roll-down “fire-shutter” doors to isolate the lobby area from either platform during an emergency.

The platform is 280 ft (85 m) long, to accommodate a train of three light rail vehicles. The width of the platform is 39 ft, 7-1/2 in. (12 m). It is divided longitudinally by a center firewall to isolate one side of the station in case of an emergency.

Large openings within the center fire wall equipped with horizontal sliding fire resistant pocket doors connect each trackway platform. In the event of an emergency, the sliding doors will be closed to isolate one half of the platform from heat and smoke allowing it to serve as a safe refuge area. Each pocket door is equipped with smaller spring loaded double swing doors to allow exiting occupants to continue to cross the separation wall after the pocket doors have closed. The resulting fire separation provides the platform occupants with a safe area to accommodate egress from the station. From the safe area, the occupants can access elevators and an exit stair for egress to ground surface, additionally, the occupants can walk out through the tunnel portals.

Two transition areas, one at each end of the platform, serve to house the tunnel emergency ventilation fans and their associated power supply. The platform ventilation fans and the associated power supply and ancillary facilities are located in the basement of the station facility at the surface.

Platform Level

The platform level consists of the station platform, a vestibule (lobby) area, and two transition areas at the ends of the station. Two transition areas, one at each end of the platform, house a total of four tunnel emergency ventilation fans. Two fans are located at each end within a two level fan plant. At either end of the fan plants are plenum areas. The plenum areas direct air flow during tunnel emergencies, by the use of by-pass dampers. The by-pass dampers are located in the plenum walls adjacent to the trackways. Based on the location of an emergency, by-pass dampers on one trackway would be opened, while the by-pass dampers to the opposite track would be closed.

Street Level

The station facilities at the street level include a plaza for waiting passengers, streetscape, bus bays for pick-up and drop-off, the shaft headhouse, the elevator machine room, the stair pressurization room and the elevator lobby. In addition, six ventilation stacks are provided for the tunnel and the platform ventilation. A separate two-story Utility building is located to the western part of the plaza at the corner of 49th Street and JFK Boulevard.

Plaza Basement

The plaza basement houses the station platform ventilation fans, and their motor control center, and the tunnel and the station ventilation ducts.

Elevator Headhouse

The elevator headhouse is a three-story structure. It houses the elevator machinery room and pressurization rooms.

Ventilation Stacks

Ventilation stacks are constructed of cast-in-place concrete walls and slabs with architectural brick walls at the outside faces. In conjunction with the ventilation stacks, emergency egress stair from the plaza basement level, employee bathroom and Emergency Aid Room are provided.

Utility Building:

The Utility Building is a two-story structure situated at the Southeast corner of the intersection of 49th Street and JFK Boulevard. A generator room, and electrical room, a mechanical room, a communication room, an Uninterrupted Power System (UPS) room, a battery storage, a Clean Air fire protection room, and a meter room are housed in the Utility Building.

Arts-In-Transit

The NJ Transit, Transit Arts Committee, set forth guidelines for aesthetics and prepared an HBLR Arts-in-Transit "Master Plan" which guided art related elements to be included in the design of the stations and station elements. The committee made every effort to incorporate the complete project including passenger stations, station elements, retaining walls, and new bridges.

The natural and cultural histories of the area provide the conceptual basis for the Bergenline Avenue art program. The Palisades are a landform with a rich geological history. It is a basaltic intrusion of Jurassic origin. When created, it lay well below the surface and only the erosion of the centuries and the ice ages exposed it in its present condition. For the first settlers in the area, it was a barrier preventing easy access to the west. With the opening of the Weehawken tunnel at the beginning of the century it became a conduit to the hinterlands, opening them for development. The communities that were established on the Palisades became home to successive waves of immigrant populations. Today, the Bergenline Avenue area is home to a wide variety of residents including Cuban, Caribbean, Latin, and South American communities.

The art opportunities for the station have been developed in three parts: the surface facility, the elevator shaft, and the station platform. The surface facility will convey the theme "The Community and the Rock" with the outcroppings of natural rock from the excavation establishing a physical connection to the Palisades. The elevator shaft will begin the theme of

"The Journey Through Time" and as passengers exit, the platform will present them with a sense of entering another dimension. The platform will express the past and future of our planet through the use of exposed natural rock and artist-designed elements.

UTILITIES

Owners

The major utility facilities within Design Unit N30 are PSE&G (underground and overhead electric lines); and Bell Atlantic/Verizon (overhead telephone lines).

All private utility companies including PSE&G and Bell Atlantic/Verizon will be relocating their own facilities. The LRT contractor in coordination will perform all other utility work in conjunction with the utility owner and local municipal authorities.

PSE&G Electric Lines

The widening of the tunnel required the relocation of two existing 230 kV line duct banks, which were located at the tunnel invert hugging the tunnel wall on either side of the existing Conrail tracks. Each of these existing 230 kV line consisted of a set of two oilostatic pipe-type cables installed inside an 8 in. steel pipe filled with a dielectric fluid under high pressure. In addition to the 8 in. (203 cm) steel pipe, each of these duct banks included one 5 in. (12.7 cm) polyvinyl chloride (PVC) conduit one of which carries a PSE&G associated fiber optic communication line and one empty conduit. These duct banks were constructed in mid 1980s directly on top of the then existing tunnel invert bedrock in order to minimize any rock excavation during the installation.

Several alternative schemes for the relocation of these PSE&G duct banks were considered, evaluated, and presented to PSE&G and NJ Transit officials in a series of joint meetings. It was finally agreed that each of the 230 kV lines will be relocated to new reinforced concrete duct banks with two 8-in. (0.8-m) steel conduits, one duct to carry one set of Oilostatic power cables (*3*) and the other will be a spare duct for future use in the event the cables fail in the operating duct while LRT is operational, and one 5-in. (12.7 cm) PVC conduit to accommodate fiber optic communication cable running along and under the proposed LRT tracks.

After the new PSE&G 230kV lines were operational, PSE&G drained the fluids from the abandoned existing 230kV circuits after removing the cables. Only after PSE&G certified that the existing abandoned ducts are environmentally safe to remove, the N30 Contractor began the demolition of these duct banks. The N30 Contractor coordinated the LRT related construction activities and the relocation of PSE&G 230kV circuits inside and outside the tunnel with the PSE&G transmission division. The N30 Contractor was responsible for developing the Construction Staging details of PSE&G circuits and LRT Construction Sequencing and obtain NJ Transit and PSE&G approvals before starting construction.

The N30 Contractor provided all necessary construction support to PSE&G in relocating their 230kV lines within the N30 design limits. This support included any excavation required at the tunnel invert and outside portals to accommodate the two 230 kV duct banks, installation of reinforcement and placing of concrete for the duct banks and the surrounding areas. PSE&G

built and tested the steel and PVC ducts needed for the relocation of their existing services in the trench provided by the N30 Contractor. All duct and cable installation, testing, tie-in and splicing to the existing cables at either ends of the 230kV circuits relocation out side of each portal, switching the services to the relocated facilities, and terminating the existing abandoned portion of the circuits was done by PSE&G's contractor.

The N30 Contractor will need to protect the 230kV circuit duct banks from all construction activities including from any debris from blasting activities.

On the surface, the Bergenline Avenue Station site development impacts some minor overhead facilities. Few poles and their associated cables require relocation.

STRUCTURAL

Tunnel

Two different tunnel cross sections were developed:

- Unlined section
- Fully lined section

A modified horseshoe configuration is used for all tunnel sections by closely matching the cross-sectional configuration of the existing tunnel in order to minimize the rock excavation.

The unlined tunnel section will be used where the rock is sound and there is no or little water infiltration. The fully lined tunnel section will be used in the bad rock conditions. The arch and the walls are lined with cast-in-place concrete.

The centerline of the tracks is offset from the centerline of the tunnel by 8 in. (20.3 cm) in order to minimize the rock excavation and limiting it, as much as possible, to the tunnel north wall.

The tunnel cross sections chosen provides an efficient and economical geometrical configuration that meet the structural and geometrical requirements yet minimize the rock excavation.

Tunnel Ground Water Control

The existing lined and unlined segments of the tunnel are subject to water infiltration and icing which is not acceptable for the operation of a transit system. Therefore, the design includes provisions for control of water infiltration.

New lined sections of the tunnel will be constructed with a waterproofing system. In the areas where full liner is anticipated, two 6 in. (15.2 cm) diameter perforated PVC pipes will be placed along the tunnel walls near the invert. Drainage fabric will be installed directly against smoothing shotcrete from the tunnel crown down the sidewalls and then wrapped around the perforated drainage pipes. A PVC waterproofing membrane will then be installed against the drainage fabric to reduce the potential for water infiltration past the fabric. Ground water will be collected at the pipes and discharged into the track drainage system.

The track drainage system consists of 10 in. (25.4 cm) or 8 in. (20.3 cm) diameter PVC drainage pipes, placed in the track slab. The pipes are sloped to drain into the drainage system outside the tunnel portals. For the ballasted track portion at the East Portal, the track drainage system consists of 10 in. (25 cm) diameter non-perforated PVC pipe, placed underneath the ballast between the two tracks, and connected to a manhole which is part of the outside drainage system beyond the portal limits

Station

The station cavern is 61 ft, 8 in. (18.8 m) wide by 32 ft, 6 in. (9.9 m) high. The structural system at the platform area consists of a 2 ft, 0 in. (0.6 m) thick concrete arch supported by 4 ft, 0 in. ((1.2 m) x 2 ft, 0 in. (0.6 m) pillars placed against the station cavern walls. The pillars are spaced 20 ft (6.1 m) on centers leaving the rock surface exposed. A center continuous footing and edge walls independently support the platform. The central wall is a 1 ft, 0 in. (0.3 m) thick self-supporting concrete wall. The upper connection of the center wall, as well as all other interior walls within the station caverns to the concrete liner, are designed so that no load from the liner is transferred to the interior walls.

Portal Structures

East Portal

The East Portal will be reconstructed utilizing a portion of the existing structure. Most of the existing portal structure has been demolished. The southern wall and a short northern wall will remain in place and will be incorporated in the support of the rock faces. New walls will be constructed of cast-in-place concrete directly in front of the existing walls and will be anchored into the rock using tiebacks. A new parapet wall and concrete ditches will be built on top of the new portal walls to collect the surface water run-off.

The new portal structure will be constructed of reinforced concrete. It will be waterproofed using the waterproofing system similar to the one described for the tunnel.

West Portal

The existing metal structures at the west portal have been completely demolished and a new concrete cut-and-cover structure will be built. The structure will be of a horseshoe shape and will extend about 50 ft (15.2 m) west from the original rock portal. West portal cut-and-cover section extends for another 45 ft (13.7 m) approximately, having the cross section that matches the section of the running tunnel.

Surface water run-off at the west portal will be channeled away from the tunnel by proper grading and by constructing an energy dissipating hydraulic structure.

Along the faces of both portals, above the overhead contact system, a 6-ft (1.8-m) high parapet wall is provided to comply with the catenary power safety requirements.

ENVIRONMENTAL CONTROL SYSTEMS

The Environmental Control System (ECS) includes the following major subsystems:

1. Tunnel Ventilation
2. Platform Ventilation
3. Stairwell Pressurization
4. Elevator Shaft Pressurization
5. Ancillary Space Heating and Ventilation (and cooling where required)
6. Comfort Heating and Air Conditioning

Functional Requirements

The ECS for the Bergenline Avenue Station and the adjacent tunnel sections is designed to provide ventilation during normal train operations and to support life safety operations during an emergency caused by a fire or a vehicle derailment.

For the Bergenline Avenue Station support facilities, the ECS is designed to control temperature and provide ventilation in electrical and mechanical rooms; and other ancillary spaces to support routine maintenance and prolong the equipment life by controlling the room temperature and humidity.

Tunnel Ventilation System

The tunnel ventilation system is designed to meet the emergency situation objectives. The primary relevant fire emergencies include fire and smoke on the station platforms, in tunnel sections or on board a train. In any of these situations the function of the tunnel ventilation system is to maintain a relatively safe path of egress in case it becomes necessary to evacuate the passengers. The platform and tunnel ventilation systems work in unison during an emergency. Together they will develop airflow patterns to assist in the emergency rescue and fire fighting personnel in gaining access to the fire scene.

For achieving these objectives, the platform and tunnel ventilation fans are operated such that they provide a source of fresh air into the evacuation path and keep smoke and heat away from the stranded passengers by exhausting air from the downstream side of the fire. Since the direction of emergency evacuation depends on the location of fire, both the tunnel and platform ventilation systems are designed with the capability of moving air in either direction.

The fire location, location of other vehicles in the tunnel, and passenger evacuation direction are the three factors that affect the required number of fans and their operating modes. The airflow capacities of the tunnel and platform ventilation systems were evaluated using the Subway Environment Simulation (SES) computer program. The SES program simulates various fire scenarios and calculates the critical air velocity required to prevent back layering of hot smoke.

Platform Ventilation System

Heat is introduced into an underground station from lights, people, electrical equipment and from the operation of trains. Mainly braking resistor grids, air conditioning condensers, friction brakes and losses from the traction power system generates train heat. This heat will dissipate into the surrounding area, and warm the tunnel and platform environment. The piston action of the moving trains will push some of the warm air from the tunnel environment, through by-pass dampers, to the atmosphere. In order to capture and exhaust some of the warm air from the station platforms, an overhead ventilation system is provided.

The results of the SES analysis for normal operations indicated that the heat sink effect of the surrounding earth and the piston action of the moving trains will be sufficient to maintain the platform temperatures below the maximum acceptable temperature of 91^{o}F (32.9^{o} C), 5^{o}F (2.9^{o} C) above the design ambient of 86^{o}F (30^{o} C). However, in order to avoid a stagnant air feeling by the passengers, the platform ventilation fans will be operated during normal condition. The operation of platform ventilation fans is controlled using temperature sensors. During rush hours and congested train operations, the platform ventilation fans may be operated manually to provide outside air circulation through the platforms. During winter, the fans may also be operated manually to provide air circulation when required.

During fire emergencies, the platform ventilation system plays a significant role by working in unison with the tunnel ventilation system.

Stairwell Pressurization System

A dedicated fan will pressurize the access exit stair from the platform level elevator lobby to the street surface. The function of this fan will be to pressurize the emergency egress stairwell with outside air during a fire emergency in the platform area to keep smoke out of the stairwell.

Elevator Shaft Pressurization System

A dedicated fan will pressurize the elevator shaft and three elevators. The function of this fan will be to pressurize the elevator shaft with outside air during a fire emergency in the station to keep smoke out of the elevators.

Ancillary Space Heating and Ventilating Systems

A supply and exhaust ventilation system is provided in ancillary electrical and mechanical rooms to remove heat produced by the equipment, and maintain the space temperature within acceptable limit. Outside air is distributed into the rooms while the warm air from the space is exhausted to the atmosphere. The supply air to rooms housing electrical and electronics equipment is filtered. The ventilation system is designed to maintain a positive pressure within the space when it is in operation.

The generator room ventilation system includes air intake wall louvers and air discharge ducts above the roof. When the generator is in operation, the radiator fan will pull air over the engine body and discharge the warm air to the atmosphere. The make up air is drawn into the room through louvers. The radiator fan is sized to overcome the pressure drop incurred by the ventilation airflow.

Toilet, janitors, valve room, and other ancillary spaces are provided with exhaust ventilation systems.

Supplemental heating is provided in all ancillary spaces to keep the space temperature above freezing in order to avoid maintenance problems. Electrical unit heaters, cabinet heaters or baseboard heaters are provided as appropriate

Air Conditioning

The Elevator Machine Room houses microprocessor and other solid-state equipment for the control of the elevator operations. During normal operations, elevators are the main egress and exit from the station platforms. Therefore, to avoid elevator breakdowns of the microprocessor due to high space temperature, a mechanical cooling system is provided. The UPS Room, which houses solid-state equipment, is also provided with mechanical cooling system. The operation of these cooling systems is controlled with space thermostats.

Comfort Heating and Air Conditioning System

The Station Attendant’s Room located next to the elevator lobby at the plaza level will serve as a command post during an incident in the Weehawken tunnel. The room houses solid-state controls for the tunnel and platform ventilation equipment and fire management panel for the station. Furthermore, the station attendant will occupy the room from time to time. Therefore, a comfort HVAC system is provided. The operation of the HVAC system is controlled with a space thermostat.

FIRE PROTECTION SYSTEMS

The fire protection systems to be provided for the Weehawken Tunnel and Bergenline Avenue Station include dry standpipes, automatic sprinklers, portable fire extinguishers, and clean agent fire extinguishing systems.

The tunnel is protected with a standpipe system. The platforms and elevator lobby are protected with standpipe and sprinkler systems. The ancillary spaces are protected with a clean agent fire protection system or fire detection and alarm system as appropriate.

Portable fire extinguishers of appropriate rating are provided in platforms, the elevator lobby at platform level, and in all mechanical and electrical ancillary spaces.

ELECTRICAL SERVICE AND POWER DISTRIBUTION

Electrical Service

Two independent electrical services from Public Service Electric and Gas supply power to two outdoor 35 kV fused load break-switches and 26.4 kV-480/277 Volt, dry-type epoxy resin transformers, two 480/277 Volt Indoor Switchgear Assemblies and two 480/277 Volt Indoor Distribution Switchgear Assemblies. Incoming service feeders terminate in the electrical room of the utility building located at the plaza level. In addition to the dual incoming utility power sources, a natural gas driven engine generator will be provided to serve critical loads such as elevators, emergency egress lighting, communication systems and other loads served by the uninterruptible power system.

Power Distribution

One substation will serve the large power requirements of the tunnel and platform ventilation systems in order to avoid electrical disturbances to other facility systems caused by voltage dip of large ventilation fan motors during starting. The other substation will serve the power requirements of the station, tunnel, utility building, plaza level and ancillary spaces including elevators, elevator shaft and stairwell pressurization fans and general power and lighting loads.

PSE&G will provide dual incoming medium voltage services. Upon the loss of one utility company service, the loads will be automatically transferred to the remaining utility company service. If the remaining service fails, normal power to the facility will be interrupted. The UPS will continuously supply power to critical loads for 90 min if the generator fails to start. During that time interval critical loads and emergency loads will be transferred automatically to the natural gas driven standby generator.

Uninterruptible Power Supply

The UPS system will be used to maintain power to the emergency egress lighting, critical life safety, and communications systems in the event of power failure. The UPS system will provide capacity for 90 min time interval.

LIGHTING

The lighting system for the station platform, plaza level, Utility Building, miscellaneous mechanical and electrical will include fluorescent, metal halide, and high-pressure sodium luminaries. Illumination level for each room, location and area will be as recommended by the Illuminating Engineering Society (IES) and the American Public Transportation Association (APTA).

Tunnel Lighting

The average maintained illumination level for the tunnel interior zone will be 1.5-ft (45.7-cm) candles. Daytime average maintained illumination levels for the first 300 ft (91 m) of the tunnel from the portals is 10-ft (3-m) candles. Nighttime levels will be reduced to the interior illumination levels as in the interior zone. Controls will be via astronomical timer/lighting contactor assemblies.

Emergency Lighting

Emergency lighting will be provided to permit passenger egress from the station platform, ancillary spaces and tunnel during an interruption in service to the facility. Emergency lighting will be provided throughout the facility, stairs, platform, and tunnels. The emergency lighting will be fed from the UPS system until the stand-by natural gas driven generator comes on line. The generator will feed the emergency egress lighting system through the UPS system.

The tunnel is designed with wayside walkways. During an emergency, tunnel trackways will be used as an alternative emergency egress path. Average maintained illumination level for emergency egress is 1 ft (30 cm) candle, minimum illumination levels is .25 ft (76 mm) candles and will be designed in accordance with the applicable sections of NFPA 130, Fixed Guideway Transit System, the NFPA 101, Life Safety Code, and the APTA Guidelines for Design of Rapid Transit Facilities.

FIRE ALARM AND DETECTION

An electronically supervised, zoned fire/smoke detection and alarm system will be installed at the Bergenline Avenue Station. This system will consist of a microprocessor based Fire/Smoke Control Panel (FACP), part of the Emergency Management Panel (EMP); remote annunciate, part of the Emergency Information Panel (EIP) and other support equipment and devices such as manual alarm pull stations, smoke and heat detectors, sprinkler water flow switches, standpipe water flow switches, speakers, strobe light, etc.

The FACP will be installed in the Fire Management/Attendant Room located at the plaza level headhouse. The FACP will monitor sensing and indicating devices and initiate alarms to the Operations Control Center. Authorized personnel can monitor the status of the FACP during emergencies from the FACP or remote annunciator in the EIP located at the elevator lobby. The monitoring of alarm status and control of support equipment/devices can also be done from the Operations Control Center (OCC) through the Mechanical/Electrical SCADA system. All fire system alarms will generate visual and audible indication at the FACP.

Public Address System

A public address system will be provided in the Bergenline Avenue Station.

Intrusion Detection

All outside entries into non-public spaces at the plaza level will be monitored for unauthorized entry. Similarly, access into ancillary spaces at the platform level and Utility Building, such as equipment rooms, fan rooms, etc., will also be monitored for any unauthorized entries. The intrusion detectors will interface with the Supervisory Control and Data Acquisition (SCADA) system.

FIRE EMERGENCY MANAGEMENT SYSTEM

The SCADA system will provide operating personnel with an effective method for controlling and monitoring the ventilation and electrical systems from a central location. The primary control SCADA video display system (VDT) will be located at the OCC, and a fallback control VDT provided within the Fire Management/Attendant Room at the Bergenline Avenue Station. Within the Fire Management/Attendant Room a hardwired Emergency Control panel (EMP) will be provided and will include the following systems:

- Ventilation System (ECS Operator Panel)
- Fire Alarm Panel

- Intrusion Detection Panel
- Elevator information
- Fire suppression systems status (shown on the Fire Alarm Panel)

The SCADA will integrate these systems.

Each of these systems will continuously send data and status information, which will be available at both the OCC and at the Station's Fire Management/Attendant Room SCADA VDT. The OCC SCADA will normally be in control with the Station SCADA restricted to monitoring and maintaining a station level database of equipment status. The SCADA system will continuously monitor and alert the control center operator following any changes in status for the systems monitored. For the ventilation system the operator may manually implement operations or accept pre-programmed automatic responses to anticipated events.

The SCADA system is to be a computer-based control system with a high-speed data bus that carries information from various devices to the central control computer via reconfiguring redundant fiber optic communications cables. Redundant equipment is to be used to increase system reliability.

CONSTRUCTION

When the HBLR Minimum Operate Segment–2 (MOS-2) work effort was negotiated with TFC, Design Unit N30 was included as an open book item. This means that an allowance was provided for this work in the MOS-2 change order. As part of TFC's responsibility, N30 was to be competitively bid. NJ Transit and the design engineer, PB, were included in the presentations to the bidders and the technical review of the proposals.

PB prepared the final design drawings and specifications. TFC prepared the contractual documents. TFC was also responsible for preparing the Request for Proposals and in charge of the negotiations during the bid process. While price was the major considerations during the bid process, the technical and contractual qualifications were also considered as part of the selection process. The bid process occurred during calendar year 2001. The N30 contractor, FKSB, was selected towards the end of 2001. The agreement with FKSB was made in January 2002 and executed on March 21, 2002.

Initial Construction

The initial construction activities were setting up of the field offices, baseline survey, pre-blast survey, asbestos abatement, rodent control survey and preparation of the health and safety plan.

On June 17, 2002 Conrail Freight Service was rerouted and the tunnel was released for construction. The initial construction in the tunnel was the removal of the ballasted track and ties and soot from the tunnel walls. Also the areas along the east and west portal were cleared and grubbed along with the initial scaling of the rock walls at the east portal. The pre-blast survey of the buildings along the tunnel surface was also completed. The fencing and gates were installed at the Bergenline Avenue Station plaza site along with the demolition of the one building still remaining on the site. The one archaeological dig at the plaza area site was completed in August 2002.

The relocation of the PSEG cables in the tunnel was a joint effort between FKSB and PSEG. FKSB prepared the trench. PSEG then laid the new conduits and FKSB installed the steel reinforcing and poured the concrete for the ductbank. After the duckbank installation was complete, PSEG placed the cables, one ductbank at a time. The cables in the second ductbank were not installed until the first set of cables were installed and up and running. This work was started in October 2002 and completed in January 2003.

The work on the elevator shaft vertical bore was started in December 2002. The initial work was the drilling of an 8 in. (20.3 cm) pilot hole from the surface to the tunnel crown. After the completion of the pilot hole, an 8-ft (2.4 m) diameter raise bore was drilled from the tunnel crown to the surface plaza. This work was done in January 2003. The enlargement of the shaft to final outside diameter of 42 ft (12.8 m) was completed in August 2003. This was done in maximum blast sections of 8 ft (2.4 m). After blasting immediate support in the new shaft comprised systematic epoxy-coated-cemented grouted rock dowels, welded were mesh and 4 in. (10 cm) of steel-fiber reinforced wet mix Shotcrete.

In the first quarter of 2003, the rock excavation at the plaza level began and work progressed in filling the existing open construction shaft. Work on removal of the brick lining and blasting for enlargement of the tunnel began in April 2003. The rock from the plaza blasting operation is key pushed through the raise bore shaft and removed via the tunnel. In June 2003, drill and blast excavation of the station transition zone started.

Future Construction

The current N30 schedule calls for the following milestone dates:

Targeted Milestone	*Baseline Schedule*
Complete all blasting	12/03
Signal Room complete to Allow Work by Signal Contractor	10/04
Release Tunnel, Station, and Plaza for Systems Work	10/04
Complete Trackwork	1/05
Complete Headhouse, Utility Building, and Plaza	1/05
Complete Station	12/04
Complete All Work	1/05

This work, upon its completion, will allow the vision of the early railroaders of providing access through the Palisades to continue.

The revenue ready status of HBLR MOS-2 Phase 2B, which includes Design Unit N30, is scheduled at this time for June, 2005

ACKNOWLEDGMENTS

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Floating Slab Trackbed Design to Control Groundborne Noise from Newark–Elizabeth Rail Link Light Rail Transit

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NJ Transit is in the process of final design for the Newark–Elizabeth Rail Link (NERL) project, a new light rail transit alignment that will connect with the existing Newark City subway system. A regional Performing Arts Center is adjacent to a portion of the new rail alignment and at some point in the future, the Performing Arts Center may also construct a concert hall directly adjacent to the new rail line. Detailed analysis of the potential for groundborne noise from ground vibration generated by light rail vehicles was performed by Wilson, Ihrig and Associates, Inc. (WIA) working with the BRW/Parsons Brinckerhoff (PB) Joint Venture team. WIA determined the track support system adopted for the NERL project would result in higher levels of groundborne noise than appropriate for the Performing Arts Center. The goal of the team's work was to determine an effective mitigation measure, which would control ground vibration and avoid interference from groundborne noise. The tracks will be at-grade and accessible by the public which was a significant consideration. Different track support systems were evaluated for their effectiveness in resolving the issues. A sealed floating slab system was selected as the most effective and offered ultimate protection should the concert hall be built at a later date. A unique construction technique developed by BRW/PB Joint Venture and KS Engineers for the concrete slabs supporting the track will also be presented.

INTRODUCTION

The Newark–Elizabeth Rail Link (NERL) Minimum Operable Segment 1 (MOS-1) is an approximately 1-mi, four-station extension of the Newark City Subway (NCS) that is currently being constructed by NJ Transit in downtown Newark, New Jersey. The NCS extension or NERL MOS-1 connects Newark's Penn Station on the Northeast Corridor with Newark's Broad Street Station on the Morris and Essex Lines as shown Figure 1. Between these two commuter rail stations the NERL MOS-1 runs through Newark's Arts District servicing the Washington Park office area, the Newark Art Museum, Newark Library, Riverfront Baseball Stadium, and the New Jersey Performing Arts Center (NJPAC).

The NJPAC is a $180-million performance center with two theaters that opened in October 1997. The opening of the NJPAC marked the return of Newark as a regional cultural

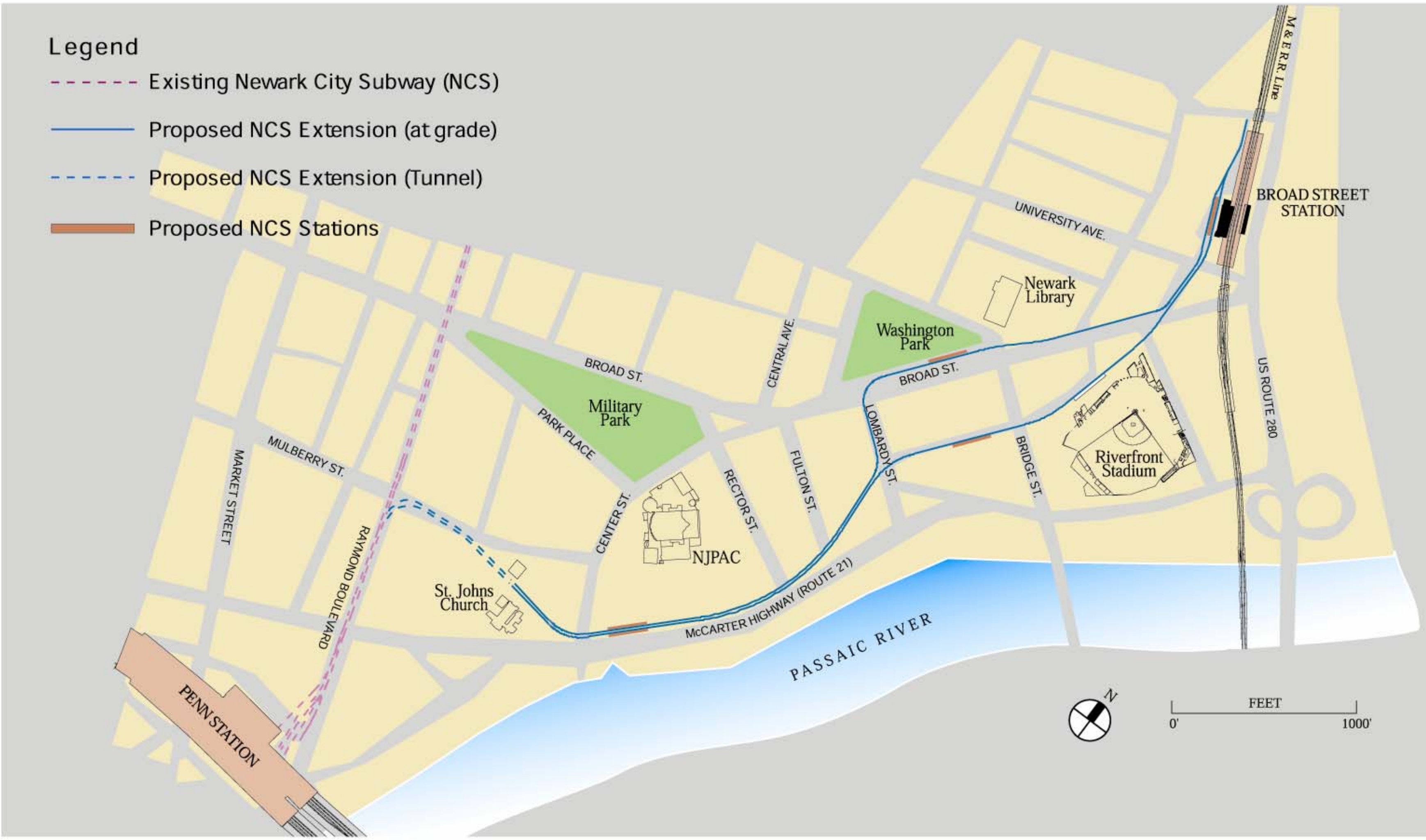

FIGURE 1 NERL MOS-1 alignment.

center and significantly improved the quality of life in downtown Newark. Many local corporations, the city of Newark, and the state of New Jersey sponsored construction of the NJPAC. An artist's rendition of the NJPAC buildings prior to construction is shown in Figure 2.

The view shown is from the north looking south towards the Passaic River with Center Street in the foreground. The planned NERL light rail transit (LRT) alignment is behind the second building (the future concert hall), which is shown in outline.

The environmental consultants to NJ Transit, URS/BRW Team, completed the NERL draft environmental impact statement (DEIS) in January 1997 prior to the opening of the NJPAC. The alignment of the NERL MOS-1 runs adjacent to the NJPAC site within 160 ft (48.8 m) of Prudential Hall and only 50 ft (15.2 m) from the site of a future concert hall that had been planned at the time of the NERL DEIS. The NERL MOS-1 will include an NJPAC station near the possible location of the potential concert hall. The NJPAC was under construction during the NERL environmental analysis and its completion was highly anticipated. The potential for the NERL trains to have detrimental noise and vibration impacts on performances was of great concern to NJPAC and the city of Newark. These concerns were communicated to NJ Transit and their consultants URS/BRW.

URS/BRW requested that Wilson, Ihrig &Associates, Inc., (WIA) evaluate the potential impacts of the LRVs on the NJPAC and recommend ways to mitigate the potential impacts. The DEIS and final environmental impact statement identified the NJPAC as a sensitive receptor that would require mitigation measures to reduce groundborne noise and vibration. WIA looked at multiple methods of vibration isolating the LRT, including special rail support systems, ballast mats, and a floating slab. NJPAC officials withdrew their objections and supported the NERL project once they were briefed on the various ways to mitigate the potential impacts to their performance halls by the consultant team, who promised further investigation during final design.

During preliminary engineering, NJ Transit evaluated the different options for mitigating potential groundborne noise and vibration impacts to NJPAC facilities. NJ Transit wanted to be certain that there would be no discernable impact from noise or vibration to the NJPAC. The final design was awarded to the BRW/Parsons Brinckerhoff Joint Venture (PBJV) and included WIA as the noise and vibration consultant. In the final design phase of NERL MOS-1, and after much deliberation, the recommendation to use a floating slab track (FST) system for the track alignment adjacent to the NJPAC site was made by WIA to the BRW/PB JV engineering team, and accepted by NJ Transit. The NERL MOS-1 is currently under construction and the plans call for an 840-ft (256-m) floating slab running from Center Street through the NJPAC Station to Rector Street in the vicinity of the NJPAC.

Several design issues presented themselves in this project to develop the FST system for NERL MOS-1. Some of these issues were practical in nature, and others involved the performance of the FST system. In this paper, the issues are discussed and the approaches taken to address them presented. Details of the design are presented along with the performance expectations for the FST system designed for NERL MOS-1.

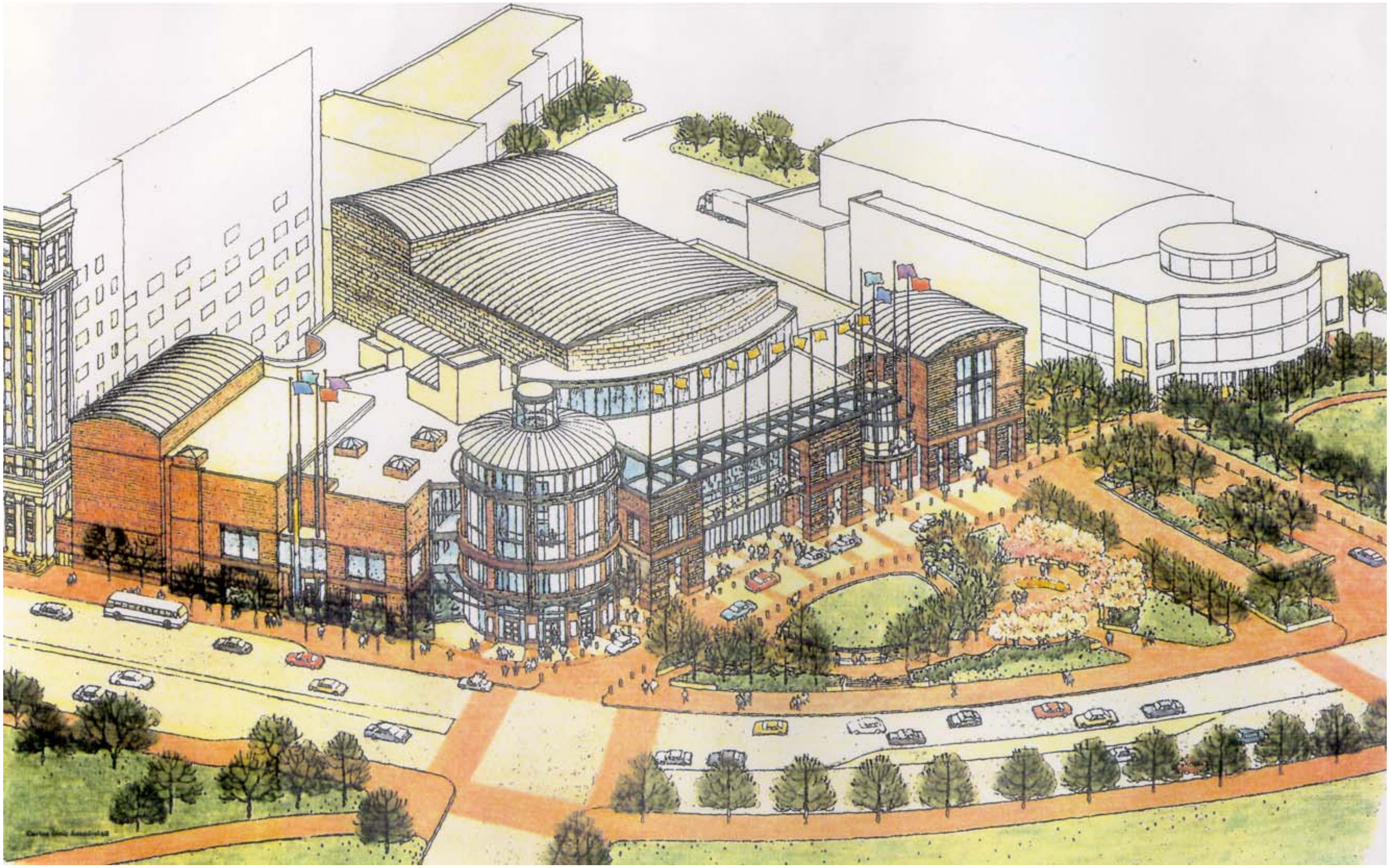

FIGURE 2 Overview of NJPAC fronting Center Street.

FLOATING SLAB DESIGN ISSUES

In basic terms, an FST system is comprised of springs and masses, which are designed to isolate vibration coming from wheel or rail interaction, and decrease its transmission to the surrounding track support structure. The amount of isolation necessary depends on the amount of vibration reduction required by the particular circumstances of each situation. The circumstances involve many factors, including

- Sensitivity of the affected building,
- Speed of the transit vehicles,
- Rail roughness,
- Dynamic interaction between the vehicle's trucks and the rail system,
- Response of the soil underlying the track,
- Ease of propagation of vibration through the soil between the track and the building,
- Response of the building to ground vibration, and
- Manner in which vibration is transmitted through the building.

The amount of vibration reduction that can be achieved using an FST depends on the dynamic characteristics of the transit vehicle, but is dictated to a large degree by the primary natural frequency of the FST system. The FST can be idealized as a simple spring-mass and damper system as depicted in Figure 3. In actuality, it is a more complex dynamic system than this, but for determining the basic performance of the FST it often suffices to model it in this manner. Field tests performed on a full scale FST mock-up (*1*) demonstrated this, in particular when the FST is under vehicle load.

The FST system will have a natural frequency determined by the stiffness of the supporting springs and the amount of mass the springs support. Contrary to an occasionally expressed opinion, the mass of the transit vehicle does not affect the natural frequency of the

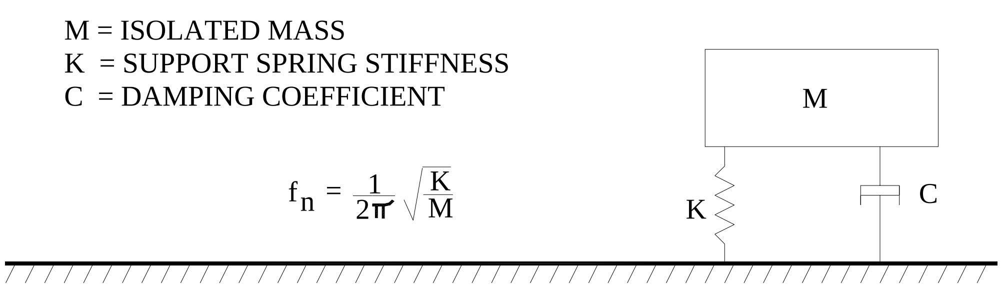

FIGURE 3 Idealized spring-mass and damper system.

FST, except by changing the stiffness of the support springs due to its static loading on the FST. The secondary suspension, located between the truck and vehicle, has a low natural frequency (typically 1 to 2 Hz) effectively decoupling the vehicle from the FST. However, the mass of the truck or some portion of it (e.g., wheelset), depending on the nature of the primary suspension system, will contribute to the dynamic mass of the FST system.

Once a suitable natural frequency for the FST is determined, the appropriate stiffness of the springs and mass of the slab trackbed can be determined. The NERL MOS-1 FST system design uses "natural rubber" springs and a hybrid pre-cast concrete slab combined with a cast-in-place (CIP) slab. Natural rubber has been used for over 100 years as a material for structural isolation elements, and has been found to be highly durable and an ideal spring material for FST after its first use in North America in this manner in 1970.

A generic FST system concept is shown in cross section in Figure 4. The rubber pads rest on either an invert or the bottom of a concrete tub as in the case of NERL MOS-1. The concrete slabs (masses) are placed on top of the rubber pads. To restrain lateral and longitudinal motion of the concrete slabs in the horizontal plane, discrete rubber pads or continuous rubber strips are used around the edges and in-between adjacent slabs.

The FST system for NERL MOS-1 presented several design issues and challenges not typically encountered. Two of the main issues involving groundborne noise and vibration projections were

- Lack of an existing fleet of vehicles to use for measurements, and
- No at-grade operations for measurements.

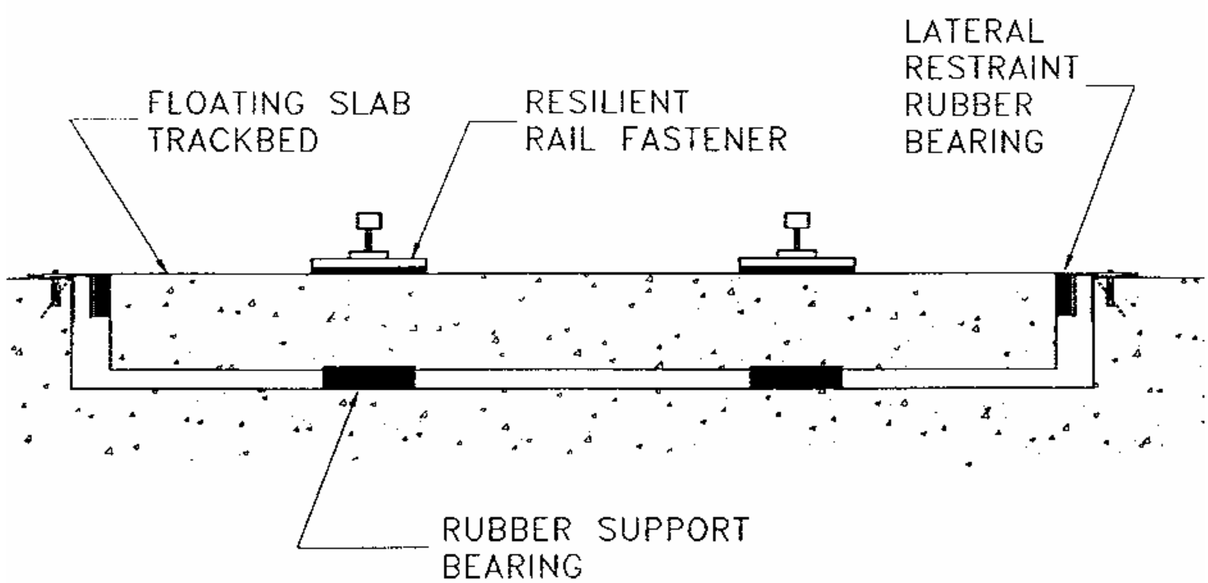

FIGURE 4 Typical FST configuration.

Most often an FST system is designed for an existing transit system with a fleet of transit vehicles already in use. Thus characteristic vibration data for the transit vehicles and track can usually be obtained by measurements using the existing system. The NCS and eventually the NERL extension are scheduled to switch over to new low-floor vehicles. These vehicles were not available during the final design phase of the NERL project. NCS/NERL will use essentially the same low floor vehicles, which were being manufactured at the time by Kinkisharyo of Japan and assembled in Harrison, New Jersey. While the existing NCS LRT is a subway, the NERL system will be essentially all at-grade, except for a short transition to grade connecting the two. These two factors complicated the task of predicting groundborne noise and vibration levels, which would be generated by the future NERL System.

Fortunately the nearby and then brand new (1998) Hudson–Bergen LRT system was finished prior to completing final design engineering for NERL MOS-1, and it was conveniently available for making vibration measurements to characterize the Kinkisharyo low floor LRV. The Hudson–Bergen system has a very similar embedded track system to NERL, and uses identical vehicles, which operate at-grade. It was therefore possible to obtain relevant measurement data on the groundborne vibration characteristics for the NERL system using the Hudson–Bergen system as an exemplar.

The receptor side of the problem also presented a challenge. NJPAC's Prudential Hall had been on the site and open to the public for a little over a year at the start of the NERL MOS-1 final design, but design and construction of the concert hall was and still is somewhere off in the future. The Prudential Hall will be 160 ft (48.8 m) from the nearest track, whereas the future concert hall, if and when it is built, would be much closer to the new tracks. Consequently, of the two buildings, the one that is more critical for groundborne noise and vibration had yet to be built during the NERL MOS-1 design process.

Although the appropriate noise and vibration criteria for the NJPAC buildings were not in question, it is unusual for a building to be protected by an FST system not to exist. Most FST systems are designed and constructed after the buildings they will protect are. In such situations, it is possible to physically measure the vibration response of the specific building and incorporate the measured data into the prediction model. In the case of NERL, since the concert hall did not exist it was not possible to do this. Consequently, data from previous measurements on similar buildings were used instead.

The Prudential Hall is a noise and vibration sensitive public facility, but it is not as critical as the concert hall would be if it were built. The concert hall would be more sensitive to noise than Prudential Hall and it would be considerably closer to the NERL MOS-1 tracks. The two theaters in Prudential Hall were designed by the acoustical consulting firm of Artec Consultants Inc. to have very low ambient noise. Measurements made by Artec (*2*) after the theaters were constructed confirmed this. However, Prudential Hall will be 100 ft (30.5 m) farther from the new tracks, than the concert hall would be. This additional distance will attenuate the vibration transmitted through the ground due to damping in the soil and spreading losses.

Contemporary concert halls are designed to have an extremely low ambient noise environment inside the performance space, with considerable effort expended to design and construct an ultra-quiet heating, ventilation, and air conditioning (HVAC) system. The noise criterion used in designing new concert halls is often driven not so much by the need to avoid interference during a live performance, but the common practice of renting the performance space for making audio recordings of concert or other types of music. Modern audio recording technology places a severe demand on the ambient noise level that is acceptable in premier performing arts facilities.

By applying state-of-the-art design techniques and carefully constructing the performance space in the new facility, noise levels in the performance space as low as N1 (a special acoustical design criterion developed by Artec) can be obtained even with the HVAC system operating. This criterion is essentially the threshold of audibility except at frequencies below 125 Hz for which the acceptable noise levels are even lower to avoid interference with recordings.

Another factor considered was the existing ambient vibration coming from traffic on the highway adjacent to the possible concert hall site. The site for the concert hall is in close proximity to McCarter Highway (Route 21), which has substantial truck traffic. NERL MOS-1 will be in-between McCarter Highway and the NJPAC site. During preparation of the DEIS for the NERL project, ambient vibration measurements made by WIA in 1995 at the approximate location of the potential concert hall façade closest to McCarter Highway indicated that the overall vibration levels are between 55 and 67 VdB (1 micro-in./s). McCarter Highway will be relocated slightly to accommodate NERL tracks and the highway will be resurfaced. Moving the highway further away would tend to reduce the ambient vibration at the concert hall site. Resurfacing the highway will, at least in the short-term, make the road smoother, which will also tend to reduce the vibration generated by vehicles (especially trucks) traveling on it. Designers of the concert hall would need to address the presence of motor vehicle generated ambient vibration and special building isolation measures may be needed to avoid interference with the performance space.

There were also practical design issues, which make the NERL FST requirements somewhat unique. The design team had to consider ways to overcome the following issues:

- Shared right-of-way
- Public access to track

Most FST systems, in particular those for heavy rail transit, are installed in subway tunnels or at least in an exclusive right of way. There are relatively few FST systems installed on LRT systems in North America. Examples are San Francisco, California; Buffalo, New York; and Toronto, Ontario. LRT systems typically share the right of way with motor vehicles, and it is common for pedestrians to have access to the trackway, such as will be the case with NERL, a factor which imposes practical design constraints on the FST.

Except for the connection with the NCS, the LRT alignment for NERL MOS-1 will be in the public right of way. Some portions will be in the roadway and others directly adjacent to the sidewalk. For public safety reasons, the basic NERL MOS-1 track was designed to be an embedded construction using a rubber “rail boot” system. The 115# RE rail and the encasing boot are held in place with an anchoring system that uses Pandrol clips.

Where pedestrians have access, but not motor vehicles, the top surface of the NERL MOS-1 standard track will be surfaced with paving stones. Where the tracks are in the street, the paving will be asphalt. For obvious aesthetic reasons, the NERL FST had to incorporate these same features into the design. Although not a major consideration in the FST design, it is a secondary factor in determining the mass of the concrete slab to be used in the FST system.

Most FST designs have gaps around the edges of the slabs to allow air to move freely from under the FST, in which case the air does not contribute to the vertical stiffness of the FST spring-mass system. For the reason stated, the NERL FST design could not have gaps at the edges, and was therefore designed as a “sealed system.”

Air is nearly incompressible, and, in a sealed FST design under dynamic loading, the air, to a large degree, is trapped and acts as a spring. The stiffness of the trapped air contributes substantially to the dynamic stiffness of the spring support system for the FST. Consequently, the added dynamic stiffness of the air affects the appropriate dynamic stiffness of the rubber support pads. For a given total vertical stiffness desired for the FST, the additional air stiffness reduces the allowable rubber pad stiffness. Whereas, under static loading, it is possible for the air to move and the stiffness of the air has little or no effect. These two competing factors must also be taken into account in the design.

Other LRT FST systems designed by WIA, which are in-street installations [San Francisco Municipal Railway (Muni), in a residential neighborhood on Noe Street in San Francisco], or accessible by pedestrians [Niagara Frontier Transportation Authority (NFTA), at the Marine Midland Bank in Buffalo] have designs similar to the NERL FST. The tracks for the systems are embedded and the top surfaces of the trackbed are paved with asphalt. Both of these FST systems are also sealed designs. A major difference though between these two designs and the NERL FST is the construction of the concrete slabs.

Both the Muni and NFTA track slabs used a CIP construction, whereas the NERL FST is a hybrid pre-cast concrete and CIP slab design. In a CIP construction, a metal pan is used as the concrete form and is left in place, becoming part of the system. The FST rubber pads support the metal pan underneath, into which the concrete is poured. The thickness of the metal pan must be sufficient enough to support the weight of the wet concrete as it cures. The span between support pads is therefore critical, if the bottom of metal pan is not to sag substantially.

The NERL MOS-1 FST system sits in a concrete “bathtub” construction with the rubber pads resting on the bottom of the tub. Each track will have its own independent FST system. The decision to use a pre-cast design was primarily dictated by the presence of a center drain in the concrete invert. The center drain affects the number of rows of support pads that can be used, in that it precludes a design with an odd number of rows. The typical pre-cast FST slab designs (e.g., Bay Area Rapid Transit, Metropolitan Atlanta Rapid Transit Authority, and Toronto) have two rows of support pads. The Muni FST has three rows of support pads, because it has no drain channel in the invert.

Using four rows of pads would result in the pads having to be much smaller than most conventional pad designs. Since the NERL MOS-1 FST is a sealed system, the air stiffness would also require that the support pads be smaller than in an open FST system. These factors would have resulted in a substantial increase in the total number of pads and use of a non-conventional pad size. Consequently, it was decided to use two rows of pads and stick as close to an existing conventional pad design as possible.

To prevent the metal pan from sagging, the BRW/PB team decided to use a hybrid pre-cast concrete and CIP slab design. As a sub-consultant to the BRW/PB team, KS Engineers (of Newark) assisted in developing the design concept and design details (in particular the steel reinforcement and attachment details), and were responsible for the contract drawings for the NERL MOS-1 FST. Each of the slabs will be constructed in two pours. The pre-cast slabs will be installed on top of the rubber pads and serve as the bottom of the concrete form for the second pour.

FLOATING SLAB DESIGN DETAILS

The final design selected for the FST is shown in plan view in Figure 5 depicting the basic slab units. The basic NERL MOS-1 FST design consists of concrete slabs that are nearly 30 ft (9.1 m) long. The concrete slabs will be a two-pour system as shown in Figure 6. Pre-cast, steel reinforced slabs that are 29 ft, 5 in. long (897 cm), 6 ft, 5 in. (196 cm) wide, and 12 in. (30.5 cm) thick will form the base for the second-pour concrete. The weight of the pre-cast slabs will be approximately 29,000 lb (125,000 N). The second-pour will add another 1 ft, 2 in. (35.6 cm) of concrete that is 7 ft (213 cm) wide. The second-pour is also steel-reinforced. Where needed, a recess formed in between the two embedded rails will contain Belgian block masonry paving stones, which are 5 in. (12.7 cm) thick. Every 200 ft (61 m) there will be a drain clean-out hole in the slab.

Except at the ends of the FST system, there will be two longitudinal rows of natural rubber support pads spaced at 33 in. (83.8 cm) apart lengthwise. This resolved the problem of the drain under the FST. At the two ends of the FST, the number of rubber support pads is increased to provide a transition in stiffness from the relatively soft vertical support for the FST to the much stiffer embedded rail support system used everywhere on the NERL MOS-1 system.

Around the perimeter of the slabs will be natural rubber strips that will be held in place with metal channels. The rubber strips will be pre-compressed during construction and will act to resiliently restrain the FST from horizontally movement. The metal channels holding the rubber strips will be welded to metal angles that will be attached to the pre-cast slab with anchor bolts prior to the second pour of concrete.

The support pads will be located on the invert using steel rings that will be preset on the bottom of the concrete tub. The steel rings also provide a form for grout that will be used to level and provide the correct base elevation for the rubber support pads. The support pads will be manufactured from natural rubber and will be 12 in. (30.5 cm) in diameter, 4 in. (10.1 cm) thick, and have a nominal 4 in. (10.1 cm) hole in the middle. The actual size of the hole in the pad is dependent on the manufacturer obtaining a specified static and dynamic stiffness for the pad. The chemical composition of the rubber to be used in manufacture of the pads was carefully developed 20 years ago for FST applications and is clearly specified in the contract documents.

The NERL vehicles will be 90 ft (2743 cm) long, and only one truck can be on top of a slab section at a time. The AW2 vehicle load is 128,000 lb (581,000 N). The NERL MOS-1 FST is designed to have a natural frequency of 10 Hz when loaded by a transit vehicle.

The pre-cast slabs will probably be constructed off site and trucked to the construction site. After the rubber pads are placed in the concrete tub, the pre-cast slabs will be lowered onto them with a crane, with care taken on placement of the slabs. The rail and its support system will be set at the correct location with jigs prior to pouring the concrete.

PERFORMANCE OF NERL FST

Projections made by WIA of the expected interior noise generated by NERL LRVs traveling at 25 mph on the NERL MOS-1 track indicated that the N1 criterion would likely be exceeded somewhat in the Prudential Hall theaters, if the proposed standard embedded track were used as planned. The noise projections for the proposed concert hall indicated that the N1 criterion would be exceeded by substantially more for the same conditions. These noise projections were

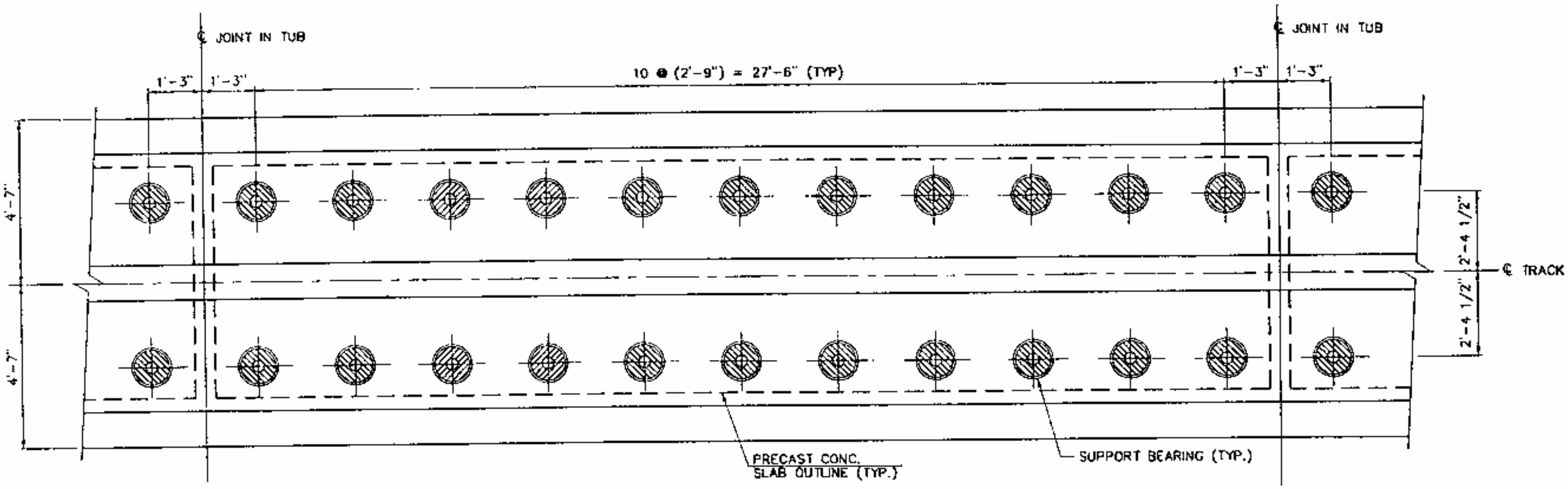

FIGURE 5 Plan view of NERL MOS-1 FST.

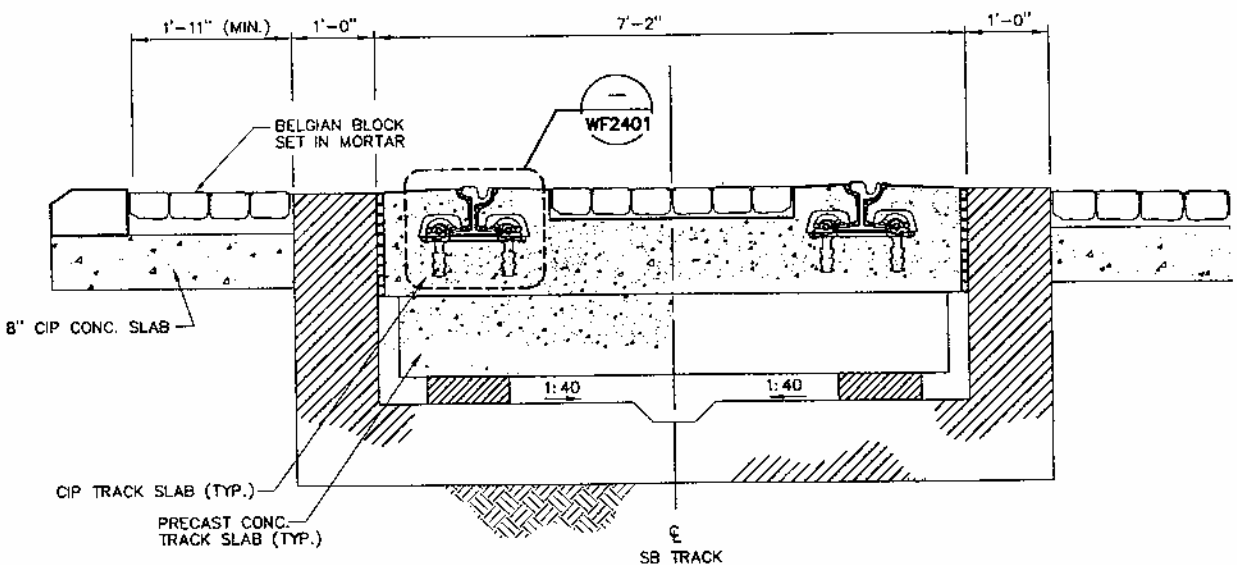

FIGURE 6 NERL MOS-1 FST.

obtained using the groundborne noise and vibration model developed by Nelson and Saurenman (*3*) and adopted by the FTA (*4*). The model relies on measurement of the transit vehicle vibration characteristics when combined with the rail system, the propagation of vibration characteristics for the surround soil, and of the response of the building of concern.

The FST system is the most effective means available for reducing vibration at the track. Without the FST, vibration would propagate through the ground and could interfere with the use of the adjacent performance spaces. It would be possible to isolate the new building or a part of the building from vibration as has been done with some concert halls (e.g., Benaroya Concert Hall in Seattle, Washington) and other critical performance spaces. However, at the time of the final design for the NERL MOS-1, it was not possible to rely on this as the sole means of groundborne noise and vibration control, as there was not even a conceptual design existed for the concert hall.

The implementation of an FST would substantially reduce the groundborne noise for both of the NJPAC buildings. The rail boot system proposed for NERL MOS-1 is relatively stiff. In comparison and FST would produce, depending on the frequency of vibration, 25 dB or more of reduction. Figure 7 shows the amount of reduction in ground vibration expected for the NERL MOS-1 FST when compared with the NERL embedded track system. Groundborne noise projections for the two NJPAC buildings were recalculated including the insertion loss provided by a 10 Hz FST in comparison with the rail boot. Groundborne noise inside the existing Prudential Hall theaters, with the NERL LRVs operating on the planned 10 Hz floating slab, is projected to be considerably less than the N1 criterion. If it were not for the possible concert hall, it would have been possible to use another, less substantial form of groundborne vibration control than the FST.

For the future concert hall, groundborne noise and vibration model projections indicate that noise levels inside a conceivable performance space have a slight chance of exceeding the N1 criterion, but an equally likely chance of being less than the N1 criterion. However, if the

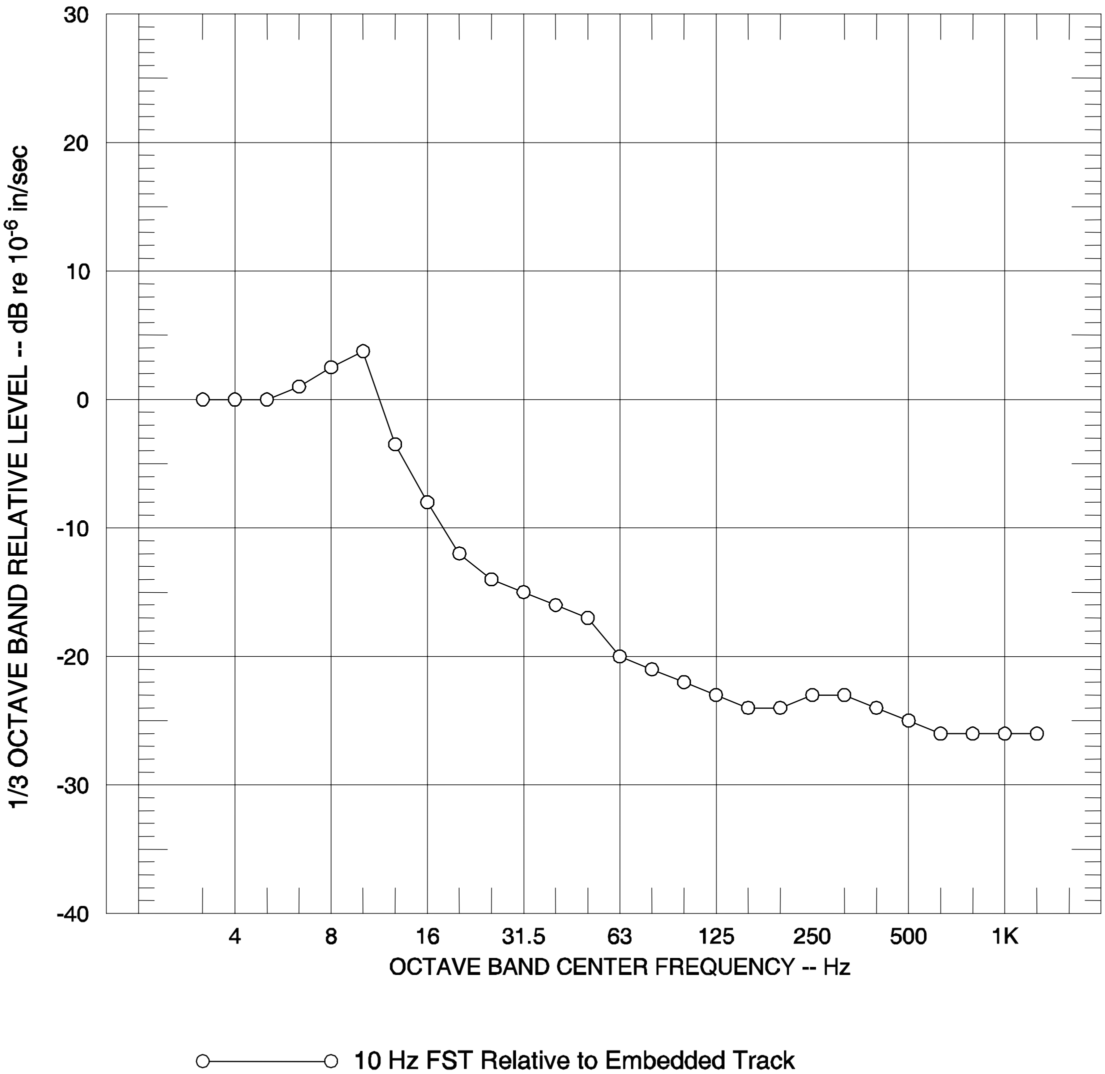

FIGURE 7 Expected vibration reduction performance for NERL MOS-1 FST.

building is removed from the model, and we consider just the vibration levels in the ground where the concert hall could be, then we can compare the predicted vibration with the existing ambient vibration. In this case, it is clear that, with the NERL MOS-1 10 Hz FST, the LRV ground vibration would be comparable to vibration generated by roadway traffic on McCarter Highway. This would be at a location which would be the future concert hall façade closest to McCarter Highway.

The analysis indicates the NERL LRT system should not affect the concert hall design anymore than the hall would by affected by McCarter Highway. The NERL LRT system therefore would impose no constraints beyond what McCarter Highway now imposes on the NJPAC site. The concert hall designers would, however, have to make a further assessment of this when the concert hall becomes a reality. That assessment would involve deciding whether the building could be designed to adequately reduce ambient ground vibration, both motor vehicle and LRT, through use of a particular foundation design (e.g., caisson) or if inclusion of some form of resilient vibration isolation system within the building to control exterior vibration would be required.

CONCLUSIONS

The NERL MOS-1 project has demonstrated that it is feasible through implementation of an FST system to have rail transit in close proximity to noise- and vibration-sensitive buildings such as a concert hall. Furthermore, it has been shown that a sealed FST system can be designed that allows public access to the right of way and incorporates the architectural aspects of the design of the rest of the LRT system. The FST design was a collaborative team effort of the BRW/PB JV, KS Engineers, and WIA that adequately resolved various constraint issues, which arose during its design. The NERL MOS-1 FST will be constructed over the course of the next year or so after selection of a contractor in the middle of this year. Start-up of revenue operation of the NERL MOS-1 is anticipated for Spring 2006.

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Fitting Light Rail Transit into Historical Centers
The Rome Experience

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The city of Rome is world renowned for its massive presence of ancient monuments, churches, and historical buildings, mostly dating from the Roman period to the Baroque Age. The noble marbles and the facades of those monuments have been severely damaged by air pollutants, mainly emitted by private and public vehicles.

To face this problem, ATAC (Agenzia per il Trasporto Autoferrotranviario del Comune di Roma), the public company which manages public transportation in Rome and in its region, began a long-term project in 1993 called "Zero Pollution Public Transportation in the Center of Rome," which aims to convert all fossil fuel operated public transportation into electric transportation through the introduction of battery operated small buses, trolley buses, and, above all, light rail transit (LRT) systems.

To accomplish this, new problems had to be faced and solved. LRT systems crossing the historical center must have minimal environmental impact; that is, unobtrusive overhead wire systems and sites for substations are necessary, as are, above all, vibration reducing track structures, since vibrations can severely damage ancient buildings. This paper will deal about the experience in Rome since 1994 with designing and testing different techniques for vibration reducing track structures.

First, the design of the two main vibration reducing track structure systems that were produced and tested will be detailed, focusing on the differences between them. Second, results of the measurements carried out at two sites in the center of Rome, before and after the installation of the vibration reducing track structures ("before works" and "after works"), will be presented.

Finally, a comparison table showing the vibration reduction and the cost of each system will be presented, the solutions adopted on the recently constructed tramway Line 8 will be shown, and information will be given about the future application of such systems in Rome.

THE VIBRATION PROBLEM

While in motion, light rail transit (LRT) vehicles dynamically impact the numerous track structure components, thereby generating unwanted vibrations, which propagate through the ground and reach the foundations of the buildings close to the LRT line (*1*).

From the foundations, vibrations extend to all the structural components of the buildings, and may also create objectionable noise levels in the apartments where people live (*2*, *3*).

Typically, there are two types of vibrations: vertical vibrations and transverse vibrations.

TECHNICAL REGULATIONS IN FORCE

For vibration limits, one must respect Technical Rule UNI 9614 (Vibration measurement in buildings and annoyance evaluation) in Italy, which is substantially in compliance with other international rules (such as ISO 2631, DIN 4150/2, and BS 6472).

For damaging effects caused to the buildings by vibrations in Italy, one must respect Technical Rule UNI 9916 (criteria for the measurements of vibrations and the assessment of their effects on buildings), which is also substantially in compliance with international rules ISO 4866, DIN 4150/3, and BS 6472.

The vibration thresholds to limit the disturbance to people inside their homes are

- Daytime—10.0 mm/s^2 (80 dB) for vertical acceleration; 7.2 mm/s^2 (77 dB) for transverse acceleration; and
- Nighttime—7.0 mm/s^2 (77 dB) for vertical acceleration; 5.0 mm/s^2 (74 dB) for transverse acceleration.

FLOATING PLATFORM SYSTEM

The floating platform system is basically made up of several layers.

The technical drawing of the floating platform system is shown in Figure 1, where the several layers are shown:

1. Stabilized base, about 5 to 10 cm (2 to 4 in.) thick;
2. Reinforced concrete platform, about 20 cm (8 in.) thick;
3. Anti-vibration mat (neoprene), about 2.5 cm (1 in.) thick, installed below the precast concrete platform;
4. Precast concrete platform, about 600 cm (236 in.) long, 230 cm (90 in.) wide, and 25 cm (10 in.) thick;
5. Side/central precast concrete slabs, which are joined to the platform by means of bolts;
6. Block pavement or asphalt; and
7. Specifically mixed rubber sections inserted along the rails, whose main functions are to reduce transverse vibrations and to take into account slight movements of the track structure.

The rails are joined to the precast concrete platforms by means of elastic fasteners. Besides the vibration abatement, the main feature of this system is that the concrete platforms and the concrete slabs are precast, and then they are sent to the construction site where they are simply installed, dramatically reducing construction time. Maintenance operations on tracks are also made easier: in the case of rail substitution, basically all the operators need to do is loosen the nuts and bolts that keep the precast concrete slabs in their place, raise the slabs up by a crane, substitute the rails and then put everything back in its place.

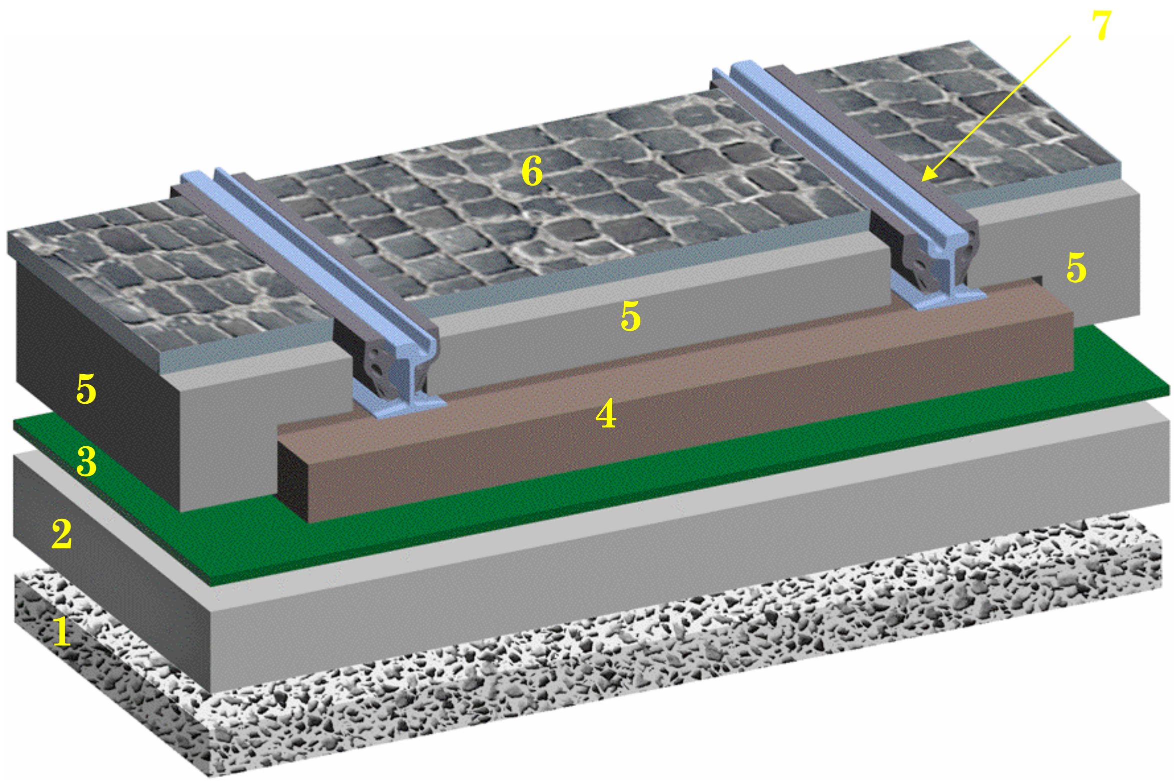


FIGURE 1 The floating platform system.

FLOATING MASS SYSTEM

The floating mass system is basically made up of several layers of concrete, precast concrete sleepers, and an anti-vibration mat (neoprene).

The main difference, with respect to the floating platform system, is that the floating mass system is not precast; instead, its construction coincides with the laying of the tracks.

The technical drawing of the floating mass system is shown in Figure 2, where the several layers are shown:

1. Stabilized base, about 5 to10 cm (2 to 4 in.) thick;
2. Reinforced concrete platform, about 20 to 25 cm (8 to 10 in.) thick;
3. Anti-vibration mat (neoprene), about 2.5 cm (1 in.) thick;
4. First layer of concrete, about 10 to 15 cm (4 to 6 in.) thick;
5. After the first layer of concrete is laid, concrete sleepers, about 27 cm (10.6 in.) long, 230 cm (90 in.) wide, and 16 cm (6.3 in.) thick, are put in place;
6. After laying, leveling, and alignment of the tracks a second layer of concrete is laid, about 16 cm (6.3 in.) thick, up to the top level of the concrete sleepers;
7. Specifically mixed rubber sections inserted along the rails, whose main functions are to reduce transverse vibrations and to take into account slight movements of the track structure; and
8. Finally, block pavement or asphalt is applied.

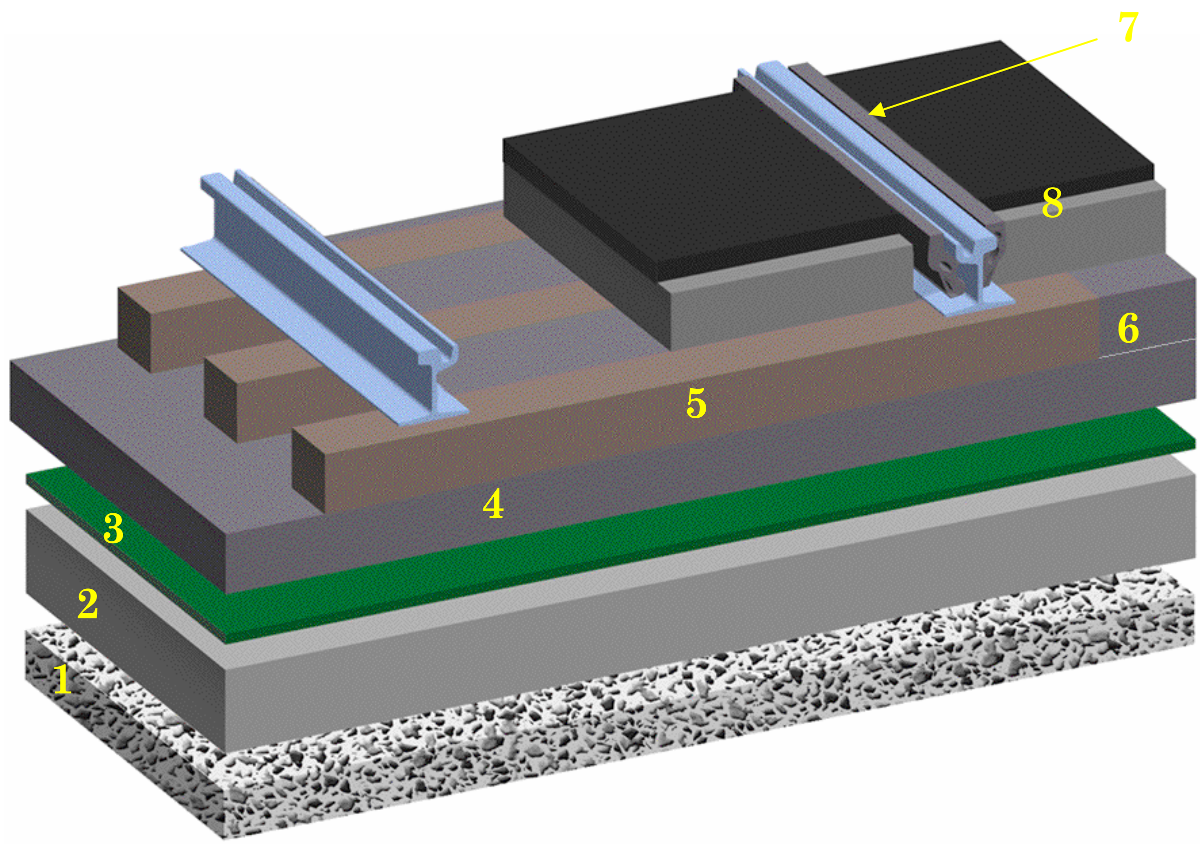


FIGURE 2 The floating mass system.

The noise and vibration abatement performances of the floating mass system are excellent. Also, a floating mass system is highly adaptable for curves and rail intersections. Unfortunately, construction time can be long and difficulties may arise when it comes to leveling and aligning the tracks.

SITE 1—VIALE REGINA MARGHERITA IN ROME

Viale Regina Margherita represents one of the major avenues radiating from downtown, and has been a tramway route since 1930.

From 1994 to 1995, large refurbishment works were carried out, with the substitution of the floating platform system for the traditional track structure system.

An aerial view of the site during the construction is shown in Figure 3, while the final result of the works is shown in Figure 4, with vehicles operating revenue service.

By means of accelerometers, vertical and transverse vibration levels were measured while the tramway vehicles were passing by, before and after the works. The measurement conditions were the same, before and after the works: same vehicles, same acceleration and velocity. Also, the "before works" rails did not show any particular signs of wear or roughness on the running surface.

The measurement points were all at ground level, at three different positions along the

FIGURE 3 Aerial view of the construction site (last phase) on Viale Regina Margherita.

FIGURE 4 The final result of the works with vehicles operating revenue service on Viale Regina Margherita.

line. At each position, three measurements were made, 7, 10, and 13 m (7.7, 11, and 14 yd) away from the tracks (nine measurement points in all). Since measurements were made before and after the works, a total of 18 measurements were taken. The building are 13 m (14 yd) away from the tracks, so the 13 m measurement gives a very good estimation of the vibration level inside the buildings.

The results of the measurement campaign are shown in Figure 5. In the Y-axis the level L_5 is shown, which is the level exceeded by the modulus of the vertical and transverse vibration for no more than 5% of the measuring time.

The results show excellent vibration reduction. The accelerometer closest to the buildings shows an average value for L_5 of 76.3 dB after works, versus 83.7 dB before works, which is approximately a 60% reduction.

SITE 2—PIAZZA VITTORIO EMANUELE IN ROME

Until last year, one of the most important open-air markets in Rome was situated in Piazza Vittorio Emanuele, a big square very close to Termini Station, the main railway station in Rome. Now, the market has moved and the square has gone back to its old look, a crowded place with a park in the middle.

The square underwent heavy reconstruction, which included substitution of the floating mass system for the traditional track structure system.

The site during the track substitution is shown in Figure 6 and Figure 7.

The before works and after works measurements have been taken at ground level, during tram traffic, at three different points along the tracks, 1.5 m (1.6 yd.) away from the tracks. Two accelerometers were used, one for vertical vibrations and another for transverse vibrations.

As for Site 1, the measurement conditions were the same, before and after the works (same vehicles, same acceleration and velocity), and the before-works rails did not show any particular signs of wear or roughness on the running surface.

The results of the measurement campaign are shown in Figure 8. In the Y-axis the average levels for vertical and transverse acceleration are shown, both before works and after works.

Also in this case, the results show excellent vibration reduction—about 12.5 dB for vertical acceleration and 14 dB for transverse acceleration, which is approximately a 75% to 80% reduction in both cases.

The average frequency spectra of the measured signals are shown in Figure 9. A constant decrease can be seen, throughout the whole spectrum. Moreover, a slight shift towards low frequencies is present, due to the increased mass of the track system.

CONCLUSIONS

Comparison of the floating mass system and the floating platform system is summarized in Table 1.

Both systems exhibit excellent vibration abatement, as the before works and after works measurements presented in the paper have shown.

In Table 1 information is given about the cost of the systems and the cost differential with respect to traditional track structures.

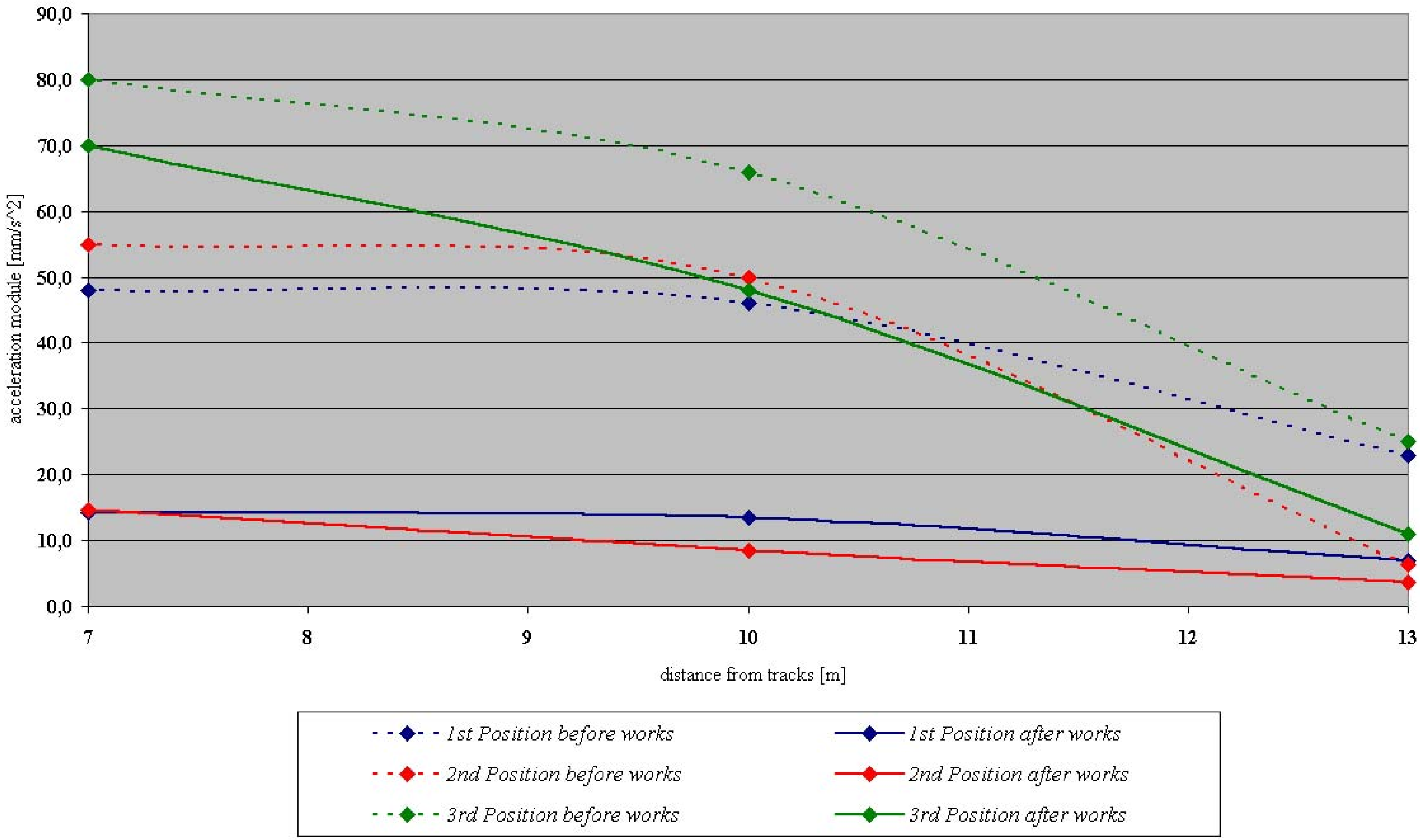


FIGURE 5 Vibration measurement results in Viale Regina Margherita.

FIGURE 6 Piazza Vittorio Emanuele under construction. On the left, the first layer of concrete has been laid. On the right, the second layer of concrete has been laid, up to the top level of the concrete sleepers.

FIGURE 7 Piazza Vittorio Emanuele under construction.

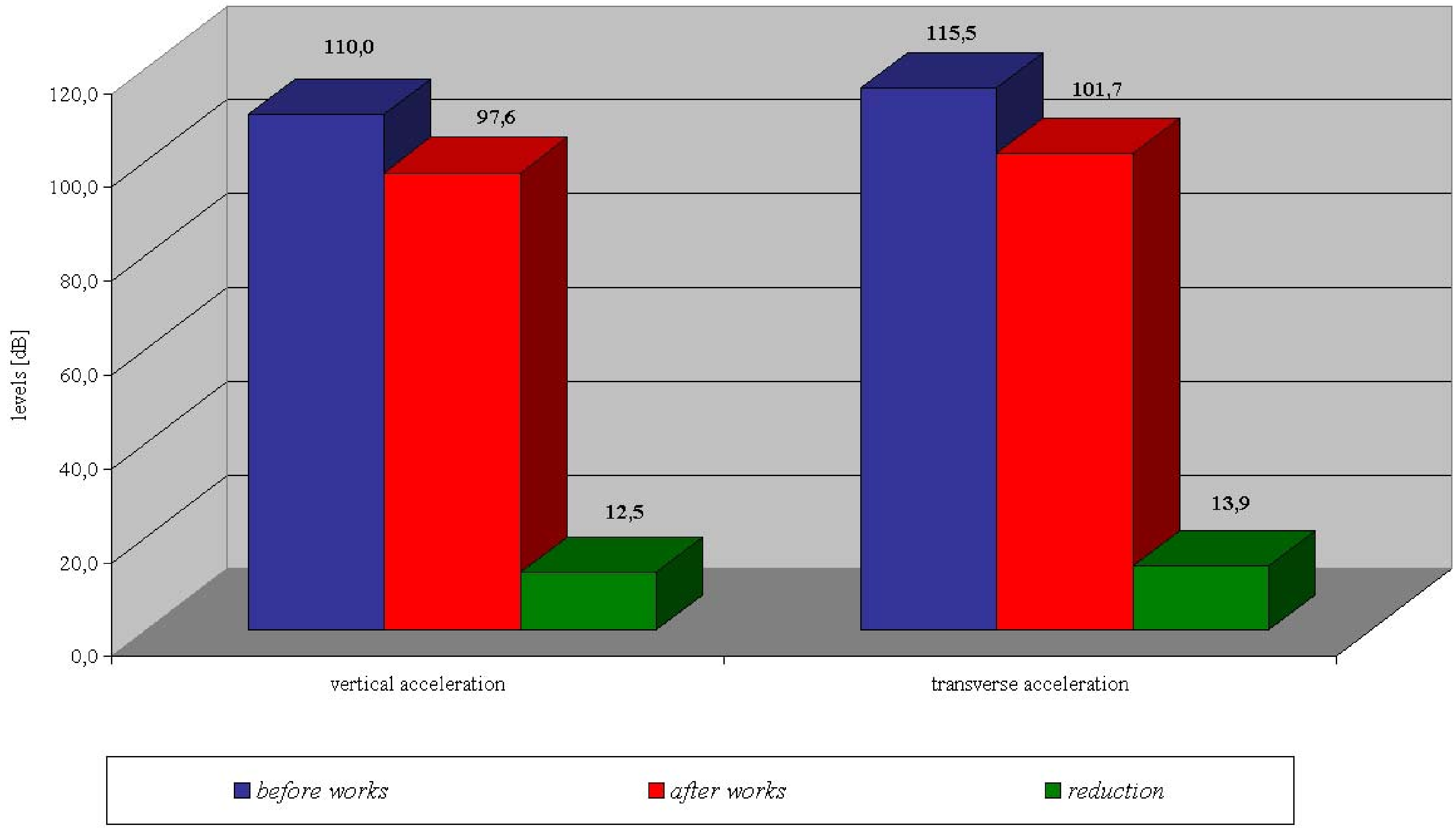


FIGURE 8 Vibration measurement results in Piazza Vittorio Emanuele.

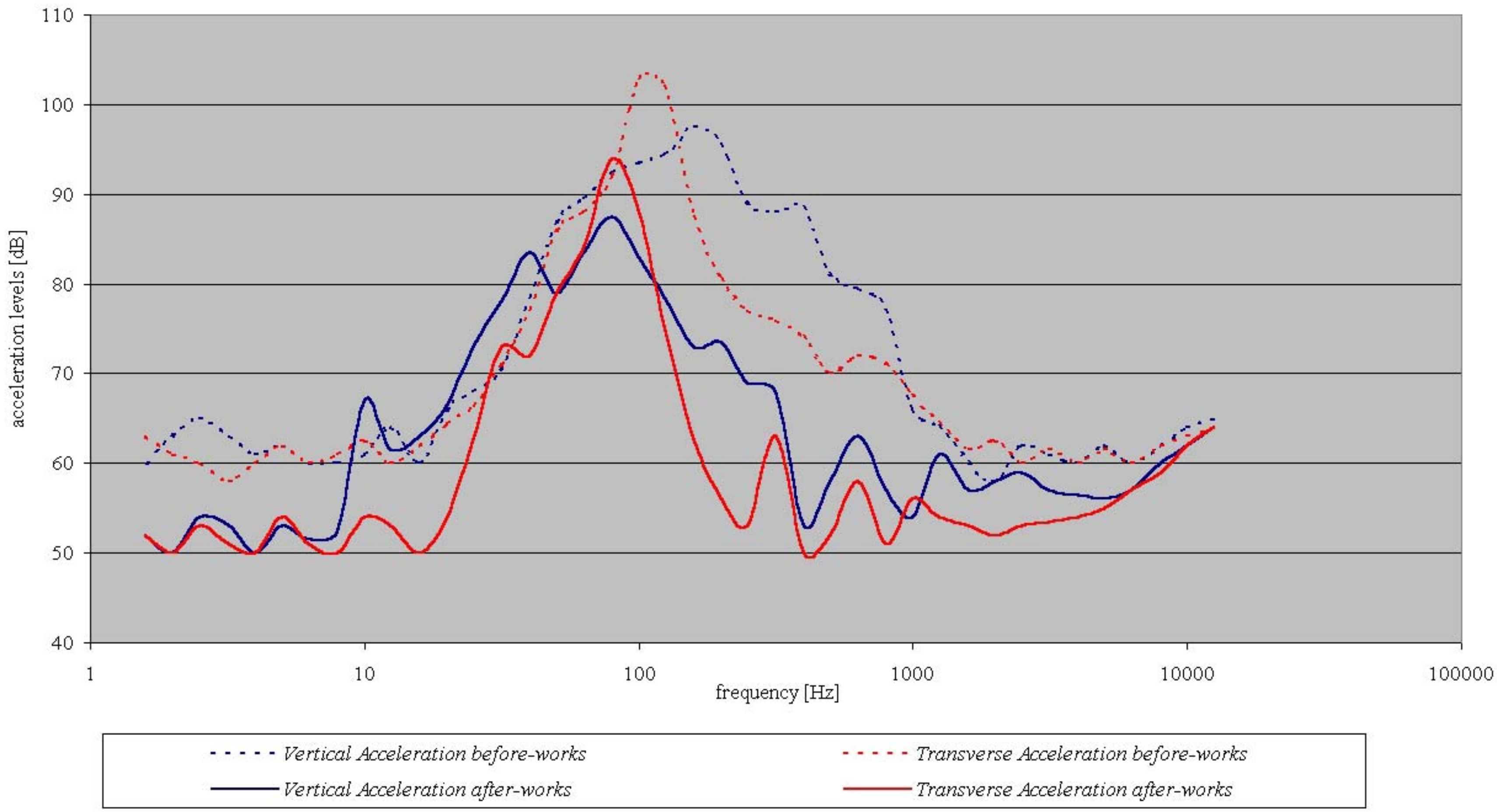
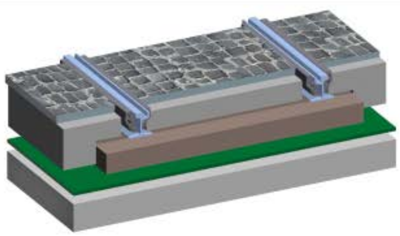
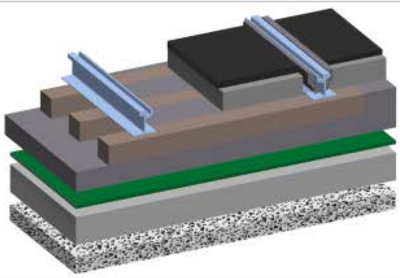


FIGURE 9 Vibration frequency analysis results in Piazza Vittorio Emanuele.

TABLE 1 Comparison Table

ANTIVIBRATION SYSTEMS	TYPICAL VIBRATION REDUCTION	COST (*)	COST RISE ON TRADITIONAL SYSTEM (**)
	dB	€x1000 per s.t.m.	%
FLOATING PLATFORM SYSTEM 	11	2,5	78
FLOATING MASS SYSTEM 	14	1,9	36

(*) s.t.m.: single track meter; (**) Traditional track structure cost: 1,4 €x1000 per s.t.m.

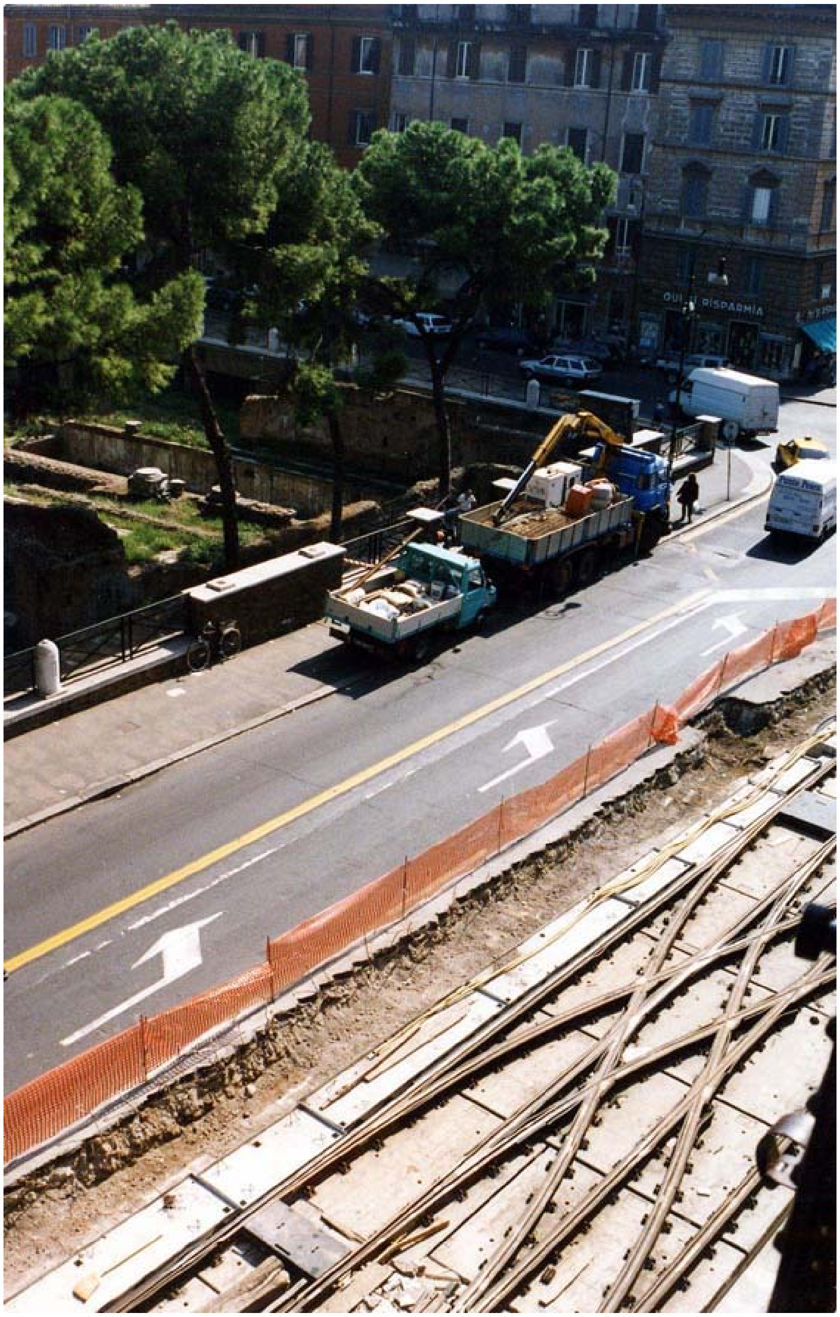


FIGURE 10 Piazza di Torre Argentina: tracks have been laid upon the precast concrete platform near Roman monuments dating back to the 3rd century B.C.

FIGURE 11 Side and central precast concrete slabs have been laid and joined to the precast concrete platform in Piazza di Torre Argentina.

Even if the cost differential is considerable, it should be borne in mind that usually vibration reducing track structures are needed just for relatively short sections of an LRT line, so the incremental cost may be acceptable.

The higher cost of the floating platform system is due to the precast concrete platforms and slabs, but this cost is compensated by shorter construction time and easier maintenance operations on tracks.

Tramway line number 8 is shown in Figure 10 and Figure 11, which is the most recent tramway line built in Rome (opened to revenue service in 1998, while actual construction ended in 2000). One of the terminals of the line is in Piazza di Torre Argentina, the heart of the historical center, where Roman monuments dating back to the 3rd century B.C. and historical buildings are located. There, a floating platform system was adopted, including an elegant block pavement on top of the track structure.

In March 2003, the preliminary phase of project design for the extension of line number 8 was concluded. Within the next 3 years, line number 8 will be extended to Termini Station, the main central railway station in Rome, crossing Piazza Venezia and Via Nazionale, doubtless among the most important places in the historical center.

Along the whole extension, about 1.6 km (1 mi) long, the floating platform system will be adopted, which will also minimize construction time.

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3. Transactions from the Symposium Traffico e Ambiente: Inquinamento chimico, acustico e da vibrazioni. Trento, February 21–25, 2000.

Embedded Track Design and Performance

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The industry is gravitating to concrete slabs for embedded track designs. Designs with concrete have proven economies in construction and long-term performance. Yet there are concerns, such as the following:

- Structural codes state that the codes do not apply to slabs on grade that are intended as the principal structural support.
- Agencies press for minimum slab thickness to minimize conflicts with existing utilities.
- Configurations to meet criteria for stray current control and ground vibration control may effect track integrity.
- Design factors for future utility trenching around embedded track are inherently uncertain, potentially governing a design, or, if ignored, jeopardizing long-term track performance.
- The effects of elastomers on the slab performance have little research.
- Embedded track is among the least maintenance friendly. Improvements in design analysis will allow confidence in new low maintenance concepts.

This paper provides embedded track analysis methodology and results that are the basis for engineering decisions on, and increased confidence in, long-term embedded track performance. The analysis method treats the rail and support slab as two continuous beams interacting through an intermediate pad, with the support slab on a continuous elastic foundation (soil). The method produces deflections, moments, and stresses independently for the rail and support slab, and pressures in the intermediate pad and supporting soil. This information allows long-term maintenance assessments (slab life, required soil load capacity, and pad criteria) of a design.

The methodology is explained and the results for the practical range of embedded track configurations are presented.

BACKGROUND

The purpose of this paper is to present analysis methodology and illustrative results for embedded track, and to identify criteria or guidelines useful for assessing the integrity of an embedded track design.

A central interest is in assessing performance differences between different embedded track arrangements including those with and without elastomeric elements between rail and slab.

The development of the analysis methodology established the following goals for the modeling:

- To reflect the individual behavior of the rail and the slab,
- To incorporate methods for realistic slab support (foundation modulus for the soils),

- To assess performance under service (fatigue, life expectancy), and
- To allow single axle or multiple axle loading and thermal rail loading.

The model uses Beam-On-Elastic-Foundation (BOEF) theory.
This report treats the material in the following order:

- Track configurations and conditions
- Description of methodology
- Illustration of methodology results
- Summary

TRACK CONFIGURATIONS AND CONDITIONS

The general embedded track configurations are

1. Rail fully embedded in concrete (Figure 1), and
2. Rail embedded in a non-structural material supported by structural concrete slab (Figure 2).

These basic configurations can be used to model any practical embedded track form (i.e., configurations) using one of these basic configurations, including track continuously in-street, grade crossings, or track at-grade (above ground slabs).

The analysis is specifically for track that contains concrete (other than concrete ties) as a structural support or as a fill material between the rails. Any other embedded track (e.g., ballasted track with asphalt in-fill) is designed simply using conventional ballasted track engineering, and is outside this discussion.

Configuration 1: Rail Fully Embedded

The first configuration, rail fully embedded, is the case where there is a base concrete slab and concrete fill to the top of rail (Figure 1).

This configuration includes construction that is poured as a monolith (single pour from base of slab to top of rail), or sequential pours (base slab poured first, followed by one or more top pours). Also included within this configuration are trough track (troughs for rail are cast in, with rail, fasteners and trough infill material placed after the trough is complete), any form of direct fixation track where concrete is the infill material between limits of the fasteners (or covering the fasteners and rail, except rail head). Some slab designers prefer reinforcement bar within or into the rail infill concrete, particularly if there are multiple pours; such additions of rebar are consistent with the assumptions in the analysis, but have no effect on analysis results.

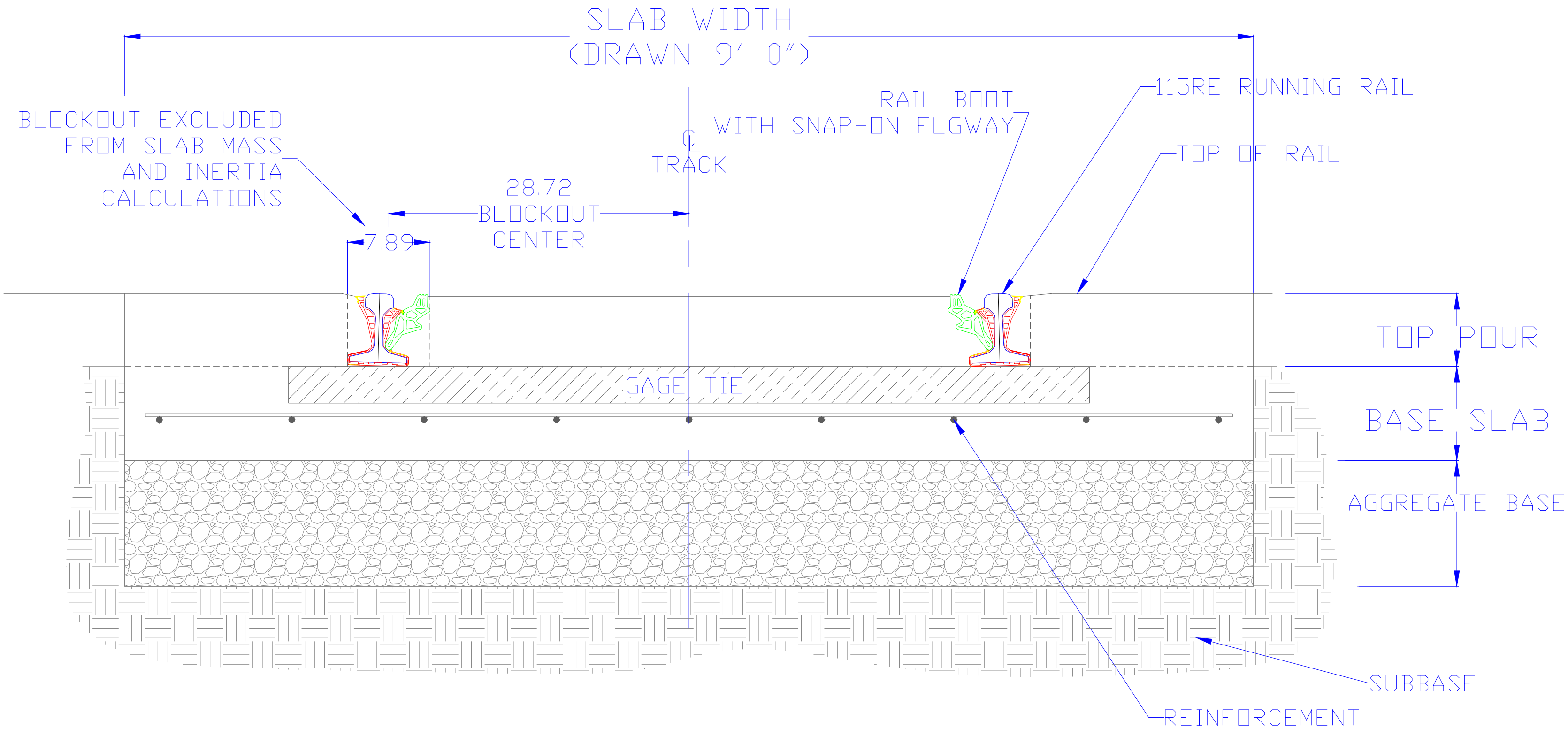

FIGURE 1 Configuration 1: Rail fully embedded in concrete (illustrated with Rail Boot).

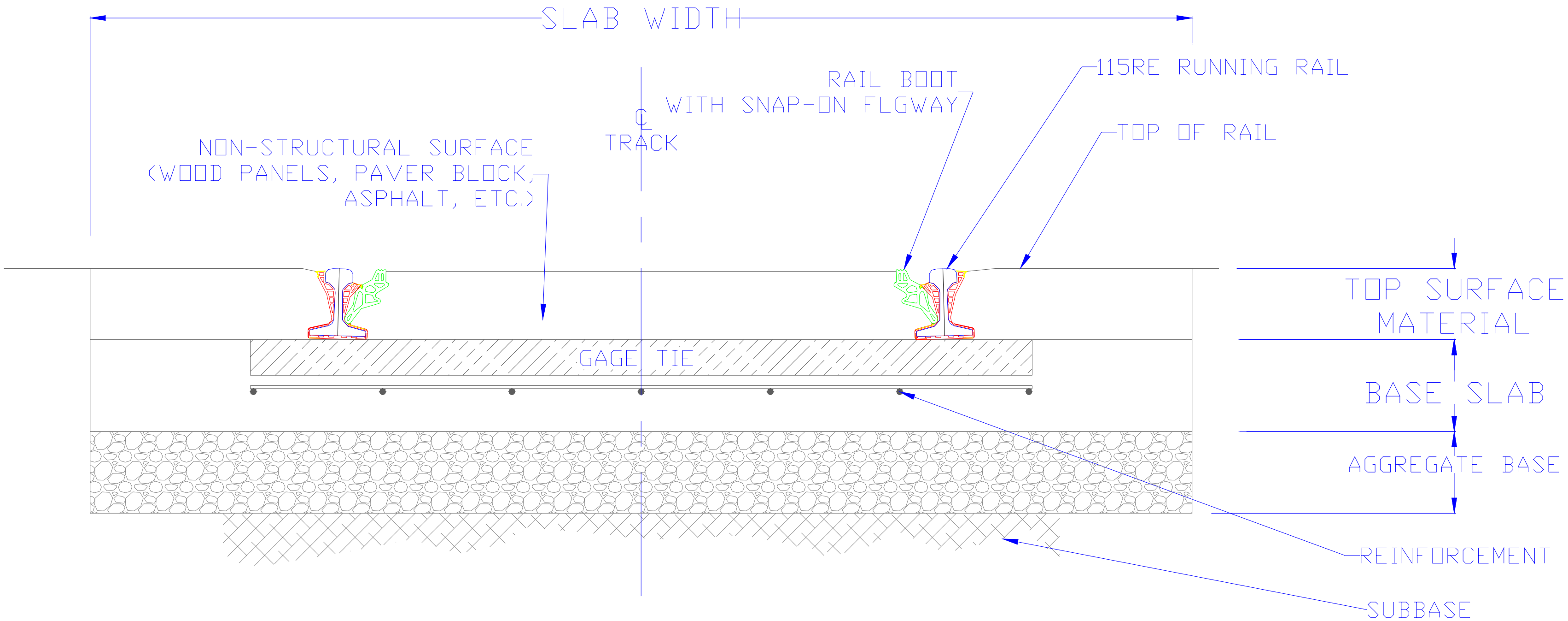

FIGURE 2 Configuration 2: Rail embedded in a non-structural material supported by concrete slab (illustrated with Rail Boot).

Configuration 2: Rail on Concrete Slab

The second general configuration is that of a concrete slab supporting the rail, with or without non-structural infill or top pour material (Figure 2).

With this configuration, infill material between rails is considered non-structural, meaning that it has no consequence in supporting rail loads other than adding dead weight to the structural supporting slab. This configuration includes any material as the "top pour" (from top of support slab to top of rail), such as asphalt paving, paver blocks, lightweight concrete, or paneling of any type. Any rail fastener arrangement is acceptable.

BEAM-ON-ELASTIC-FOUNDATION ANALYSIS PROCEDURES

Analysis Method and Idealizations

The methodology implemented in this paper is the BOEF theory generally used to analyze track, except this method allows two beams (the rail and slab) where the traditional analysis allows only one beam (the rail). This method, developed by Hetényi (*1*), allows assessment of the rail and slab interaction through a continuous series of springs between the rail and slab.

These intermediate springs represent rail pads, rail fasteners, or any membrane (such as Rail Boot) that have measurable stiffness (spring constants). The model can be used to represent any intermediate material, as well as the case with no intermediate material (a very stiff spring). An elastic material (the soil or aggregate) supports the slab in the model. These idealizations, illustrated in Figures 3 and 4, can represent any continuous track, including floating slab track as well as embedded track.

This analysis is linear, which means that this analysis allows cumulative addition of individual effects, such as two adjacent axles on a truck where the effects of each axle are superimposed.

The model considers wheel loads as "point" loads, and loads from rail thermal expansion and contraction are "distributed" loads, placing a load continuously along the length of the slab. The effects of distributed loads can be superimposed on the wheel load results in this model implementation.

Parameters in Analysis

The model includes a fairly complete set of influence parameters including vehicle parameters, train operation (braking, speed, traffic density), soil characteristics, track geometry (horizontal and vertical curves), environmental (thermal), structural parameters (slab geometry, concrete material design properties, reinforcement type, and configurations), rail properties, and elastomer properties for the rail support.

Slab Structural Analysis Method

The structural analysis procedures applied to model results are in accordance with applicable American Concrete Institute Code (*2*).

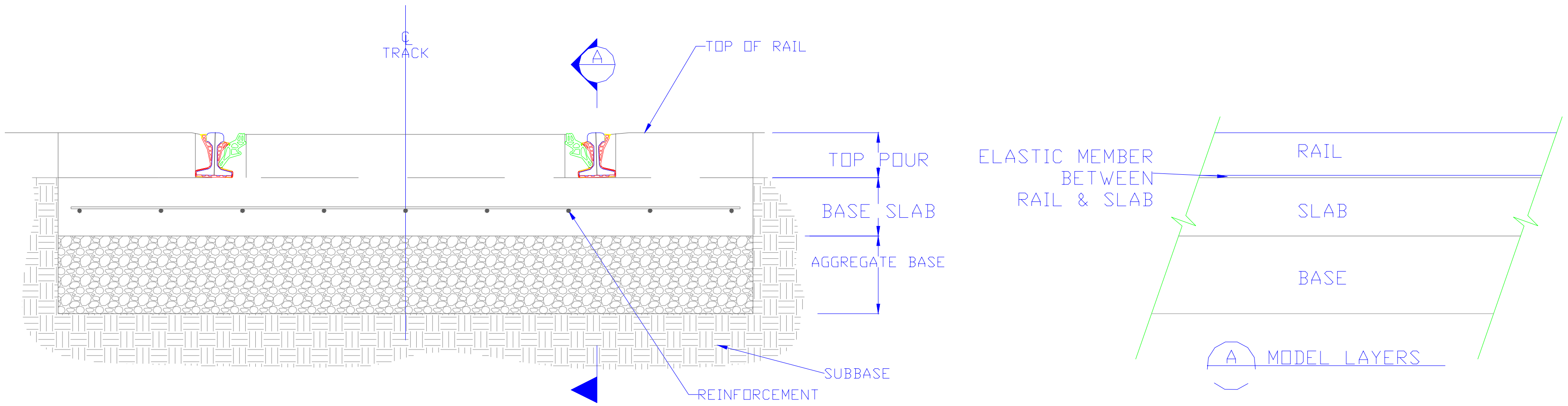

FIGURE 3 Track section and associated model elements.

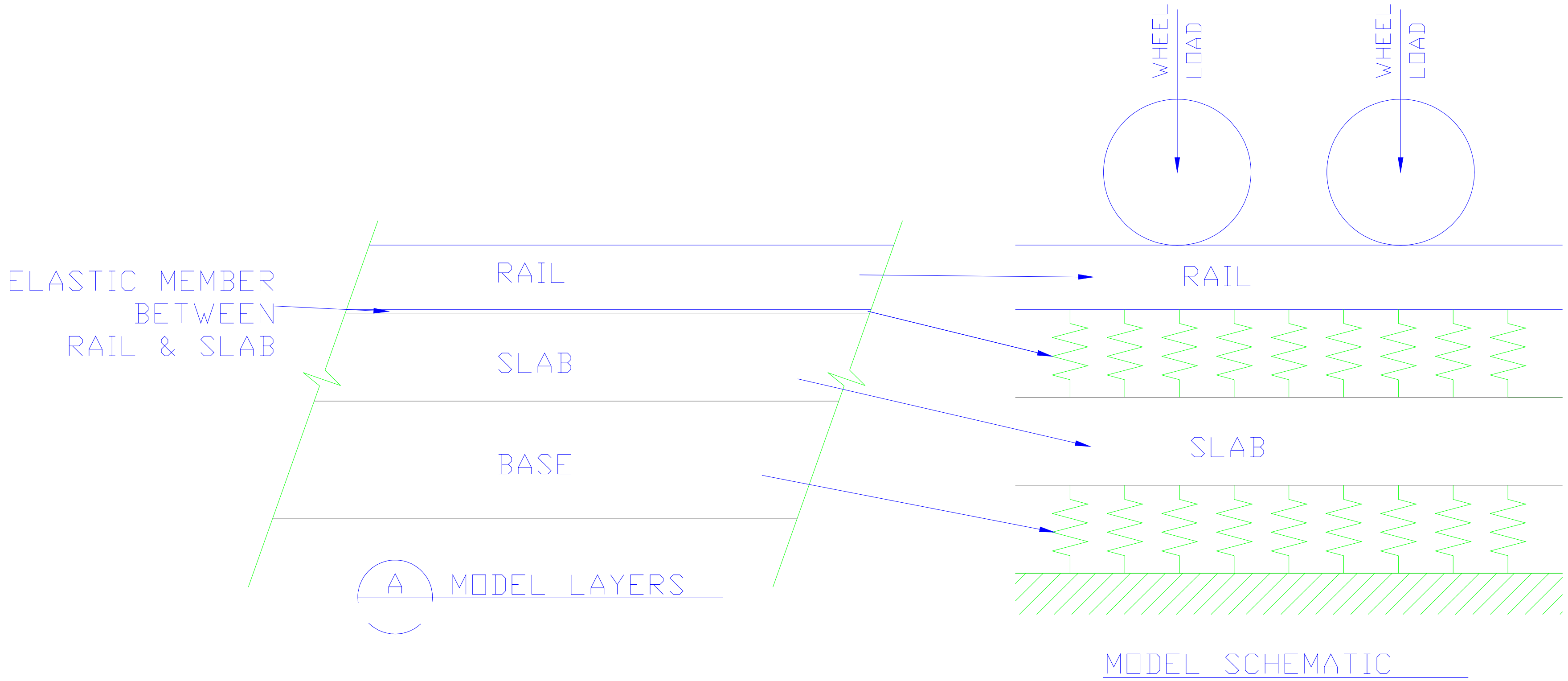

FIGURE 4 Idealizations for modeling.

Fatigue Calculations

Fatigue is calculated as slab life in years of service. Fatigue is calculated at the design load, the nominal wheel load multiplied by a design factor (typically 2). Fatigue for slabs under special trackwork (frogs, switches, and rail crossings) uses the full design load. This reflects a notion that loads are generally higher as wheels cross frog flangeways and flangeways in rail crossings.

Outside special trackwork, the track slabs will endure infrequent loadings at the full design load. The procedure incorporates a "load distribution factor," a percentage of the design load, that may be used for fatigue analysis of normal embedded track.

Fatigue is calculated by methods developed by the Portland Cement Association (*3*).

Base Support Stiffness

The support stiffness of the base soils, gravel, or other material directly under the slab is critical in embedded track analysis.

The considerable literature on soils and foundations lacks data in terms required by embedded track analysis. The design guideline (ACI 360, Design of Slabs on Grade) requires field measurements to obtain the required modulus, not entirely useful for preliminary assessments, or for parametric studies of embedded track configurations. This requirement can hinder new track design processes unnecessarily because the track configuration is central to the design development of all other facilities associated with a railroad or transit. In reality, the urban environment provides new embedded track with engineered base materials (streets, previous rail routes) and ample past borings nearby to provide information suitable for track design.

A preferred available approach is to estimate support modulus for the assumed base materials, generate track designs compatible with all criteria, then confirm the track design when geotechnical data is eventually produced. Assuming base materials and their properties has little risk not only because the urban base material is well known, but also because there is reliable consistency in properties that effect embedded track design in existing urban environments.

In the cases where embedded track may be placed other than in existing infrastructure, it is then, by definition, virgin development that necessitates knowing the requirements for the embedded track base in advance of all other project parameters. The required base will then be engineered to meet track base requirements.

The available method for calculating a reasonable support modulus for a variety of circumstances is provided by Richart et al. (*4*) using straightforward selection of the soil type and the geometry of the slab and base course. The method's authors developed a series of curves from tests relating soil shear modulus, soil void ratios, shear wave velocity, soil grain type, slab dimensions, and base course thickness to spring rates (foundation modulus). The method allows consideration of confining pressure (the pressure from adjacent soils on the base material when it deforms under load), important in embedded track applications. The method provides results for vertical spring rates, horizontal spring rates, and rocking spring rates (the stiffness against slab twist about its longitudinal axis).

The Richart et al. data and methodology are implemented in this analysis for base support stiffness.

Results Available from Analysis

The results of the BOEF analysis are estimates of the rail and, separately, the slab deflections, moments, and shear force. The results also include pressures between rail, rail support (elastomer, Rail Boot, rail pad, Direct Fixation fastener), slab, and slab support (gravel or soil base).

The analysis uses these fundamental results to calculate rail and slab stresses and strains, which in turn are used for fatigue life estimates.

The analysis also provides other useful values such as slab safety factors and allowable stresses, and estimates of rail and slab natural frequencies, as design or evaluation aides.

The analysis provides structural results for reinforced slabs and non-reinforced slabs, and calculates slab reinforcement for crack control.

BOEF Analysis Results

This section presents results from the BOEF analysis.

These results illustrate trends in slab reactions (deflections, moments, and stress) and performance (fatigue life). This demonstration explores these results for the following parameter ranges:

- Slab configurations: full slab (Configuration 1) and base slab (Configuration 2)
- Rail support stiffness (elastic property of the rail pad, Rail Boot, or Direct Fixation fastener): 100,000 lb/in. to 3,000,000 lb/in.
- Slab thickness below the rail: 6 in. to 20 in.

For perspective, Rail Boot static stiffness is about 400,000 lb/in., Direct Fixation fasteners typically have a stiffness between 100,000 and 200,000 lb/in., and rail pads generally have stiffness values between 750,000 and 3,000,000 lb/in.

All other parameters in the model are held constant (see Table 1) to allow a direct comparison of results, although a number of parameters such as soils, temperature variants, curvature, and so on would be adjusted in practice for particular circumstances.

The loading and vehicle parameters are typical of a high-floor North American light rail vehicle (LRV). The trends in these results are also indicative of that expected for heavy rail vehicle loading, because the heavy rail vehicle weights and capacities are within 20% of those for LRVs, and heavy rail higher speeds are insufficiently different to effect these types of analysis.

All results are from calculations of both single axle and double axle loads, where the higher value from either is used when appropriate for each parameter explored. Double axle loads are those from two adjacent wheels representing a single truck.

Track Modulus and Support Stiffness

This is a brief aside to clarify the physical meaning of track modulus and support stiffness, and how those apply in this analysis. A support stiffness and its associated foundation modulus are directly related but different.

TABLE 1 Parameters and Values Held Constant

Parameter	Assumed Value
Wheel Load	17,000 lb
Load Factor (design safety factor)	2
Curve	200 ft radius
Track Superelevation	2 in.
Design Wheel Load (includes load factor, curve forces, etc.)	36,302 lb
Vertical Load Reduction Factor (for normal track fatigue analysis)	95% of Design Wheel Load
Rail	115 RE
Track Gage	56.5 in.
Train Speed	25 mph
Vehicle Axle Spacing	72 in.
Axles per Truck	2
Maximum Vehicle Brake Rate	3 mphps
Annual Traffic Volume	355,300 Axle loads per year
Slab Concrete Strength	4,000 psi
Slab Reinforcement	2 layers of #6 rebar at 12 in. spacing
Base Course (slab support material)	12 in. thick gravel

The physical measure of an elastomeric material is its stiffness, a simple spring rate obtained from a measured load deflection curve. The modeling uses a related, but different value called the foundation modulus to represent the idealized series of springs.

Also, where traditional BOEF calculations have a single track modulus, this analysis has two, which are more correctly called the rail foundation modulus (between the rail and slab) and slab foundation modulus (the material supporting the slab).

In this paper, the term support stiffness refers to spring rate unless specifically qualified.

Slab Life Expectancy

Life expectancy is the most useful indicator of embedded track slab performance because it intuitively provides a sense of track degradation processes that escape clear definition in other terms.

The life estimates are those earlier referenced portland cement concrete methods that depict concrete (as well as other roadway materials) cracking, and loss of useful structural integrity. The life estimates presented here are the predicted life to slab replacement. The life estimates apply equally to reinforced and non-reinforced concrete.

Normal, Non-Special Trackwork, Track on Base Slab (Configuration 2) Life expectancy is presented first in Figure 5 for the most common embedded track configuration: normal track (any track outside special trackwork) installed on a base slab. This is Configuration 2 (see the section on Track Configurations and Conditions). Recalling the description of Configuration 2, the material surrounding and between the rails is not considered as contributing to the structural support, consisting of asphalt, paver blocks or road crossing panels. In this configuration, the rail is supported by a rail pad, a Direct Fixation fastener, or is surrounded by the Rail Boot.

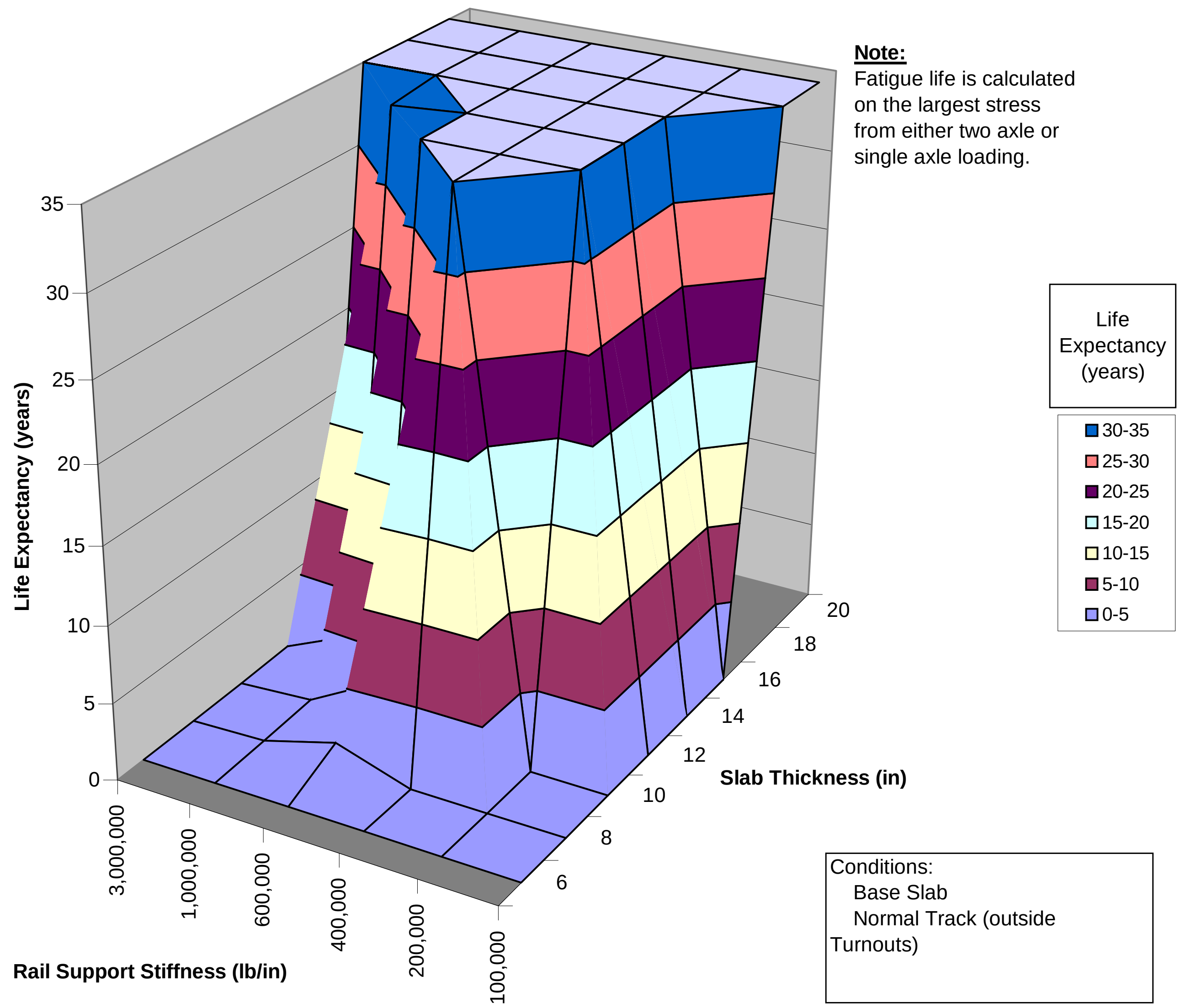

FIGURE 5 Life expectancy for normal embedded track on a base slab, only (Configuration 2).

Figure 5 assumes all wheels will produce a load that is 95% of the design wheel load. The idea is that actual wheel load populations will be lower than the design wheel load, with only incidental occurrences near the design wheel load from derailments or severely flat wheels. The 5% reduction in wheel load is very conservative, where the actual population of fatigue loads would be expected to distribute the static vehicle load (wheel load is 17,000 lb in this case, or less than half the design wheel load).

This reduced loading is applied to the fatigue calculation only. The structural calculations use the full design wheel load.

This and following charts are truncated at 35-year life expectancy, representing infinite slab life for practical purposes.

Figure 5 shows that life expectancy increases with the base slab thickness in normal (non-special trackwork) track.

Insights from Figure 5 include

- Rail Support Stiffness between 200,000 lb/in. and 600,000 lb/in. improves life expectancy for slabs less than 16 in. thick, compared to softer or harder rail support stiffnesses.
- Embedded track with rail support stiffness of 1,000,000 lb/in. or greater require a minimum base slab thickness of 14 in. to have any life expectancy, and 16 in. thickness to achieve reasonable life expectancy.

Special Trackwork on Base Slab (Configuration 2) The next example in Figure 6 is for special trackwork loading on a base slab (Configuration 2). The only difference between Figures 5 and 6 is that Figure 6 assumes all wheel loads are at the design wheel load, whereas Figure 5 assumes the wheel loads are 95% of the design wheel load. This assumption reflects a belief that special trackwork will eventually, if not initially, produce increased loads on the embedded track, and the increased loads will approximate a full impact load (double the static load).

Figure 6 shows that

- Thicker slabs are required under special trackwork for equal life expectancy of normal track with the same loading.
- The minimum base slab thickness under special trackwork should be 16 in. to achieve reasonable life expectancy.
- Rail support stiffness has little influence on life expectancy for turnout loads.

Normal, Non-Special Trackwork, Track, Full Slab (Configuration 1) The increased strength of a full slab is beneficial to life expectancy, as would be expected, with all but the thinnest slabs (6 in.) having infinite life for all rail support stiffness values.

Special Trackwork, Full Slab (Configuration 1) Analysis results for special trackwork assumptions (full impact load) with a full slab indicate that the minimum slab thickness under the rail for a full slab should be at least 12 in. where the base slab requires a minimum of 16 in.

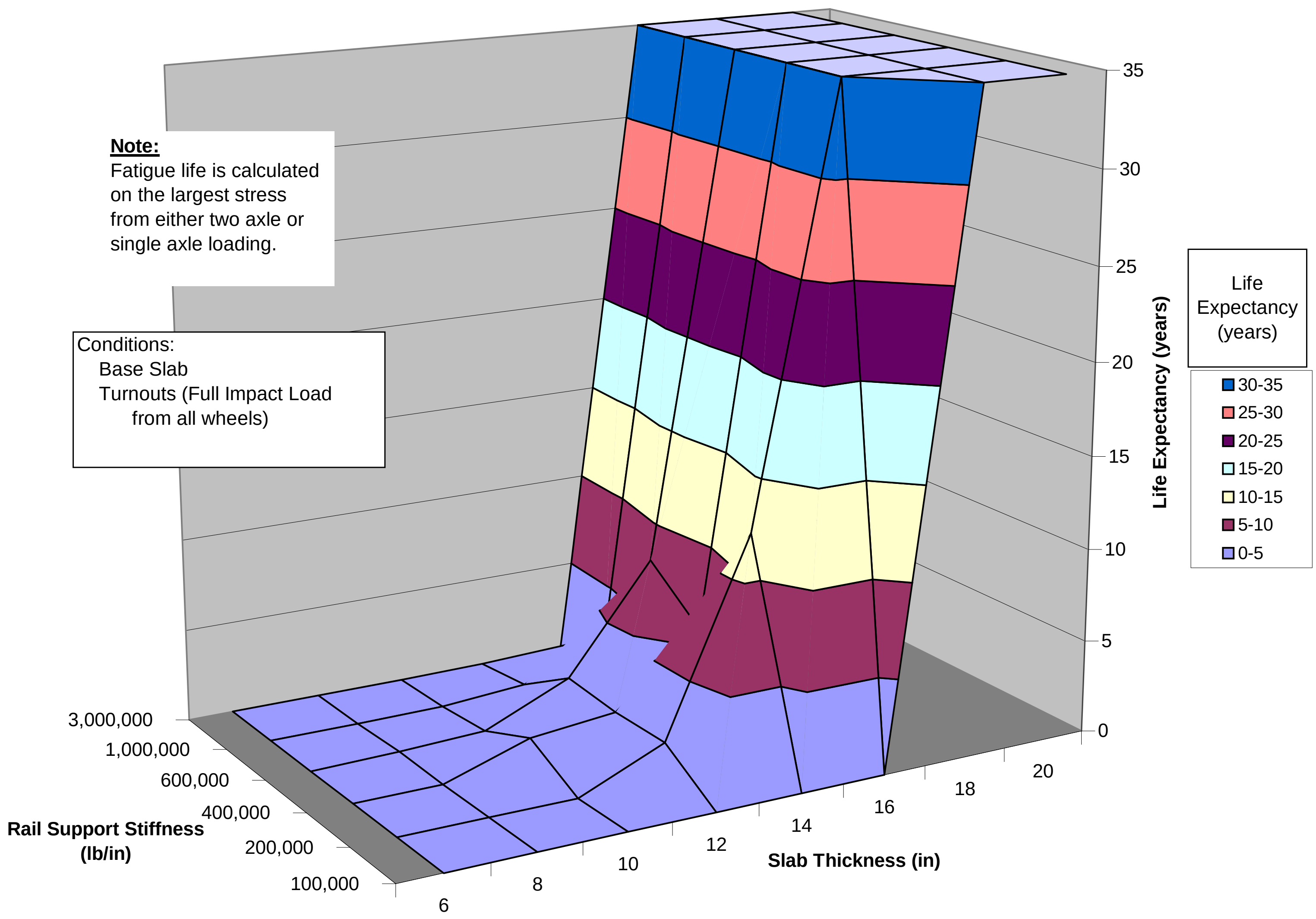

FIGURE 6 Life expectancy for special trackwork on a base slab, only (Configuration 2).

Fatigue Life and Slab Structural Design

The fatigue analysis applies equally to reinforced and non-reinforced slabs, and is not influenced by structural details of reinforcement.

The fatigue calculation and slab design calculations both use the slab maximum stress from the BOEF analysis. This means that the analysis selects the maximum bending moment (from which stress is calculated) from single-axle loading or two-axle loading, whichever produces the higher stress.

The fatigue life and the slab structural design are based on the same basic parameters, bending moment and stress, but are calculated independently. This approach identifies those designs that meet required criteria (safety factors, etc.) but have an undesirable life expectancy. In the foregoing fatigue life presentation, the configurations that have unsatisfactory life expectancies meet required criteria.

The separate calculation of fatigue life and structural safety factor allow the possibility that an increased structural safety factor may not result in a commensurate extension in fatigue life.

Deflections, Moments, Shear Force, and Pressures

This section discusses response to loading.

The analysis shows cases where the peak or maximum rail deflections from two axles are less than from one axle, even though two axles obviously have twice the load. The second axle cancels a portion of the rail and slab bending, thereby reducing the deflections produced by a single axle. The stress in the slab is similarly reduced. This effect can be significant, depending on parameter values, with a 10% to 15% decrease in two-axle deflections and stress from that of a single axle.

This effect is more pronounced as the rail support stiffness is reduced below 1,000,000 lb/in. In other words, as the rail support becomes softer, beneficial stress reduction from two axles is greater compared to single axle deflections. As the rail support stiffness increases above 1,000,000 lb/in., the two-axle response (rail deflections, slab stress) is greater than the single-axle response because the increased rigidity defeats rail bending over the interval between axles.

These findings raise the point that the design of slab tracks must consider both single-axle and multiple-axle loading.

Although infrequent, derailments most likely will commence as a single-axle event. More frequent, wheels traversing frog points and rail crossings approach the single-axle load condition. These conditions will govern the design in many cases.

However, multiple-axle loading may govern the design where, for example, the rail support stiffness is high.

Importantly, the designer should analyze both the single axle and multiple axle cases because the specific configurations and choices of parameter values may end with either case producing the larger response, which then becomes the governing case for design.

Pressures: Rail Support

One of the unique results of this modeling method is the ability to calculate the pressure of the rail on its support (rail pad, Rail Boot, etc.), of the rail support material on the slab, and of the slab on the material under the slab.

This information is very useful in the design of elastomers for the rail support and design of the subbase layer under the slab, usually an engineered selection of gravel base course and select soils.

Figure 7 shows pressures by the rail on the rail support (rail pad, Rail Boot, etc.) for a base slab, with two axle loading.

The pressure by the rail is negative for the stiffer rail supports. The negative values mean that the slab is deflecting more than the rail. The negative values mean the rail and slab are placing the rail support material in tension.

The magnitude of these negative pressures can exceed 900 psi at the stiffest (3,000,000 lb/in.) rail support. Under this condition, any fastener holding the rail to the slab will incur significant loading because these pressures are continuous along the rail and any fasteners are necessarily discrete devices that must accommodate the fully developed pressure each side of its location. For example, the load on a pair of anchor bolts (holding the rail to the slab) is over 25,000 lb, or 12,500 lb per anchor bolt, and where anchor bolt pairs are spaced at 24 in. Slab anchor inserts typically are designed for a maximum 12,000 lb pull-out load. While typical anchor bolt configurations could be altered, it is better to use a softer rail support to avoid this condition.

Pressures: Slab Support

Slab pressures on the slab support material (gravel, soils, etc.) range from 5 to 10 psi (Figure 8), acceptable for most soil conditions. It should be kept in mind that embedded track is used most often in urban streets where there are numerous underground utilities. Utility activity over the life of the slab can include trenching beside and burrowing under the slab. This activity can cause uneven slab support if not properly back-filled. The slab must therefore have reserve structural capacity for bridging unknown future support conditions.

Slab Natural Frequency

While not a dynamic model, the information in the model allows calculation of undamped natural slab frequencies, useful for understanding qualitatively at least the relationship ground vibration created from train vibrations. The slab structure will filter train vibrations greater than the slab's natural frequency, will amplify any vibrations near the slab's natural frequency, and will transmit all train-induced energy that occurs below the slab's natural frequency.

For a 9 ft wide slab, a full depth slab (Configuration 1) will have a natural frequency between 13 and 17 Hz, with little variation among slab thickness values. Base slab (Configuration 2) natural frequency varies from 30 Hz for 8 in. thick slabs to 17 Hz for 20 in. thick slabs.

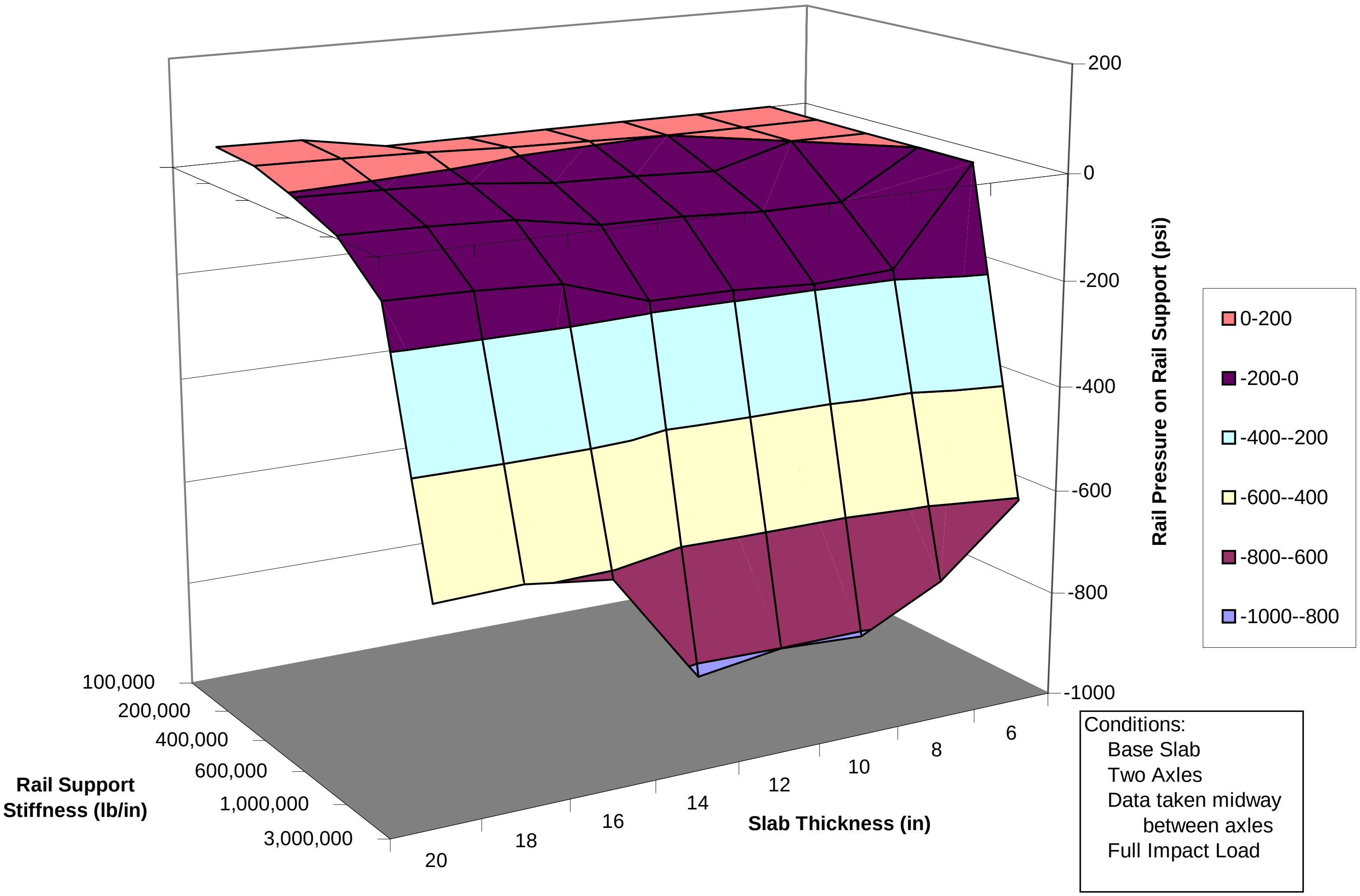

FIGURE 7 Rail pressure on rail support, base slab.

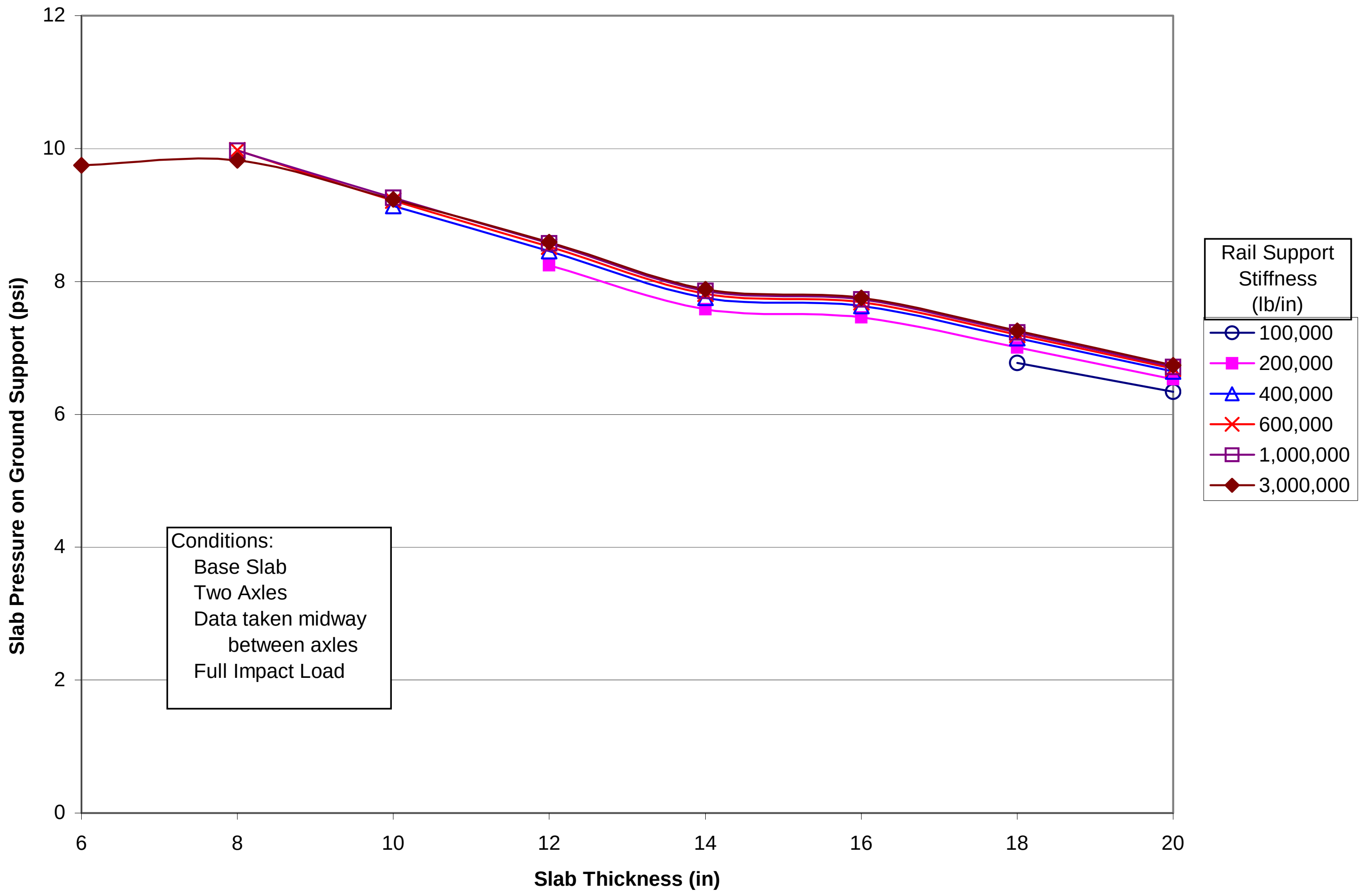

FIGURE 8 Full slab pressure on its support (gravel layer, prepared soil base).

Additional Notes on the Analysis

This subsection explains how the model treats the rail support elasticity.

In the foregoing presentation, we observed circumstances that had the rail deflecting less than the slab, meaning that the slab and rail were separating. We would have expected the rail and slab to move together, and, if anything, the rail deflect a little more into its support elastomer than the slab because the rail has more of the direct load and is a much more slender beam than the slab. This expectation is realized when rail support stiffness is 600,000 lb/in. or less.

When the elastomer stiffness approaches or exceeds 1,000,000 lb/in., the rail modulus becomes much greater than the slab support modulus, creating the circumstance for slab to deflect more than the rail.

In the latter circumstance, the rail is of course fastened to the slab or constrained by embedment concrete, thus the rail will deflect with the slab. However, this circumstance induces tensile load in rail fasteners or shear forces in constrain concrete that could cause degradation or failure.

Evidence that the rail support is too stiff would be sprung elastic rail clips, loose anchor bolts (either pulled out from concrete or loss of bolt torque), or concrete cracks (where rail is fully embedded in concrete) parallel to and within about 7 in. of the rail.

Effects of Rail Thermal Loading on Embedded Track

The analysis includes estimates of loads produced by thermal contraction and expansion of the rail.

In horizontal or vertical curves, Continuously Welded Rail thermal effects create radial loads on the rail support. The force in horizontal curves is determined by rail temperature difference from the rail neutral temperature and the curve radius. In vertical curves, the force is determined by the rail temperature difference, the change of grade through the curve and the length of the vertical curve.

This force is inversely proportional to the curve radius (i.e., the smaller the radius, the higher the force). The rail size has a lesser effect.

This force is a distributed force, meaning that the force is uniform along the length of a curve and is stated in pounds per unit rail length. Figure 9 shows thermally induced rail loads on vertical curves for the practical range of grade changes and curve lengths.

For even the most severe grade change and shortest curve length, the distributed loads are fairly low (under 140 lb/rail foot) compared to vehicle loads, assuming a 90^{o}F rail temperature difference from the rail's neutral temperature.

Figure 10 shows the lateral rail force in horizontal curves for the practical range of curvatures and temperature differences. The horizontal loads on slabs from rail thermal effects can become significant for curves with a radius of 200 ft and less. A track assessment would consider whether this effect along with other circumstances present (wheel loads, rail pre-curving) is within the rail restraint capacity.

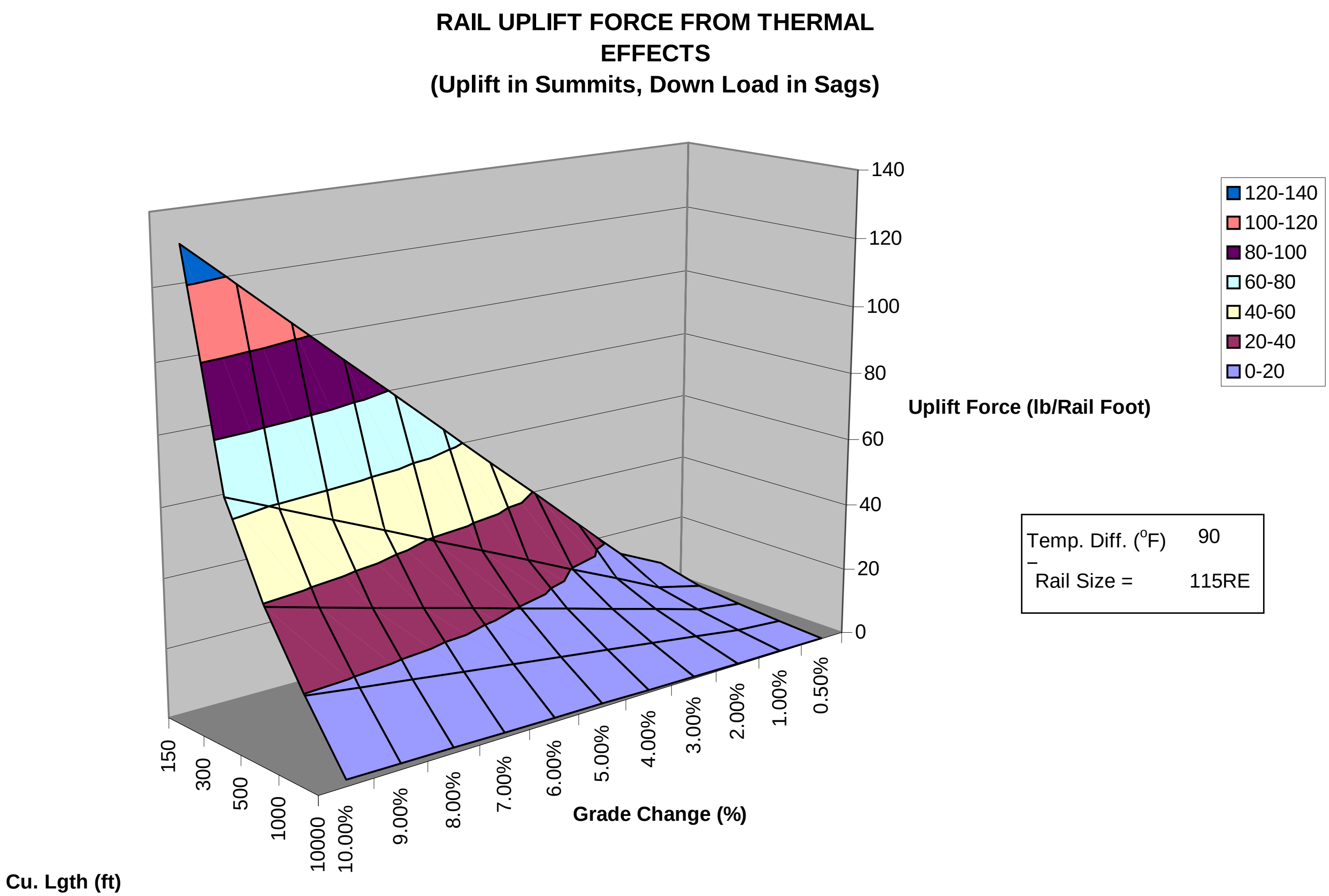

FIGURE 9 Vertical rail force on slabs in vertical curves from thermal effects.

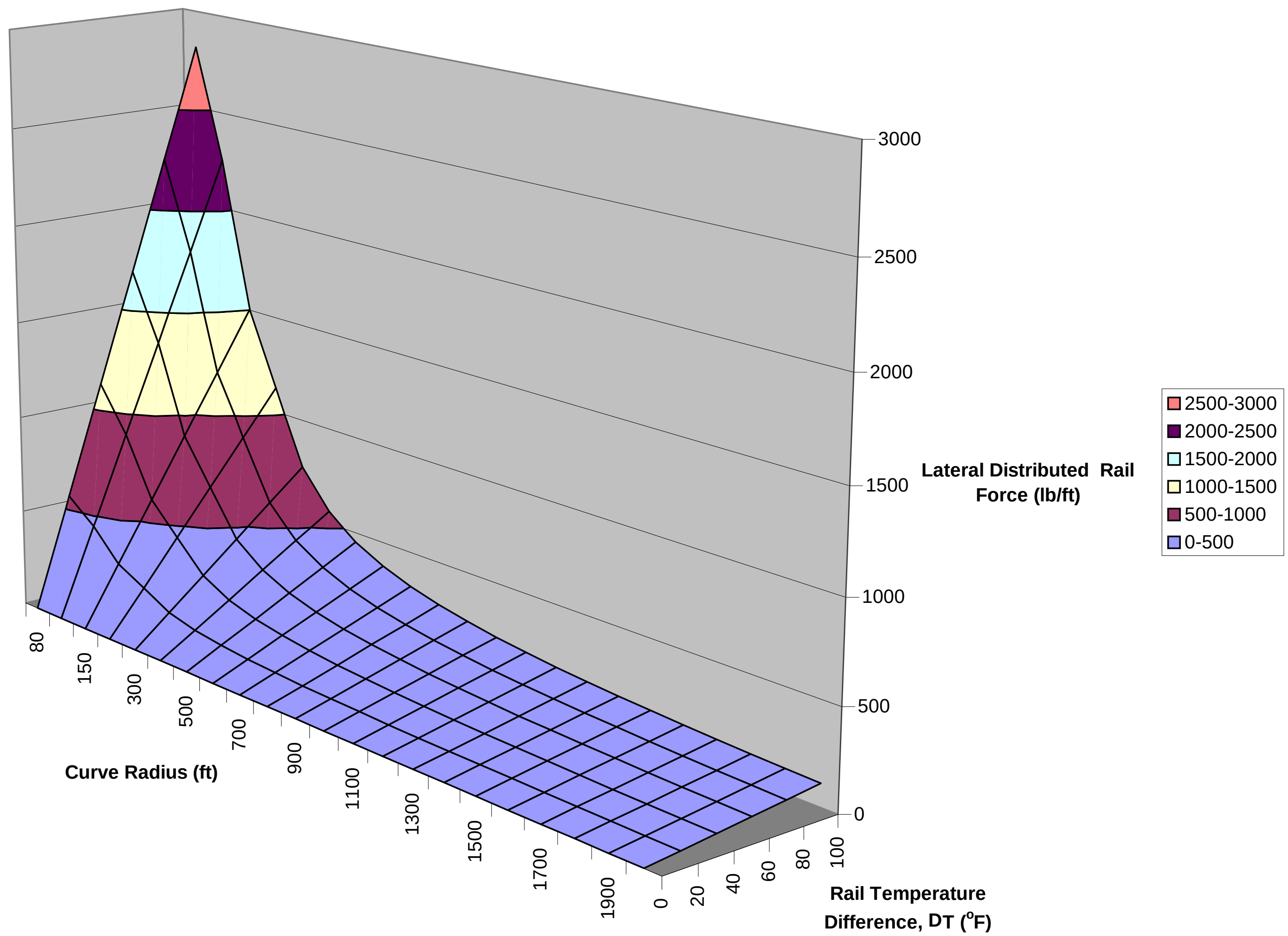

FIGURE 10 Lateral rail force on slabs in horizontal curves from thermal effects.

SUMMARY

Analysis of embedded track using a multi-layer model provides insight on performance of embedded track. The model is a static, linear representation (compared to dynamic, non-linear representation) of elasticity within the track system of rail, rail support elastomer, slab, and ground support of the slab. The analysis method incorporates subordinate methods for estimating ground support for a practical range of conditions, for determining rail thermal effects on slab loading, for determining slab natural frequencies, and for estimating track life.

The method is demonstrated for a practical range of slab thickness and rail support elastomer values. The summary of these results is

- Rail support stiffness, the spring rate (not the track modulus) between rail and slab, generally has a significant effect on slab life and stresses.
- Rail support stiffness of 400,000 to 600,000 lb/in. is the ideal range for overall slab response and performance.
- High rail support stiffness (above 1,000,000 lb/in.) creates high slab stresses requiring thicker slabs.
- Typical slabs (those with simple base support and a non-structural fill between rail) should be at least 14 in. thick in normal track and 16 in. thick in turnouts to avoid fatigue deterioration. Full depth slabs (concrete to top of rail) may be 6 in. thick in normal track and 12 in. thick in turnouts for acceptable life expectancy within the ideal rail stiffness range (above).
- Rail deflections are less than slab deflections when rail support elastomer stiffness is greater than 1,000,000 lb/in. In these circumstances, the rail will place upward force on the concrete and any rail fasteners. The upward force can exceed current fastener allowable force, or damage embedment concrete, at the stiffest elastomer values.
- Rail deflections from a single axle are generally greater than deflections from two axles when the rail support stiffness is less than 1,000,000 lb/in. This means that slab evaluations should analyze both single axle and two axle loading cases.
- Maximum allowable slab tensile stress will be exceeded when slab thickness (base slabs only) is less than 12 in. and the rail support stiffness is 3,000,000 lb/in. or greater.
- Slab natural frequencies (important to ground vibration issues) are estimated.
- Slab pressure on its support (gravel, engineered soils) is between 5 psi for thicker slabs to 10 psi for the thinnest slabs.
- Rail upward or downward force from thermal effects in vertical curves on slabs is innocuous, attaining 140 lb per rail foot for a 90^{o}F temperature above a neutral temperature, 150 foot curve length, and 10% grade change.
- Rail lateral force from thermal rail effects in horizontal curves may require additional lateral restraint for curves with radius 200 ft and less. The effect on rail restraints should be assessed in combination with other circumstances (wheel curving loads, lack of rail pre-curving).

NOTES

1. Hetényi, M. *Beams on Elastic Foundation*. The University of Michigan Press, Scientific Series Volume XVI, copyright 1974, pp.179–185.
2. American Concrete Institute, *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)*. However, ACI 318 specifically excludes structural at-grade slabs from the scope of its Code. The analysis incorporates *Design of Slabs on Grade (ACI 360R-92)*, reapproved 1997, partially addressing some track slab design issues. The interpretation of ACI 318 and ACI 360 that is most appropriate for track slab design, and implemented in this work, is in *The Structurally Reinforced Slab-on-Grade*, published by the Concrete Reinforcing Steel Institute in Engineering Data Report Number 33 (1989), and re-published by ACI in *Practitioner's Guide, Slabs on Ground*, American Concrete Institute PP-4 (1998). The results reported are by the "rational method." Four other structural design procedures are available in the calculations.
3. Packard, R. G., and S. D. Tayabji. New PCA Thickness Design Procedure for Concrete Highway and Street Pavements, *Proc., Third International Conference on Concrete Pavement Design and Rehabilitation*. Purdue University, 1985, pp. 225–236.; as implemented by Dr. Yang H. Huang, P.E., Finite Element Analysis of a Proposed Trackbed, prepared for Iron Horse Engineering Company, Inc., Feb. 19, 1991, p. 2.
4. Richart, F. E., Jr., J. R. Hall, Jr., and R. D. Woods. *Vibrations of Soils and Foundations*. Prentice Hall, 1970, pp. 350–353.

Debate of At-Grade Versus Grade Separation Construction Interstate MAX Project, Portland, Oregon

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Tri-County Metropolitan Transportation District of Oregon

The 5.8-mi Interstate MAX Light Rail Project, extending from the Rose Quarter due north to the Expo Center, is currently under construction and is targeted to open for service in September 2004. As part of the former South/North Corridor Study Project, a draft environmental impact statement for the project was completed in 1998. The final environmental impact statement along with preliminary engineering was completed for the Interstate MAX as an independent project in 1999. The majority of the Interstate MAX alignment is designed and built with ballasted track within the existing right-of-way along the middle of North Interstate Avenue.

The alignment starts to divert from the main roadway at Argyle Street, the beginning of the Expo Segment. The Expo Segment crosses major roadways including Columbia Boulevard, Union Pacific Railroad, Schmeer Road, Highway 99W, and Victory Boulevard, as well as the Columbia Slough, a tributary of the Willamette River. During the last 40% of the final design, there was much controversy regarding the vertical light rail train (LRT) alignment crossing Schmeer Road and Victory Boulevard, the crossing of Highway 99W, and the Highway 99W southbound to Victory off ramp. This paper discusses at-grade versus grade separation options through analyzing the special crossing situations, the selection process perspective, LRT operations, and project aesthetics and economy. A comprehensive analysis of all project elements ultimately favored grade separation with aerial structures from Columbia Boulevard until north of Victory Boulevard. The alignment evaluation and decision making process provide valuable experience to future planning and design of similar facilities.

INTRODUCTION

As the northern portion of the original South/North Corridor Study Project, the Interstate MAX Light Rail Transit (LRT) Project extends 5.8 mi from the Rose Quarter Area due north, along the existing Interstate Avenue (Highway 99W) to a north terminus at the Expo Center just south of the Columbia River. The project was ranked number one to be funded in 2000 by the Federal Transit Administration (FTA) based on federal criteria. Currently under construction, the project is projected to open for revenue service by September 2004.

The Interstate MAX LRT Project, including a total of 10 new stations, was subdivided into three segments for design and construction: the Rose Quarter Segment (10A), the Upper Interstate Segment (10B), and the Expo Segment (10C). Segments 10A and 10B are situated in the established north Portland neighborhood characterized by a mixed community of commercial, residential and industrial uses. With extensive involvement of the local communities, the trackway of these two segments were designed within the existing Interstate Avenue right-of-way. The trackway is primarily ballasted track, located exclusively in the middle of the roadway. One of the highlights of the design is no business or homes will be displaced because of the project. Segments 10A and 10B were designed at-grade construction without much question due to right-of-way constraint and the well-established business and residential communities. As the project progresses northward reaching Argyle Street where the Expo Segment starts, the LRT alignment and profile began to generate much controversy. Should the existing Denver Viaduct and the Columbia Slough Bridge be replaced with new bridges to support both Denver Avenue (Highway 99W) traffic and the LRT? If new independent bridges are built for the LRT, how far away should they be from the existing bridges? These issues directly affect the crossing location at Schmeer Road at the north side of the Columbia Slough. Where and at what angle should the alignment cross Highway 99W? Where should the alignment cross Victory Boulevard and the Highway 99W to Victory Boulevard ramp? And finally, perhaps the most difficult question to answer was what the LRT profile should look like between Argyle Street and Victory Boulevard.

It was an easy decision to make during all stages of the process that grade separated constructions should be assumed over Columbia Boulevard due to terrain characteristics and Union Pacific Railroad (UPRR) tracks along Columbia Boulevard, over the Columbia Slough for obvious reasons, and at Highway 99W and the Highway 99W to Victory Boulevard off ramp due to crossing this major highway. However, the decision regarding how to cross Schmeer Road and Victory Boulevard, was not easily made. During review of the 60% final design submittal, FHWA rejected the idea of having an at-grade crossing at Victory Boulevard. At-grade crossings of Schmeer Road and Victory Boulevard were part of the design since the draft environmental impact statement (DEIS) and the final environmental impact statement (FEIS). This late FHWA's rejection led the design team to reconsider other alternatives.

The planning and design process of this Interstate MAX Project provided valuable lessons that can be applied to future similar projects. This paper discusses the argument regarding the decision of elevated versus at-grade construction through the thinking of both soft and hard aspects. The soft aspects included discussion of decision making in the early planning of the project and involvement of interested parties. The hard aspects included analyzing LRT track geometry, safety issues, operation concerns, aesthetics, and project economy.

THE EXPO SEGMENT LRT ALIGNMENT

As illustrated on Figure 1, existing Highway 99W is supported by a bridge over Columbia Boulevard called Denver Viaduct. Highway 99W is then at-grade north of Columbia Boulevard before it is again on bridge over the Columbia Slough. The Columbia Slough extends 18 mi between Fairview Lake on the east to the Willamette River at Kelley Point Park on the west. Construction of any new bridge over the Columbia Slough requires obtaining a U.S. Coast Guard permit. After various studies and field inspections, it was determined that it would not be practical to replace or widen either the existing Denver Viaduct or the Columbia Slough Bridge to accommodate the new LRT trackway. First, it would be very difficult to stage the construction in order to detour the busy traffic along Highway 99W for replacement. Second, it would be difficult to restore the historical merits of the existing bridges. Third, from a cost standpoint, it is

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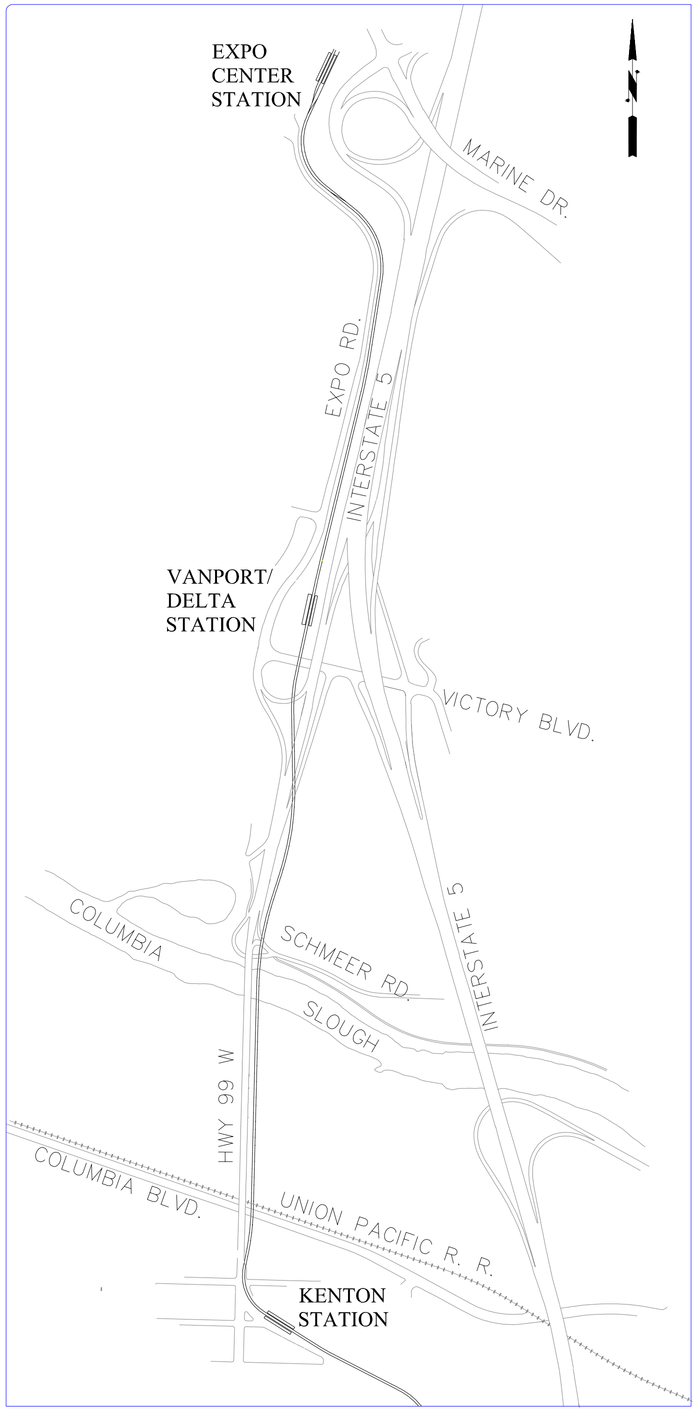

FIGURE 1 Expo Segment LRT alignment.

more expensive to replace or widen the bridges than to build new separate LRT bridges. Therefore, it was determined that independent structures would be built for the LRT trackway between Argyle Street and Schmeer Road. Based on the space and right-of-way availability, the LRT alignment on the east side of Highway 99W was selected.

To shorten the overall alignment length before it ultimately reaches it destination, Expo Center, the alignment was kept as close to Highway 99W as possible. More reasons will be discussed later on the crossing requirements at Schmeer Road. In order to serve the Portland International Raceway (PIR) and lead the alignment eventually to the Expo Center located west of Interstate 5 and just south of Marine Drive, the ideal LRT alignment is to cross Highway 99W between Schmeer Road and Victory Boulevard. North of Delta Park Station, the LRT alignment was chosen to run parallel to Expo Road with minor realignment of the existing Expo Road and wetland mitigation west of Expo Road. The whole alignment of the Expo Segment was designed for double track operation, except a short third track was designed to serve an event platform at the terminal Expo Center Station. Three surface park-and ride lots were designed adjacent to the Delta Park Station.

SPECIAL SITUATION OF SCHMEER ROAD AND VICTORY BOULEVARD CROSSINGS

Schmeer Road Crossing

Currently, Schmeer Road ends at Highway 99W on its west end (Figure 2). Highway 99W northbound is accessible to Schmeer Road at-grade through a tight curve at the north end of the Columbia Slough Bridge, while Highway 99W southbound accesses to Schmeer Road through grade separation under the Columbia Slough Bridge. Schmeer Road has access to Highway 99W northbound, and there is no access to Highway 99 southbound. If at-grade crossing for the LRT were assumed as it was planned during the preliminary engineering and early final design stage, the intersection of Schmeer Road would need to be modified as demonstrated in Figure 3. The flood levee on the north bank of Columbia Slough is immediately adjacent to the south edge of Schmeer Road. This would prohibit lowering the existing Highway 99W southbound to Schmeer Road off ramp to provide enough vertical clearance underneath the LRT structure. As a consequence, a traffic signal would have to be added at the intersection to allow at-grade left turn movement from Highway 99W southbound to Schmeer Road. At least two railroad gates would have to be installed at each approach to Schmeer Road, and there was a question regarding whether a third gate would have to be installed to prevent traffic from entering the LRT operation envelop from Highway 99W southbound to Schmeer Road. Other components required to ensure the at-grade crossing to work properly would include necessary electrical circuits to control the signals, gates and crossing panels at the conjunction of the LRT track and the roadway.

Victory Boulevard Crossing

The vicinity of the intersection of Victory Boulevard, Interstate 5 and Highway 99W is already a complex traffic operation center, especially during auto racing events at the PIR just west of the intersection. Victory Boulevard has full access to Interstate 5 and Highway 99W. After diverging

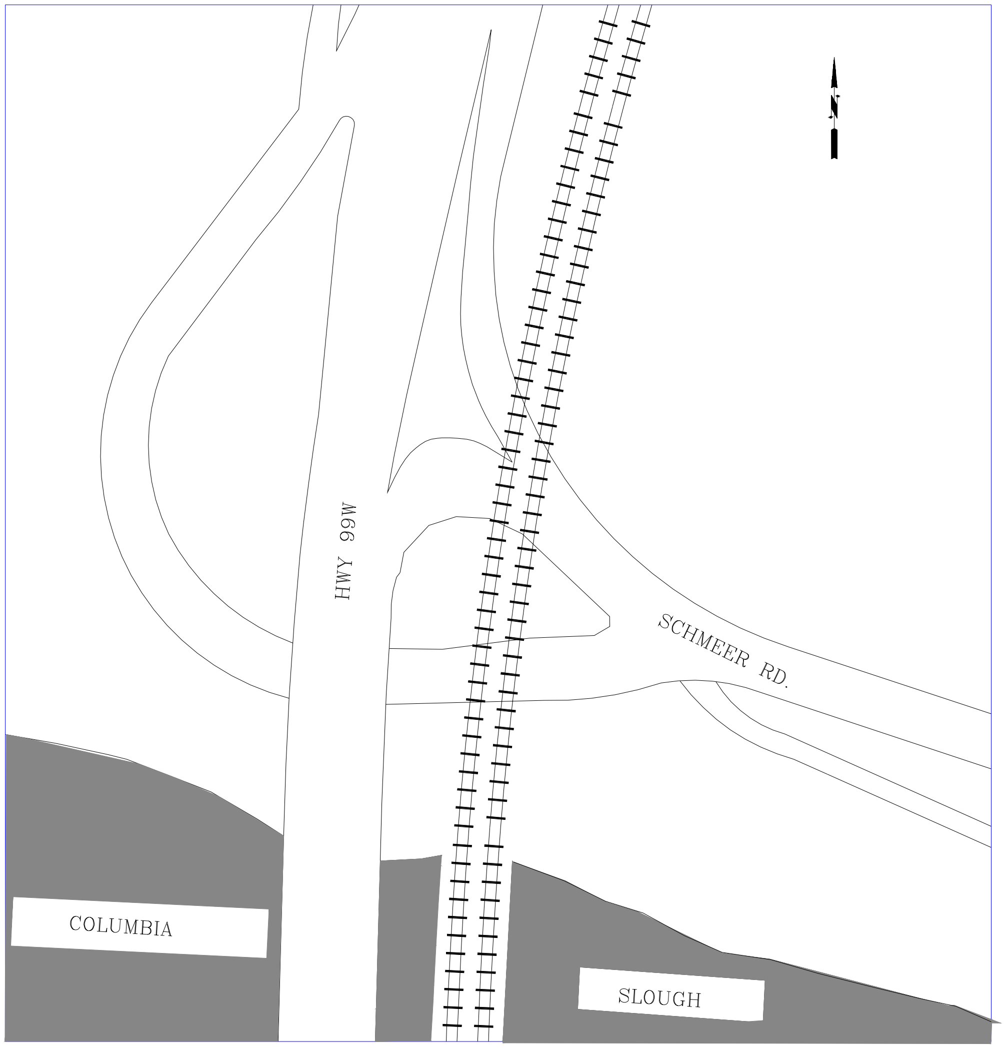

FIGURE 2 Existing Condition of the Intersection of Highway 99W and Schmeer Road with New LRT alignment.

off Interstate 5 north of Victory Boulevard, Highway 99W is less than 300 ft west of Interstate 5. The space between the on and off ramps for Interstate 5 and Highway 99W is already in a substandard operation mode. An at-grade crossing for the LRT within the vicinity would further complicate the traffic operation.

The proposed LRT alignment is about 60 ft west of Highway 99W. If the LRT profile were to pass under Highway 99W, as it was determined early in the project, it would also need to go under the Highway 99W southbound ramp to Victory Boulevard in order to cross Victory Boulevard at-grade. Gates and special electrical circuits would be required to control the crossing. In addition, due to the LRT coming out from a depressed profile and tunnel, retaining walls on both sides of the trackway as well as the aerial structure of Highway 99W would limit the sight distance. Therefore, advanced warning devices would be required for westbound traffic on Victory Boulevard east of Highway 99W.

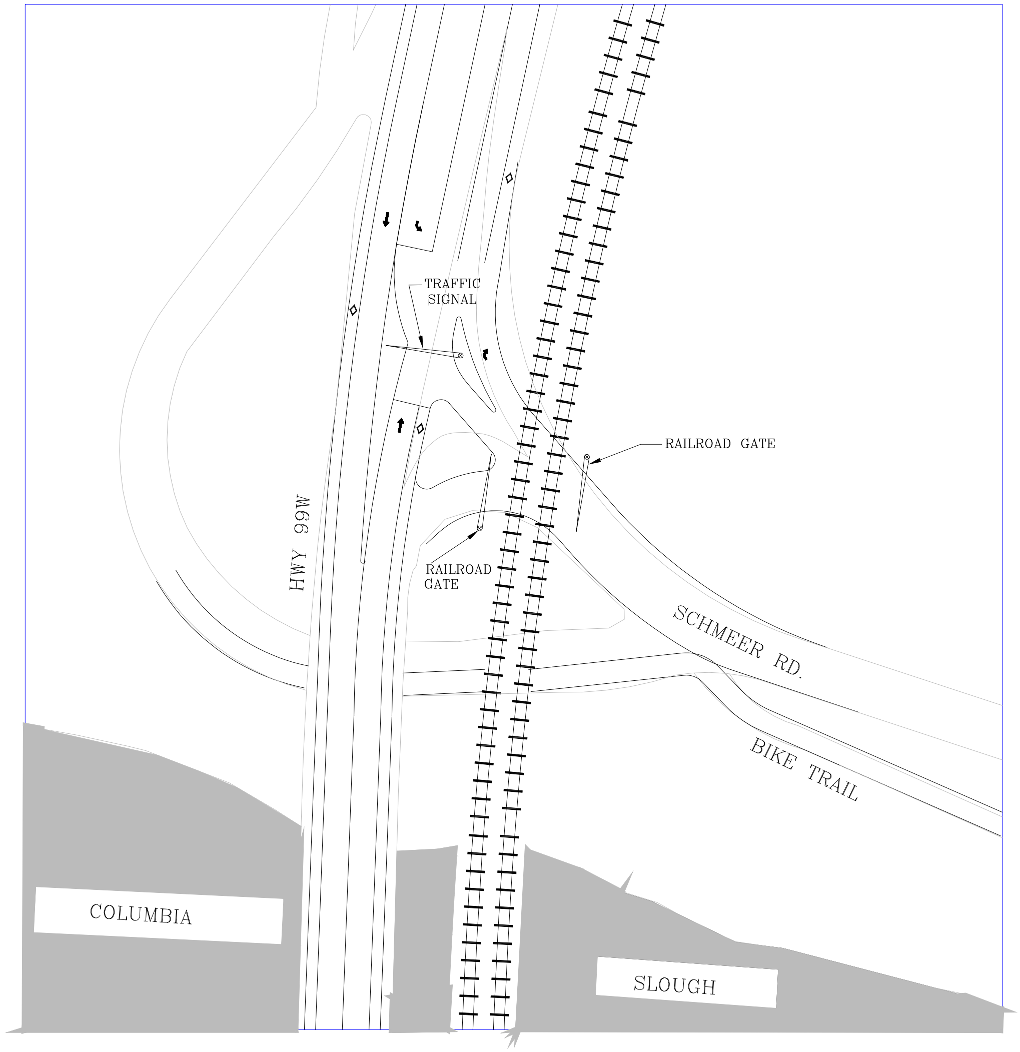

FIGURE 3 Modification of the intersection of Highway 99W and Schmeer Road due to the LRT at-grade crossing.

EARLY DECISION MAKING ON THE LRT PROFILE

As mentioned earlier, this Interstate MAX Project had gone through the DEIS process for the former South/North Project when the conceptual engineering was carried out. Then, preliminary engineering was completed as requirement for the FEIS. Immediately after the at-grade crossing Argyle Street, the LRT profile was brought up with a 5% grade so that impacts to a historic-eligible building south of Columbia Boulevard could be minimized. Like the existing Denver Viaduct, it was decided that the LRT would be supported on a bridge over Columbia Boulevard, simply because of the natural terrain; Columbia Boulevard is more than 30 ft below the existing Highway 99W grade. In addition, UPRR has railroad tracks in parallel to Columbia Boulevard. The U.S. Coast Guard requires minimum vertical clearance over the Columbia Slough due to its navigability. The city of Portland has a strategic bike route proposed along the north bank of Columbia Slough (Figure 3). The city required a 10-ft vertical clearance. With a high profile over the historic building and Columbia Boulevard, as well as a bridge over the Slough, it was a logical decision to connect these two major structures by a low profile aerial structure that would span over business driveways and avoid conflicts with at-grade crossings of these business access points.

During all phases of engineering until 60% final design, the LRT profile was always assumed to have an at-grade crossing at Schmeer Road and Victory Boulevard and grade separating Highway 99W and the Highway 99W to Victory Boulevard Ramp by tunnel since grade separating from Schmeer Road to Victory Boulevard with aerial structure(s) was considered too expensive. This decision was made assuming that the LRT could operate under railroad pre-emption through Victory Boulevard and Schmeer Road. The decision was based on consultations with local state transportation personnel. In hindsight, the lack of involvement by the FHWA was a critical oversight.

EVALUATION OF THE HIGHWAY 99W AND VICTORY RAMP UNDERCROSSING

The undercrossing was the proposed structure consisting of cut-and-cover tunnels under Highway 99W and the Highway 99W southbound off-ramp to Victory Boulevard, with retaining walls for the tunnel portals. The undercrossing structure would begin with a cantilever retaining wall on the west side of the alignment to retain the fill slope for Highway 99W. A short retaining wall might have been required on the east side of the alignment before the alignment reached the tunnel's south portal. The tunnel crossed under Highway 99W at a skew of approximately 18°, requiring 515 ft to reach the highway's west side. After the north portal, the structure transitioned to a U-shaped open-top box. The cut-and-cover tunnel structure was required again as the alignment crossed under the Highway 99W to Victory Boulevard ramp. A U-shaped structure with variable height retaining walls was proposed for retaining the ramp fill slopes for approximately 45 ft after the north portal.

Through in-depth research of the existing utilities within the corridor, it was discovered that several utilities would require protection or relocation during construction of the proposed undercrossing. Most surprisingly, there is a buried U.S. West (now Quest) fiber optic telephone line in the northbound shoulder of Highway 99W, crossing the LRT alignment. Consultants for U.S. West had proposed a temporary bridge to support this line during construction of the cut-and-cover undercrossing. U.S. West estimated the cost for this temporary bridge at $300,000. This line would be lowered and re-embedded in the roadway after completion of the undercrossing. The vertical alignment of the tunnel would require accommodating the minimum cover requirements of the telephone line. As a result, the original LRT vertical profile from preliminary engineering would have to be lowered substantially. Consequently, a sag curve with a low point in the tunnel near the middle of the undercrossing appeared to be necessary to achieve sufficient clearance under the roadway to avoid conflict with the existing buried telephone line. This low point would cause problems with drainage and water disposal. The tunnel would need to include a drainage system to remove water inflows. The inflows could come from the following major sources:

1. Seepage from water infiltration;

2. Rainfall on the tunnel approaches;
3. Rainfall entering through open-top box section;
4. Flood events; and
5. Fire flows during emergencies

Water entering the tunnel would need to channel to a floor drain at the low point of the tunnel. A sump would need to be built beneath the bottom of the tunnel slab. A permanent sump pump would be required to discharge the water.

The estimated cost for this undercrossing increased more than 50% from the estimate performed during preliminary engineering because of the new drop in vertical alignment. Because of this drop, excavation depths increased beyond the capacity of conventional sheet-pile shoring assumed in the original estimate. This also resulted in increased quantities of tied-back shoring walls, excavation, and backfill. In addition, concrete and reinforcing had to increase due to additional soil loads at the new alignment depth.

FHWA's REJECTION ON THE AT-GRADE CROSSING AT VICTORY BOULEVARD

Upon reviewing the 60% final design submittal, FHWA rejected the at-grade crossing proposal at Victory Boulevard based on the following reasons:

1. The crossing is within the interchange vicinity of Interstate 5 and Victory Boulevard. The at-grade crossing is too close to major freeway and highway ramps.
2. The at-grade crossing would create intrusion to the highway access control zone.
3. Advanced warning devices could not guarantee safety because of the limited sight distance.
4. The at-grade crossing could induce potential problem during events at PIR.

All these reasons are associated with safety issues. Additionally, FHWA and Oregon Department of Transportation (ODOT) maintained their opposition to the Schmeer Road at-grade crossing.

TriMet immediately conducted management and technical level workshops to review options with ODOT and FHWA. Seven different alignment options were investigated. Options included variations on the location of the Delta Park Station, flyovers, undercrossings, and at-grade crossings. Factors considered for each included safety, local access to the station, and proximity of the station to the park-and-ride facilities, security, impacts on PIR events, traffic impacts, and cost impacts.

Although it was not critically affecting the decision whether or not at-grade crossing should be placed at Victory Boulevard, it might be worthwhile to mention that during early final design, Multnomah Drainage District discovered that the LRT profile north of Vanport/Delta Station cut into the flood control levee by 13 ft. If the crossing at Victory Boulevard altered to grade separation with an aerial structure, this flood levee issue was almost automatically solved.

An elevated LRT profile over Victory Boulevard would naturally require an aerial structure over the Highway 99W to Victory ramp and over Highway 99W to grade separate the ramp and the highway. Once the design of long bridges south and north of Schmeer Road were being considered, there was little hesitation to grade separate this intersection as well, since the at-grade crossing had complicated the intersection as discussed previously.

After review of all design, construction, cost, and operating factors, TriMet decided to change the Expo Segment design to incorporate a single elevated structure, extending from Argyle Street to the Delta Park Station. ODOT and FHWA concurred with this decision.

OPERATIONAL ADVANTAGES OF GRADE SEPARATION

The resulting 4,000-ft long aerial LRT structure between Argyle Street and north of Victory Boulevard would ensure train service with no interruption between Kenton Station and Delta Park Station (Figure 4). Some of the operation advantages with grade separation versus at-grade crossing through Schmeer Road and Victory Boulevard include:

1. With no sight distance constraints coming out from the tunnel and U-shaped box, the aerial structure would allow light rail vehicles to operate in full design speed. It could speed up the service by saving up to 20 s each trip to the north.
2. No railroad gates are needed at the intersections, therefore the maintenance at the crossings, such as weekly inspections and occasional replacement of gates is not required. Crossings of business driveways are also avoided, thus increasing overall safety and reducing the impacts to those businesses.
3. No additional traffic signal is needed at the intersection of Schmeer Road and Highway 99W. Highway 99W southbound to Schmeer Road ramp can operate as they are today without traffic interruption on Highway 99W.
4. Additional illumination is not needed at the at-grade crossing; and no additional control circuits for the gates and signals are required.

FIGURE 4 Grade-separation with long aerial structure between Argyle Street and Victory Boulevard (looking south from Delta Park Station).

AETHETICS CONSIDERATION

There are no residential homes along the entire Expo Segment. Only limited industrial businesses are situated along the southern portion of the long aerial structure. If there is a visual impact from the project, it would be mainly on the travelers driving along Highway 99W. However, since the structure has to be high to clear the historic building and the cross roadways (Schmeer, Highway 99, Highway 99 to Victory ramp and Victory), for most part of it, travelers on Highway 99W would able to see through and under the structure (Figure 5). Although there might be different opinions on this aspect, the authors believe that looking through the bridge piers is better than looking at the catenary power poles and wires at a typical at-grade design.

COSTS COMPARISON

Table 1 tabulates costs comparison for the affected construction items between Argyle Street and the Delta Park Station. With more detailed investigation and design, the costs estimate for the cut and box under Highway 99W and Highway 99W to Victory Boulevard ramp during 60% final design was approximately $4 million higher than that during preliminary engineering. As previously discussed, this significant increase of costs for the cut and cover box is due to the fact that the LRT vertical alignment has to be lowered substantially in order to protect major fiber optic telephone line.

The final estimated cost comparison between the original design and the change to an aerial structure actually indicated a savings of over $600,000 to the project. Consideration of the cost saving from construction, plus that from maintenance for gates and signals down in the road during operation, would favor the grade separation option.

FIGURE 5 LRT structure (near side) higher than the highway structure (far side).

TABLE 1 Estimated Costs Comparison of At-Grade Versus Grade Separation Crossings

Key Evaluated Cost Items	100% PE: At-Grade Crossing at Schmeer and Victory and Cut and Cover Box Under Highway 99W	60% Final Design: At-Grade Crossing at Schmeer and Victory and Cut and Cover Box Under Highway 99W	Final Design: Grade Separation with Long Aerial Structure
Overall Civil Construction	$12,650,000	$16,360,000	$16,151,000
Cut and Cover Box	$4,570,000	$7,620,000	N/A
Mobilization/Permits	$330,000	$550,000	$1,000,000
Design Costs	$510,000	$840,000	N/A*
Additional Aerial Structure	N/A	N/A	$8,000,000
Insurance	$470,000	$570,000	$550,000
Track Materials	$600,000	$600,000	$740,000
Signals	$470,000	$470,000	$0
Contingencies	$2,300,000	$2,900,000	$2,800,000
Total Evaluated Costs	$16,490,000	$20,900,000	$20,250,000

* Hidden in civil construction as design–build contract.

CONCLUSIONS

An independent LRT structure and alignment parallel to the existing Highway 99W for the Expo Segment of the Interstate MAX Project has proved to be a wise decision. Utilizing the limited right-of-way seamlessly, the alignment crosses Highway 99W and Victory Boulevard at the right locations in order to maintain the locations of the Delta Park Station and PIR park-and-ride.

The determination of an optimum, and approvable, vertical LRT profile proved to be more complicated than was assumed earlier in the project. A more detailed and complete analysis prompted by the actions of FHWA demonstrated that a long aerial LRT structure, grade separating the LRT from the ground traffic operation between Argyle Street and Victory Boulevard, will be a better vertical alignment. The full grade separation with aerial structure has proved not only safer and faster for operation, but also more cost competitive based on the actual construction contract bid.

Through the evolution of the Expo LRT alignment, valuable lessons-learned can be provided for other similar projects. The important ones include:

1. Identification and involvement of all interested parties early in the project is essential to the success of project down in the road.
2. Keep an open-mind for options during early project planning to produce optimum outcome.
3. “Guesstimate” of tunnel construction costs without knowing all underground utilities and construction staging issues could be hazardous.
4. Comprehensively analyze all the project elements to gain a thorough understanding of the true cost benefits should make the project a great success.

Designing New Light Rail
Taking Engineering Beyond Vanilla

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As light rail transit (LRT) systems mature and expand, outlying passengers are faced with increasingly longer trip times to reach the urban core. Providing service to these customers by conventional means can be disproportionately expensive for the transit carrier in terms of operating and capital expense. Innovative operational practices to expedite train movements, however, are often confounded by current LRT design and deployment methods. This is partly attributable to design methods that follow a "stovepipe" approach to individual engineering disciplines and components, rather than directing focus on optimizing railway functionality and flexibility as a comprehensive entity. It is also attributable, in part, to a failure to address the ultimate potential of a railway at the definition/developmental stage and to subsequently articulate and document the operational requirements that are necessary to support the stated mission.

This paper provides a survey of the critical engineering "systems" that comprise a light electrified passenger railway, and suggests those that are most significant in affecting innovative operational practices. It illustrates the model relationship between operations and systems design by a case study based on the first implementation of express service on a modern LRT system.

INTRODUCTION

As prospective light rail transit (LRT) systems undergo conceptual design and preliminary engineering, achieving implementation of the minimal operable system is a more pressing concern than any consideration of a future "maximal operable system" (MOS). Nevertheless, most light rail systems eventually expand as they mature, pushing increasingly farther and farther out from their original core.

System expansions can quickly reach a point of diminishing returns as new passengers at outlying stations face longer travel times to the urban centers—an experience punctuated by stops at each and every station enroute. Providing service to these customers by conventional means can be disproportionately expensive for the carrier in terms of operating and capital expense. Longer trip times translate into a less attractive service that is less capable of competing against travel by automobile, which result in a lower modal split and diminished ridership potential.

EXPEDITED SERVICE

The Interurban Era

The interurban railway industry—the functional progenitor of modern LRT—faced a similar challenge in attracting passengers for longer distance trips a century ago. In response, several midwestern interurbans augmented local train service with expresses that skipped intermediate stops outside of towns. A few lines went a step further, adopting limited service with stops only in major towns and destinations. A major period of interest in limited operations began in 1922 as interurbans faced increasing competition with automobiles. (*1*)

Interurbans that operated high-speed intercity service frequently handled heavy commuter service, which also required a large terminal population. A combination of the two represented a vital advantage that enabled many carriers to outlive the majority of the interurban industry. The most notable high-speed systems of yesterdays that successfully employed expresses and other forms of expedited train service to attract and keep commuters were:

- Chicago, South Shore, and South Bend Railroad (South Shore Line)
- Chicago, North Shore, and Milwaukee Railroad (North Shore Line)
- Chicago, Aurora, and Elgin Railway
- Sacramento Northern Railway (Northern California)
- Bamberger Electric Railroad (Utah)
- Pacific Electric Railway (Southern California)
- Indiana Railroad
- Detroit United Railways
- Milwaukee Electric Railway & Light Company
- Lehigh Valley Transit Company (Eastern Pennsylvania)
- Philadelphia and Western Railway

The first four interurbans on the preceding list expedited service to city centers by running over grade-separated rapid transit rights-of-way (ROWs) belonging to other carriers with few or no stops. The last two systems on the list enjoyed a synergistic relationship in which the former ran in an expedited manner over the lines of the latter. All of these systems intertwined the operation of local, express, and often additional limited services on predominately two-track ROWs using train control and communications systems and dispatching techniques that appear primitive in comparison to modern day capabilities.

Philadelphia and Western Railway

The level of complexity expedited operations of the interurban era achieved is best illustrated by the Philadelphia and Western Railway (P&W) in 1951. By this time, the Lehigh Valley Transit trains had ceased operation over the P&W. What remained was a two-branch railway consisting of two tracks except for pocket tracks at Wynnewood Road and Bryn Mawr where trains reversed direction clear of the main line. All switches were manually operated by motormen except for the junction at Villanova.

Every 15 min in the evening peak period, five trains were dispatched westward from 69th Street Terminal in Upper Darby in short order (Figure 1):

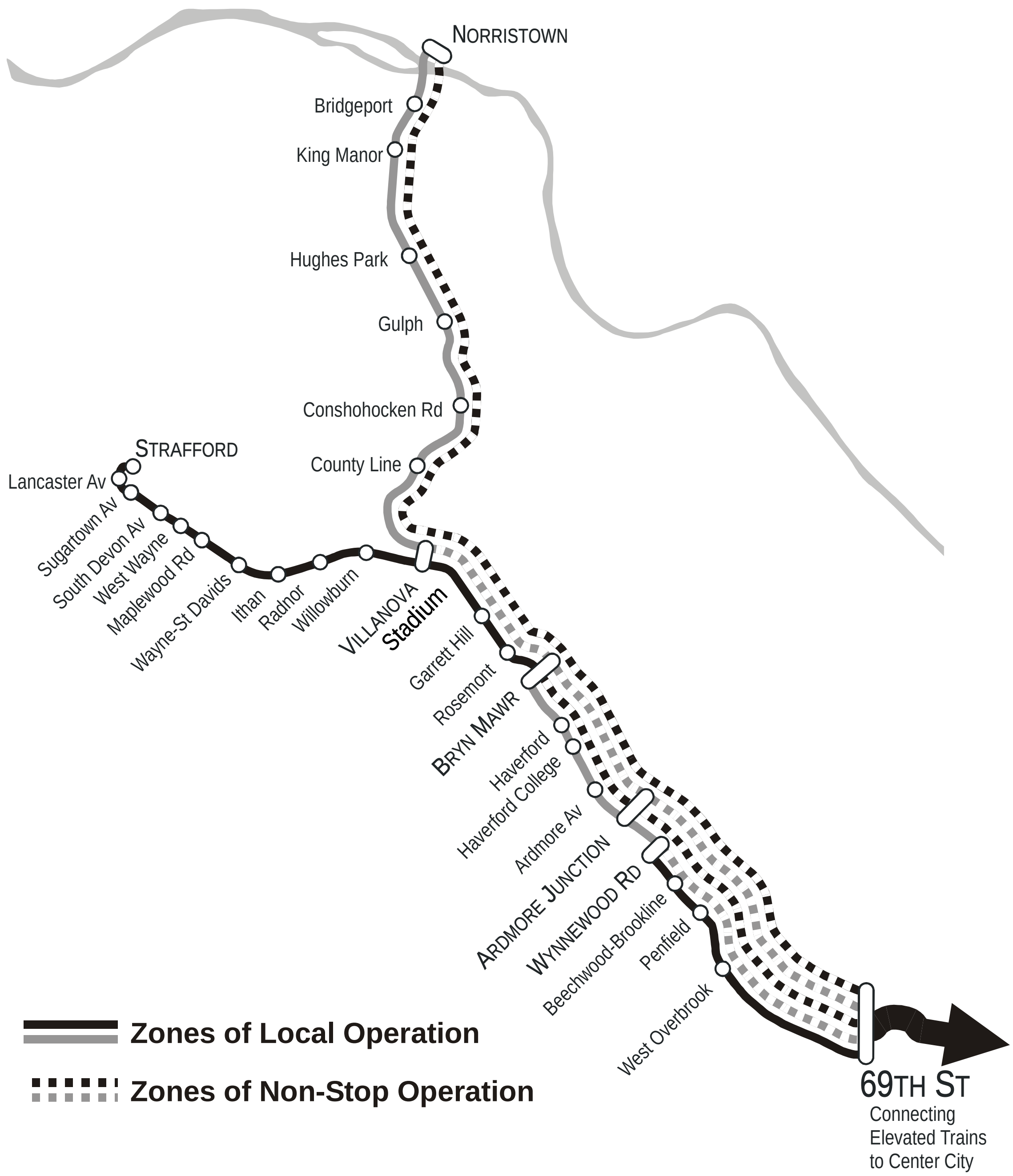


FIGURE 1 Philadelphia and Western Railway peak service configuration (1951).

1. Norristown Limited (non-stop to Norristown);
2. Norristown Express (express to Villanova with stops at Ardmore Junction and Bryn Mawr);
3. Strafford Express (express to Bryn Mawr with a stop at Ardmore Junction);
4. Bryn Mawr Express (express to Wynnewood Road); and
5. Wynnewood Road Local (*2*).

Expedited Service Techniques

Following is a brief overview of the available techniques for expedited service:

- *Demand Stops.* Trains stop only upon demand at minor stations ("flag stops") except at high-traffic stations (e.g., Central Business District, terminals, high volume, transfers). This requires that an on-board passenger signal to stop the train. Minor stations also must be equipped with a passenger signal to stop train, or train operators must observe where passengers are waiting as they approach each station. This can be a particularly efficient way to increase line schedule speed and reduce operating costs except at higher capacity levels when all trains will stop at all stations. Demand stops are rare on new North American light rail systems [e.g.: Southeastern Pennsylvania Transportation Authority (SEPTA) Route 100], even where there would clearly be benefit from bypassing low-volume stations in off-peak periods. (*3*)
- *Skip-Stop Express.* Lower trafficked intermediate stations are alternately designated as "A" or "B" stops, while high-traffic stations are designated as "all stop." Alternate movements are designated as "A" or "B" trains that stop only at their respective stations and at "all stop" stations. This method is only applicable if headways are sufficiently short that the "up to two-headway wait" at minor stations will be acceptable to passengers. Skip stops provide faster travel times for the majority of passengers with less equipment and fewer staff but do not increase capacity as the constraint remains the dwell time at maximum load point stations at which, by definition, all trains must stop. In fact, capacity can be slightly reduced as the extra passengers transferring between A and B trains at common stations can sometimes increase dwell times. Skip-stop operation increases speed but not capacity. (*3*)
- *Zone Express.* Outlying stations are grouped into zones. Two or more different routes are overlaid with trains bypassing stations between the terminal and the start of their designated zone. The 1951 P&W operation illustrated in Figure 1 is a LRT example of a zone express operation. Zone express is capable of providing high schedule speeds and meeting a customer perception of true express service. However, because zone operation on a transit line essentially consists of zone expresses overtaking "ghost slots" (discussed later), this service is not suitable for lines running at or near capacity.
- *Skip-Zone Express.* This technique is a combination of skip-stop and zone expresses. Outlying stations are grouped into zones. Similar to simple skip-stop service, trains make all the stops in one zones, then skip the stops in the next zone. This makes service patterns that are easier for riders to understand and the longer stretches of non-stop service are perceived as faster by riders.
- *Short Overtake Tracks or "Reverse" Shots.* Railroads traditionally utilized relatively short passing tracks, or have "reverse" run in order to permit faster trains (passenger of freight) to overtake and pass slower, inferior trains). Application of this technique in a short headway, transit environment requires both a detailed adaptation of the railway configuration (i.e., systems

design and integration) to a well conceived operating plan, and precise management of train operation so that trains arrive at their designated locations on schedule. Use of short overtake tracks was commonly used in Chicago, particularly for the Chicago, Aurora, and Elgin interurban trains operating over the Chicago Elevated to a terminal at the Loop. Recently, this practice was utilized on the Port Authority of New York and New Jersey's Port Authority Trans-Hudson system to operate non-stop express service in the morning peak between Newark and the World Trade Center Stations. The overtake was timed to occur at Journal Square Station utilizing a spare "running" track but the speed through the running track was not sufficient to accomplish the overtake without some delay to the local.

Expedited service may be provided on two-track rail lines by a variety of methods, each with merits and drawbacks. There is no singular "superior" method as the approach to service planning must be tailored to best reflect the operational configuration and the customer service requirements of each particular system. The only proper response to the question of "What works best?" is "It depends."

Contemporary Expedited Service

The long heritage of expedited service applications in interurban operations has not translated to modern LRT operations. Contemporary examples are limited, for the most part, to commuter rail and rapid rail transit (RRT) operations. Virtually all modern LRT systems operate trains from one terminal to the other making all stops enroute. The two present-day LRT exceptions are the aforementioned P&W (now Route 100/Norristown High Speed Line of the SEPTA) and NJ Transit's new Hudson–Bergen LRT System (HBLR).

Attempts to introduce expedited service and other innovative operational practices in the modern LRT environment is often confounded by current design and deployment methods. This is partly attributable to design methods that follow a "stovepipe" approach to individual engineering disciplines and components, rather than directing focus on optimizing railway functionality and flexibility as a comprehensive entity. It is also attributable, in part, to a failure to address the ultimate potential of a railway during the definition/developmental stage and to subsequently articulate and document the operational requirements necessary to support the stated mission.

Vanilla Rail

The result of these processes is labeled by the authors as "Vanilla Rail"—a cookie-cutter sameness in LRT operations pervading the North American transit industry with little or no regard of the site and situation of a specific application. There is nothing wrong per se with vanilla (it is, in fact, the preferred flavor of one of the author's daughters). "Vanilla Rail"—in the form an "Up-and-Back" railway making all stops, end to end—is often the appropriate operational approach in many LRT applications. The pejorative distinction of "Vanilla Rail" (in LRT operations as well as in the choice of ice cream) comes about when a decision is made in the absence of full consideration of the alternative "flavors."

At its worst, "Vanilla Rail" results in limited operating flexibility and growth potential at the same time individual systems are designed as high end. One such example (drawn from one recent anonymous LRT system but equally applicable to many) results in:

- Track constructed to 80 mph standards, comprised of all new continuous welded rail laid on concrete ties.
- Constant tension, compound catenary, also suitable for 80 mph operation.
- Full cab signaling with Automatic Train Protection/Automatic Train Control (ATP/ATC) with reverse-running signal capability.
- High-performance light rail vehicles (LRVs) with a 65-mph balancing speed.
- Maximum authorized speed on level, tangent track limited to 55 mph by signal block length and level crossing starts.
- Low speed crossovers at terminal stations and junctions.

Two casual factors may be suggested as contributing causes for “Vanilla Rail:”

1. Operational planning practice that fails to comprehensively and concisely establish Operating Requirement Documentation (ORD) at the commencement of systems design and to advocate for adherence with the ORD throughout the design evolution. This is particularly important with respect to Systems Integration (i.e.: How do individual systems intereract to support a defined mission for LRT?).
2. Engineering Practice which uses “bottoms-up” design, that is, each system (track, train control, traction power) is designed to standards which optimize individual systems. Integration is often limited to physical parameters (loads, dimensions), but does not sufficiently consider functionality of the entire railway or operational parameters.

Challenge of Moving Beyond Vanilla

With its mix of ROW types and train control technologies, LRT offers the widest range of latitude in the areas of systems design, applications engineering, and operating practices. The challenge in design is to fully realize the potential of LRT in any given application while avoiding over-design that results in excessive capital investment beyond what would suffice for its intended mission. This issue can be expressed as building a rapid transit infrastructure in accordance with the LRT mission defined in the ORD.

A corollary challenge would be—given a particular level of capital investment—to utilize good applications engineering and systems integration practices to maximize the operational flexibility designed into an LRT system. This would provide capability to satisfy reasonable changes in the ORD beyond those originally baselined. Such flexibility is important to recognize at the earliest stages of design, acknowledging the inexorable tendency of most LRT systems to expand beyond the original extent of their MOS.

HBLR (Figure 2) provides one example of LRT that has evolved (and is continuing to evolve) beyond vanilla. This claim can be demonstrated in terms of its route structure and integrated service plan that optimizes use of core capacity with current zone express service and future consideration of making use of “overtake” opportunities. HBLR design processes borrows freely from the operating practices of interurban and regional/commuter railroads. A case study is presented pertaining to the HBLR express service.

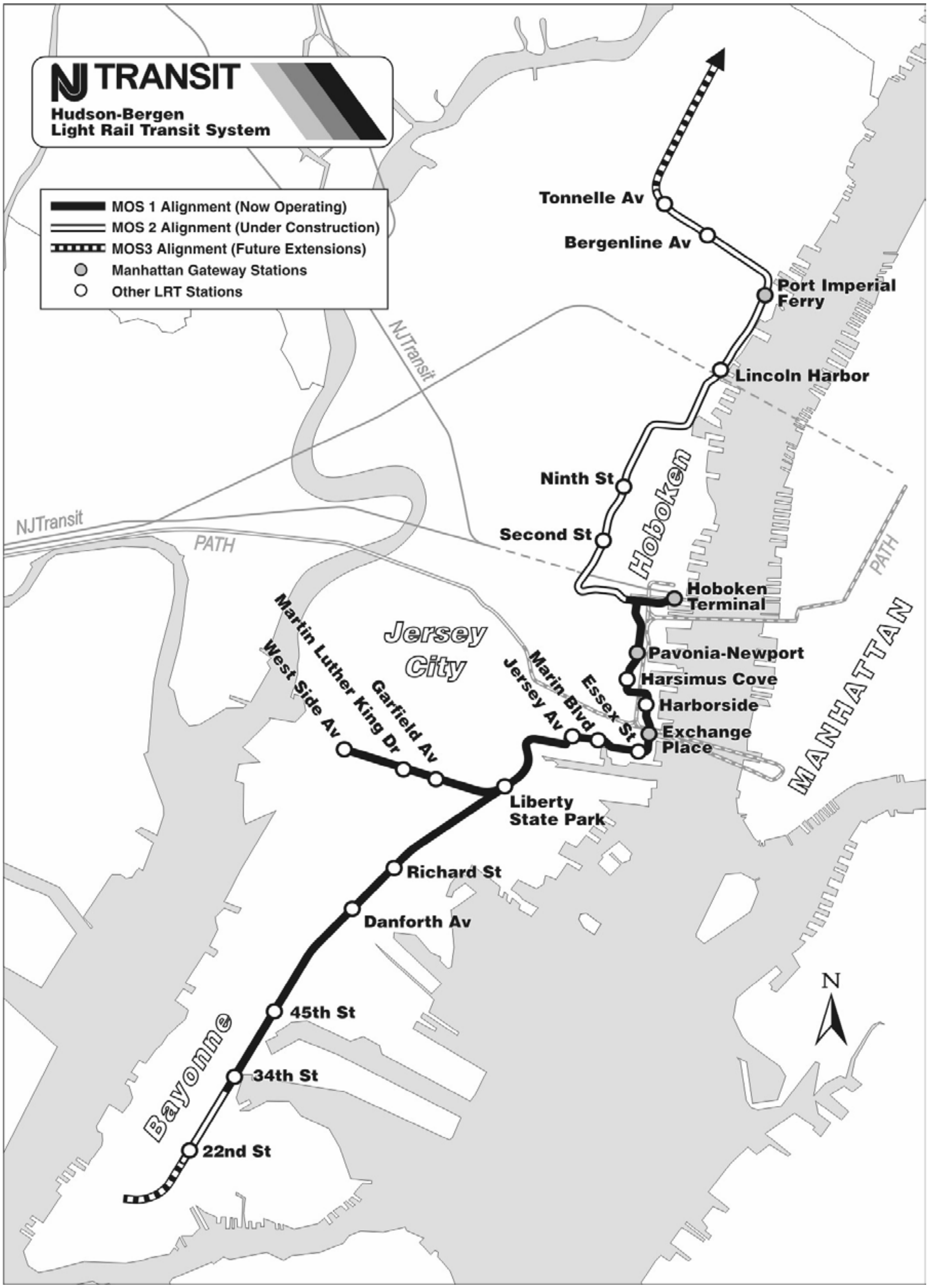


FIGURE 2 HBLR Transit System

LIGHT RAIL: A SYSTEMS PERSPECTIVE

Concept of a System

Complex engineering equipment is commonly categorized by "systems", wherein each system provides a defined, stand-alone capability, and wherein each system—in conjunction with other systems—supports the stated mission of the equipment. Complex systems like an aircraft or spacecraft are developed and designed according to their component systems, such as air frame, navigation system, propulsion, and possibly weapons systems (*4*). Perusing the table of contents of an automotive shop manual for a 1950 Dodge demonstrates how even a relatively simple product is often organized around its component systems:

> *Ignition, Electrical (differentiated from Ignition), Suspension, Chassis, Drive Train, Fuel System, etc.* (*5*)

An engineered product is developed by systems, with proper attention throughout the product development cycle to satisfying the mission of the product and the derivative operational requirements, and to systems integration/interface requirements. Systems are defined by their function, not by their engineering discipline. Systems are hierarchical in nature, with each system further broken down into sub-systems, and then typically into assemblies, parts, components, etc.

In developing the HBLR, particularly with respect to assuring ultimate satisfaction of the operating and systems integration requirements expressed in the Mandatory Design, Build, Operate, and Maintain Criteria, Washington Group developed a formal protocol for defining systems and sub-systems on an electrified railway. This protocol was presented to the industry as a recommended practice (*6*).

HBLR Protocol

Table 1 summarizes the recommended protocol for systems and sub-systems. On HBLR this serves as a basis for design, railway commissioning, and of Safety Certification of revenue ready status. On operating segments it provides the basis for the maintenance organization (including a work breakdown structure for those craft positions covered by a collective bargaining agreement), for failure reporting and for the accumulation and analysis of reliability and availability data. The systems protocol has also served as the basis for operational planning wherein the contribution (or lack of contribution) of each system to a candidate operating scenario is evaluated based on the engineering performance designed into that system.

Categorization by Systems

The systems protocol provides an excellent basis for categorizing light rail as a sub-mode within the rail transit mode. Following Vuchic (*7*) and others, the ability to operate on exclusive and semi-exclusive ROWs as well as in mixed-traffic with automobiles, and to gain the maximum benefit of the particular ROW, is seen as the primary differentiator between LRT and other rail transit modes (reflected in Table 1 as Systems 11.0).

Viewed from the system perspective, consideration of the ROW directly leads to two additional systems whose functionality and design differentiate LRT from RRT and streetcar

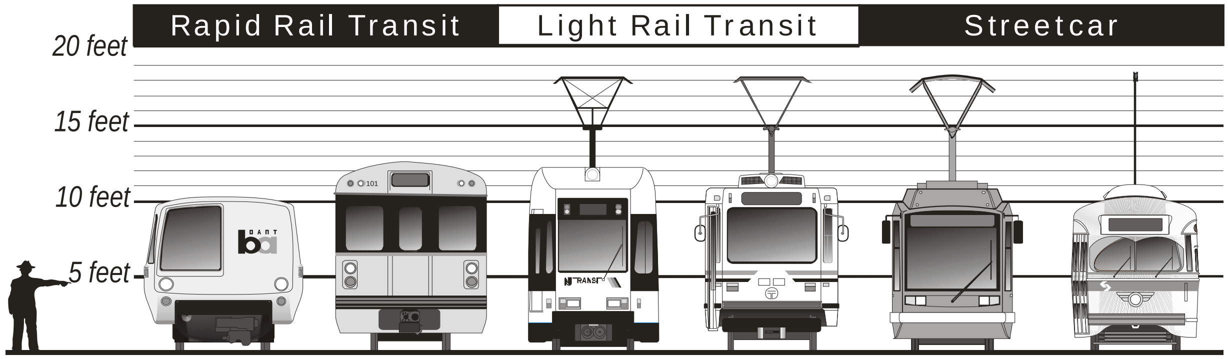
TABLE 1 HBLR Engineering Systems and Subsystems

System	Subsystem
1.0 Rolling stock	1.1 Light Rail Vehicles 1.2 Non-Revenue Rail Equipment 1.3 Track Cars/Hi-rail Equipment
2.0 Electrification	2.1 Substations 2.2 Overhead Contact System 2.3 Stray Current Mitigation
3.0 Track	3.1 Ballasted Track 3.2 Embedded Track 3.3 Direct Fixation Track 3.4 Special Track/Ballasted 3.5 Special Track/Direct Fixation 3.6 Miscellaneous Trackwork
4.0 Train Control	4.1 Interlockings 4.2 Train Separation-Automatic Train Protection 4.3 Signal Power 4.4 Wayside Equipment 4.5 Intrusion Detection 4.6 On-Board Equipment 4.7 Grade Crossing Protection
5.0 Communication	5.1 Telephone 5.2 Passenger Information Subsystem 5.3 Security Subsystem 5.4 Communication Backbone 5.5 Radio 5.6 Systems Control and Data Acquisition
6.0 Integrated Control System	6.1 Workstations 6.2 Software/Hardware 6.3 Traffic Operations Interface

System	Subsystem
7.0 Fare Collection	7.1 Ticket Vending Machines 7.2 Ticket Validators 7.3 Software
8.0 Administrative Systems	8.1 Maintenance Management System
9.0 Traffic Operating System	9.1 Traffic Signals 9.2 Light Rail Transit “Bar” Signals 9.3 Area Controller 9.4 Local Controllers 9.5 Local Network
10.0 Stations	10.1 Plaza 10.2 Platforms 10.3 Stairs & Structures 10.4 Parking
11.0 Right-of-Way	11.1 Drainage 11.2 Fencing 11.3 Minor Structure 11.4 Slabs 11.5 Line Equipment
12.0 Tunnels	12.1 Ventilation 12.2 Fire Protection 12.3 Egress Facilities 12.4 Structure 12.5 Electrical 12.6 Drainage Subsystem
13.0 Guideway	13.2 Viaduct 13.3 Major Bridges
14.0 Shop	14.1 Electrical 14.2 Mechanical 14.3 Electronics 14.4 Local Communications 14.5 Special Equipment 14.6 Structure
15.0 Yard	15.1 Ladders & Leads 15.2 Car Storage Building

(SCR). These are “Rolling Stock” and “Train Control” (System 1.0 and System 4.0, respectively, in Table 1).

LRVs are distinguished from RRT rolling stock by their capability for operation in mixed traffic, generally resulting in a narrower car body and articulation in order to operate in a mixed-traffic street environment (Figure 3). Conversely, LRVs generally outperform SCR vehicles in terms of capacity and top end speed, and almost all modern LRVs are capable of multiple-unit operation. Particularly on exclusive ROW, the LRV can provide much higher “production” (i.e.: capacity multiplied by scheduled speed) than a SCR. Thus a 45-mph SCR operating on exclusive ROW cannot be considered as “light rail”. The latest generation of LRVs is significantly larger and faster than their predecessor, typically of length of 90 ft with maximum speeds of 60 to 70 mph.



Manufacturer	Rohr	Budd	Kinkisharyo	Siemens Duwag	Sköda-Inekon	St Louis Car
Model	BART A-Car	PATCO	HBLRTS	SD-400	10 T	PCC
Width	10.5 feet	10.0 feet	8.8 feet	8.7 feet	8.0 feet	8.3 feet
Length	75 feet	66.3 feet	89.6 feet	81.7 feet	67.0 feet	46.5 feet

SCALE APPROXIMATE

FIGURE 3 Comparative size of rail transit rolling stock.

Partial low-floor; high-performance cars offering good ride quality, as typified by the HBLR car, represent the coming generation of LRVs.

LRT train control practice differs from RRT [where Automatic Train Operation (ATO) is the present day norm] and from SCR [where line-of-sight operation (LOS) is the norm, augmented perhaps by limited signaling at turnouts, stations, or other critical locations]. Train control practice for light rail is currently evolving (that represents an area requiring attention from the operational community) and can currently be categorized by two factors. They are:

- "High end" technologies are typically limited to cab signal application with ATP, with many LRT operations employing only Automatic Block Signaling (ABS) on exclusive right-of-way route segments.
- LRT will generally utilize multiple types of train control over a given route. This is also a function of the variety of ROW types.

A derivative of LRT is light rail rapid transit (LRRT), also referred to as "Light Metro." Such railways are characterized by fully exclusive ROWs, "high end" train control systems with short headway capability, and floor level boarding. The HBLR fits this category, as does Los Angeles Metropolitan Transportation Authority Green Line and SEPTA Route 100.

The final "system" crucial to LRT is the train operator. Unlike modern RRT operating with ATO/ATP, the operator is a key element in a safe, high-quality LRT operation; a "train attendant" concept will not suffice. A LRT operator must be trained, qualified, observed, and periodically re-qualified. While this imposes responsibilities upon operational supervision, it also pays dividends when considering innovative operating practices. In many respects the operator of a light rail train more closely resembles the engineer on a commuter train than a "train attendant" on an ATO System.

CASE STUDY: HBLR BAYONNE FLYER

Role of Systems Engineering

While a large body of literature exists regarding the techniques and customer service implications of expedited service [e.g.: Vuchic (*7*) and Eisele (*8*)], little exists that analytically relates the design of engineering systems to a particular technique of expedited operations. This case study addresses zone express operation and delineates specific engineering design requirements that were critical to supporting this capability. The systems with the most significance to these operations are:

- Train control (block layout, reverse running);
- Track (turnouts, sidings);
- Integrated Control Systems (ICS);
- Vehicle (performance, configuration);
- Stations (signage, walkways); and
- ROW (high-speed operations, high confidence control of schedule performance).

HBLR presently provides revenue service between Hoboken Terminal and 34th Street, Bayonne, and between Hoboken Terminal and West Side Avenue (see MOS-1 in Figure 2). Extensions to 21st Street in Bayonne and to the north of Hoboken (see MOS-2 in Figure 2) are scheduled to open in November 2003 and March 2004, respectively. HBLR is a complex system with an intermediate terminal located on a branch (Hoboken) accessed through a half grand union junction.

- The line to Bayonne was constructed on the former four-track mainline of the Central Railroad of New Jersey (CNJ), providing am exclusive, high-speed ROW free of grade crossings (one active freight track remains, paralleling the two LRT tracks).
- The West Side Line is built on the exclusive ROW of the former CNJ Newark Branch. It consists of two LRT tracks with one street intersection and two gated grade crossings.
- Between Yard North (the junction between the Bayonne and West Side Lines, near Liberty State Park) and Marin Boulevard, HBLR consists of two tracks built on former CNJ railroad yards. While on exclusive ROW, speeds are generally limited from 15 to 25 mph due to track geometry and a number of street intersections.
- The tracks enter mixed traffic north of Marin Boulevard while the tracks enter mixed traffic. Cab signals are “latch” out and trains continue the approximately 1.5 mi on LOS operation (full train control cab signal with ATP/ATC exists elsewhere on HBLR).

HBLR initially opened on April 15, 2000, with service between 34th Street/West Side Avenue and Exchange Place. Service was extended a year later to Newport, then to Hoboken Terminal on September 29, 2002. A simple (“vanilla”) operating plan was originally envisioned that did not anticipate any form of expedited service.

Bayonne Flyer-Morning Peak

Following a relatively short shakedown period after the April 2000 opening, a 12-min peak hour headway was established on both branches. The individual branch services combined to provide a 6-min headway on the trunk between Yard North and Exchange Place.

Ridership on West Side trains was light south of Liberty State Park. While Bayonne trains were not at crush loads, high ridership was observed at 45th and 34th Street Stations, each of which have large park-and-ride lots. Selected trains in the peak period had large numbers of standees when they arrived at Liberty State Park. Options for providing extra capacity at these stations included:

- *Use of two-car trains on Bayonne Line.* This was rejected as inefficient with respect to rolling stock utilization. Interline operation of trains provides optimal usage of LRVs, use of two-car trains on Bayonne would require alteration of this practice or else cause wasteful interline operation of these two-car trains over the lightly patronized West Side Branch.
- *Reduced headways on Bayonne.* This was rejected since the ridership during the three-hour peak did not justify establishing shorter peak period headways, and ridership at stations other than 34th, 45th, and Liberty State Park did not justify such action.
- *Use of extra trains.* Based on a detailed, train specific ridership survey a total of three additional departures were scheduled at maximum load times. Ridership at other stations served by Bayonne trains was light, with the exception of Liberty State Park. Therefore, it was decided to operate these trains as zone expresses—named "Bayonne Flyers"—originating at 34th Street and stopping only at 45th Street and Liberty State Park enroute to Exchange Place. This would provide a premier, high-speed service for commuters.

Flyers were scheduled to operate the 5.1 mi to Exchange Place in 14 min, resulting in a commercial speed of about 21.5 mph (which includes a mile of in-street running). This represents a 5-min improvement on the local schedule between these points. It should be noted that the Bayonne Flyers originated as a means of providing additional capacity. An improved product stimulates demand and there are currently six morning Flyers are operated on 24-min headways.

While the Flyers operate as a zone express, they must be scheduled without interference or delay to any local trains. Figure 4 illustrates the morning Flyer operation using a simplified stringline. Of relevance from the perspective of engineering systems is:

- *Train Control.* HBLR is equipped with a cab signal system with ATP/ATC providing theoretical headway design for train separation of 90 to 120 s. The Flyer can close to within 90 s of its "leader" without being penalized by a "cab signal" downgrade.
- *Interlockings.* Headway capability at Yard North interlocking for alternating movements if 120 to 150 s. This headway degradation below "fleeting" capacity is due to the length (which includes a yard lead) of this interlocking.
- *Stations.* Bayonne Line stations are island platforms and all pedestrian walkways are located across the southbound track. The entire northbound track is clear of pedestrian walkways.

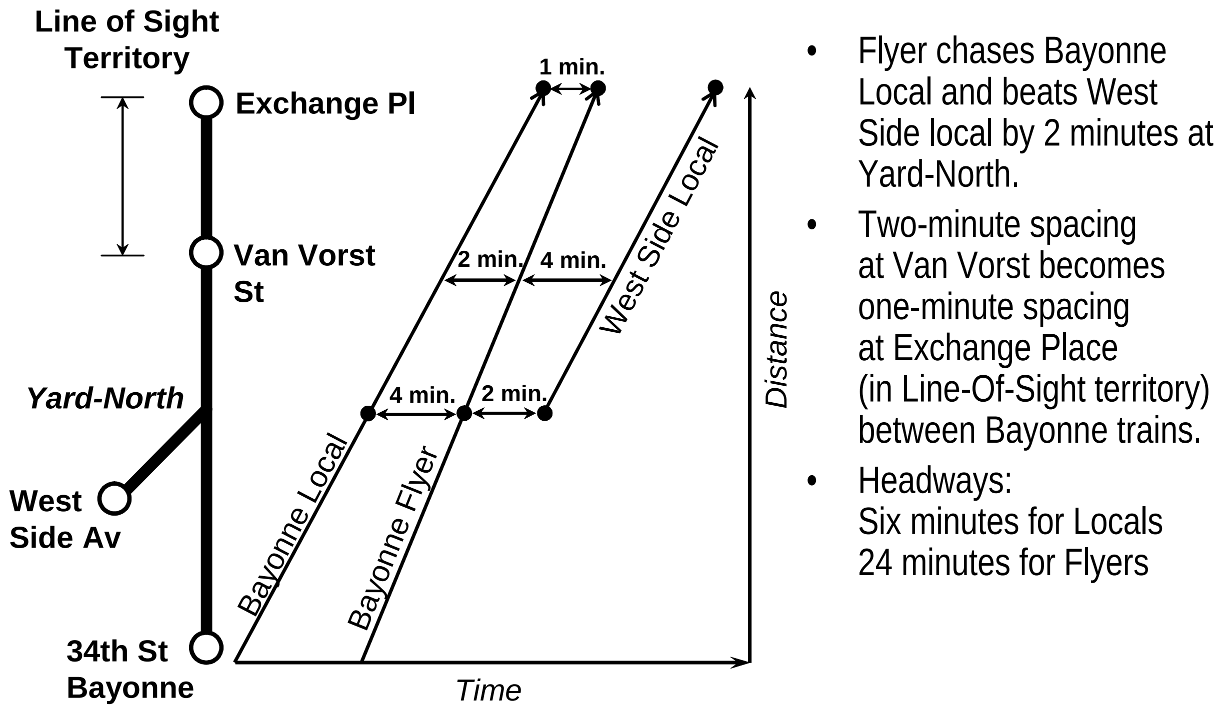


FIGURE 4 Time–distance diagram for northbound morning flyer.

- *Traction Power & Track.* These systems were constructed to be capable of supporting 80 mph operation, well above a maximum authorized speed of 57 mph; all curvature to accommodate widening of track centers is on southbound track.

Figure 4 shows that the "schedule point" for Flyers is at Yard North. Schedules for all trains were built from this point with Flyers scheduled to arrive at this interlocking 2 min ahead of trains from West Side Avenue. This placed Flyers 4 min behind their "leader" (a local from Bayonne). Since Flyers traverse the Bayonne Branch 2 min faster than locals, the Flyer departure time from Bayonne was set at 6 min after the Local, positioning it to address "peak of the peak" demand.

From Liberty State Park to Exchange Place Flyers bypass three stations, two of which are within train control territory. In this section the Flyers gain an additional 90 to 120 s on their leader as they cross Van Vorst Avenue. At that point, they have used up all of the spare capacity provided by the train control system and are about to "catch" their leader (i.e., begin to experience cab-downgrades), when they enter street running territory. North of this location, train separation is maintained by LOS operating rules and in bypassing Essex Street the Flyer closes to within 60 s of its leader.

Figure 5 shows signal control lines for clear capacity and "ghost" slots overlayed on the stringline. The "slot" for the Flyer is scheduled for clear capacity and overtakes "ghost slots". If the line were operating at capacity, a real train would occupy each ghost slot and it would not be possible to schedule the Flyer as a zone express. In such a case, a "skip-stop" service might be implemented as an alternate to a zone service.

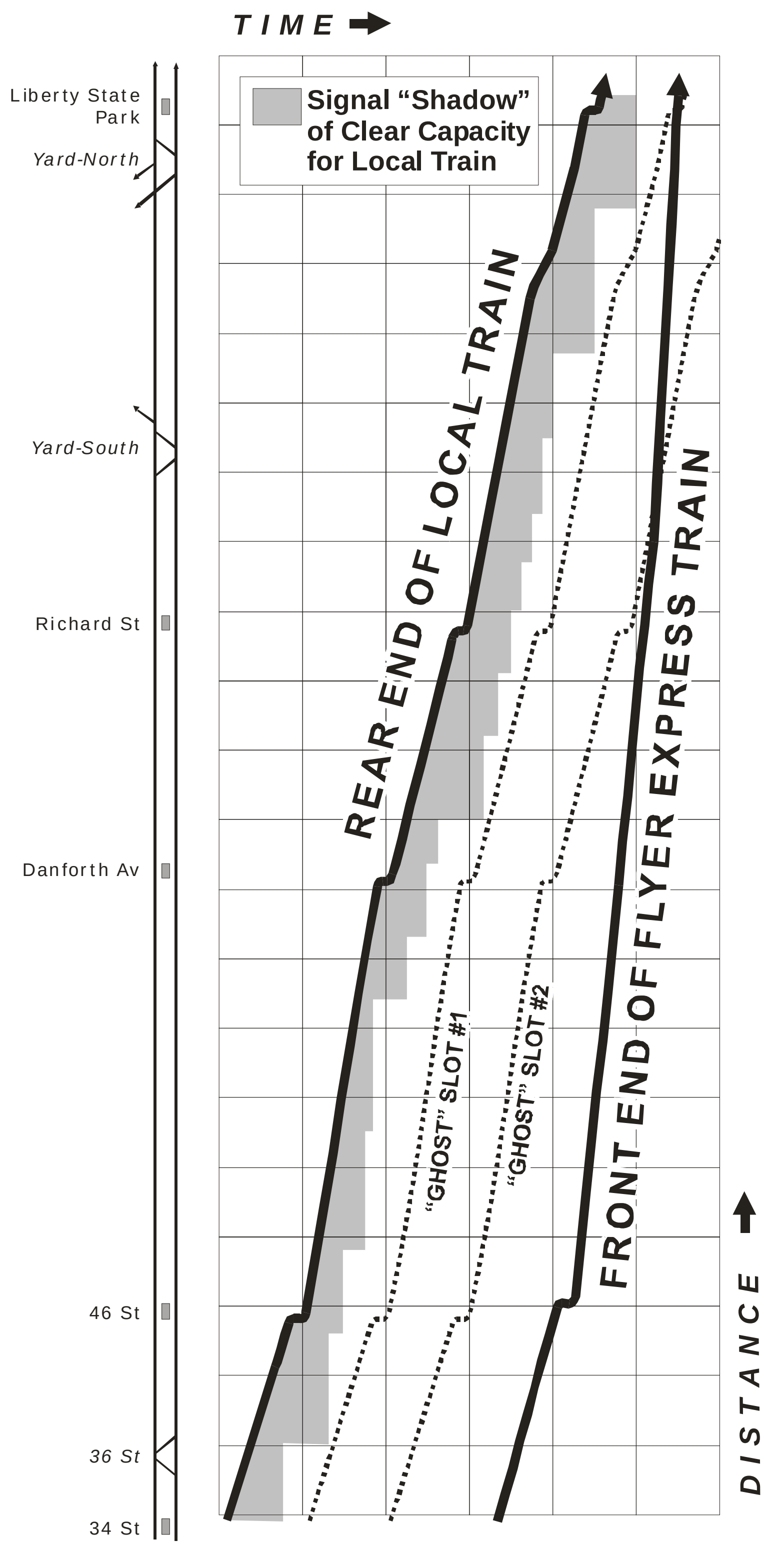


FIGURE 5 Time–distance/signal control diagram for northbound morning Flyer

Prior to implementation of Flyer operation, a system safety review was conducted; as a result the following measures were implemented:

- All Flyers are marked with special signage and operate with flashers on.
- Maximum speed of station by-pass is at 45 mph; this causes the train operator to take positive action to control the train.
- Horns or bells are utilized when bypassing stations.
- Operation of the Flyers is given specific surveillance by train controllers.

The Evening Bayonne Flyer

With the success of the morning Flyers, customer demand arose for an evening peak express. The configuration of the Bayonne Line stations, with unprotected pedestrian crossings (except for static signage) across the southbound track, presented special challenges in “retrofitting” a zone express operation onto a railway designed only for local service. System safety review determined that—as a minimum—fully active gate and flasher protection would be required for operation over these crossings at speed.

The operational design of the evening express considered other options such as operating only the Flyers south on the northbound track. Stringline analysis validated by field tests showed that this would cause delays to local trains. The best “reverse fit” of an evening zone express, given the existing system configuration, was in operating the entire Bayonne Line “left handed” during evening peak hours. The dispatching pattern around which schedules were developed is illustrated in Figure 6, and the stringline for the evening operation is illustrated in Figure 7.

The low speed design of the turnouts is an important factor in determining the dispatching pattern. The Flyers cross over within low speed (25 mph) territory, thereby minimizing the time lost. Due to congestion at Yard North, Locals cross over at another low speed interlocking (Yard South). Because Yard South is comprised of 15 mph turnouts within 55 mph territory, an approximately penalty of 30 s is incurred to the running time of local trains.

Note that the basis of operation for the morning Flyers differs from the evening in that the zone express “chases” a West Side Branch train from Exchange Place. The schedule point for designing evening timetables is the 2 min after West Side Locals.

Table 2 provides a summary of engineering systems which were critical to the Flyer operation.

Next Steps

Construction of MOS-2 is nearing completion and conceptual design of MOS-3 extensions in Bayonne and northward into Bergen County are well underway. Expedited train movements have been an on-going consideration throughout the development of MOS-2 and -3, in contrast to MOS-1 where the Flyers were retrofitted into a system designed only for Local trains. MOS-2 operations north of Hoboken will likely combine a zone express service with overtake tracks, while MOS-3 may entail multiple zone express trains overlaid in the manner demonstrated by the P&W.

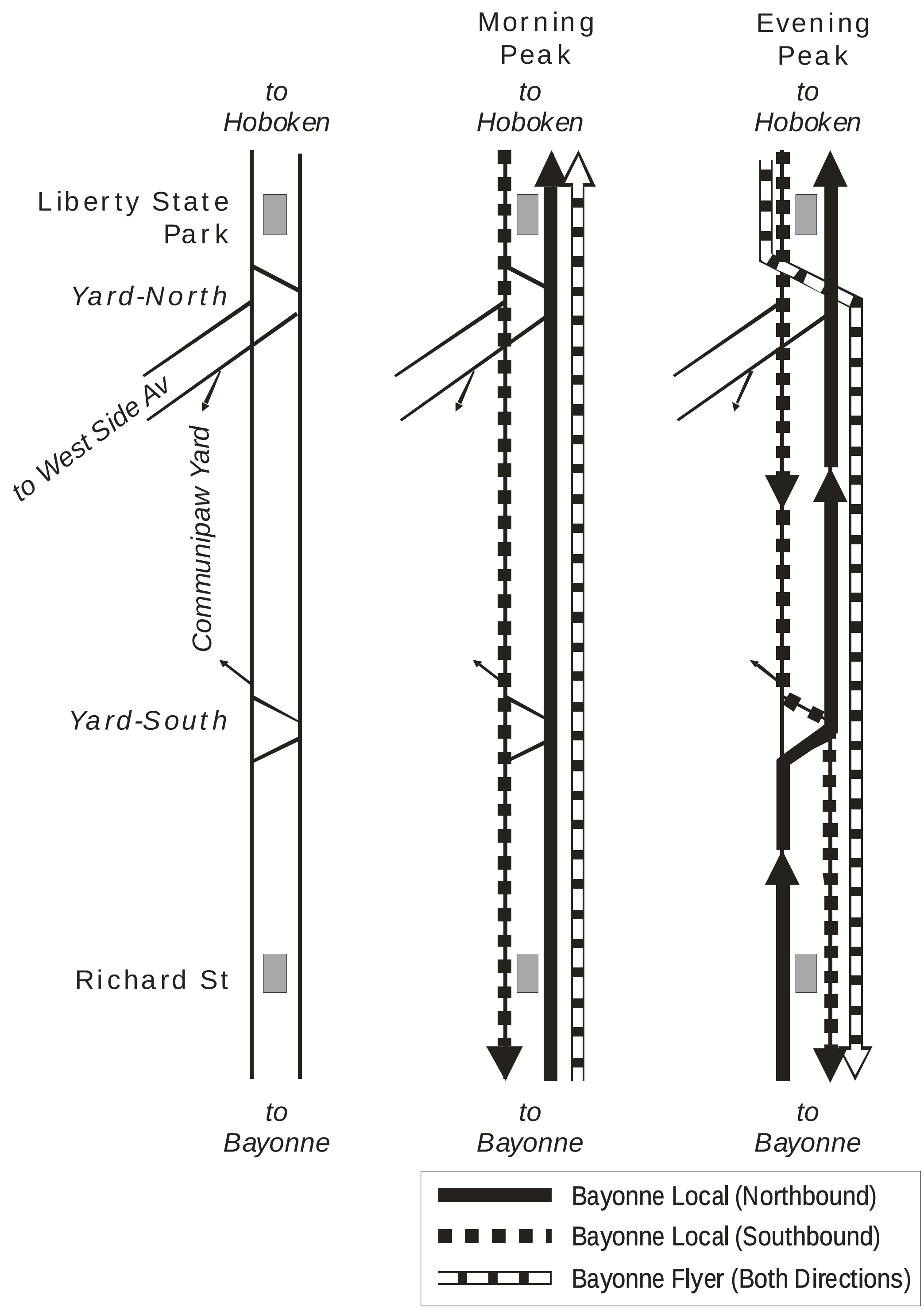


FIGURE 6 Time–distance diagram for northbound morning flyer.

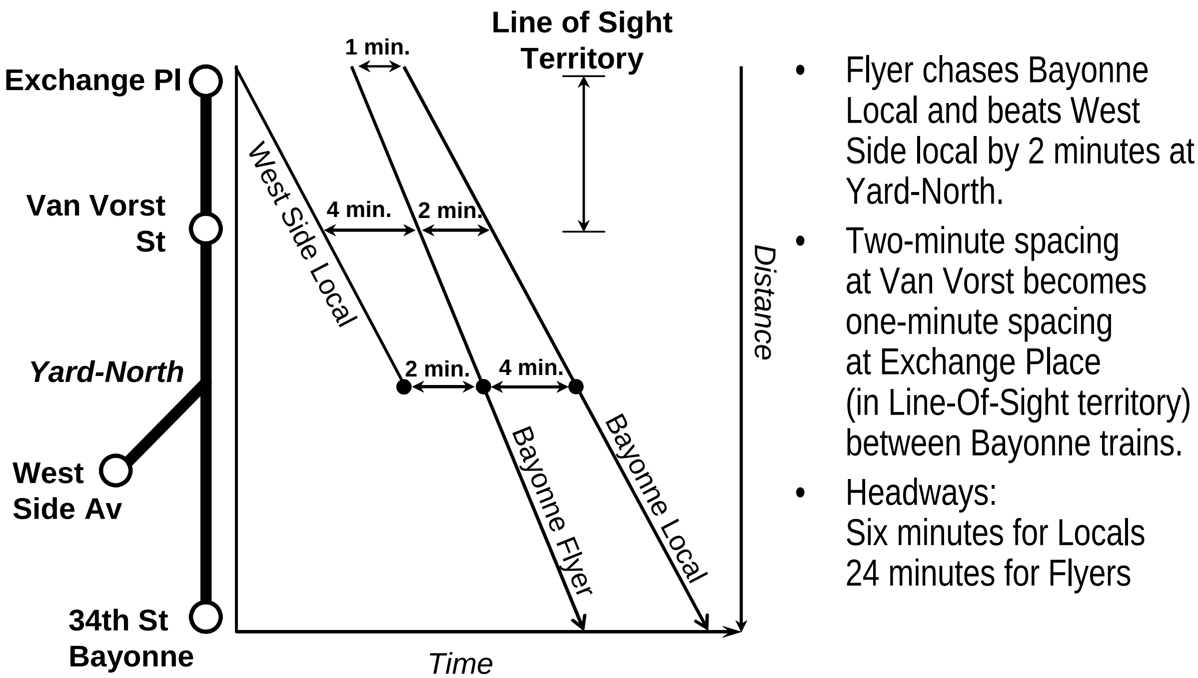


FIGURE 7 Time–distance diagram for southbound evening flyer.

TABLE 2 Systems Utilized for Flyer System

System	Functionality Utilized	Desired Improvement
Track	High Speed.	Low speed crossovers are unsuitable. Need higher speed.
Train Control	2-min headway capability permits “zone” express operating on 5-min headway. Reverse signaling at 2-min headway permits evening Flyer.	None.
Stations	Island platforms on Bayonne Line conform to reverse operation. Signage does not conform to reverse operations.	Pedestrian walkways across southbound tracks are unsuitable for express.
Supervisory Control (ICS)	Permits convenient reversal of Bayonne Line and effective and timely train management.	Overview display required at control center to improve SA.
Right of Way	Exclusive run on Bayonne Line favors high speed and precise scheduling.	

CONCLUSION

Innovative operational practices to expedite train movements can reap benefits in terms of customer service and operational efficiency. They are often confounded, however, by current LRT design and deployment methods. This is partly attributable to design methods that follow a "stovepipe" approach to individual engineering disciplines and components, rather than directing focus on optimizing railway functionality and flexibility as a comprehensive entity. It is also attributable, in part, to a failure to address the ultimate potential of a railway at the definition/developmental stage and to subsequently articulate and document the operational requirements that are necessary to support the stated mission.

Implementation of the HBLR Bayonne Flyers demonstrates that a comprehensive design approach that combines attention to the details of operational planning and critical engineering systems can yield significant dividends in system performance. It illustrates a model relationship between operations and systems design that resulted in the implementation of the first zone express service on a modern LRT system, showing the way that leads to moving beyond vanilla.

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San Diego Trolley
From Super Bowl Rookie to Super Bowl Veteran

TOM DOOGAN
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JUDITH LEITNER
Metropolitan Transit Development Board

Every January the National Football League (NFL) presents its premier sporting event of the year in a major United States city. The selection of the host city is based on a rigorous competition involving countless factors. The winning host city expects to receive millions of dollars in economic benefit plus equal or more value through major media on-air and print exposure in the months leading up to the game and during Super Bowl Week.

The NFL has selected San Diego to hosted the Super Bowl three times—in 1988, 1998, and 2003. San Diego Trolley, Inc., (SDTI) became a "major player" during San Diego's 1998 Super Bowl Week when more than 500,000 fans used the Trolley to go to the various events and the game. And that was one of the factors that contributed to San Diego being selected to host the game in 2003.

Together, SDTI and the Metropolitan Transit Development Board Regional Marketing Team leveraged their experience and lessons learned from the 1998 and subsequent special events and provided an entire new game plan for providing service and marketing.

This paper will provide history of public transit's role at the 1988 and 1998 games plus compare and contrast the operating and the marketing strategies, activities, and outcomes for the 2003 game. The 2003 strategies were developed based on previous experience and the goals and objectives set by the NFL and the San Diego Local Host Committee, and new opportunities and challenges that arose in the interim.

INTRODUCTION

San Diego has hosted three National Football League (NFL) Super Bowl games—Super Bowl XXII in 1988, Super Bowl XXXII in 1998, and Super Bowl XXXVII in 2003. San Diego, like other cities, vigorously competes to host the event in the same way cities and countries compete to host other major special events like the World Cup or the Olympic Games. The motivation is the expectation of significant economic impact plus major media exposure.

A study commissioned by the San Diego Super Bowl XXXVII Host Committee (SBHC) and the NFL (*1*) estimates that Super Bowl XXXVII generated $367 million in San Diego. The region also received extensive media exposure in the months and days leading up to the game and during the game where advertisers spent upwards of $2 million for a 30-sec commercial (*2*).

The Super Bowl itself has transitioned from what was initially a football game with minimal pre-game hype in 1966 to an actual celebration of the sport with significant media and corporate hype. Once a city is selected, the committee begins a multiyear planning process to address countless issues for the game and the associated special events that cover a 7- to 8-day period. One of the primary areas of planning is on transportation to the game and events.

When the NFL selected San Diego to host the NFL's January 2003 Super Bowl Game, the goal was for the NFL and San Diego Trolley, Inc., (SDTI) to leverage their experience from the 1998 game. That experience, plus heightened security concerns due to September 11, 2001, (9/11) terrorist acts, created an entirely new "game plan" for service and marketing SDTI.

While previous Super Bowls have generated significant transit ridership, there had been renewed interest in pre- and post-game public transportation due primarily to restricting Qualcomm Stadium's parking lot for other activities such as corporate hospitality, media set-ups, NFL invitation-only tailgating, and emergency services.

In 2002, tightened security intensified the need to eliminate almost all parking at the stadium as part of the additional mandated security measures due to 9/11. Because the strong security focus has continued, the 2003 game also included plans to eliminate almost all parking at Qualcomm Stadium.

Transportation consultants began meeting with local authorities approximately 1 year before the game. During these initial meetings, general plans were developed that provided local transit representatives with a broad perspective of the issues that required attention. Also participating in these meetings were members from the local SBHC and law enforcement.

For Super Bowl XXXVII, virtually all of San Diego Qualcomm Stadium's 19,000 available parking spaces would be unavailable for general parking, and all recreational vehicle parking was eliminated. Approximately 3,000 spaces were to be reserved for special VIP pass parking (limousines), disabled individuals (Americans with Disabilities Act), and reserved charter buses (which would take up the majority of these spaces).

OPERATING PLAN OVERVIEW AND STRATEGIES

With the ban on general parking and the experience from the 1998 Super Bowl, it was understood that public transit would shoulder the responsibility for carrying the majority of fans to the game with SDTI expected to be the largest ground transportation element for the game as well as most of the downtown Super Bowl events. The challenge for Super Bowl XXXVII was to create a plan that would allow SDTI to maximize resources to serve the highest expected demand in its history. This required executing a plan that would:

- Balance passenger loads between the Trolley and the local buses serving the game, and
- Allow the Trolley to adequately serve other Super Bowl special events located in downtown.

These challenges were made even more complicated by the need to address overriding security concerns.

Emphasis on Security

Super Bowl XXXVI (January 2002) held in New Orleans took place within months of 9/11. As a consequence, the event was designated a National Special Security Event (NSSE). The NSSE status is provided to any event determined to be of national significance. The results of such a designation required federal authorities such as the Federal Bureau of Investigation (FBI), U.S. Secret Service, and Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) to maintain primary responsibility for determining the appropriate security measures that would be incorporated into the planning of the event. Further, while local and state police authorities were involved, they assumed a secondary or support role to federal authorities.

For Super Bowl XXXVII, the city and governor of California both requested NSSE status, but the Department of Homeland Security (DHS) rejected the request. Instead, the DHS granted a special Level 2 status, giving state and local police authorities the primary role with federal agencies providing secondary support. However, by all accounts, security measures were determined to be at a level that would have been consistent with measures initiated had the NSSE status been granted.

The two primary areas of security focus at the stadium involved establishing a perimeter control barrier that varied in location but was generally established at 300 ft from the stadium structure. The reinforced barrier also contained several sections with clusters of 20 or more magnetometers through which all fans would pass for security clearance.

Additionally, the event was determined by the city to be an “overflow capacity event.” This determination allowed the city to impose entry restrictions so only those with Game Day tickets or special NFL credentials were allowed access into the stadium from either the Trolley station area or into the parking lot.

Security Orientation and Drills

SDTI security and safety staff personnel, in conjunction with San Diego Transit (SDT), coordinated with local, state, and federal authorities in a variety of drills and orientation sessions.

- Multi-agency simulated terrorist disaster drill simulated a bomb exploding on a bus under the light rail transit (LRT) stadium station. All local, state, and federal (FBI) authorities participated. Various technical issues and response protocols were generated and applied to plans for Super Bowl XXXVII. The San Diego MTS director of transit security acted in a lead role and funds to cover the cost were generated by an FTA grant.
- On-site training at light rail vehicles (LRV) facilities familiarized ATF agents and specially trained bomb-sniffing dogs with the unique characteristics of LRVs and station facilities.
- Approximately 75 FBI Terrorist Response Team agents developed a variety of tactical approaches to entering an LRV that was otherwise secured.

Super Bowl Game and Associated Events

The NFL and SBHC worked over the course of a year and developed a variety of events including: recognition for community projects, VIP-ticketed events, general public ticketed events, and free public celebrations. Some (but not all) of the planned events affected public transportation:

- Martin Luther King Jr. Parade……………. ....Saturday, January 18, 2003;
- Multi-Cultural Festival..Saturday, January 18, 2003;

- NFL Experience..Sat.–Sun., January 18–19, 2003;
- NFL Experience (continued).....................................Thurs.–Sun., January 23–26, 2003;
- Super Hub/5th Quarter in the Gaslamp......................Thurs.–Sun., January 23–26, 2003;
- Cultural Arts Bowl and Festival ....Thurs.–Fri., January 23–24, 2003;
- Concert Series at Embarcadero.................................Fri.–Sat. January 24–25, 2003;
- Downtown Fireworks..Saturday, January 25, 2003; and
- Super Bowl Game..Sunday, January 26, 2003.

With the exception of the game, all of the above events including the Fireworks, NFL Experience, and Super Hub/5th Quarter (which drew the largest crowds), were held in the downtown area along the Bay and in the Gaslamp Quarter. On Saturday night, the Fireworks and NFL Experience attracted a combined estimated crowd in excess of 200,000. Both events ended at the same time, creating a tremendous burden on the road network and Trolley service.

Lessons Learned from Super Bowl XXXII

In the aftermath of 1998's Super Bowl XXXII, a final report (*3*) prepared by the city of San Diego addressed a variety of issues and occurrences that took place on Game Day affecting transit services. SDTI undertook its own "lessons learned" report (*4*) to look at planning strategies and several equipment failures that affected the Trolley's efficiency with which service was provided. Both reports concurred that San Diego should:

- Develop a plan to provide a better mode split between LRT service and regional bus services. In 1998 over 29,000 used LRT service to the game while bus service ridership barely exceeded 1,000.
- Develop a more efficient means of handling pre- and post-event crowds at Qualcomm Stadium Station by reducing platform overloading.

In addition, the Trolley report concluded it should:

- Incorporate a train location feature to provide central control personnel more efficient monitoring of train movement.
- Install wayside emergency access gates in the vicinity of the golf course (about 4 mi west of the stadium).
- Purchase permanent manual ticket sales booths for Mission Valley Station locations where recurring high ridership is generated.
- Increase post-game service operations on the Mission Valley segment in order to improve over-the-line efficiency between Qualcomm and Old Town.
- Maximize pre-ticketing of fans and enhance use of the MTS website.
- Modify Mission Valley traction power substations to provide pass-through power from adjacent locations in the event of loss of an individual substation.
- Develop a contingency plan for sustaining a high degree of LRT service by strategically staging reserve backup buses in the downtown and Mission Valley areas.

While all of the elements contained in the Trolley report were implemented, installed, or acted up favorably before the 2003 game, it should be noted that several of the items noted occurred as a result of only 2 months of operating experience on the new segment serving the stadium. By the time the 1998 Super Bowl Game was played, SDTI had only provided service to two football games.

Between the 1998 and 2003 Super Bowl, SDTI had handled more than 500 special events along the Mission Valley West route including: Major League Baseball's 1998 Championship Playoff, Pennant, and World Series Games; 81 Padres baseball home games; 10 Chargers football home games; a Rolling Stones concert; and the annual college Holiday Bowl Game.

This wide variety of experience allowed SDTI to refine its operations to efficiently handle large crowds during capacity stadium events. This has also given staff at all levels significant experience in dealing with equipment, line operational characteristics, crowd handling/platform control, and service efficiency variations.

NFL Recommendations

The NFL relied heavily on SDTI staff to develop the plans for Trolley service levels, however the NFL recommended that SDTI:

- Develop a plan to deploy reserve buses in the event of a system failure. The NFL's initial request for 100 buses was pared down to 35 to be situated at various locations. This included small clusters of buses at locations along Harbor Drive (covering the Bayside area) to a variety of other locations covering Old Town and stations along Mission Valley. SDTI provided these buses and all drivers were given special route maps to a precise route if supplemental service was deemed necessary.
- Maintain an additional fleet of stand-by buses to use during the post-game time frame to relieve the anticipated crowding and excessive waits. The plan called for a total post event stand-by bus fleet of 85 to 100 units. Of this number, 35 were to be redeployed from the SDTI pre-event pool and the remaining number (50 to 65) would be dispatched from the main bus park-and-ride lot as described in more detail in the next section.

Bus Service Summary

Fans

Rather than repeat the 1988 and 1998 Super Bowls plans which offered bus service from a series of satellite park-and-ride lots, the NFL worked with the region's public bus operators, SDT, North County Transit, Chula Vista Transit, National City Transit, County Transit System, and ATC Vancom to create a single lot that was sufficiently large enough and strategically located to attract fans coming to the game from locations north of Interstate 8.

The lot selected was approximately 4 mi north of the stadium and could accommodate up to 8,000 cars. The NFL arranged for an overflow lot nearby for an additional 3,000 vehicles. Motorists could only enter if they had game tickets and paid $10 per vehicle. All occupants received round-trip bus service to the game. The NFL handled all arrangements and paid $60 per-bus, per-hour to the regional transit agencies for providing the 109 buses.

There were some communication difficulties between the bus operators and NFL representatives. Some of the issues related to insufficient NFL personnel to provide necessary directives to bus operators. Also, bus operation directions were changed at the last minute. Bus operator supervisors were quick to track down the problems and arrive at immediate solutions, thus eliminating complaints by attendees as well as operational oversights like sending out for water and refreshments for drivers and other staff.

Stadium Employees

Since there was no room for stadium employees to park at the stadium, a separate lot was used as a park-and-ride lot for stadium employees. SDTI operated this service beginning at 4:30 a.m. and continuing until 10:00 p.m.; 3,300 employees took advantage of this service.

Light Rail Service Plans

Enhanced Service by Day and Time

Service level adjustments were made to coincide with Super Bowl events anticipated to have an impact on Trolley ridership based on their location and projected attendance. Enhanced LRT service consisted of one or more of the following components:

- Increased frequency,
- Increased consist size,
- Extended hours of operation, and
- Overlay of special Green Line and special trains. The Green Line's direct service between the Convention Center area and adjacent hotels to Mission Valley was the most important component of the game day plan (Figure 1)

Super Bowl Week events officially opened the weekend before the Super Bowl Game with the opening of the NFL Experience and continued in varying degrees until the close of the Super Hub/5th Quarter in the Gaslamp activities that continued after the game ended Sunday until early Monday morning.

Special Run Pick

The scope of the operating plan was to manage available resources (i.e., equipment and personnel) in a way that allowed for maximum efficiency. Train operator assignments were adjusted to better distribute the workload over the course of each operating day, which would require fewer train operators to facilitate. The train operators were then able to bid their shifts based on seniority. This exercise was a critical element and the key reason that the level of service needed, could be offered. Under normal circumstances, this amount of service would have required a greater number of personnel to operate.

FIGURE 1 SDTI special event service map.

Game Day Operations

Game-day service enhancements were designed to provide a sufficient level of service between downtown and Qualcomm Stadium through increased service on the Blue Line and Orange Line plus an overlay of additional service on the special event Green Line. The adjustments were based upon past experience and projections.

Blue Line

Normal Sunday 30-min headway would increase to 15-min service by 8:00 a.m. and every 7½ min at 10:00 a.m.

Green Line

Begin 15-min service at 8:00 a.m. and every 7½ min by 10:00 a.m.

Orange Line

With the increased number of Blue and Green Line trains operating on the Bayside and through downtown, it was determined that normal Orange Line service would add unnecessary traffic congestion on these corridors. Instead, Orange Line trains would terminate at a temporary station east of the 12th and Imperial Transfer Station starting at 8:00 a.m. on Game Day. This also provided additional vehicles as the Orange Line fleet requirements were reduced by two two-car train sets.

Mission San Diego Station

The tracks to this station, east of Qualcomm Stadium, were needed to store trains on game day. Therefore on Super Bowl Sunday, wheelchair accessible shuttle bus service carried 593 passengers between the Mission San Diego and Rio Vista Stations from 8:00 a.m. to 10:00 p.m.

Supplemental Mission Valley Service

Two four-car Trolleys were coordinated to meet the four Coaster train arrivals at the Old Town Transit Center. (The Coaster is a commuter rail line service operating along a 40-mi route between Oceanside and Downtown San Diego.)

This extra capacity provided adequate service for the hundreds of transferring Coaster passengers without overburdening the other Trolley trains operating at near capacity through Mission Valley. In addition, these special four-car trains also provided extra service between Hazard Center and the stadium to ease congestion through Mission Valley.

Post-Game Service

Eighteen trains were scheduled to be stored east of the stadium in preparation for post-game crowds. A number of additional consists were also to be sent from the yard during the game.

Game Day Results

Well over 9 h before kickoff on Super Bowl Sunday, the first extra Blue Line train departed the yard to begin service to Qualcomm Stadium. This was the first step toward the full deployment of the SDTI game-day operating plan. The expanded service was implemented in stages based upon expected ridership demands as shown in this game day implementation schedule summary:

Pre-Game Service

5:52 a.m.—With the Blue Line operating every 30 min, the first extra train begins service in order to increase the frequency to 15-min intervals throughout the Blue Line by 8:00 a.m.

8:00 a.m.—Special Event “Green Line” service begins operating at 15-min frequency between the Bayside/Convention Center area and Qualcomm Stadium. The combined service through Mission Valley is averaging every 7½-min. Alternative shuttle bus service begins operating between the Mission San Diego and Rio Vista Stations.

Westbound Orange Line service begins terminating at temporary station just east of the 12th and Imperial Junction. The Orange Line is still operating a normal 30-min headway and the expanded Blue and Green lines provide an adequate alternative for transferring passengers. The Mission San Diego Station is closed and shuttle bus service begins.

9:00 a.m.—Two four-car trains depart the yard to meet the southbound Coaster trains at Old Town Transit Center. In addition to facilitating the transfer passengers from four Coaster arrivals, these trains run intermediate trips between Hazard Center and the stadium. A total of five trips originated at Hazard Center between 11:45 a.m. and 1:45 p.m. Passenger volume had declined significantly by 2:00 p.m. At that point, these trains continue to operate trips between Old Town and the stadium as needed.

10:00 a.m.—Green Line service frequency increases to 7½-min intervals, which doubles the amount of service. Blue Line service between downtown and the stadium is also increased by the same amount. By 10:32 a.m., the first additional train reaches the stadium and service frequency through Mission Valley is now operating at a system capacity of 3.75-min. This level of service remains in place for 5 h, until the 3:25 p.m. kickoff. The Orange Line transitions to regular 15-min frequency.

2:36 p.m.—Although almost 50 min remains before kickoff, ridership has slowed to a trickle into the stadium. Event trains begin being stored east of the stadium station for post-game service. Orange Line service resumes downtown shortly after 3:00 p.m. Regular Blue Line service continues to terminate at the stadium.

5:00 p.m.—All event trains are in place east of the stadium and ready for post-game service.

Post-Game Service

6:05 p.m.—Regular Blue Line trains begin carrying significant passenger loads departing the stadium. At this time, the regular 15-min headway is adequate.

6:46 p.m.—The first event train departs the stadium. Although the game is far from over, the lopsided score has convinced some fans that the outcome is inevitable. Demand is sufficient that trains are departing at the optimum 4-min rate. The demand ebbs somewhat as the score becomes surprisingly close after the trailing team scores a couple of quick touchdowns late in the game. The rate of departures is slowed accordingly for a short time.

7:17 p.m.—The game is over and the stadium begins to empty. The line begins to form into the stadium LRT station. There are still some activities inside the stadium (the post-game trophy presentation followed by a concert) so many fans remain inside.

9:23 p.m.—The final, fully loaded train departs the stadium. There have been 38 train departures in just the 2½ h since the first event train left averaging one departure every 4 min. Over-the-line trip times between the stadium and Old Town average about 17 min compared to 14 min under normal conditions. In 1998, some trains took an hour to make the trip. Credit for the improvement goes to the strict 4-min departure schedule, which kept the system from becoming overloaded, as well to the use of station teams to minimize dwell times at down line stations.

LRT Service Summary

On the event days leading up to Super Bowl XXXVII, the planned service was operated as scheduled with the largest crowds occurring on Friday and Saturday nights. Although the Green Line appeared to have the highest level of ridership each day, both Orange and Blue Lines realized a significant amount of activity.

Friday night crowds were significant. Inbound and outbound traffic patterns were steady with noticeable peaks at the close of the NFL Experience and as 5th Quarter in the Gaslamp activities concluded. Extra Green Line trains departed the yard as needed.

Saturday was by far the busiest day with the added attraction of what was billed as the largest fireworks display in the history of San Diego. The events attracted an estimated 200,000 people to downtown. Fully loaded trains were arriving from all points for several hours leading up to the 9:15 p.m. fireworks. The most intense activity occurred when the fireworks show and the NFL Experience concluded at the same time. The tens of thousands of people left their vantage points along the Bay and walked either to Bayside stations or across the tracks into the Gaslamp Quarter as did thousands of those attending the NFL Experience. All Trolley stations between Gaslamp and Santa Fe Depot were inundated with people attempting to board outbound trains. Demand not only exceeded train capacity, but also exceeded station capacity as the crowds spilled over into the surrounding streets. People who were driving also experienced gridlock as they attempted to exit downtown.

Train operation was slowed considerably due to the volume of pedestrian traffic in the stations and at the grade crossings. Transit security officers performed admirably keeping the tracks clear for train movement. When possible, some trains expressed through the Gaslamp Station in order to provide relief to the stations down line. Passengers at these other stations were having difficulty boarding due to the “full trains” departing the Gaslamp Station. Heavy passenger loads continued to all points until well after midnight. Over 200 additional train trips were operated to satisfy the demand.

Contingency Plan Summary

In almost every case, the benefits of executing the “lessons learned” and the contingency plans were seen during the Super Bowl.

Back-up Buses

Seven hours before kick-off, 35 buses were deployed at selected locations including downtown, Old Town, and selected Mission Valley locations. During the game, the buses went to the Qualcomm Stadium LRT station to join a group of 50 buses to create a larger fleet of buses to be used for post-game overflow capacity relief in the event crowds exceeded LRT service capability. The cost for the reserve was shared between SDTI and the NFL.

While the stand-by buses were not used for any line failure, during the post-game egress, the NFL diverted an estimated 3,000 passengers from the LRT queuing line to the 85 buses for express service to downtown hotels. This resulted in relieving some of the post-game wait that would ordinarily be experienced by passengers.

Special Teams Summary

In 1998 it was clear that any delay in the field, whether related to passenger boardings or equipment failure, created a “domino” effect in delaying train service. Once a delay occurred, given the magnitude of the Super Bowl Game Day service, the Trolley could not easily recover. As a result, it was determined that Trolley could prevent the domino effect by deploying a variety of staff, contractor, and outside agency teams, who would be ready to respond to a wide range of potential problems in the field.

Station Teams

The NFL’s ticket distribution formula only allows 5% of tickets to be distributed to host team fans. In 1998, the vast majority of those riding to the game were not familiar with the operation much less procedures for boarding and de-boarding. Field personnel could document first-hand the significant problems this lack of familiarity created in both pre- and post-game operations. The problem worsened during the intense post-game close headway operations when station dwells were excessive. Passenger confusion created loss of efficiency and trains backed up.

SDTI created station teams under the control of a management employee designated as the station manager. The plan called for the teams to range from a minimum of 8 employees to as many as 12, depending on station location and volume. Each team consisted of personnel in a variety of categories, including security, code enforcement, LRV maintainers, or other supervisors.

Team managers wore an orange vest for easy recognition. Teams were deployed in the field prior to the enhanced service initiated on game day, and their responsibilities included: assisting passengers, distributing riders evenly along the platform, and responding to operational or vehicle problems. The teams remained deployed throughout game day until after the crowds had diminished at approximately 10:00 p.m.

Station teams proved extremely helpful and provided the essential assistance we were looking for. Having fans evenly spread out along the platform resulted in quicker more uniform boarding. During the post event, their ability to assist passengers with de-boarding improved the over-the-line efficiency. Also, the LRV technicians in the team proved extremely beneficial. In one particular case, passengers boarding a post-game train at Qualcomm Station experienced an air conditioner compressor failure. It caused a small explosive noise and a small amount of smoke. But the experienced technician on the platform immediately recognized the symptoms and took corrective action by tripping the circuit breaker while the train was still loading allowing an on-time departure.

Track Crew and Equipment Deployment Teams

Separate teams made up of staff with track expertise were deployed to a variety of locations including Old Town Transit Center, Qualcomm Stadium, and where train service merged at the Santa Fe Depot at Broadway. Further, specialized equipment was also strategically deployed at locations along the route extending from downtown to Qualcomm Stadium. This included the track-truck, re-rail, and other specialized on-track equipment in the event of a derailment or track appliance failure.

A rule infraction early in the game day operating plan resulted in minor damage to a crossover switch near Old Town. Because the field track crew was assigned to this critical location, they responded within minutes and made the necessary adjustments to the switch allowing unimpeded continuation of train movement. This event was transparent to the public.

Wayside/Train Control Deployment Teams

The Wayside Department maximized its force of field technicians and assigned them to interlocking locations as well as traction power substations at all critical locations from Downtown through Mission Valley. Had such a plan been in place for Super Bowl XXXII (1998), the temporary power failure experienced could have been minimized and power restored almost immediately when the feeder breakers tripped.

In 2003, a minor technical malfunction caused a brief period of red signals for trains leaving Qualcomm Station during the post-game operation period. The Wayside Train Control supervisor assigned to the station quickly responded and manually selected desired routes and cleared signals. This was a single occurrence and did not recur during the evening.

Overhead Catenary Response Teams

In order to provide the existing SDTI maintenance staff with an expanded capability, a highly specialized overhead line contractor assembled a team for centralized deployment. This included a variety of specialized equipment that could be immediately put into service in the event of any failure in the overhead power line distribution system. This arrangement was deemed necessary due to the deployment of other personnel and the interest in maximizing our capability to quickly respond and restore service.

Local Electric Utility Company Provides Trouble Teams

The San Diego Gas and Electricity deployed up to six “trouble teams” at locations extending from Downtown to Mission Valley. SDTI staff were provided with direct communication with these teams in the event a power failure occurred that affected LRT service.

Advance Facilities Enhancement Summary

Line and Vehicle Inspections

Vehicle and line inspections were intensified during the months preceding Super Bowl XXXVII. The LRV Department initiated enhanced inspections of LRVs with particular emphasis on overhead power collection devices (pantographs). This effort was mirrored by the Wayside Maintenance Department with increased emphasis on switch inspections and overhead catenary equipment. This effort included a complete replacement of all wayside signal bulbs in order to ensure no dark signal conditions. All this work was completed by mid-January.

Comprehensive Station Appearance Program

The Facilities Maintenance Department initiated this effort and repainted station equipment, structures, warning strips, disabled symbols, etc., at all of the 21 stations between Qualcomm Stadium and Downtown. In addition, minor repairs were made to station facilities as required. This effort resulted in an extremely positive image that was recognized by visitors, the media, and local residents.

California Public Utilities Commission Approval for Expressing Trains

This California Public Utilities Commission activation was contingent upon SDTI modifying their expressing procedure, and incorporating several additional measures at grade crossings to further enhance recognition of unprotected crossings. Transportation Department staff worked very closely with Metropolitan Transit Development Board (MTDB) consultants to accelerate the changes deemed necessary to modify grade crossings along the Green Line route. This route was selected in consideration of the efficiency improvements that would result from trains circulating between Qualcomm Station in a shorter time frame for second and third trips. The desired level of efficiency was achieved by trains along the Green Line route returning back to Qualcomm Station within 1 h and 10 min of their previous departure.

Train Location Feature

The ability to monitor train movement and initiate field commands from Central Control and the Supervisors booth at Qualcomm Station was part of MTDB-directed improvements post Super Bowl XXXII. This capability was finalized and fully activated in early January 2003. The controllers were able to monitor all train movements from County Center Station to Mission San Diego and make critical decisions regarding operations and service levels.

Enhanced Closed Circuit Television

The existing closed circuit television (CCTV) capability from Old Town to Qualcomm Station was upgraded and additional operating flexibility was provided. Additional cameras were provided with tilt-pan-zoom capability. Further, monitoring of the CCTV cameras was transferred from the Old Town Transit Center to the centralized security center in Building C at the main maintenance facility in advance of Super Bowl. This monitoring proved to be very efficient and benefited SDTI security as well as state, local, and federal authorities.

Ticket Sales Booths

Four ticket/information booths (with either two or four sales windows) for permanent installation at stations with recurring special event patronage were purchased. The booths ere installed in December at the Morena/Lind Vista, Fashion Valley, Hazard Center, and Mission Valley Center Stations.

These fixed booths enabled SDTI to rotate the existing seven mobile ticket booths to other essential locations for Super Bowl Week. However, because the need for still other manual ticket sales locations was determined, an effort was made to solve this by procurement of portable tent units with single or multiple positions for ticket sales. Nine of these units were purchased and most placed into service during Super Bowl Week.

These additional units allowed staff to provide 19 manual ticket sales units to be deployed at 15 separate station locations. This represented a significant improvement over 1998 when manual ticket sales were restricted to less than half that number. Further, many of these units were in service for 3 to 4 days and service hours extended from 16 to 20 h in order to cover the enhanced service period for each of the high-volume days. Fans purchased 60,864 round-trip tickets or Commemorative Day Tripper passes during the 4-day period from January 23–26 (the equivalent of over 117,000 single rides) generating $218,387 in fare revenue.

MARKETING, INFORMATION, AND ADVANCED SALES OVERVIEW

In the summer of 2002, a cross-functional team of Operations, Information Technology, Finance, and Marketing staff began meeting to outline and implement the various marketing, public information, and advanced sales programs and strategies.

Target Markets and Strategies

The primary marketing and information programs were targeted to four specific groups:

- 500,000+ fans (locals and visitors who came downtown to be part of the "party").
- 200,000 daily riders who would be impacted by changes in regular service and the "special event" riders.
- 67,500 fans with game tickets (with only several hundred parking spaces available for NFL owners and suite-holders) all other fans were to arrive via the Trolley or special buses.
- 7,000+ Volunteer Ambassadors (recruited by SBHC) to work the various special-events like the NFL Experience, Cultural Arts Bowl and Festival, and Downtown Fireworks.

In addition, a unique advertising program was targeted to "NFL approved" sponsors who were interested in reaching the Super Bowl fans and taking advantage of the incredible media exposure that would accrue to San Diego and SDTI.

Specifically, the marketing/information/sales plan included:

- Super Bowl website pages. Various pages were developed for the transit website at www.sdcommute.com to provide with travel information from hotels and to the venues. This would also be a resource for locals who were going to the venues either as volunteers or as fans.
- eStore launch. In fall 2003 the region opened its first online "eStore". This multipurpose site would be used to sell Super Bowl Commemorative Day Trippers for 1, 2, 3, and 4 days to out-of-town visitors. The need for an advanced sales outlet for out-of-towners had been documented in the 1998 Super Bowl Experience.
- Group sales program. Advance sales of Commemorative Day Trippers (1 to 4 days) for orders of 100 or more units.
- Point-of-sale and information materials. Develop and distribute materials to hotels, visitor information centers, and the SBHC.

- Super Bowl edition of the *MTS Newsletter*. This was posted onboard buses and Trolleys; 80,000 copies were printed and in addition to distributing them to riders, they were used in training sessions for the SBHC volunteers.
- Super Bowl XXXVII window decal. This was produced and installed on 123 LRVs and 600 buses.
- Transit Training Program. This was presented to front-line hotel and visitor information staff as well as SBHC volunteers.
- Advertising plan for print and electronic media.
- Secure board approval for a one-time-only sales effort to sell advertisers interested in “wrapping” 10 SDTI vehicles during the Super Bowl time period.

San Diego Super Bowl XXXVII Host Committee Partners with Metropolitan Transit Development Board

Just prior to the January 1998 Super Bowl, MTDB waived policy and approved the SBHC’s last-minute request to provide complimentary transit passes for 7,000+ Super Bowl ambassadors. The approval was based in part because it was deemed a good way to introduce the then “just opened” Mission Valley LRT extension to the large number of San Diegans who were volunteering their time for the Super Bowl.

Before the 2003 Super Bowl, the SBHC and MTDB developed a partnership agreement that provided MTDB and SDTI in excess of a three-to-one ratio of in-kind value. In return, MTDB provided 7,000 high-quality, reflective stickers that could be affixed to the reverse side of each volunteer’s valid California driver’s license. The sticker allowed volunteers unlimited access on the public transit routes from January 18–26, 2003. As a security feature, SBHC staff affixed the sticker on the volunteers’ drivers license and the sticker would shred if removed.

The partnership agreement gave MTDB/SDTI use of the host committee’s logo for promotional purposes and 25 volunteers to staff key Trolley stations during the events to help visitors navigate the system. The SBHC also included Trolley information in its collateral information, news releases, and website. In December 2002, the president of the SBHC went to the Transit Call Center for a television news interview promoting the Commemorative Super Bowl Day Trippers. The SBHC included MTDB, SDTI, and SDT in the “Sponsor Thank You” media campaign following the game.

Transit Super Bowl Web Page

During 1998 the Internet was just beginning to increase in use and popularity. The following year, MTDB began enhancing the MTS website. Given the increased popularity of websites there was significant interest in expanding the MTS website for Super Bowl to provide specific information, trip planning, and generating related links to the SBHC, NFL, and San Diego’s Convention and Visitors Bureau sites.

Additional enhancements included a special section dealing with “getting to the game” which provided a wide range of options based on geographic location. The Web development staff, in conjunction with marketing and graphics staff, created a hotel locator feature. Visitors who clicked on their hotel or point of origin would automatically see a screen that illustrated their proximity to closest Trolley station or bus park-and-ride as well as provide walking and/or driving directions.

The enhanced website received substantial use during Super Bowl Week and for several weeks in advance of the game. According to statistics generated by the Internet Service Provider, page views increased 74% and visits increased 66%. During the period from January 18–27, total page views were 323,197 and visits were 38,180 for an average of 3,818 visits per day. Overall, the total number hits and unique visitors in January 2003 showed dramatically increases over the month before and after.

	December 2002	*January 2003*	*February 2003*
Hits	479,124	**816,286**	541,626
Average Hits/Day	15,455	**26,331**	19,343
Unique Visitors	37,910	**61,988**	41,624

Commemorative Day Tripper Sales

MTDB produces Commemorative 1-, 2-, 3-, and 4-day Day Trippers for special events that have the potential for advance or walk-up sales. The Day Tripper passes were priced at $5, $8, $10, and $12 for 1, 2, 3, and 4 days, respectively. Besides appealing to visitors as souvenir the pass provided operational benefits by:

- Reducing queues at ticket machines or ticket booths on the day of the event;
- Reducing chance passenger would either leave or not buy a ticket before boarding to avoid waiting in line; and
- Eliminating rider confusion at the vendomat about what type ticket to purchase.

Most importantly, advance pass sales also create a stronger commitment by the visitor to using public transit.

Group Sales Program

This effort was targeted to sales of 100 passes or more. Given the fact that the two teams wouldn't be selected until 1 week (January 19) before the January 26 Super Bowl Game the number of advance sales fell short of the 1998 number. (In 1998 the teams had 2 weeks in between the playoffs and the Super Bowl.) As the final games were played in December and January, travel agencies that specialize in sporting events set up contingency plans to book hotels and ground transportation in case their customers' team won. In 2003, group sales exceeded $24,000.

eStore

Plans to open the eStore began in Spring 2002. The eStore opened in September 2002 as MTDB's first e-commerce program. This provided 3 months experience before introducing the Commemorative Super Bowl XXXVII Day Trippers. Advance work involved setting up the agreements with the banks, designing the online store pages, promoting the eStore to customers, setting up the proper procedures to fulfill the orders according to finance regulations, and creating links to the site from the SBHC website.

The eStore was promoted on the transit website home page and in all SBHC printed materials that went to fans and ticket holders. News releases were sent to the cities whose teams were contenders for the NFL's Super Bowl. Fans purchased $4,228 (not including shipping fees) in Commemorative 1-, 2-, 3-, and 4-Day Super Bowl Day Tripper passes.

Trolley Station Manual Ticket Booths

Each day, sales kits were prepared containing round-trip tickets as well as quantities of the appropriate Commemorative Day Tripper passes. Booth sales staff sold a total of 4,273 Commemorative Day Tripper passes (150 4-day passes; 481 3-day passes; 815 2-day passes; and 2,827 1-day passes), totaling $17,403 or 8% of the total manual ticket booth sales.

Advertising "Wraps" Generate Significant Revenue

In summer 2002, sports marketing consultant, ACME Marketing presented an unsolicited revenue-generating proposal to the MTDB Board of Directors. MTDB approved a one-time suspension of Policy 22 (adopted in 1981) prohibiting exterior advertising on the Trolley to generate one-time dollars (Figure 2).

The impetus to approve this suspension was to jump-start the exterior rehabilitation of SDTI's LRV fleet. In 2002, about 50% of SDTI's 123 vehicles were in dire need of repainting. Sun, wear, and damage had discolored the "bright red" paint on more than half of the fleet. Underneath the paint, most of the vehicles also required significant bodywork and there was only funding available to rehabilitate six to seven LRVs.

During the Super Bowl, SDTI anticipated the entire fleet would be needed to maintain service levels and handle excess crowds. ACME Marketing's proposal that MTDB market a "modified wrap" to NFL sponsors met with the Board's approval because the wraps would serve two purposes. First, the wraps would mask the exterior condition of up to 10 vehicles. Second, the wraps would create a funding source that could double, or more than triple, the existing rehabilitation dollars in FY 03. Because of security concerns and the long-standing advertising ban, the Board set the number of cars to be wrapped at 10 and that wraps would not be allowed to cover any passenger windows unlike most full bus wraps.

FIGURE 2 Eight SDTI cars wrapped by advertisers generate incremental revenue.

By August 2003, MTDB and ACME launched an aggressive marketing campaign sending out more than 300 proposals. In this short time frame, and despite the numerous restrictions, ACME sold eight wraps: one to a local bank, one to a San Diego-based national electronics firm, one to a local television station promoting its network's programs, and five to an international electronics firm. The wraps earned $290,000 in revenue for SDTI. During FY 03/04 SDTI used these funds to rehabilitate 24 cars.

Nineteen cars have been repainted and another five cars, which did not require extensive bodywork, were "wrapped" red. One LRV can be wrapped in 2 days at a cost of approximately $6,000 versus repainting which can take between 10 to 15 days to complete at a cost of $30,000 to $40,000.

Additional Revenue

SDTI also generated revenue from two other sources. SDTI received $5,300 from licensing the sale of Super Bowl memorabilia at key stations and another $12,421 in commissions from the sale of soft drinks from vending machines located at stations throughout the system. The soft-drink commission for January was 28% over January 2002. And the increase was more than four times higher than increases for the months of December 2002 and February 2003.

Media Coverage

Trolley and bus service received wall-to-wall press coverage during Super Bowl Week. MTDB and SBHC press releases, press conferences, press interviews, and advertising promoted the Trolley and bus to all the Super Bowl events around town, and to the big game itself.

The majority of the electronic media was purchased on local radio stations. MTDB purchased spots that ran in the traffic reports on the local Clear Channel radio network (14 stations) plus there was a cross-promotion with NFL Experience tickets. Spanish radio tags were purchased on the Metro Traffic Network. Ads appeared in the *San Diego Union-Tribune* and *The San Diego Reader* newspapers. Spanish language TV promotions and traffic sponsorships appeared on the Univision and Telemundo networks.

MTDB's Communication Manager lined up dozens of TV interviews and live shots for SDTI President Peter Tereschuck and Special Event/Operations Coordinator Tom Doogan as well as other MTDB Marketing and Communications staff. On January 23, a KUSI-TV's news personality did a live shot at the Stadium Station, interviewing Peter Tereschuck and NFL Transportation Consultant Paul Ridgeway. Peter Tereschuck also appeared on national TV on Saturday's NBC Nightly News. Other staff were interviewed by the NBC affiliate in San Francisco.

On Super Bowl Sunday, three local television stations, KUSI, KNSD, and KGTV broadcast live from Old Town and the Convention Center Trolley Stations. The final priceless publicity for SDTI took place during the game itself. The ABC network broadcast a beauty shot of downtown San Diego with the Trolley running through the shot. Reportedly, advertisers paid $2.1 million for each 30-sec commercial that ran during the Super Bowl Game and traditionally, Super Bowl Games, according to the Nielsen rating service website, rank in the top 10 programs viewed.

SDTI also received extensive coast-to-coast print coverage. During and following the Super Bowl the *San Francisco Chronicle*, *The Oakland Tribune*, *Contra Costa Times*, *The*

Sacramento Bee, The Hartford Courant, The Miami Herald, San Antonio Express-News, New York Daily News, New York Times, and *USA Today* ran stories praising the Trolley and the ease of travel.

The *San Diego Union-Tribune* re-cap article carried the headline “Transit Plan Near Perfect” and quoted the NFL as saying “Trolleys and buses kept traffic running smoothly.” In the letters to the editor section, one reader wrote that the Trolley service was “superb”.

Ridership, Cost, and Revenue Summary

Ridership

SDTI’s 4-day total estimated ridership was calculated at 801,430 passengers. The ridership level achieved on the Saturday before Super Bowl XXXVII exceeded the 219,034 ridership level in 1998 by 56.4%.

Utilizing all data available in conjunction with the standard ridership formula, the following Trolley ridership information was provided for the 4-day period beginning Thursday, January 23 through Sunday, January 26 (Super Bowl Day).

- Thursday, January 23, 2003………………...105,841
- Friday, January 24, 2003………..…………224,322
- Saturday, January 25, 2003………………....342,615 (highest day on record)
- Sunday, January 26, 2003……………………128,652

Mode Split

On Sunday, January 26 buses and trolleys carried a 57% share of all fans attending the game and a 59% share of all stadium trips (fans and employees.) The ridership was well balanced between Trolley and bus with the 30.4% of trips on the Trolley and 29% on the bus.

- Pre-game to stadium.....…………………………..….23,000 (trolley)
- Post-game from stadium.. ………………………..…18,000 (trolley)
- Fan park-and-ride to stadium………..…………..16,500 (bus)
- Employee park-and-ride to stadium……………..….3,300 (bus)
- Post-game fans from stadium to downtown.…..…3,000 (bus)

Operating Costs

Total operating costs incurred by SDTI for Super Bowl XXXVII and related events was estimated at $430,795 (Table 1).

Revenue

SDTI received $793,441 (Table 1) and includes fares, wrap, and commission revenue.

TABLE 1 San Diego Trolley Super Bowl XXXVII Expenditure and Revenue Summary

Item	Expense	Revenue	Notes
3rd Generation Embroidery	$2,083.62		Employee Hats
Airgas	$753.04		Safety Cones & Caution Tape
Applied Industrial	$1,128.14		Station Paint
ATC VanCom	$1,181.25		Pre-game S/D support (3 veh.)
ATC VanCom	$1,500.45		MSD to Rio Vista Shuttle (2 veh.)
Barnes Printers	$53.00		Business Cards
Batteries Plus	$261.18		Various Batteries
Batteries Plus	$678.59		Radio Batteries
Communications Co.	$337.50		Stadium PA Repair
Communications Co.	$875.20		Qualcomm Amplifier
Communications USA	$2,466.90		Radio batteries and chargers
Communications USA	$28,349.00		Handheld Radios
Costco	$85.50		Bottle Water for Field Personnel
Delux ICI Paint	$628.83		Yellow ADA Paint—Qualcomm
Delux ICI Paint	$2,335.60		Yellow ADA Paint
Deter’s	$85.16		Portable Restroom—Morena Station
Emergency Equipment	$400.31		Radio Holders
Fire Hawk	$240.19		Fire Extinguishers (MVW)
Firehawk	$484.60		5 Fire Extinguishers
Fixture Pronto	$771.59		Pedestrian Barriers (Qualcomm)
Grainger	$595.00		Chairs for Ticket Booths
H&L EZ UP	$3,639.40		Collapsible Ticket Booths (9)
Home Depot	$61.96		Ticket Booth Supplies
Home Depot	$127.95		Totes for Ticket Kits
Home Depot	$135.46		Booth Lights & Cords
Hornberger Wedges & Blocks	$385.20		MOW Equipment
ICI Delux	$1,292.68		Paint (Qualcomm)
ICI Delux	$1,292.75		Paint (Qualcomm)
IDG	$406.90		36 45-type locks
Kinko’s	$10.78		USD Overflow Parking Signage
Laidlaw Transit Services	$2,681.70		MTS Access Vehicle Support
Mass Electric	$4,020.91		Game day support
McMaster-Carr	$181.27		Anti-Fatigue Mats (Ticket Booths)
Misc. Office Supplies	$23.20		Ring Binders
Misc. Office Supplies	$233.07		Ops Plan Binders, Inserts, etc.
Misc. Other	$1,500.00		
MTDB SB 37 Marketing	$50,000		Media buys, collateral, volunteer stickers, pins, *MTS News*

continued

TABLE 1 (*continued*) San Diego Trolley Super Bowl XXXVII Expenditure and Revenue Summary

Item	Expense	Revenue	Notes
Nextel	$772.14		Cell Phone Billing
Nextel	$1,201.00		Cell Phone Batteries
Office Depot	$206.89		Ticket Booth Supplies
OneSource	$60.25		Ticket Booth Power Cords
Onfield Apparel	$4,514.18		Employee Shirts
Payroll—CCI	$19,192.49		
Payroll—Facilities	$21,265.30		
Payroll—LRV	$18,235.14		
Payroll—MOW	$22,068.68		
Payroll—Revenue	$5,286.68		
Payroll—Stores	$626.67		
Payroll—Transportation	$71,681.87		
Petty Cash	$131.99		
Safety Gear Depot	$325.00		(24) Station Manager Vests
San Diego Plastics	$1,627.02		Lexan for Timetables
SD Lamps	$226.28		Stadium Lighting
SDTC	$1,737.00		USD Shuttle—3 Buses
SDTC Post-game Support	$5,324.50		30 buses @ 177:29 billable hours ($60 ea) x 50%
SDTC Post-game Support	$19,918.50		NFL Portion (payable to SDTI per agreement)
SDTC Pre-game Support	$11,460.00		30 buses @ 191:00 billable hours ($60 ea)
Select Personnel Services	$806.26		Manual Ticket Sales Personnel Support
Sir Speedy	$632.40		Ticket Printing
Sir Speedy	$632.40		Ticket Printing
Sir Speedy	$736.11		Ticket Printing
Sir Speedy	$821.11		Ticket Printing
Sir Speedy	$865.22		Round Trip Tickets
Sir Speedy	$921.11		Ticket Printing
Sir Speedy	$960.52		Ticket Printing
Squires Belt	$12.22		Portable Booth Weights
Tops Staffing	$4,380.30		Manual Ticket Sales Personnel Support
Traction Power Use	$61,004.53		61,783 car mi at $.9874 each
Transit Security Personnel Hours	$86,589.96		
West-Lite	$1,066.73		Signal Bulbs
West-Lite	$2,285.65		Stadium Lighting
Willy’s	$404.06		Handheld Radio Antennae
Willy’s	$691.75		Bullhorns

continued

TABLE 1 (*continued*) San Diego Trolley Super Bowl XXXVII Expenditure and Revenue Summary

Willy's	$835.77		Station Amplifiers (MVW)
Wrap Commission on Sales	$31,900.00		To consultant
Advance Group Sales		$24,889.10	
Coca-Cola Commission		$12,421.00	
Internet Sales on eStore		$4,060.30	
Kobeys—Commission		$5,300.00	Souvenir Sales at Stations
Ridgeway International		$19,918.50	Bus Support Contribution
Ridgeway International		$3,500.00	Driver's Party Fares
Ticket Booths		$230,071.32	Manual Ticket Sales
Ticket Vending Machine Sales		$203,281.32	Estimated Excess Over Average Sales Volume
Wrap Sales		$290,000.00	Eight Trolley Wrap Advertising Revenue
TOTALS	**$512,695.57**	**$793,441.54**	
DIFFERENCE		**$280,745.97**	

CONCLUSION

Super Bowl XXXVII represented the most significant challenge for transit in terms of commitment of vehicles, resources activated, special plans developed, and ridership generated. Public events directly and indirectly related to the Super Bowl created levels of activity that may never be exceeded in San Diego again. Crowd estimates varied in the downtown area but have been estimated in the general range of 250,000 to 300,000 people. Major objectives were achieved and additional lessons were learned:

- Public transit achieved a 59% share of trips to the game through a more effective use of the same resources that were available in the 1998 game.
- Trips were closely balanced between bus and LRT services compared to 1998. The Trolley carried 41,000 trips and buses carried 39,600 trips to and from the stadium.
- Group sales and the eStore generated significant advanced ticket sales.
- Expanded number of manual ticket booths at 15 locations captured increased revenue.
- Pre- and post-game service was provided without any noticeable problems.
- Deployment of various specialized teams that separately focused on passenger needs, track needs, LRV needs, and power needs proved highly effective for the public and beneficial for train movement, efficiency, and reliability and allowed quick response to on-line conditions and minimized service impacts.
- Major special events create new revenue opportunities including the sales of eight wrapped LRVs and licensing Super Bowl memorabilia sales outlets at stations.

There was also general consensus that the lessons learned from the1998 Super Bowl XXXII provided valuable input for the operational issues for Super Bowl XXXVII. It was the response to these issues and aggressive planning that created an environment for success. As the

Senior NFL Transportation consultant Paul Ridgeway put it in his letter to SDTI, “compared to 5 years ago, this time it was magic.”

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Click here to see Doogan and Leitner’s Powerpoint slide presentation.

From Magnet Boards and Grease Pencils to Flat Panels and Overview Displays
TriMet Case Study

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The evolution of a light rail system from a simple single-line system to a multiple-line system with integrated bus operations is a complex process, requiring careful coordination by operations, information systems, and capital projects staff. The problems involved are complicated by the need to maintain service and cascading technology.

TriMet is now on its fifth phase of control center development. Each phase has been a learning process. Each phase has required increasing levels of involvement from all stakeholders. The evolution through each phase is described by providing the perspectives of each of the major stakeholders and the major lessons learned in each phase.

TriMet's experience is that the ongoing process of implementing technology and integrating operations has been workable and desirable. The current phase of development will bring the Interstate project on line in the joint bus and rail command center. The process of implementing new technology works best when all of the stakeholders are active participants, because all of the project goals are more clearly identified.

INTRODUCTION

Since TriMet began operating light rail in 1986 in Portland, Oregon, the systems used to manage the operation have been in almost constant evolution. The system is called MAX, for Metropolitan Area Express. The original system, about 15 mi in length with one service route was relatively easy to manage with flip charts, grease pencils, and magnet boards. Seventeen years later we are on the verge of opening our fourth line, comprising 45 mi and three main routes. Additionally, the bus dispatch and rail control centers have been located together. The operations management task has become increasingly complex, and many of the processes have been automated. Three points of view of TriMet's control center evolution are provided here: operations (the users), information systems [(IS) maintenance and development], and capital projects (design and procurement). Further, this paper describes the evolution in practices that has permitted these projects to be increasingly successful.

TriMet has gone through five phases of control center evolution so far:

- The Banfield era,
- The Westside years,
- Airport expansion,

- Bus dispatch relocation, and
- Interstate expansion.

Though some of the phases overlap in time, each marks a change in the way the control center has done business.

THE BANFIELD ERA

Description

In 1986, TriMet began operating a 15-mi light rail line. At that time the Control Center consisted of a 450 MHz desktop radio with 2 channels, a DOS computer system for logging events, a magnet board to track yard storage of 26 light rail vehicles, and a strip map of the alignment. Within a year an additional computer and radio system was installed to track alarms from ticket machines and traction power substations. Also, a flow chart was developed in-house as an aid to Controllers to graphically show scheduled train positions. This system was used with minor upgrades until 1998.

Figure 1 shows the Control Center during the Banfield Era. The layout was crowded and did not lend itself toward expansion of any sort.

Figure 2 shows the arrangement used to track yard storage. This arrangement was effective for handling 26 cars in one yard, but today's fleet of over 100 cars in two yards demands some sort of automated tracking.

FIGURE 1 Rail operations Control Center during the Banfield years.

FIGURE 2 Essential tools for yard operations: magnet board, telephone, two-way radio, and binoculars.

Procurement

There was no formal procurement process for the Banfield Control Center. The basic structure was provided as part of the "turn-key" Banfield construction and was quite bare-bones, consisting of a small room in a corner of the Ruby Junction Maintenance Facility offices. The Control Center was handed over to operations as the contractors walked out the door. As new needs were discovered, the operations department did research to find the right solution, and worked with the purchasing department to put the solution in place. Generally, the solutions selected reflected what was available on the open market, for example, the radio-based Supervisory Control and Data Acquisition (SCADA) system was provided by a local two-way radio supplier. While functional, this approach did not produce the best solution, but produced solutions that could go into service expeditiously.

Control Center Staffing

The Control Center was staffed with one person at a time, 24 hours a day, 7 days a week, with employees who held the dual status of Rail Supervisor and Rail Controller. No additional support staff was assigned. When a technological problem arose, the two-way radio vendor or the IS department would send help.

Operations Limitations

The original Control Center was cobbled together, generally based on immediate needs rather than design. It grew as the controllers grew into their job. As the operating department discovered new requirements, attempts were made to expand the Control Center's capabilities. These ad hoc expansions were often rather awkward. The one-controller arrangement was adequate for most operations, but special events and emergencies often resulted in tense moments.

As the operation started, use of Standard Operating Procedures (SOPs) was limited. Gradually SOPs were developed to handle all sorts of operational conditions. At this stage of system development, SOPs were strictly on paper and not integrated with the control systems.

Information Systems Perspective

In 1986, at the dawn of light rail in Portland, the Banfield Line, TriMet's IS Department was in the middle of the mainframe computing era. Applications were one tier, systems were proprietary and not open, all resources were centrally managed, and user interfaces consisted of "dumb terminals." In the early 1980s, a state of the art IBM mainframe was installed for over $1 million with less computing power than today's personal computers. The department was focused on deploying large-scale mainframe systems such as Fleet Maintenance, Payroll, Accounting, and Driver Scheduling. Except for Fleet Maintenance and a simple DOS-based event logging application, the focus of the department was integrating the new Rail Division with existing, agency-wide, large-scale mainframe systems, not developing or maintaining systems directly related to the running of a railroad. The technology and focus of the department were soon to change.

Lessons Learned

The controllers need the proper tools to be able to handle extraordinary situations.

A lack of advance planning for operations will result in operations tools that poorly support operational requirements. In fairness to the builders of the system in 1986, at that time operations really did not know what tools were needed. Some neutral outside help was needed to moderate between the system builders and the eventual users. This is especially important for a starter system where the users may have little rail experience.

THE WESTSIDE YEARS

Description

In 1998, TriMet opened the Westside light rail extension. This expansion was 18 mi of alignment with a tripling of service. Included was the opening of a 3-mi long tunnel with a station 260 ft underground. A new yard and maintenance facility was opened. The size of this expansion along with the tunnel and expanded level of service required a proportional expansion of control capability. The 1986-era Control Center was replaced with a state of the art Central Control System (CCS), married to a SCADA system in the field. This system tracks trains in real time and monitors and controls most field equipment, including

- Ticket machines,
- Traction power substations,
- Communications equipment,
- Signal equipment,
- Elevators,
- Public address systems,
- Variable message signs,

- Ventilation equipment,
- Standpipe systems, and
- Intrusion detection.

When the Westside extension came on line, the MAX system expanded to 33 mi in length.

Procurement

TriMet's Capital Projects division hired a consultant staff to design all systems (traction power, signals, communications, and fare collection), integrate the systems with concurrent civil work, prepare specifications, and manage the procurements through to final acceptance. Procurement of the Westside CCS and SCADA was part of a system-wide communications contract. In addition to CCS and SCADA, the contractor installed a fiber optic backbone and SONET equipment, telephone systems, public address and variable message signs, and closed circuit television.

The central control design was prepared based on Westside project criteria, and it was prepared generally with input from the operations department, but there was little operations department hands-on involvement during the design stages. Operations did participate in design reviews after contract award, but these reviews were late in the process and did little to establish basic requirements for operational functionality.

The communications procurement was a two-step process: A request for proposals was sent out to likely bidders; then proposals were received and evaluated. Specifications were adjusted and sent out again to a short-list of bidders, and a best and final offer (BAFO) was requested. The low-bidder on the BAFO was awarded the contract.

One IS staffer was assigned to support the procurement on a part-time basis, but IS was not really integrated into the process.

Control Center Staffing

Staffing levels increased in 1998 when this system was brought on line, and the dual qualification was split so employees could specialize in Control or Supervision. The Control Center continued to be staffed 24 hours a day, seven days a week, and the number of controllers on duty at one time has increased. During day and swing shift there are three controllers on duty at one time. Two controllers are responsible for geographic segments of the mainline as well as yard operations within those areas; the third controller is responsible for administrative duties, communication with the maintenance departments, writing Train Orders, Special Instructions, and relieving the on-air controllers for breaks.

At the start of Westside operations, the IS department also assigned one full-time person to provide day-to-day system maintenance, in conjunction with the Control Center vendor's full time support. As the vendor's support was cut back, the IS department assigned another full-time staffer.

Operations Limitations

This system has worked well from an operational point of view, but shortly after the start-up we realized that the incident reporting function of this system did not meet our needs. The cost of a vendor upgrade was prohibitive, and overall the system was not as configurable as we desired.

Based on operations input, the IS department created an accident/incident database (ACID) to meet our current and future needs. This incident tracking system is maintained on our TriMet IS network, rather than on the CCS network. This makes it easier for our IS staff to maintain, and it does not clutter up the CCS screens. When the new incident tracking system came on line in 2000, we stopped using that function in the CCS.

Information Systems Perspective

By 1998, when the second light rail line (Westside) opened and the first Rail CCS went into operation, a lot had changed in TriMet's IS department. Applications were now two tiered, in some cases multi-tiered, and databases remained centrally managed, but system development, maintenance, and support were now shared with users, and PCs had proliferated to every corner of the agency. The mainframe computing era was dead. The era of client server computing was here.

The focus of the IS Department was evolving as well, from integrating users into existing agency wide mainframe applications, to understanding the client departments, business needs, and developing or maintaining systems that met those needs. This evolution was not yet complete in 1998 when the Rail CCS appeared.

The CCS system had been specified by an outside consultant and procured by the Capital Projects Division as a very small part of the much larger Westside Light Rail Communications Contract. At the time, IS had a Manager of Rail Information Systems, one programmer, and one analyst located at Ruby Junction, the main Rail Operations facility. While IS staff was located at the rail facility, they were not always dedicated to Rail or Operations only projects. The Manager of Rail Information Systems was the primary liaison between the IS department and the Capital Projects Division.

Unfortunately, during the Westside procurement, the interaction between the Capital Projects Division and the IS Manager and staff was primarily limited to information sharing. The Rail Operations Division participation, while greater than that of the IS Department, was also limited in scope. As a result of these limited relationships the IS Department had very little to do with the design and implementation of a large mission critical system that it was expected to maintain, and likewise, the Rail Operations Division had limited input into a system they were expected to use to perform their daily work. It was sheer luck that the vendor, Union Switch and Signal (US&S), chose Oracle as the relational database and Sun Solaris as the operating system, both TriMet IS standards.

The inadequacy of IS Department and Rail Operations participation in the procurement became obvious shortly after installation, and significant changes to the system were required. The most apparent shortcomings in the Westside specification, from the IS perspective, were in the database design, the accident and incident capture interface for controllers, and the scalability of the hardware and the software.

The database was designed for the day-to-day operation of the rail line only; that is to say, any data captured was considered "throw away" data, stored for a maximum of 48 h. Effective reporting or data analysis could not be accomplished against a database that held only 48 h of data. A replication scheme was developed and implemented by TriMet's IS Department and US&S, where the data stored in the US&S Oracle database would be replicated immediately to a second Oracle database on a separate machine, known as "Replica." Replica was designed to store the data for years, and it became the primary reporting and analysis database.

The accident and incident capture interface originally specified did not adequately meet the needs of the Rail Operations. This was not surprising considering the limited amount of input from Rail Operations during the specification phase of the contract. Coincidentally, the (completely separate) Bus Dispatch System also lacked an adequate accident and incident capture interface, so it was decided that the IS Department would develop a separate application for capturing incident information that Bus, Rail, and Accessible Transportation could use. The system, ACID, was developed using Sybase's Power Builder against an Oracle database. ACID uses data directly from the Replica database. This data included train, vehicle, operator, location, and route and schedule adherence.

The third shortcoming of the specification was the scalability and support of hardware and software. At the time the Westside contract was implemented, the hardware and software selected by the vendor was state of the art, but was designed to meet the current requirements only. Future rail lines and increased data requirements were not clearly defined, and so capacity for expansion was very limited. By the time the system was in service in 1998 the operating system software and hardware were fairly old by technology standards and were reaching their limits of scalability and vendor support. The specification did not call for scalable hardware and software, and the long time between specification (early 1990s) and implementation (late 1990s) resulted in shortened life cycles.

Lessons Learned

The main lesson learned from the procurement of the Westside Rail CCS was that inadequate stakeholder participation results in an end product that doesn't meet the stakeholder's needs. This sounds trite and in some ways is a replication of the lessons learned from Banfield. But it did turn out that way and the lesson deserves repetition. In the case of Westside, the technology was such an advance that TriMet just did not know how to get organized to identify stakeholder requirements. One thing was clear; the amount of IS staff support needed was severely underestimated at the beginning, leading to a second lesson: a dedicated IS staff is not a luxury but a necessity.

Systems integration was also critical in this project. The communications system is typically the "tail of the dog." All other civil and systems work is well on the way to completion before the communications work really begins. The CCS/SCADA system is the glue that holds together all the other systems and provides the Operations Department with the tools they need to do their work. Furthermore, because this part of the work is at the end of the project, there is often tremendous schedule pressure. On Westside, this situation was counter-productive. Schedule pressure and unclear requirements conspired to give Operations less of a system than they needed. Good advance planning and early buy-in by all concerned parties are mandatory.

In the technical details area, when choosing a central control system, the system standards should match those of the rest of the IS department—in this case, Oracle databases and Sun UNIX operating systems. This allows IS to leverage staff capabilities and provides an easier interface to related systems.

The CCS database needs to be designed to meet the agency's reporting needs. Even with the expansion of capabilities implemented after the system went on line in 1998, new and unforeseen requirements have developed. Since this time, database requirements have become more and more standardized at TriMet. The Control Center system must match up to these standards, so information can be shared among various applications. One of the main online data users at TriMet is the Transit Tracker system, which provides real-time bus and train schedule information to the public. If the databases are not set up correctly, systems like this just will not work.

Alternatively, the incident tracking system is an example of the sort of information that you may not want to have married to a CCS. In an emergency situation, it might tend to clutter screens needed for immediate operational requirements.

Lastly, one must plan for system expansion. Clearly this is difficult to do when the likely system extensions are undefined. The capability for system expandability is needed.

AIRPORT EXPANSION

Description

In 2001, TriMet expanded the rail system again by opening a 5.5-mi extension to Portland International Airport. Airport MAX was TriMet's third light rail line, a unique public–private partnership. This line incorporated all of the systems elements seen on the Westside project, with the exception of the tunnel. When the Airport extension came on the line the MAX system was 38.5 mi in length.

Procurement

The Airport expansion was, from TriMet's perspective, a single design–build contract. US&S, the vendor of the 1998 CCS, provided the new software and hardware as a subcontractor to Bechtel, the primary contractor for the Airport Line expansion.

For the Airport expansion, the decision to add onto the existing CCS, as opposed to procuring a completely separate system, was made for several reasons. First and foremost, TriMet had learned from the experience of several other transit agencies, which had added separate vendors for each new rail expansion. This strategy has resulted in a duplication of support staff, higher support costs, and trouble with data integration. Additionally, US&S was able to provide the addition in the very short time frame demanded by the Airport expansion project. The disadvantages of this approach were that the issue of the system's age and scalability were not addressed with the expansion. These issues would soon rise to the forefront.

Staff Levels and Operational Issues

The staffing levels did not change for the Airport extension. Operationally, the major change was in relocating the geographic boundary for the responsible areas between the two on-air controllers.

Information Systems Perspective

By the time of the Airport extension, the IS department had taken over responsibility for administration of CCS and had two full time Unix administrators dedicated to the support of the rail control system. The administrators reported to a Manager of Operations (division) Information Systems. The Airport expansion was the first major upgrade since the implementation of the 1998 CCS and resulted in an addition to the current system of one additional server and new software.

Lessons Learned

The design–build approach presented a number of challenges for TriMet, primarily in the area of specifying systems designs. The approach taken was to use the Westside as-built documents as a baseline for the Airport extension. This approach did not permit for correction of Westside design problems. In the CCS area, the problems of system functionality and expandability were never addressed.

BUS DISPATCH RELOCATION

Brief Description

In late 2001 the Bus Dispatch Center was moved to Ruby Junction so it could be located with the Rail Control Center. This was done due to a change in philosophy within the agency; the idea is that the Bus and Rail divisions can work more closely together if they are coordinated under one management structure. An all-inclusive Field Operations Department was created to make this concept a reality. Rail Control is now part of the Operations Command Center where there are leads and a manager who directly oversee the operations of both Rail Control and Bus Dispatch. Relocation of the Bus Dispatch center was a homegrown project. The co-location and change in agency philosophy has worked well, and it has led to a closer working relationship between the Bus and Rail employees. This, in turn, has lead to better customer service.

Procurement

There were two phases to the relocation project.

First, a new home for Bus Dispatch was required, adjacent to the existing rail control center. This effort happened in conjunction with the construction of Ruby Junction's new South Shop building. Many rail maintenance staffers were moved from the Ruby Main building to the new South Shop building, leaving space for Bus Dispatch. The contractor for the Ruby Yard expansion, a part of the Interstate Project, prepared the physical space.

Second, the actual relocation of equipment and bus dispatch staff from TriMet's Center Street facility to the Ruby Main building required shifting of many communications circuits and a phased movement of workstations and related equipment. TriMet staff internally coordinated all the moves and equipment cutovers required. On-call contractors were used to shift communications circuits, provide power and network wiring, and move the furniture. This was successful because very little technology was changed. The Orbital Bus Dispatch System and radio equipment was relocated from TriMet's Center Street office to Ruby Junction one workstation at a time over a weekend, constantly maintaining service.

Figure 3 shows the post-relocation floor plan and several associated photographs.

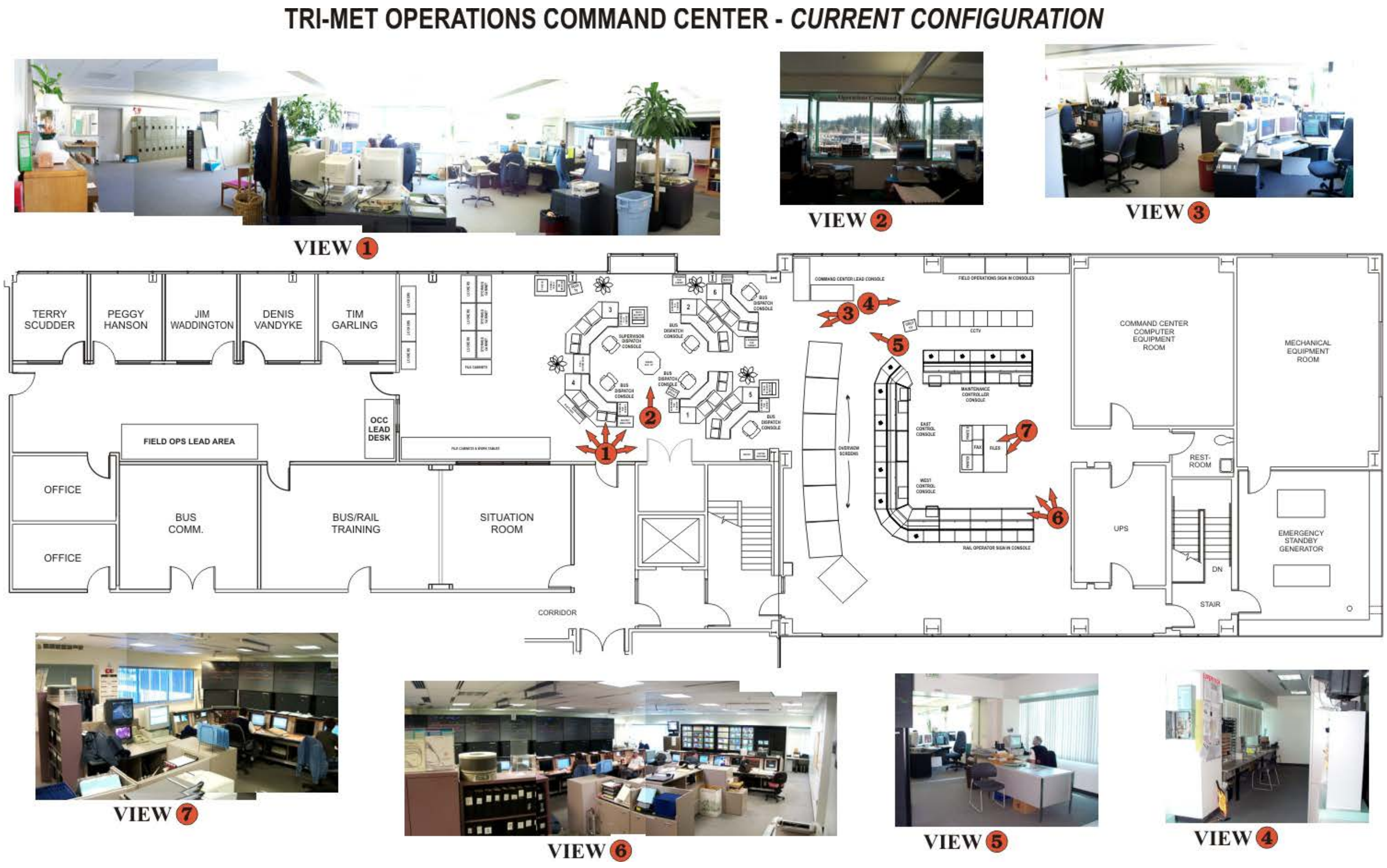

FIGURE 3 Control Center floor plan, following integration of Bus Dispatch.

Staff Levels

Staff levels have not changed for rail controllers and bus dispatchers. The number of supervisors has changed, with one supervisor managing both bus and rail.

Lessons Learned

We learned that with teamwork and careful coordination, our internal staff could be successful in undertaking of a project of this type.

INTERSTATE EXPANSION

Description

While construction of the Airport expansion was underway, the design process was begun for the Interstate Avenue extension. The rail portion of the existing Operations Command Center will be refurbished in conjunction with the Interstate extension opening, planned for start-up in the spring of 2004. The MAX system will be a little over 44 mi in length when the new Interstate line is up and running.

A number of rail control changes will be taking place: 1) the layout of the Control Center will be changed dramatically because of a need to better align geographically in the room with the Bus Dispatchers and to accommodate the increased amount of equipment needed to handle the expansion of the rail system; 2) the number of workstations and the number of overview displays will be increased; and 3) the CCS software and hardware will be changed to a system that will accommodate the Interstate project as well as future requirements.

Figure 4 shows the Control Center arrangement following reorientation of the Control Center and full implementation of the new CCS.

Procurement

As planning began for the new line, the question of how to incorporate the new line into the existing Rail CCS became paramount. Three options were considered: add onto the existing system as was done with the Airport extension, procure a new and separate system for the Interstate MAX, or specify a completely new system for all four lines.

For option one, adding on to the existing CCS, the IS staff responsible for the maintenance of the CCS determined that to expand the Westside and Airport CCS system to accommodate Interstate Max, the hardware would have to be replaced, the operating system would have to upgraded to a version supported by the vendor (US&S), and the software code would have to be ported to a currently supported operating system (the existing operating system is obsolete and no longer supported). This task was beyond TriMet's in-house capability, but an outside vendor might wish to pursue the option.

The option of adding a new system solely for the Interstate Line was rejected for the same reasons that this option had been rejected for the Airport expansion. The added staff required to maintain two separate systems was not a viable option.

TRI-MET OPERATIONS COMMAND CENTER

RECONFIGURED CONTROL AREA FOR INTERSTATE MAX - SPRING 2004

VIEW 1

VIEW 2

VIEW 3

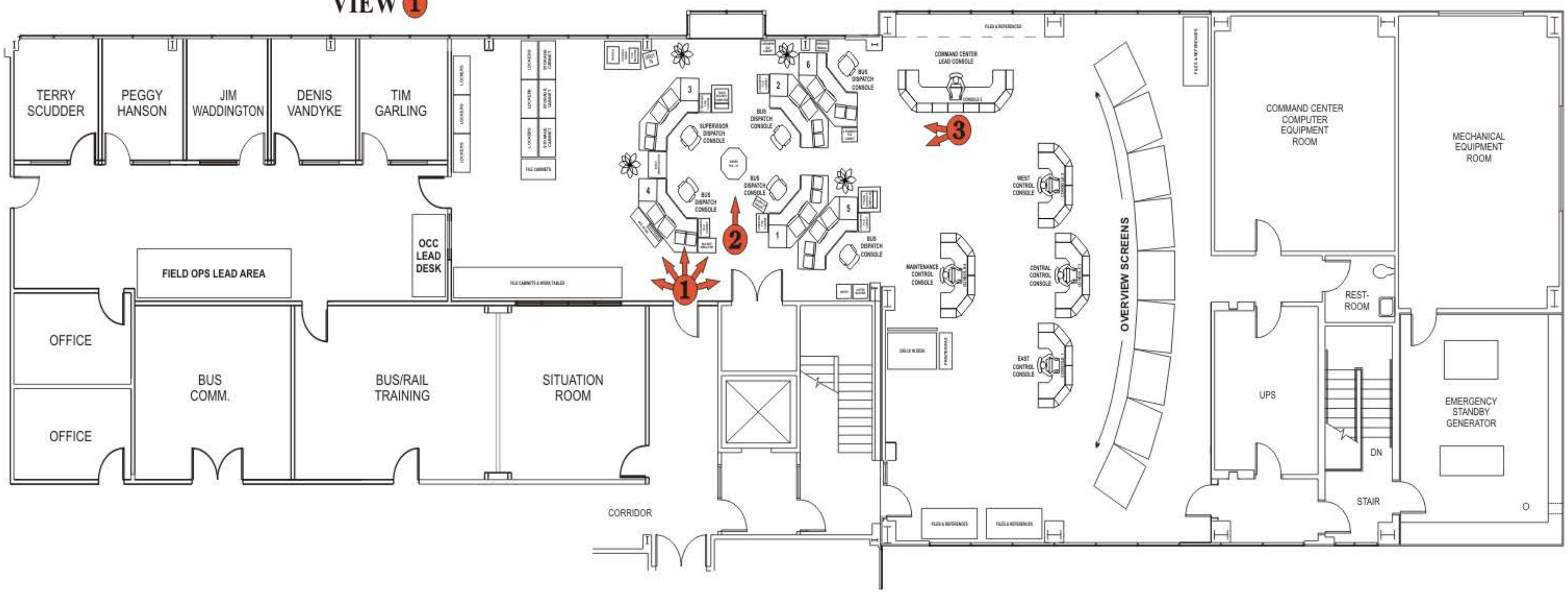

FIGURE 4 Control Center floor plan, following Interstate Line expansion.

To investigate the possibility of a wholesale replacement, TriMet staff contacted potential vendors for a whole new CCS and became educated with the marketplace. This research was a cooperative effort by operations, IS, and capital project staff. TriMet prepared a preliminary specification and requested budgetary quotes from all likely vendors. Based on the responses, TriMet decided to pursue replacing the entire existing CCS.

For this procurement, TriMet returned to the two-step procurement model, very similar to that used on the Westside project. The major difference between this procurement and the Westside procurement was the separation of the CCS procurement from the Interstate communication procurement. This was done to foster competition on both the Signals and Communication contract, and on the CCS contract. Our assessment was that marrying signals, communications, and CCS into one contract would have been very limiting. Potential suppliers for the CCS contract were given the option to either upgrade the existing CCS, or completely replace the CCS.

The follow-on task of replacing the CCS is currently under contract to ARINC, Inc. As of March 2003, final design for the new CCS was nearly complete.

To effectively support the new CCS, significant infrastructure changes were required. Additional workstations, additional overview displays, and reorientation of the room to better facilitate the Bus Dispatch area were all needed. The Control Center infrastructure is being reworked as a part of the Interstate Signals and Communications contract.

Staff Levels

The staffing of the Control Center will increase to allow for a third on-air controller position. This new position is needed to keep radio traffic at workable levels. At this time the amount of radio traffic is nearing maximum levels for the two controller positions. At peak hours, two on-air controllers would find the radio traffic to be unworkable. The use of three territories with three radio talk-groups will keep radio traffic to a workable level. Additionally, a Maintenance Controller position is planned.

Operations Limitations

One of the key goals of the new CCS is easier user-configurability, allowing TriMet staff to make minor changes and upgrades to the system without CCS vendor involvement. The new system, by design, will be more capable of expansion in the future. As is typical of many rail properties, field configuration changes to optimize operations occur on a regular basis. In the past, TriMet often was unable to make minor CCS changes due to budget constraints; CCS changes were expensive. TriMet now anticipates being able to make most CCS changes in-house as the field configuration changes.

Operations Perspective

While the Interstate line is in itself relatively simple to operate, the line’s tie-in to the existing system at Rose Quarter will be the most complex interlocking in the system. The new on-air Controller will be responsible for the new alignment, the half-grand union interlocking, and the central business district areas of the alignment. The other on-air positions will have their geographic areas realigned to match up with the new position.

Information Systems Perspective

The Interstate MAX line was the first major expansion in TriMet's history where the IS Department was an equal participant in the specification, vendor selection, and creation of the new CCS. The IS Department was able to insure that all hardware, software, and software design met TriMet IS standards, which are designed to allow for scalability, reliability, and customer support.

Lessons Learned

Learning from the missteps in the procurement of the first CCS and the Westside system, a comprehensive selection team was formed. The team consisted of personnel from Rail Operations, Capital Projects, IS, Procurement, and one consultant who specialized in transit control systems. However, the team is larger than just those members, because the team members actively brought in staff from every group that might be affected to provide design input. Though this seems cumbersome at first, it works to get all the issues on the table and avoid expensive changes down the road. The most important lesson to learn is to allow enough time for this process.

In order to maximize competition for procurement of the Interstate field communications equipment (which was bundled with the signals system), the CCS procurement contract was separated from all other Interstate MAX contracts. There is a downside to this: the burden for integration falls on the agency. If the agency does not have the right staff available this can be very problematic.

OVERALL LESSONS LEARNED FROM TRIMET'S CONTROL CENTER EVOLUTION

First and foremost, an agency should take a strategic, holistic, organization-wide perspective when embarking on a brand new CCS, modifying an existing control system, or replacing your CCS. As you can see from TriMet's evolution, our perspective has broadened with each successive expansion. The Westside CCS was designed and implemented primarily by the capital projects division. At the end of the Westside project the CCS was handed over to the Operations Division. After a short time operating the system, the Operations Division asked the IS Department for assistance in the care and feeding of the system. Each group passed a baton of responsibility to the other group. Learn from our growing pains and involve all stakeholders at the beginning of the project, whatever the project scope may entail. Operating in departmental vacuums, turf wars, and silos of administration and responsibility do not work to create an efficient CCS that delivers effective service to customers. Cross-divisional teamwork, consensus decision making, and collaboration do make a CCS work.

Secondly, specifying, procuring, implementing, administering, and maintaining a CCS requires dedicated transit operations, IS, and engineering staff. Do not let vendors dictate your agency system requirements or how the system should be operated and maintained. A dedicated agency team will know what is best for your operating and information systems environments and your customers. The operation of the system should correspond to your standard operating procedures, and should fit with your agency's information systems standards. Do not allow a major system of the import of a CCS to drastically violate your standards, or be willing to change your standards to reflect the CCS. If a vendor says "It cannot be done," but the consensus is that it can be done, you probably do not want that vendor.

Implementing Passenger Information, Entertainment, and Security Systems in Light Rail Transit

VALENTIN SCINTEIE
ALSTOM Transport Information Solutions

Passenger information, entertainment, and security systems are becoming indispensable in LRT and other mass transit transportation modes. They respond to the changes underway in the railways and mass transit global environments, such as government debt reduction, demands of the aging population, integration of disabled people in society, private–public partnerships, utilizing information technology to lower costs, improved customer services, and enhanced commuter safety and security.

Several major cities (New York; Montreal, Quebec; Hong Kong; Santiago, Chile) around the world have successfully introduced passenger information, entertainment, and security technologies that also allow for the generation of advertising revenues.

Before implementing new passenger information, entertainment, and security systems, the operator needs to carefully assess the technical solution to be implemented, the impact on passengers in terms of satisfaction and increased ridership, the advertising potential and new revenue streams, and the set up of media and security operations. The methodologies to implement emergency, assistance, safety, and public information via real time electronic customer displays, audio systems, and surveillance systems are described.

INTRODUCTION

Over the last decade, passenger information systems (PIS) have evolved from standalone simple audio and visual displays to multimodal integrated systems that keep passengers informed, safe, and entertained all along their journey in public transit systems (metro trains, commuter rail, station platforms, buses, or bus shelters). Today's passenger information and security systems encompass multiple technologies, including advanced visual displays, public address, emergency intercom, digital surveillance systems, IP networks, wireless networks, video streaming, coders, decoders and many more. These systems deliver real time information seamlessly on-board vehicles and in stations, while controlled and managed from a single control centre.

This paper describes the implementations an integrated trainborne and wayside passenger information and security systems. It results from our experience deploying multimodal systems in Santiago, John F. Kennedy Airport, Singapore, Paris, and New York City. The difficulties encountered and the lessons learned from those projects can certainly benefit other operators.

MULTIMODAL PASSENGER INFORMATION AND SECURITY SYSTEM

The multimodal passenger information and security system architecture is illustrated in Figure 1 and explained in the following sections.

System Description

On board each vehicle, the passenger information and security system consists of displays (text-only LED, advanced LED, TFT LCD and/or dynamic end route maps), a public address system, emergency intercoms, cameras, controllers for closed circuit television (CCTV) and media, operator console for PIS and CCTV, high-speed train local area network (LAN) and wireless interfaces to the wayside. The controllers can interface with the train management system (TMS) or other external systems to obtain train position information.

In the stations, the passenger information and security system also consists of displays (text-only LED, advanced LED, TFT LCD and/or plasma screen), a public address system, emergency intercoms, cameras, controllers for CCTV and media, wide area network (WAN) and wireless interfaces to the trains. The controllers can interface with the Supervisory Control and Data Acquisition System (SCADA) system at the control center to obtain train arrival information, which is sent to the platform displays. The passenger information and security system are also integrated at the control center via a common management interface.

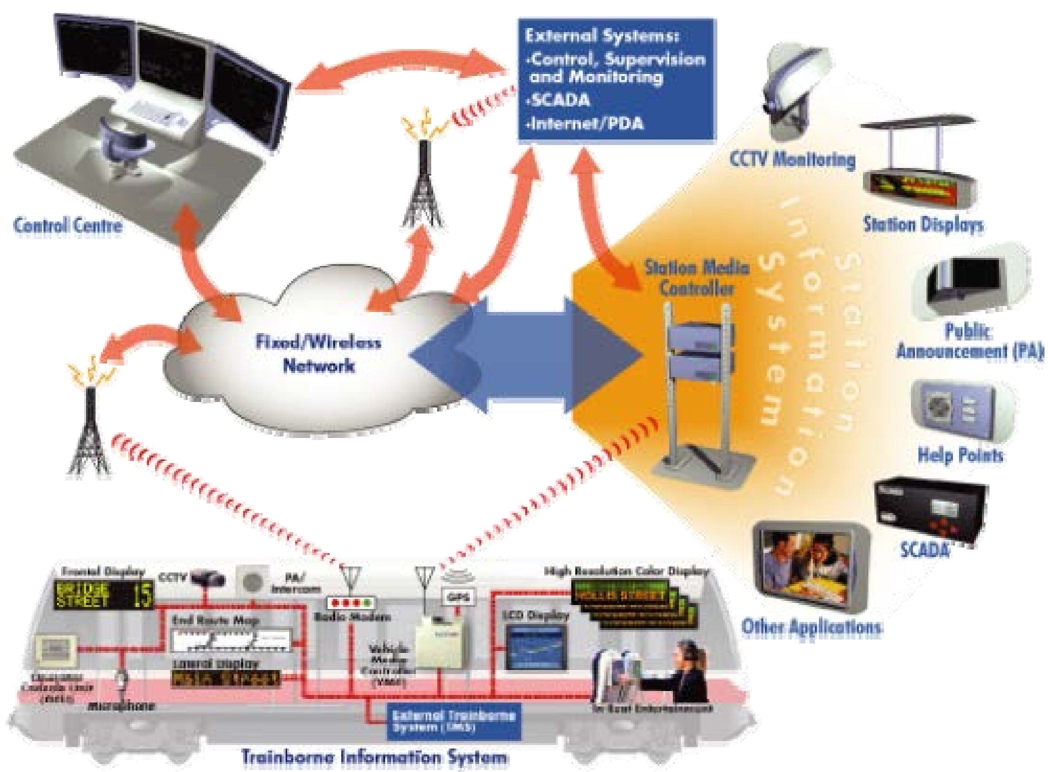

FIGURE 1 Multimodal passenger information and security solution.

Integration of Passenger Information and Security

PIS are part of a global security concept. An Integrated Transport Security System (ITSS) for passengers, installations, and operations performs the following functions: passive and active surveillance, fire and gas detection, and anti-intrusion and access management.

The integration of passenger information within the ITSS is performed at three levels:

- Fusion of ITSS and PIS information at operator level via a generalized Human Machine Interface (HMI) at the control center and the trainborne Operator Console;
- Common infrastructure: high-speed train LAN, WAN, and wireless WAN and LAN; and
- System health monitoring and event triggered alarm interfaces (when the passenger emergency intercom is activated, the digital video recorder can record at a higher frames per second rate than normal).

A common HMI for both PIS and CCTV provides several advantages. It improves the efficiency in transit operations and optimizes the response time during emergencies, while reducing human intervention errors. A common HMI optimizes usage of cab space on board transit vehicles.

COMMUNICATION INFRASTRUCTURE REQUIREMENTS

The communication infrastructure within public transit vehicles and between vehicles and the wayside is a critical part of the passenger information and security solution. New CCTV and media applications requiring high bandwidth data transfers have driven the evolution of the communication infrastructure.

Low Bandwidth

The following are examples of passenger information or security user applications requiring low bandwidth: train and destination identification, next stop and connection announcements, broadcast of audio and visual emergency messages, and passenger emergency intercom.

A low bandwidth network has the following characteristics:

- Provides transmission rates in the order of tens of kbps;
- Supports very good quality of service for vital applications (emergency intercom);
- Leverages the existing trainborne network infrastructure;
- Uses standards-compliant trainborne protocols such as IEEE 1473, LonWorks, FIP, CAN, RS-485, MVB, or IBIS; and
- Uses low-bandwidth train-wayside protocols such as GSM, GSM-R, CDMA, TDMA, GPRS, CDPD, DAB, or Tetra.

High Bandwidth

The following are examples of passenger information or security user applications requiring high bandwidth: media entertainment and advertising broadcasting (web-like content), trainborne

CCTV video streaming to the wayside, platform CCTV video streaming to the trains, in-seat information and entertainment, and interactive Internet or Intranet access.

A high bandwidth network has the following characteristics:

- Support transmission rates from few to hundreds Mbps and very good quality of service for vital applications;
- Leverage the existing trainborne network infrastructure in refurbished trains;
- Standards-compliant trainborne protocols: adapted or standard Ethernet, power-line protocols, Wi-Fi, IDB 1394, or MOST; and
- High-bandwidth train-wayside protocols: IEEE 802.11 a/b/g/e/h, UMTS (3G), leaky coaxial cables, waveguides, DVB-T, and DVB-S.

LESSONS LEARNED

This section describes the lessons that we learned from deployments of multimodal passenger information and security systems. The following are shared for illustration purposes only to help prevent similar mistakes in the future while promoting good practices:

- Proper identification of cross-functional stakeholders and key end-users at the beginning of the project is essential (rolling stock, signalling, control center, security, maintenance, information technology, customer service, etc.).
- Implement a product strategy approach, in addition to the traditional project-driven approach, to ensure that core system functions and components evolve properly from project to project to a rich and optimized feature set.
- It is critical to also have an integrated multimodal information strategy that clearly defines the interfaces between train, station, bus, control center, external systems, and so on.
- Manage the risk of turnover (and in some cases absence) of key end-users throughout the project lifecycle.
- Acknowledge that advanced CCTV and media functionalities require enhanced train and train-to-wayside communication infrastructure
- System operability, reliability, and maintainability can be increased via integration with the TMS/Communications-Based Train Control (CBTC) and ATS/SCADA systems.

Proper Identification of Project Team Members

In order to successfully deploy a multimodal project, the appropriate team needs to be put in place from the beginning, both on the customer and the supplier side. The introduction of a multimodal system requires involvement and commitment by all cross-functional stakeholders and end-users, as well as technical and management leadership during the entire duration of the project. If third-party car builders or multiple suppliers are involved in the project, strong teamwork and open communication between all the parties is crucial to success.

Product Strategy Approach

Most of the time, passenger information and security systems are adapted electrically, mechanically, and software-wise for specific train configuration and specific customer needs. Thus, the short time vision is to develop systems one project at the time. A clear product strategy allows the definition of the base product functionalities that are available in a specific system in a given release. This baseline can be customized by adding features tailored to specific operator needs. If a feature can benefit other operators, then it becomes part of the baseline of the next release. Furthermore, the baseline is enriched by research and development activities.

Integrated Multimodal Information Strategy

Contrary to standalone systems, multimodal systems have the particularity that they affect several parts of the transit network. Therefore, the transit operator needs to have an integrated multimodal information strategy and the interfaces should be clearly defined between train, station, bus, control center, and external systems. This is important even if—due to budget constraints—the implementation is phased in several stages.

Manage Risk of Turnover of End-Users

It can occur that after passenger information or security systems are fully deployed, as a result of some organizational changes, a new group of users starts using the systems. This change needs to be managed carefully. The new users have to be trained. If the system's new functionalities were not captured in the initial requirements, the system may require modifications to satisfy the new requirements.

Importance of Communication Infrastructure

The communication infrastructure within public transit vehicles and between vehicles and the wayside is the pillar of the passenger information and security solution. Most of the new applications, like web-like entertainment content or streaming video surveillance, require large amounts of bandwidth. It is important to take into account the impact on the communication infrastructure. Communication networks have evolved quite a bit, and there are many options to choose from. The selection of a specific infrastructure depends on the applications, the public network, and the specifics of the operator's network.

Integration with External Systems

The reliability and the maintainability of an entire passenger information and security system can be enhanced by its integration with other external systems, such as TMS/CBTC and ATS/SCADA system. TMS provides the train location to the trainborne PIS, while ATS gives train schedules to the wayside PIS. A common HMI for both PIS and CCTV, integrated with ATS/SCADA, improves the efficiency of the transit operators and optimizes the response time during emergencies. PIS and CCTV alarms and diagnostic data can also be presented in a standard format with other operator subsystems.

CONCLUSION

This paper described some of our experiences in implementing integrated passenger information and security systems in several cities. Nowadays, providing passengers with relevant travel information and making their trip safer and more enjoyable is an essential part of the modern transit landscape. The innovations on communication technologies, electronics, and software enable applications that did not exist less than a decade ago. As an example, live video surveillance image transmission from vehicles to a control center in real time is now a reality.

Based on our experience, the following should be considered when implementing multimodal integrated passenger information and security systems:

- During the requirements definition phase, keep in mind the whole picture (public announcement, signs, CCTV, trainborne, wayside, control center, bus, etc.), including all subsystem interfaces.
- Select a solution that can evolve with your needs and evolve with multiple technology facets.
- Compare a base passenger information and security system versus a more entertaining and revenue-generating, advertising-enabled media system.
- Select a system that has a lifetime of at least ten years (innovative with limited risk).

PROJECT MANAGEMENT

Procurement of Federal Property for Light Rail Transit
Case Study of the Minneapolis Hiawatha Line

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Metropolitan Council of Minneapolis–Saint Paul

As in many other cities around the United States, bringing the first light rail transit line in Minneapolis to reality was, and still is, fraught with many challenges. The Metropolitan Council, which will operate the line, and the Minnesota Department of Transportation, which is building the line, have dealt with tight budgets, compressed time lines, lawsuits, and continued political opposition. Other starter lines have faced all of these problems. But one of the unique challenges that faced the Hiawatha Project Office was the acquisition of federal property through the Fort Snelling military reservation.

To acquire the 1.5 mi of alignment through Fort Snelling, property exchange agreements were negotiated with five separate military services and federal agencies. The procedures followed to develop each of these agreements and the compensation provided in exchange for the land varied by agency. The process of acquiring federal property will be described, and some important lessons learned from the Minneapolis experience will be highlighted.

INTRODUCTION

When completed in 2004, the Minneapolis Hiawatha Light Rail Transit (LRT) line will extend from downtown Minneapolis to the Mall of America through the Minneapolis–Saint Paul Airport (Figure 1). The line will be operated by Metro Transit, a division of the Metropolitan Council, the metropolitan planning organization for the region. Minnesota Department of Transportation (MnDOT) is constructing the Hiawatha line on behalf of the Council. The Hiawatha Project Office (HPO) is responsible for project management. HPO includes employees of both agencies and O'Brien–Kreitzberg, the project management consultant for the Council.

In downtown Minneapolis, the Hiawatha line will operate on reserved right of way on the new 5th Street transit mall. After leaving downtown, the line then crosses to the former Milwaukee Road mainline, on the same right of way once followed by the famous Hiawatha passenger train connecting Minneapolis and Chicago. South of 28th Street, the alignment parallels Hiawatha Boulevard on land once cleared for an eight-lane freeway that was opposed and eventually defeated by the community.

When first considered, the Hiawatha line was to be constructed to Fort Snelling. However, the development of the Mall of America in 1992 created a logical new terminus for the line. When preliminary engineering for the project was initiated in 1999, an extension through the airport and a terminal station at the Mall of America was included. Construction of the line, begun in 2001, required the boring of two parallel 7,400-ft tunnels underneath two active

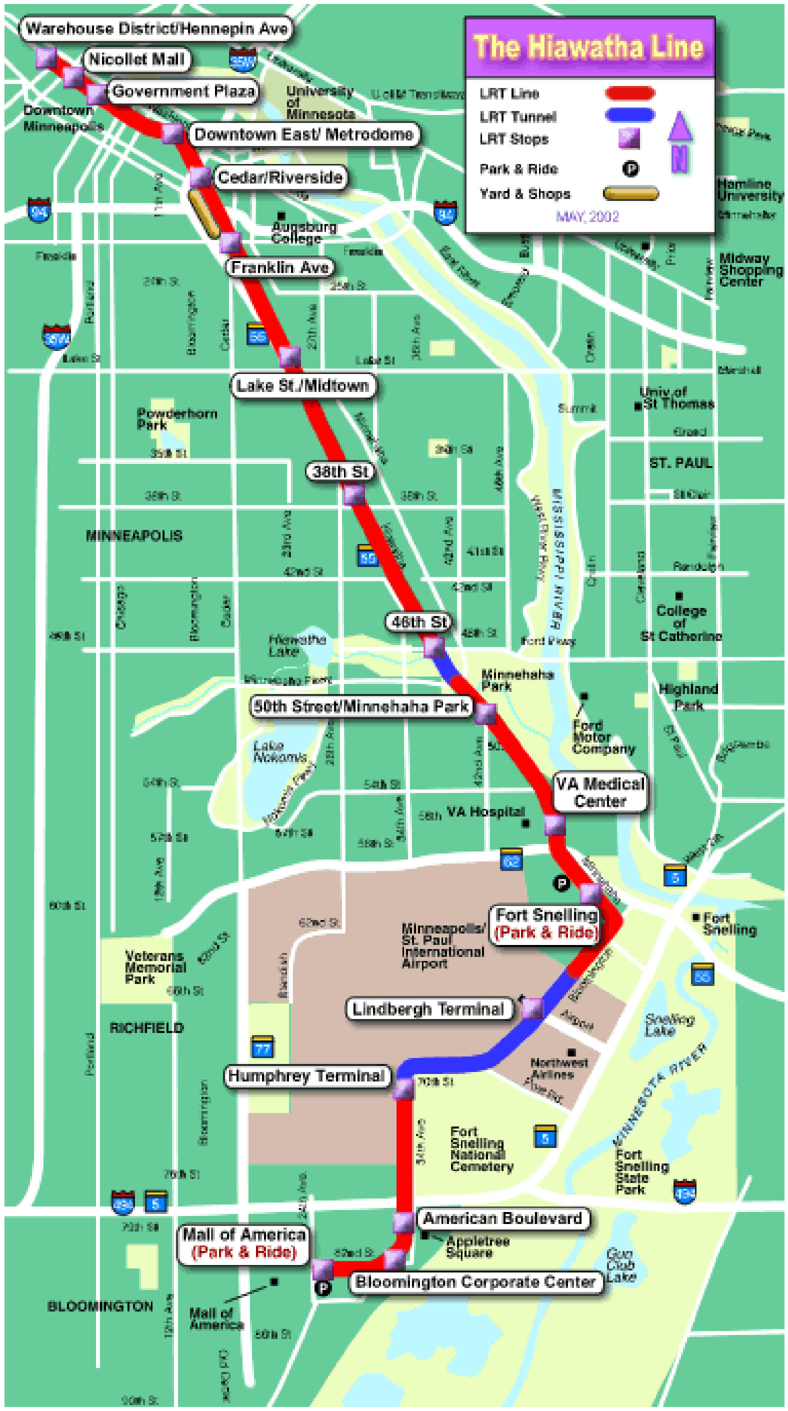

FIGURE 1 Map of the Hiawatha Line.

runways at the Minneapolis–Saint Paul International Airport and the excavation of an underground station at the Main terminal.

To get to the airport, the alignment has to pass through the Fort Snelling military reservation (Figure 2). From an engineering perspective, going through Fort Snelling and then tunneling under the airport is the logical path to get from the south end of Hiawatha Avenue to

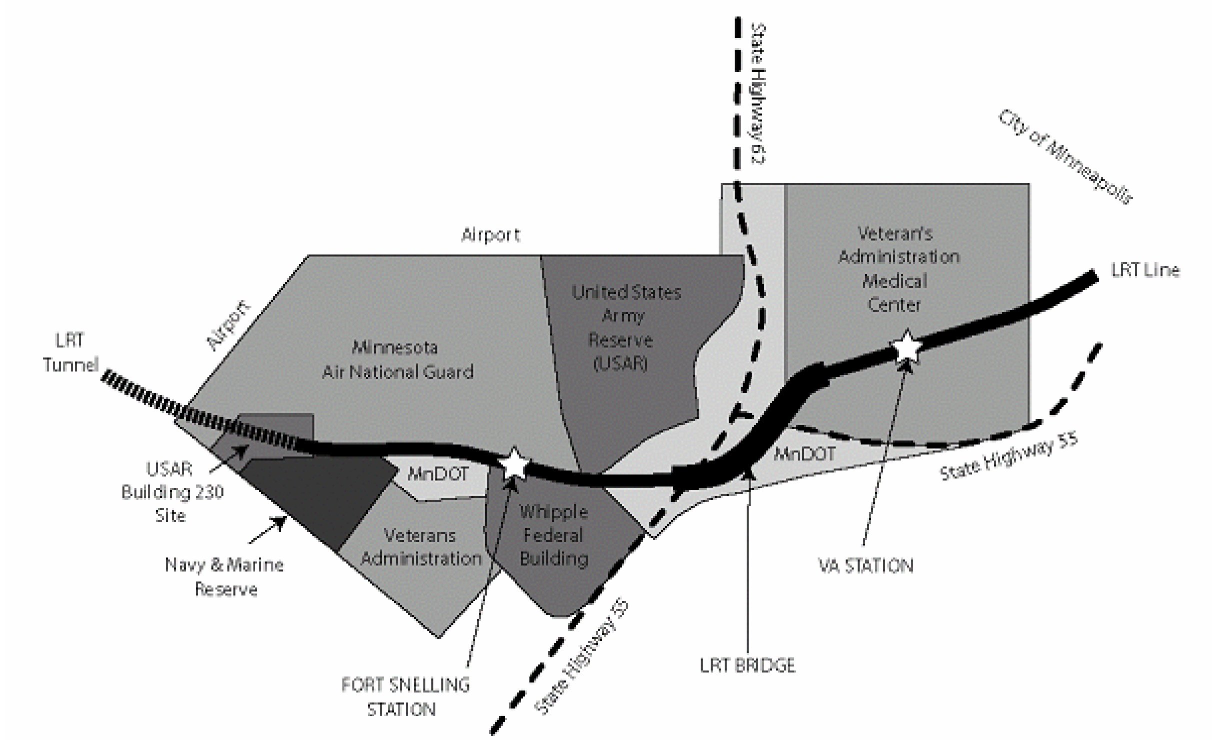

FIGURE 2 Hiawatha LRT alignment through Fort Snelling.

the Mall of America. There really is no alternative route. But in 1999, no one in Minneapolis really understood what it was going to take to procure the land at Fort Snelling.

Built on a bluff overlooking the confluence of the Mississippi and Minnesota Rivers, Fort Snelling was the site of the first Euro-American settlement in the state of Minnesota and played a key role in the development of the region. Fort Snelling continued to fulfill an important military role through World War II. But after the war, Fort Snelling was decommissioned and the property was gradually parceled out to several new uses. One of these parcels eventually became the Minneapolis–Saint Paul International Airport. There is also a national cemetery, a Veterans Hospital, a large federal building and several military bases. A portion of the site has been restored as Historic Fort Snelling, and the area below the bluff and around the rivers has been converted to one of the largest urban state parks in the country. Recently, the Minneapolis Park Board has constructed baseball and softball fields, soccer fields and a tennis center at Fort Snelling.

The multiple landowners meant that in order to secure the necessary right of way to cross Fort Snelling, the Metropolitan Council had to procure land from the following agencies:

- U.S. Army Reserve (USAR);
- Minnesota Air National Guard (ANG) and United States Air Force (USAF);
- Veterans Administration (VA);
- General Services Administration (GSA); and
- United States Navy (USN).

In addition to these agencies, the Council had to work with the following:

- United States Coast Guard Reserve,

- Minneapolis Park Board,
- Minnesota Department of Natural Resources, and
- Minnesota Historical Society.

Since neither MnDOT nor the Council has the authority to condemn land owned by a federal agency, negotiations with each federal landowner were conducted with the Council and MnDOT at a distinct disadvantage. The land was needed to complete the alignment and the agency did not have to give it. Further complicating the relationship was the fact that none of the agencies could simply accept cash payment for their property but required the construction of replacement facilities for those displaced by the LRT line.

In 1999, MnDOT began negotiating with a group consisting of representatives from each of the agencies that owned land in the area. In all cases, local representatives of these agencies were supportive of the LRT proposal and favored having the alignment come through the Fort Snelling area. But these negotiations involved a complicated give and take on the part of each participant, so much so that the alignment came to be described by MnDOT's chief negotiator as a "house of cards." Each agency was willing to give up some land but needed to continue to carry out its mission at that location.

After several months of negotiating, an initial alignment was selected. This alignment included the construction of a park and ride facility, the removal of an Army building and the removal of several wood frame houses that had been vacant for several years. The Fort Snelling station was to be located in the middle of the existing Federal Building parking lot. The alignment was later modified to place the station alongside the Federal Building parking lot.

The first major complication in the effort to procure land at Fort Snelling came in the summer of 2000 when the Minnesota attorney general's office issued an opinion that concluded that MnDOT did not have the statutory authority to provide in-kind construction services in exchange for property. This decision came as MnDOT was completing the group negotiations cited above. Subsequent to this, the Council continued negotiating with the individual agencies.

TERMS OF PROPERTY EXCHANGE AGREEMENTS

The primary vehicle for the acquisition of federal property was the property exchange agreement. This document defined the property that was to be received by the Council as well as the compensation to be provided. The general principle was that the agency affected by the construction of the LRT line should continue to function in the same manner as before. In general, new facilities were intended to replace facilities that were on the proposed track alignment.

U.S. Army Reserve

The principle impact on USAR was the removal of Building 230, which was situated on the alignment. As compensation, the Council agreed to construct an addition to an existing office building known as Building 506. The Council also paid for the relocation of the three military units formerly housed in the Building 230 and the renovation of three other buildings to accommodate these units. Upon signing the agreement, the Council received a permanent easement for three parcels of land including the Building 230 site and land needed by MnDOT for the construction of an interchange. Upon completion of all the construction provided to USAR, the Council received title to the land.

General Services Administration

GSA operates the Whipple Federal Building. The GSA was naturally concerned that the federal building parking lot, which has about 1000 spaces, would become a de facto park and ride for the LRT line. The Council reconstructed the federal building parking lot to limit access to two entrances that are secured with card readers and gates. The Council also provided additional security cameras, which were integrated into the Federal Buildings security system to monitor the area near the station. In exchange for this consideration, the Council obtained a permanent easement for land that is now the site of the Fort Snelling station.

Minnesota Air National Guard and U.S. Air Force

At Fort Snelling, the Minnesota ANG leases land from USAF for an air base. ANG uses the Minneapolis–St Paul Airport to provide cargo airlift services to the military. Since the alignment parallels the boundary of the base for a considerable distance, several facilities were affected. Two storage buildings were removed and replaced with a single larger storage building. A liquid oxygen storage facility, a weigh scale, and a loading dock were also relocated. The roadways and parking lots in the vicinity of the tracks and the relocations were modified to fit the new facilities.

The project also used USAF and ANG land for a staging area for the tunnel construction. Once this construction is complete, the Council will reconstruct the roadway to the back gate and construct a new guard shack at the back gate.

In exchange for this consideration, the Council received an easement for a parcel of land for the LRT alignment, an additional parcel for the relocation of a roadway, an easement for a portion of the airport tunnel, and an easement for a staging area for the construction of the tunnel.

Veteran’s Administration

VA was affected by the LRT alignment primarily in front of the VA Hospital. At that location, the LRT track and the VA Hospital station are located on land that was already in use as a state highway. Modifications to the front gate and to the VA property along the alignment were provided to match the station.

At the Fort Snelling station, the VA owns land that the Council will be purchasing for a park and ride. Because of recent changes to the design of the park and ride, the property exchange agreement for this property has not been completed. However, the VA has granted the Council a 3-year license, granted locally, to allow construction to proceed.

U.S. Navy

The impact on USN was minimal. A .3-acre parcel was necessary for the alignment. USN is receiving a parcel of land about the same size as the land that they are providing. The land that USN is receiving is a portion of the Building 230 site transferred to the Council by the USAR.

NEGOTIATION PROCESS

The negotiation process with each of the agencies was a unique experience. Each agency has different management structures and different rules for the transfer of the land. Learning these rules was sometimes difficult because the situation was novel, and agency representatives themselves sometimes struggled with determining what needed to be done.

In all cases, the local representatives of each agency were completely cooperative with the project and worked hard to make the project possible. This is because the local representatives could see the value of bringing the LRT alignment and a station directly into their midst, connecting the base to not only downtown but particularly to the airport. The greatest challenge came when actions needed to be taken at other locations, either regional or national offices. In some cases it became necessary to rely heavily on assistance from Congressional staff.

United States Army Reserve

The first priority in working in the federal area was to secure ownership of what was then known as Building 230. This USAR-owned building was not only situated directly over the proposed location of the tracks, it was the location of the north portal of the airport tunnel. Construction on the tunnel was scheduled to begin in April 2001; the building needed to be cleared of its occupants, cleared of hazardous materials, and demolished before that time. It also needed to be acquired from the USAR. In order to do this, a property exchange agreement had to be negotiated with the USAR and either an easement or title needed to be secured by the Council for the building and surrounding property.

USAR is structured around several Regional Support Commands that oversee the activities of the wide variety of Reserve units in its geographic area. A Regional Support Command is somewhat analogous to a division in the active army. The 88th Regional Support Command (RSC), formerly the 88th Division, has its headquarters at Fort Snelling. From there, the 88th RSC commands units in Minnesota, Wisconsin, Illinois, Michigan, Indiana, and Ohio. The engineering section of the 88th RSC is responsible for maintaining existing USAR facilities in this region as well as the development and construction of new facilities and the disposition of unused facilities and excess property. The point of contact for the USAR was the 88th RSC Division Engineer.

Negotiations with the USAR had been on going since early 2000. In August 2000, the basic terms of the agreement were that in exchange for the Building 230 site, the land necessary for the highway interchange and a small parcel, the Council would temporarily relocate the three units and construct a new building on the main campus of the USAR.

The property exchange agreement was negotiated with the local division engineer but approval of the agreement was necessary at several levels. This included the Army Corps of Engineers in Omaha, USAR Command in Atlanta, the Office of the Army Reserve (OCAR) in Washington, D.C., and the Department of the Army at the Pentagon. The draft agreement was finalized in the fall and agreed to by the local authorities. It then began the long process of gaining approvals through the chain of command. Since this was to be a direct sale, it was also necessary for two congressional committees to review the agreement. At this point the office of Congressman Sabo was enlisted to help track the progress of the approvals and the congressional review. Through regular communication with USAR and prodding from the congressman’s office, the agreement progressed until finally it reached the Department of the Army.

This was one of the critical moments in the project. One of the characteristics of the lengthy approval process was that the rationale for the agreement and the importance to the local USAR installation of executing this agreement needed to be explained at each level. The same problem occurred at the Department of the Army. Those responsible for approving the final document expressed concern over the project to the congressman's office and requested additional information. At this point in time, demolition of the building needed to occur within the next two weeks in order to maintain the scheduled beginning of the tunnel construction.

It was late on a Friday afternoon that the congressman's office informed the Council that the Department of the Army was not going to approve the agreement. It was clear that the information that they were requesting was already available and all the necessary environmental documentation had been completed, but significant questions were being asked all the same. That same afternoon, the Council contacted the Department of the Army directly to discuss these issues and suggested that a Council representative come out to Washington, D.C., to explain the project in person. On the following Monday, a meeting was arranged for the following day, Tuesday, at the Pentagon. That meeting was held with representatives from the Army General Counsel Office, Department of the Army, OCAR, and the Army Corps of Engineers. The Council representative was able to explain the project and was invited back the following day to pick up a completed property exchange agreement and an easement that allowed the project to go forward.

The tunnel contractor moved onto the property the following week and the project stayed on schedule.

General Services Administration

In the same way that working with USAR was filled with drama, negotiations with GSA were filled with frustration. For USAR, determination of the appropriate compensation, once decided, remained fixed. For GSA, determination of the appropriate compensation was a moving target until the agreement was finalized.

As part of the application for the Full Funding Grant Agreement (FFGA), it was necessary to demonstrate that all of the federal land owner's agencies were willing to work with the Council on allowing the LRT line to be built across their land. Most of the agencies provided their written consent. However, GSA, which operates the Federal Building, required a little extra.

When the negotiations to determine the alignment through the federal area had been completed, MnDOT moved forward with the PE design based upon the initial proposal to build a parking ramp over the federal building parking lot. At the same time, a team of Council employees began working on the FFGA application. When written confirmation of GSA's approval of the alignment was not forthcoming, the Council made a startling discovery.

It turned out that the local representatives, who had negotiated the agreement, did not have the authority to commit the agency to the project. The regional office in Chicago needed to be involved. When informed of the Council's desire to construct an LRT alignment through their property and construct a park and ride over their parking lot, their initial response was to say no. A hastily arranged meeting had to be held in Chicago with GSA representatives and representatives from MnDOT and the Council. The initial reaction of the Chicago representatives was to ask to have the project moved off their property. It took some effort to convince the Chicago regional office that it was going to be necessary to work with us to build this rail line. Once the Council convinced the Chicago GSA that there was no alternative to the alignment selected based upon negotiations with local GSA representatives, the Chicago GSA put together a team to provide the HPO with input for the design of the parking garage to be situated on their property.

Before September 11, 2001 (9/11), the worst case of domestic terrorism was the bombing of the Murrow Federal Building in Oklahoma City. For this reason, the design of the parking garage became a topic of intense discussion. The Federal Protective Service in charge of protecting the Whipple Federal Building was concerned about a similar event occurring in Minneapolis. Working with the GSA design team, several unique features were added to the parking garage to increase the security of the facility:

1. The upper levels of the garage had to be stepped back to allow for blast deflection.
2. Entry/exit ramps and stairs for the park-and-ride users had to be physically separate from the portion if the parking structure was reserved for building employees.
3. Extensive security camera coverage and other security elements had to be included.

The parking ramp design criteria developed by GSA were included in the bid package issued in early 2000 for the solicitation of design-build construction teams. Although the design-build package was bid on a lump sum basis, this garage was included as an add-alternate allowing the reviewers of the proposals to know what this particular element was going to cost. After the proposals were received, it was clear that the construction of a parking ramp was not cost effective. The parking ramp concept was dropped and the park and ride moved to a surface lot on nearby land.

Renewed negotiations with GSA focused on developing a concept design and design criteria for the federal building parking lot, which was to be reconstructed to prevent rail users from parking in the lot illegally. This process began in early 2001. A package of design criteria was completed in May 2001 and forwarded to the design build contractor. The design criteria completed by GSA with the assistance of HPO were very detailed. This detail was necessary to ensure that the design met GSA's needs. It also became valuable later to ensure that no additional work was requested by GSA.

Design of the lot proceeded through the latter half of 2001, but the completion of a property exchange agreement was not possible until a final design was presented to the GSA. Design of the lot was complicated by the fact that the design build contractor was doing the design in conjunction with the design of the rest of the project. GSA was forced to work within the design review procedures established in the DB contract. This was difficult to coordinate and required that GSA respond to plans that they were presented with within 10 days of receiving the plans. To their credit, GSA always responded to the plan review in the time allotted.

But completing the agreement was also complicated by an underlying mistrust of HPO by Chicago GSA. GSA wanted assurances that once they signed over an easement to the Council that they would in fact receive the construction for which they had bargained. GSA requested a performance bond, but the Council could not secure that type of instrument because the Council was not the contractor doing the work. The contractor was under contract to MnDOT, so the GSA did not have recourse to the contractor's performance bond. Eventually, it was decided that the Council would put into escrow an amount equal to the estimated cost of the work that was being performed on GSA property.

The escrow agreement was executed simultaneously with the property exchange agreement. At this time, an easement was granted to the Council for the property used to build the Fort Snelling station. This occurred in spring 2002 with the contractor ready to mobilize onto the property as soon as the easement was received.

Air National Guard and U.S. Air Force

The 934th Airlift Wing of the Minnesota ANG is based at Fort Snelling. The base itself is on property officially owned by USAF. Because of this, negotiations with the ANG and USAF occurred jointly. The USAF provided the easements necessary to proceed with construction. The primary impact was on the ANG itself and the compensation negotiated with the two parties ended up being directly related to the ANG facilities as described above.

There was also some time pressure involved with these discussions because a portion of the land provided by the ANG both for temporary easement and for permanent easement was to be used for a staging area for tunnel construction, and therefore the easement needed to be obtained in a timely fashion to allow construction to proceed.

But compared with the examples cited above, negotiations with USAF and ANG were straightforward. One of the reasons for this was the decision to seek just a permanent easement rather than fee title. This avoided the need to have congressional review of the agreement and allowed speedier review at all levels of the chain of command. In this case, higher headquarters processed the paperwork in a timely fashion and work on the tunnel was not affected. It is still the intention of USAF, however, to begin the process of transferring title to the land to the Council once the project is completed, but this is not part of any written agreement.

U.S. Navy

USN had the smallest parcel affected by the alignment, but it was in a key location. Local authorities were extremely cooperative with the project and an agreement was easily drafted, because the compensation for the land was another parcel adjacent to the Navy of about equal size. In this case it was merely a land-for-land swap.

Had it not been for the critical time line of tunnel construction, this agreement would not have been that difficult, but, as with the Army agreement, once it left the local authorities, the going was slow. Eventually, the congressman’s office was enlisted to track the agreement down and push it along. This effort was effective and the Navy easement was granted in time to allow construction to proceed.

Veteran’s Administration

Each of the agencies that the Council dealt with had different management structures and local authorities had varying powers. Local authorities at VA turned out to have the greatest power to grant property rights.

VA was affected by the alignment in two locations: in front of the VA building and at the park-and-ride site. In front of the VA building, MnDOT had been operating a state highway on a transportation easement from the VA for many years. As part of the reconstruction of the highway along with LRT, the state highway was shifted to a new alignment away from the hospital and the LRT line put where the state highway had been. In front of the hospital, the state already had a transportation easement and did not have to buy additional land. Some changes had to be made on VA property here because an entrance to the parking lot was closed and the fence had to be relocated. But the changes were relatively minor.

At the park-and-ride site, several white frame houses had to be cleared, but these were vacant and did not affect the existing function of the VA. Local VA representatives were able to grant a 3-year license to allow construction to begin. Ultimately, a permanent easement will be negotiated with VA to allow continued use of the property, but, because of the effort that was being put into the other agreements, it was agreed that the completion of the property exchange agreement would be deferred.

As it has turned out, recent changes to the park-and-ride design will require the Council to acquire more land than was originally thought. As a result, the property exchange agreement with VA has not been completed.

IMPLEMENTATION

The project itself is being constructed primarily through a design-build (DB) contract with a joint venture called Minnesota Transit Constructors (MnTC), which includes Granite Construction, McCrossan Construction, Parsons Transportation Group, and Edwards and Kelcey. Providing the in-kind construction described above was accomplished in one of two ways, either MnTC performed the work under the larger DB contract or the work was contracted for separately through the Metropolitan Council.

One of the difficulties in implementing these agreements was that even though the compensation is described in the property exchange agreement, each building, structure parking lot, or roadway needed to be designed. In the case of USAR and GSA, where there was no clear budget, a natural tendency existed where the agency attempted to continue to add elements to the scope while the HPO tried to hold the line on additional spending.

In general, it was much easier to manage this process if the construction provided to the federal agencies was kept out of the DB contract and managed as a separate procurement. This was not always possible. Because the GSA parking lot was adjacent to the Fort Snelling station, the parking lot reconstruction had to be included in the DB contract. The same was true of changes to the parking lot at the VA Hospital. In the case of ANG, the DB contractor handled the relocation of the liquid oxygen facility because the facility was on the alignment.

U.S. Army Reserve

All of the work provided on behalf of the USAR was managed directly by the Council outside of the DB contract. FTA approved procurement procedures were used to hire all outside contractors.

In the fall of 2000, concurrent with the negotiation of the property exchange agreement, the Council began the process of moving the units out of Building 230. The 3rd Brigade of the 84th Division was moved into vacant quarters in Building 507, but the print shop and the maintenance unit were to be moved into quarters that required renovation. A rifle range was renovated for the print shop. The maintenance unit was moved into a building occupied by the Fort Snelling Military Museum that in turn was moved to an adjacent building. Once the renovation and repairs to the new quarters were completed in November 2000, all of the occupants of Building 230 were relocated to their new spaces using commercial moving companies.

Once the building was empty, environmental remediation was conducted. The building was surveyed for hazardous materials, and special arrangements were made for the removal of any material that could not be present during demolition of the building. This included asbestos and mercury in the lighting fixtures.

Preparation of the new quarters, the moving of the units, and the preparation of Building 230 for demolition was accomplished prior to the signing of the formal property exchange agreement as well as the approval of the FFGA. A demolition contractor was procured and was ready to demolish the building as early as October 2000. When the agreement was finally signed in March, the demolition contractor was able to mobilize almost immediately and the building was removed within 2 weeks. The site was then handed over to allow construction of the tunnel, which began in April 2001.

The next step was the construction of the new building. Council procurement rules require that the design and construction phases be separate contracts. A design firm was procured in the spring of 2001and the design prepared through the summer of 2001. The USAR participated in the selection of the design firm and worked closely with the Council on completing the design of the building. Design was complete in the fall of 2001 and construction commenced in the fall. Construction of the new building proceeded through the winter and completed the following summer. USAR took possession of the building in September 2002.

General Services Administration

The reconstruction of the GSA parking lot was included in the DB contract. This was because the original design included a parking garage over the tracks and the PE drawings included with the bid package included the parking garage. The shift to the new alignment came during contract negotiations with MnTC. The parking garage was eliminated and the alignment moved. Consideration was given to removing the GSA parking lot from the DB contract but because the parking lot is immediately adjacent to the track, the design of the lot is closely related to the design of the track and the coordination of construction between two contractors would have been difficult.

Negotiation of the property exchange agreement included a detailed scope of what was to be provided to the GSA by the Council. This included a conceptual layout of the new lot, which identified the orientation of the parking rows, the number of spaces, the location of entrances and the general layout of the lighting system. The scope also included the provision of card readers, gate arms, and security cameras. The scope identified in the property exchange agreement was provided to the DB contractor for inclusion in the design.

Design of the parking lot was included in the design of the other elements of the alignment. The review procedures established with the DB contractor had to be followed. The GSA and the engineering firm that they hired to represent them reviewed the design at the definitive design stage, at the issued for construction stage, and at the final design stage. Comments made by GSA had to be reconciled with the detailed scope of work provided in the property exchange agreement. Additional work requested by GSA that was not detailed in the original scope had to be refused. Ultimately, GSA approved the final construction plans prepared by MnTC.

MnTC carried out reconstruction of the parking lot and the roadways in the vicinity. GSA hired an engineering firm to monitor construction on their behalf. This was in addition to the quality control and quality assurance procedures already in place for construction by the contractor. GSA's engineers could not report directly to MnTC if there were issues to be dealt with but instead had to go through HPO representatives.

While all of the individual projects on the federal properties had weekly construction project meetings, for GSA the HPO also held a weekly meeting with building management, representatives of the tenants of the Federal Building, and representatives of the surrounding agencies. This project included the reconstruction or relocation of the principle roadway serving this area. This and the fact that the federal building has over 1000 employees made it necessary to reconstruct the lot and the surrounding roadways in stages. This allowed the building to continue to use most of the lot during construction, but it also meant that there were periodic changes in traffic patterns and the location of available parking. These weekly meetings helped to communicate to the employees in the area what could be expected during the upcoming weeks of construction.

Reconstruction of the lot occurred during the 2002 and 2003 construction seasons.

Air National Guard

The construction performed on behalf of ANG was performed in part by the DB contractor with the remainder being contracted for separately.

The DB contractor was responsible for modifications to the front gate roadway because it intersected the roadway through the area that was being relocated. This also involved the relocation of the main gate sign. The DB contractor is also responsible for the relocation of a liquid oxygen storage facility that is situated in the alignment. This action was included in the DB contract because it was necessary to construct the track.

The remainder of the work will be performed in two stages. One reason for this is because the tunnel contractor is using a portion of the ANG base as a staging area and this site will not be available until spring 2004. The other reason is because the material stored in the older storage buildings cannot be removed until the new storage building is built.

The first stage involved the construction of the new storage facility and the site work on that portion of the base that was not being used for construction staging at the tunnel. The first phase was designed in early 2002 and then constructed in late 2002 through early 2003. The design of the second phase is being coordinated with the tunnel contractor's restoration work and is not yet completed.

Veterans Administration

The Council and VA are still determining what sort of compensation will be provided to the VA.

SPECIAL CHALLENGES

There were many special challenges faced when implementing the property exchange agreements.

To some degree or another, the DB contractor had to perform some of the services promised to the agency because the work needed to be coordinated with track construction. Having the DB contractor do any work for a federal agency is difficult to coordinate. The federal property owners had to work within the review procedures established in the contract with the DB contractor. This usually meant that the agency had to review plans within the 15-day review period that the HPO had to work with. In the future it is recommended that separate review procedures be established whenever work is to be performed on private property.

Another significant challenge was working on military bases during the recent military actions overseas. On 9/11, a Council contractor was working on the USAR base constructing the office building. That afternoon, the contractor was forced to vacate the site and was not allowed to resume work for a week. Once allowed back on, what had been a relatively relaxed atmosphere had turned into a situation with armed guards and searches. At first, the contractors were not allowed to bring their trucks on site, which was challenging for the workers. After a couple of weeks working in this environment, a fence was erected around the work zone and a separate entrance provided for the contractor. The site was secured at night but it was no longer necessary to pass armed guards every day. When work on the Air Guard base began, the same technique was used to segregate the construction of the building from the rest of the base. However, some of the work still had to be performed in the secure area and this required that security personnel escort workers.

LESSONS LEARNED

The experience with federal agencies described is necessarily in summary form. It would be impossible to provide a complete history in such a short paper. But there are important lessons that can be learned from the Minneapolis experience.

Avoid Federal Land if Possible

Attempting to acquire federal land introduces both schedule and financial risks to the project. Unless pushed energetically, the process can be slow, tedious, and frustrating. Until negotiations are complete, costs are difficult to predict. If possible, federal land should be avoided.

There are cases however, when using federal land can clearly benefit a project and the federal landowner. For example, serving a Veterans Hospital is clearly beneficial to the project and to the public good. In these cases, the federal agency is much more likely to do what is necessary to bring about the project. In the case of Fort Snelling, all of the agencies involved were cognizant of the benefits of having a station near their bases.

Learn About the Agency

Each federal agency is different, with different personalities and different rules. It is important to take the time to understand the structure of an agency, the agency’s mission, and the decision-making structure. Question the agency in detail regarding their decision-making structure. Sometimes, if the situation is novel, the people you are dealing with may not even know what their procedure is. Be certain that you know who has the authority to sign an easement or to grant title to the land. Be certain also that you are dealing with the people who have the authority to determine what just compensation is for the property that you are receiving.

Learn enough about the mission of an agency to determine what the project can do for them. If the agency can see a clear benefit from the project, cooperation will be much more likely.

Assign a Single Project Manager

Just as it can be difficult for you to understand the agency that you are dealing with, they can have difficulty understanding you. Assign a single individual to be the principle contact with the agency. This person needs to have enough authority to be able to negotiate in good faith with the agency.

The project manager must establish a relationship of trust so that the agency knows that you will follow through with promises made. Do not promise what cannot be delivered. Legal documents can memorialize agreements, but eventually the two sides need to trust each other to make the deal work.

Do Not Allow the Agency to Dictate Terms Unilaterally

While the agency has the advantage during negotiations, do not allow them to dictate terms unilaterally. Eventually you need to hold the line somewhere. Focus on preserving the agencies mission without providing extras. This can be difficult at times.

Establish a budget for compensation to the agency and work with them to preserve that.

Use a Separate Contracting Process for Each Agency

Wherever possible use a separate contracting process for each agency’s work. Allow the agency to participate in the selection process giving, them ownership in the process. Have regular construction updates to ensure the agency knows how the work is progressing.

Involve your Congressional Delegation

Enlist the assistance of a key congressman or senator. Keep them informed of the progress being made. Enlist their assistance if necessary, but hopefully it will remain a last resort.

CONCLUSION

Obtaining federal property for an LRT project is a challenging enterprise. But if planned properly, it can be done. In the case of the Minneapolis project, establishing an alignment through the Fort Snelling area was a time consuming, sometimes frustrating process. But in the end, the overall project will be much better for it because the activities located at Fort Snelling will generate increased traffic for the line, and the agencies involved will continue to benefit from the transit service for a long time to come.

Communicating the Timeline

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How do you communicate a multidiscipline project schedule for a new light rail extension that spans a 4-year time period? Significant elements must include illustrating the geographic area of a new 5.8-mi track alignment; representing the major scope or work activities within each region; planned construction durations and contract completion dates for work associated with utility relocation; civil and track construction; electrical, mechanical, and communications installation; vehicle manufacturing; major structures construction; and systems testing and startup.

Tri-County Metropolitan Transportation District of Oregon (TriMet) and their contractors utilize sophisticated scheduling software to efficiently manage large multidiscipline light rail design and construction projects. When projects are large and complex the critical path scheduling methods (CPM) are vital for managing multiple interrelated projects, as well as being a crucial element in the accurate monitoring and reporting of the overall effort. However, as the project grows in size, scope, and complexity, so does the schedule. When the number of detailed activities in the schedule expands, with complicated logic and sequencing ties, it becomes hard to review at a glance and has the potential to lose some audiences.

See the geographic schedule developed for the TriMet Interstate MAX light rail project. This schedule format is a graphical representation of the project detailing multifaceted activities planned along the alignment over the duration of the project. The geographic schedule has worked as a planning tool for various disciplines to plan their work, coordinate turnover to follow-on contractors, and serves as a communication tool to present general audiences with a view of the scope and overall timeline of the project.

INTRODUCTION

Schedules are an integral part of all types of projects ranging from planning, design, engineering, manufacturing, and construction. Virtually all projects go through some sort of exercise in planning out the work, development of a timeline, lists of major activities to accomplish the project within the scheduled timeframe, and monitoring progress compared to the schedule plan. Budget can also be a major element of a project plan and is often incorporated into the schedule to determine capital needed per year, quarter, or month. The most commonly used form of scheduling is the critical path method, or CPM. This is particularly true for large-scale design and construction projects. In scheduling terminology, the CPM uses what is called precedence diagramming to formulate the project plan. This involves identifying all of the major steps needed to perform the project and putting them in logical order and sequence based on what needs to happen before another activity can start. This methodology is crucial for all phases of the project and useful in setting goals and making sure the project schedule is sound and the target completion goals are reasonable.

Communicating the project timeline is essential in all phases of project development, and may be one of the biggest challenges as the overall program schedule grows in complexity and excessive detail, as was the case with our Interstate MAX light rail project. This paper will discuss project scheduling methods used by Tri-County Metropolitan Transportation District of Oregon's (TriMet) for light rail design and construction projects, and offer some examples of what we use to communicate our timelines.

Program Schedule

Using some of TriMet's projects as an example, the first step in developing a program schedule may start when a director provides you with a list of key dates and asks for a detailed schedule outlining the approach to the project and supportive of the targeted timeline. This is often when the first outline of the project is formulated, and the start of kicking off a more detailed approach to identifying the project plan in a formal schedule. As the project evolves and various complexities begin to take shape the overall program schedule begins to take on a form that becomes harder and harder to communicate on a simple one page format. For most of us, the one page summary is very useful in communicating our project progress without losing people in the details. There are many ways to address this particular issue, and no one way that serves a project best. At TriMet, we have utilized various summary, geographic, and detailed barchart schedules for our major light rail projects. Finding something that works early on in the development of your project works best, and should be able to be utilized throughout the life of your project as you communicate your timeline.

In the initial stages of a typical TriMet light rail project we begin at a conceptual level planning the particular route, or alignment, while working with local jurisdictions and neighborhood groups to identify the best possible alignments through that region and addressing specific concerns by these groups. As these plans progress and it becomes necessary to produce documents at the local and federal levels for project approvals and financial plan considerations we then begin to formulate a long-term plan, or strategy, to design and build the project. This is typically when the schedule begins to develop, or when an added resource or specialist may assist project managers in the development of the overall schedule plan. A typical light rail design/construction project for TriMet requires the following major elements:

- Draft and final environmental impact statements;
- Project management plans/finance plans/contracting plans, etc.;
- Design team procurement;
- Preliminary and final engineering plans;
- Right-of-way acquisition;
- Intergovernmental agency agreements;
- Federal, state, and local permits;
- Owner-furnished materials;
- Vehicle procurement;
- Civil and systems construction team procurement;
- Systems testing;
- Simulated revenue; and
- Startup.

Numerous interim milestones need to be captured in the schedule defining submittals that need to be reviewed and approved by the FTA or other agencies before we can initiate the next steps. After we have been granted approval to proceed with a project we continue to outline all of the major steps by further breaking out the work to determine various contracting plan approaches, determine design and construction packages, and help identify when to begin the request for proposal process to bring on firms to help us continue to advance our overall design and construction program. When we have had success in producing the preliminary engineering and environment impact statements, with the necessary approvals by FTA and other agencies, and are granted approval to enter final design and construction the real fun begins.

For the Interstate MAX light rail project the schedule had been developed using the standard approach to a previous light rail project schedule, the Westside–Hillsboro light rail project, but took on a slightly changed format for communicating the schedule after the TriMet began final design. When we entered final design the schedule already had over 1,000 activities for preliminary engineering, initial final design tasks, and preliminary construction planning activities through grand opening. When final design proceeded more details continued to be added to the schedule as TriMet began preparing construction bid documents. The additional activities in the schedule came about as TriMet prepared the construction bid documents with time of completion milestones. These milestones were important because they told the contractor how much time they had to complete their work prior to turning over to follow-on contractors. For example: civil, road, and track construction needed to be completed with X number of months or years before being turned over to the follow-on systems contractors to install signals/communication cables, overhead catenary system, etc. A tool that would help visualize the entire alignment, illustrating the different types of civil and systems construction, time of completion milestones, and overlaps between contracts, became necessary as it was getting harder and harder to visualize with the 10+ page master schedule bar chart detail that was available. Thus, inspired the development of the geographic schedule. (FIGURE 1 Geographic schedule.)

Conception of the Geographic Schedule

As it became apparent that a tool was needed to visualize the entire alignment on a single page, fitting together all of the various types of civil and systems work throughout the alignment, the development of the geographic schedule began. Note that this form of schedule does not in anyway replace the necessity of having a good, sound CPM schedule that is logic based and can be updated and recalculated as the work progresses.

This schedule was first formulated to put together a pictorial of the alignment, show when we were going to do major civil and systems construction, and also illustrated the Interstate 5 (I-5) highway that ran parallel to Interstate Avenue. This schedule was first utilized to coordinate I-5 historic preservation project work the Oregon Department of Transportation (ODOT) was doing with what our project was doing along Interstate. For example, we did not want ODOT re-directing traffic from I-5 onto Lombard Street when we had that intersection closed for utility and track crossing work. (FIGURE 2 Early Geographic Schedule.)

While this geographic schedule was more simplistic in its origin; it became more detailed as work plans progressed. We began adding directional arrows so one could determine the start and sequence of sewer construction, added various shading to illustrate which side of the road the primary work was being construction, tension segments for the overhead catenary wire, and so forth. The geographic schedule as shown in Figure 1 shows the following major components:

- Street alignment shown in the gray shading with street names and major structure crossings.
- Major civil contract segments, reaches, and areas defined by contractors.
- Light rail structure construction in the green-shaded area.
- Major work scope components:
  - Storm/sewer construction in aqua blue;
  - Street and sidewalk work in light orange (also depicted traffic on inside lanes);
  - Track construction (traffic in outside lanes) in dark orange;
  - Overhead catenary and traction electrification (TES) construction in light green;
  - Signals/communications installation in magenta checkerboard;
  - Integrated testing in transparent navy blue;
  - Simulated revenue in maroon;
  - Station and artwork in lavender
  - Bridge substructure in gray and white diagonal stripes;
  - Superstructure in gray shading;
  - Pile driving with directional arrows with rounded ends;
  - Girder setting with directional arrows with diamond-shaped ends;
  - Deck forming in light orange with dark orange dotted borders by units (units defined by contractor);
  - Dark orange lines depict plinth construction;
  - Blocks with brick-like pattern depicting systems building construction;
  - Green-shaped building with black outline, monopoly house-like, depicts substation equipment installed and energized;
  - Sharks with gray blocks depicting in-stream work window period; and
  - Green block with blue dots depicting wetland construction.
- Major civil to systems milestone turnovers depicted with blue-dotted line.

A legend is provided on the bottom of the geographic schedule, as well as a revision date. This schedule is updated at least quarterly, and has served as an excellent tool to use as we review contractor's updated schedules and while we update our own master schedule. It also serves as an excellent tool to evaluate civil to systems turnover milestones and see float, if any, between the various contract segment completions. For instance, it became apparent early on in the project that if civil contractors continued their ahead of schedule progress, and if systems crews could take advantage of earlier access dates, that we could potentially open up our system 4 months early.

Interstate MAX light rail project staff have became aware of the many details that are offered in this pictorial and have come to use this schedule as a tool to support some of their work. Staff have used this as an alignment map when giving tours, review street crossings, and get stationing orientation, etc. This schedule also became favored by our customer relations staff as they struggled with how to communicate our overall schedule timeline to the public. A bar chart summary schedule was available. (FIGURE 3 The CPM summary schedule.) This schedule was prepared early on in the project and used as a summary schedule for FTA presentations. This is a simple timeline showing the major components of work and the milestones met along the way, including such things as the 60-90-100% design phases. However, customer relations liked the detailed geographic schedule and they worked at putting together a simpler version that showed the timeline in quarters and simplified the shading to just reflect the major scope of work common through the entire alignment. (FIGURE 4 Interstate MAX 4-year construction schedule.)

Other projects utilized similar approaches to illustrate their project and schedule timelines. These schedules, or graphical representations of the schedule, can take on many forms and shapes so there is no one style that fits every project.

Overall Master Program Schedule

The development of the geographic schedule as a timeline communication piece would not have evolved had it not been for our master program schedule that is a very important part of managing our entire program. (FIGURE 5 Interstate MAX Overall Summary Schedule.) This is a 2-page summary schedule of the overall schedule which contains 1,300+ activities and currently prints out onto 23 pages in a full detailed report. The master schedule was developed using a sophisticated scheduling package called Primavera Project Planner and has an established work breakdown structure, as well as other criteria based on our various contract packages, for monitoring and reporting purposes.

The technical specifications portion of our contract documents require contractors to submit a 90-day plan, baseline schedule, and monthly schedule updates utilizing the same scheduling platform TriMet uses for the master schedule. This is helpful in overall management and review of the project schedules for our light rail projects.

The master schedule is updated monthly and a report is distributed to project staff. milestone summary reports are also produced and reported regularly to the FTA, and project management oversight committee, during their monthly and quarterly project reviews. While many staffers and top-level managers are not always concerned with the various details of the CPM, they are aware that the detail is there and having the details and logic correctly applied keeps our project team focused on managing our work efficiently to meet our project milestones. FIGURE 6 Milestone summary schedule is another sample schedule report that is used regularly in our monthly and quarterly project reviews and reports.

Interstate MAX Light Rail Major Project Elements

The overall Interstate MAX light rail design and construction program budget is $350 million. Of this amount, $280 million are for design and construction. The light rail extension is 5.8 mi in length. It includes 4.4 mi of in-street work, a 3,850 ft light rail only structure, systems elements compatible with existing light rail operations, expansion of the existing central control facility, and a minimum of 17 new light rail vehicles (LRVs).

Major contracts include:

- LRV Procurement: $55 million, 17 low-floor vehicles, exercising an option to purchase 10 additional cars. Compatibility with TriMet's existing fleet of 78 LRVs, and existing TES and train to wayside signaling systems.
- New Satellite Operations Facility, Ruby Junction South: Construction including yard and track expansion and test track construction: $15 million.
- Rose Quarter to North Argyle (10A/B): Includes in-street civil and utility construction, 4.4-mi in-street track construction. $100 million Interstate MAX interconnects with the existing Banfield (Eastside), and Westside–Hillsboro Lines near the Rose Quarter, then heads north on Interstate Avenue for 4.4 mi. The contract includes special track work, signalization,

and switching to accommodate merging vehicles. The contract also included roadway and sidewalk demolition and reconstruction. One lane for vehicular traffic in each direction was required to be maintained at all times. Nearly all private and public utilities along Interstate Avenue had to be relocated. The final roadway configuration requires that existing Portland General Electric power poles be moved. Other private utilities to be relocated include Qwest, Pacific Power, ELI, ODOT, Paragon, TCI, NW Natural Gas, and AT&T. Also, all city sewer and water mains and laterals along the alignment must be relocated.

- North Argyle to Expo (10C): $35 million. This portion of the alignment is 1.4 mi in length, inclusive of a 3,850 ft light rail only structure. The structure crosses the Columbia Slough, Schmeer Road, and Victory Boulevard. The alignment runs through an environmentally sensitive zone and requires mitigation to wetland impacts. The existing roadway viaduct links businesses and communities on both sides of the Columbia Slough. Tie and ballast track extends to the northern terminus at Expo Center. Coordination of work with major events at Expo and Portland International Raceway (PIR) will be critical. Expo Road will be rebuilt. Park-and-ride facilities will be constructed at Expo and PIR.
- Rose Quarter to Expo Light Rail Systems Work: $35 million. Systems elements of Interstate MAX include TES, signals, communications, and fare collection. TES includes six substations, installation of all of the overhead catenary conductors and poles. Joint use poles are planned for street lighting. Wayside signaling will control train movements at the Steel Bridge and Rose Quarter, and between Kenton and Expo Stations. Between Rose Quarter and Kenton stations, train movement will be governed by traffic lights in conjunction with train-to-wayside communications. Fare collection equipment will be included at each of the new 10 light rail stations.
- Central control system.

SUMMARY

This paper primarily illustrates a variety of detailed schedules, or a sort of show and tell of schedule formats, utilized at TriMet. All of these schedules tell our project story and timeline. Schedules are a necessary part in every step of the project from conception, through early planning, and finally through design and construction.

Developing the Design and Construction Contracting Plan for a Major Light Rail Extension Project

DON IRWIN
Tri-County Metropolitan Transportation District of Oregon

Major light rail extension projects are complex to design and construct. Complexities arise from community and political expectations; multijurisdictional agreements; permitting at local, state, and federal levels; financing partnerships; unique technical considerations; coordination with existing operating systems; property takes; and impacts to the public during construction. Design and construction work generally is accomplished through contracts. The question that arises is which contracting methods are most likely to allow the agency to effectively deal with the complexities and meet its objectives.

TriMet develops a contracting plan prior to commencement of major design and construction projects. The plan breaks the project into its major elements, identifies overall objectives and critical factors, analyzes contracting options, and concludes with a recommended plan. TriMet applies an analytical framework that is intended to determine which contract procurement methods will put TriMet in the best position to accomplish a successful project. Options include design-build, construction manager at risk, low bid, request for proposal, and sole source. The contracting plan for the Interstate MAX project is used as a basis for this discussion. Interstate MAX is a $350 million, 5.8-mi light rail extension currently in construction, under budget, and ahead of schedule.

TriMet's experience is that a detailed contracting plan is an effective tool for organizing a successful approach to the design and construction of a major light rail project.

INTRODUCTION

Major light rail extension construction projects are complex. As with most major public construction projects, significant risks are inherent in the design and construction elements. Additionally, light rail extensions entail other complexities. Complexities arise from community and political expectations; multijurisdictional agreements; permitting at local, state, and federal levels; financing partnerships; unique technical considerations; coordination with existing operating systems; property takes; and impacts to the public during construction.

The plan presented here is intended to provide assistance in the development of an overall contracting plan that an agency may use to accomplish the design and construction of a major light rail extension project. Generally, the agency procures all design and construction work through contracts. The question arises as to which contracting methods will put the agency in the best position to effectively deal with the project's complexities and to meet its objectives.

BACKGROUND

One objective for all design and construction contracts is to meet budget. Traditionally, construction contracts have been awarded based upon low bid. TriMet's experience is that on complex, public works projects such as light rail extensions, the initial low bid is not a reliable indicator that the budget will be met.

Three contracts from TriMet's recently completed Westside-Hillsboro light rail extension project illustrate the point. First, on a \$29-million low bid contract to extend light rail in downtown Portland, Oregon, TriMet received a \$13-million claim late in construction. Second, on the \$104-million low bid tunnel contract, costs increased \$75 million. Third, on an \$8-million utility relocation low bid contract, TriMet was forced to delete certain work from it and issue a separate contract for approximately \$2.5 million to accomplish the deleted work.

Importantly, for a light rail extension project to be considered a success, other objectives in addition to cost control must be met. In the latter stages of preliminary engineering for the Interstate MAX project, TriMet developed an overall contracting plan. The plan breaks the project into its major elements, identifies overall objectives and critical factors for success, analyzes contracting options, and concludes with a recommended plan.

Overall, the Interstate MAX budget is capped at \$350 million. Of this amount, \$280 million are for design and construction. The light rail extension is 5.8 mi in length. It includes 4.4 mi of in-street work, a 3850 ft long light rail only structure, systems elements compatible with existing light rail operations, expansion of the existing central control facility, and a minimum of 17 new light rail vehicles (LRVs).

Objectives for Success

For Interstate MAX to be successful, TriMet identified key overriding objectives prior to the start of design and construction. These objectives are:

- Meet critical schedule milestones.
- Minimize construction disruption to public and third party claims.
- Meet budget; control costs through value engineering and constructibilty reviews.
- Assure public safety and safe traffic management throughout construction.
- Assure adequate quality control and meet FTA/community/city expectations.
- Assure maximum responsiveness to community needs.
- Provide best opportunity for local and disadvantaged business enterprise (DBE) contractors and workforce diversity.
- Procure services from experienced, expert contractors that match needs of project.
- Avoid construction litigation.
- Create owner, contractor, and designer "team approach" to resolve issues or complexities.

As the above objectives indicate, the success of Interstate MAX depends upon considerations other than the initial low bid price for construction. Therefore, TriMet considered alternatives to low bid contracts.

Legal Constraints

Public contracting law generally requires the award of a construction contract to the lowest responsive and responsible bidder. However, exemptions to low bid award may be justified and implemented when applicable law allows.

FTA requirements do not mandate only low bid award of construction contracts. The competitive proposal method may be used. FTA allows the award of a third party contract to a party other than the lowest bidder, provided the award complies with applicable state and local laws and regulations, and FTA requirements.

Oregon law requires procurement of nearly all public improvement projects by low bid, unless an exemption is granted by the state, or by the local contract review board for agencies other than the state. Oregon statute requires that the local contract review board approve two findings submitted by the agency: 1) that the exemption is unlikely to encourage favoritism in the awarding of public contracts, or substantially diminish competition for public contracts; and 2) that the awarding of public contracts pursuant to the exemption will result in substantial cost savings to the agency. Before the agency may finally adopt these findings to exempt a contract for a public improvement from competitive bidding requirements, the agency must hold a public hearing. Also, agency findings in support of the exemption must include information regarding:

- Operational, budget, and financial data
- Public benefits
- Value engineering
- Specialized expertise required
- Public safety
- Market conditions
- Technical complexity
- Funding sources

TriMet developed an analytical framework to determine which contracting method was the best choice for each particular element of Interstate MAX. In the end, a contracting plan emerged that put TriMet in the best position to accomplish its key overriding objectives.

CONTRACTING OPTIONS FOR DESIGN AND CONSTRUCTION

In order to select the best match for particular work, the advantages and disadvantages of each alternative contracting method must be understood. The alternative methods for construction contracting may be broadly categorized as design-bid-build and negotiated procurements.

In design-bid-build, the design contract is the result of a quality based selection process (QBS). The construction contract is awarded based solely on lowest bid price. All responsive and responsible bids are considered. One variation is a two-step low bid process in which proposals are solicited and pre-qualified in step one, followed by step two: bidding and subsequent award of the construction contract to the lowest bidder from the pre-qualified list.

In negotiated procurements, construction contract award is based upon evaluation of proposals against objective criteria that consider both performance and price competition.

Negotiated procurements include request for proposal (RFP), construction manager at risk (referred to as CM/GC in Oregon) and Design-Build (DB).

Low Bid

Advantages and disadvantages of traditional low bid are listed below.

Advantages

- Competitive bidding ensures lowest contract award price.
- Owner may benefit from checks and balances by having the designer and contractor under separate contracts.
- QBS process allows owner to directly evaluate and select the designer.
- Owner controls the preliminary engineering and final design.
- The legal rights and obligations of the parties are generally well settled.
- No public hearing or record findings are required to execute contract award.

Disadvantages

- Lowest contract award price is not a reliable indicator of the final cost to the owner for construction because of contractor-initiated changes, claims, and bids not reflective of intended scope.
- Adverse relationships may develop among the owner, designer, contractor, and other stakeholders, jeopardizing successful performance.
- Prior to award, there is no opportunity for the owner to work with the contractor-at-risk regarding technical requirements, scope and quantity reconciliation, value engineering opportunities, or work plans.
- Lack of budget and schedule certainty until project closeout hinders the owner's ability to manage and allocate resources for project and other purposes.
- General condition items such as quality control and safety may be adversely affected by the least-cost approach typical in low bid.
- Design-construct project delivery timeline is difficult to streamline.

Two-Step Low Bid

The two-step low bid is intended to increase the likelihood that a contractor with a record of proven performance in similarly complex work is awarded the contract.

The general guidelines on when to consider two-step low bid are

- Owner findings do not justify exemption from traditional low bid.
- Contractor understanding of project complexity is key to successful performance.
- Owner concern over budget, schedule, public impacts, technical expertise or capacity, working relationships, or jurisdictional matters is high.

Negotiated Procurements

In negotiated procurements, the owner has the opportunity to evaluate each contractor based upon experience, work plan, proven performance, scheduling capability, safety program, subcontracting program, DBE and diversity participation, quality control, cost control, technical expertise, pricing and other critical criteria. The procurement is intended to result in an advantageous contractor match to the requirements of the project, ultimately resulting in timely performance at a final, closeout price that is less than would have occurred through a low bid procurement. Negotiated procurements differ in their relative advantages and disadvantages.

RFP Procurement

Final design is accomplished through the QBS process and under separate contract to the owner. Following completion of final design, RFP procurement is utilized to select the construction contractor based upon criteria that are weighted by the owner in the RFP. Price of construction work is only one of the criteria. Either a one-step RFP or multiple-step (request for qualification to shortlist pre-qualified proposals, then issue RFP) process may be utilized.

Advantages

- Owner has opportunity to develop and weight RFP criteria that match the demands and objectives of the project.
- Owner retains QBS process for design and directly controls preliminary engineering and final design.
- Owner reduces its risk of contract award to a construction contractor who lacks the experience, expertise, or capacity to perform successfully.
- Construction price component of evaluation criteria is competitive.
- Similar to low bid, the legal rights and obligations of the parties are generally well settled.

Disadvantages

- The RFP exemption must be justified, evaluated in a public hearing, and approved by the entity having contract authority.
- An unrealistically low bid price, even when carefully weighted, may effectively defeat the advantages of the RFP process by nullifying higher technical qualifications in competing proposals.
- The contractor-owner commercial relationship is similar to that in low bid, inclusive of its disadvantages.
- No opportunity exists for the construction contractor-at-risk to provide input during design regarding matters such as value engineering, constructability, scheduling, work plan, pricing options, and public impact mitigation.

The general guidelines on when to consider an RFP are

- Owner findings justify an exemption from low bid.

- Quality, safety, or public interface demands of the project exceed those usually achievable through typical low bid.
- Owner desires to manage design and construction in traditional manner.
- Early construction contractor involvement is not considered a key to a successful project.

CM/GC Procurement

In the CM/GC procurement, final design is accomplished through the QBS process and under separate contract to the owner. During the design process, the construction contractor is selected based upon criteria that allow the owner to evaluate performance and price competition. Bid price for construction work is not a selection criterion because the design is not complete. The general contractor also performs construction management duties during design and construction, as defined by the owner. The CM/GC is also at risk for the performance of the construction, following negotiation of an agreement with the owner for a guaranteed maximum price (GMP) based upon the defined scope of work.

A CM/GC contract may include preconstruction services such as constructible and design reviews, value engineering, scheduling and staging of the work, pricing of construction options, hazardous materials planning, and quantity reconciliation. The overall GMP for construction may consist of low bid work, value-based selection of subcontractors, or self-performed work by the CM/GC, as governed by applicable rules.

Advantages

- Owner has opportunity to weight CM/GC selection criteria to match the demands of the project.
- Owner retains QBS process for design and directly controls preliminary engineering and final design.
- Owner lessens risk of contract award to a construction contractor who lacks the experience, expertise, or capacity to perform successfully.
- The contractor at risk for construction is brought on board during design, providing assistance to the owner regarding value engineering, constructible efficiencies, scope clarity, design reviews, pricing, schedule, and budget control.
- Early contractor involvement results in a better understanding of the contract, fairer risk allocation, and less risk of claims.
- Prior to the start of construction, a GMP for construction is established, providing greater budget certainty for the owner.
- Owner can significantly influence the contractor’s work plan as it relates to quality control, safety, schedule, and mitigation of impacts to the public.
- Competitive pricing is obtained and confirmed through “open book” cost reviews.
- CM/GC process allows for adequate process time to resolve design, public, and jurisdictional issues, prior to locking down the construction schedule and price.
- Collaboration among owner, designer, jurisdictions, and contractor during design builds constructive team approach that is likely to carry through construction.

Disadvantages

- The CM/GC exemption must be justified, evaluated in a public hearing, and approved by the entity having contract authority.
- There is less competitive leverage on the general contractor when pricing the construction.
- Although the risk of claims is reduced, claims may still occur, particularly in low bid subcontractor work.
- The GMP construction agreement must clearly define what is in or out of the scope, and how owner and contractor contingency will be handled.
- Each CM/GC contract is unique and complex. The legal rights and obligations of the parties may vary from traditional understandings and must be clearly identified. Special attention should be given to allocation of risks.

The general guidelines on when to consider CM/GC are

- Owner findings justify an exemption from low bid.
- Construction contractor input during design is considered key to successful project performance.
- Public expectations that impacts will be mitigated are high.
- Owner needs budget and schedule certainty at time of contract award.
- Owner desires to retain control of design because of in-house expertise or unsettled matters such as property access, permitting, environmental issues, community process, aesthetic requirements or technical compatibility issues.

Design-Build

Under DB procurement, the owner executes a single contract for both design and construction services. Selection of the DB contractor is based upon evaluation criteria that are weighted by the owner. Price may be bid or negotiated.

Advantages

- Owner has opportunity to weight selection criteria to match the demands of the project.
- DB provides single point accountability to the owner for design and construction.
- Owner lessens risk of contract award to a construction contractor who lacks the experience, expertise, or capacity to perform successfully.
- Owner risk for designer-contractor cost issues is avoided.
- Overall design-construct schedule may be shortened by fast-tracking construction elements and by fewer public procurement processes.
- Owner may fix a not-to-exceed price, based upon known scope.
- DB contractor has inherent incentive to consider constructible and value engineering opportunities during design.
- DB final design cost likely to be less than for similar QBS services.

Disadvantages

- The DB exemption must be justified, evaluated in a public hearing, and approved by the entity having contract authority.
- Owner gives up QBS process for design, does not directly control final design, and may be disappointed with the final design product.
- Great care should be taken in selection of a DB contractor. The owner generally does not control of the selection of key subcontractors or designers, thereby increasing reliance upon the DB contractor with regard to quality and performance.
- Stakeholders may not break the "business as usual" approach, offsetting advantages of the DB approach.
- Definition of scope is critical. A poorly defined or unsettled scope may result in significant cost increases or sacrifices in project quality or function.
- Lack of checks and balances may expose the owner to shortcomings in design and construction.
- Each DB agreement is unique and complex. The legal rights and obligations of the parties may vary from traditional understandings and not be understood. Special attention should be given to allocation of risks.
- The DB contractor will likely desire to expedite construction, resulting in time pressured design, permitting, community, and jurisdictional processes.

The general guidelines on when to consider D/B are

- Owner findings justify exemption from low bid.
- Owner lacks in-house expertise to manage design and construction.
- Owner desires to transfer risk of on-time, on-budget delivery of design and construction to single entity.
- Owner able to clearly define scope at time of agreement.
- Jurisdictional, community, and property access issues settled at time of agreement.
- Required product quality and technical compatibility with existing systems can be accomplished without direct owner control over design.
- Owner seeks shortest design-construct time period.
- Design is straightforward and owner desires minimal cost design services.

Sole Source

Sole source public contracting is a last resort. It is applicable when there is no alternative in order to accomplish the desired design, installation, or construction objectives, or if an emergency exists.

Advantages

- Allows contracting with entity that can comply with the owner's unique requirements.
- Procurement process timeline is short.
- Owner has near certain control over deliverables.

Disadvantages

- No contractor competitive cost incentive; price likely to be high.

The general guidelines on when to consider sole source are

- In an emergency.
- Only one source satisfies owner requirements.

APPLICATION TO INTERSTATE MAX

Considering the above contracting options, advantages and disadvantages, TriMet developed a contracting plan for Interstate MAX. The analytical framework that TriMet utilized consists of the following:

- Work description
- Critical factors for success
- Evaluation of options
- Preferred contracting method

TriMet developed a checklist, “Criteria for Selection of Construction Contracting Method,” to facilitate evaluation of options. The criteria are comparatively weighted as to their effect on the desired outcome. Each criterion is assumed to be important for a traditional low bid project. Criteria are evaluated as “Very Important” or “Extremely Important,” in lieu of “Important,” when judged to require a greater level of attention or certainty of performance than that obtained in a typical, traditional low bid project. The completed checklist forms the basis for determining whether there is justification for a contracting method other than traditional low bid.

MAJOR INTERSTATE MAX PROJECT ELEMENTS

The primary elements, with approximate contract values, of Interstate MAX construction are

- Light Rail Vehicle Procurement: $55 million
- Ruby Junction Central Control Facility Expansion: $15 million
- Rose Quarter to North Argyle, In-Street Civil and Utility Construction: $100 million
- North Argyle to Expo, Structures, Tie and Ballast Civil Construction: $35 million
- Rose Quarter to Expo Light Rail Systems Work: $35 million

LRV Procurement

Work Description

Interstate MAX includes the procurement of a minimum of 17 low-floor LRVs in order to satisfy projected service needs. The vehicles will be similar to the Type 2 cars acquired under the Westside-Hillsboro project. They must be compatible with the existing fleet and systems.

Upon startup of Interstate MAX revenue service in 2004, TriMet's fleet will be 95 LRVs. It is further projected that an additional 20 LRVs may be required to support service demands into 2020. Consequently, the procurement includes the option to purchase additional vehicles.

Critical Factors for Success

Compatibility with TriMet's existing fleet of 78 LRVs, and existing traction electrification and train to wayside signaling systems.

Evaluation of Options

The contractor will design, manufacture, and furnish the vehicles to meet the specified standards. Three procurement options are available: sole source, low bid, or RFP. Table 1 provides the criteria for the selection of a construction contracting method.

Sole source is not preferred as a general public contracting method because it lacks competitive pricing. Additionally, in this case, TriMet is aware of at least three manufacturers who could provide the required vehicles.

It is critical to TriMet that the vehicles be technically compatible with the existing fleet. It is advantageous for TriMet to consider both technical qualifications and price in this procurement. A low initial price, in and of itself, may not result in the technical compatibility that TriMet needs.

On the Westside–Hillsboro project completed in 1998, TriMet successfully used a two-step RFP process to procure 45 vehicles. Technical proposals were submitted and evaluated, then qualified proposers submitted their best and final offers inclusive of technical qualifications and price. Westside vehicles had to be compatible with the existing Banfield fleet and systems, similar to Interstate MAX. Therefore, a similar RFP approach is recommended.

The preferred contracting method is two-step RFP.

Ruby Junction Central Control Facility Expansion

Work Description

In order to accommodate the increased number of vehicles, TriMet must increase its maintenance and operations capabilities. TriMet has maintenance facilities at Elmonica and Ruby Junction. As part of Interstate MAX, TriMet's central control facility at Ruby Junction must be expanded. Also, its existing building space must be renovated in both the light rail and bus central control areas. The expansion includes additional yard track, maintenance bays and equipment, signaling and communications provisions, and a traction power substation for the yard itself. TriMet has

TABLE 1 Criteria for Selection of Construction Contracting Method: LRV Procurement

Key Criteria	Extremely Important	Very Important	Important	Legal Finding Required
COST SAVINGS/CONTROL		**X**		YES
Lowest Bid			x	
Technical Complexity Risks	x			YES
Funding Source Impact on Costs		x		YES
Scope Certainty/Scope Clearly Defined			x	
Must Meet Tight Budget	x			
No Follow-On Delay/Impacts		x		
Shortest Duration to Avoid Market Increases			x	YES
Maximum VE Savings		x		YES
SPECIAL EXPERTISE REQUIRED	**X**			YES
Hazardous Materials/Environmental Impacts			N/A	
Railroad Coordination/Impacts			N/A	
Utility Conflicts/Relocation			N/A	
Permit/Jurisdictional Relationships/Reqs			N/A	
Access/Site/ROW Constraints			N/A	
Minimize Light Rail Operational Impacts			N/A	
Engineering/Technology Knowledge	x			
Subsurface Conditions			N/A	
QUALITY ASSURANCE		**X**		
3rd Party/Public Approval			x	
Minimal Defective Work		x		
Effective Contractor QC/Minimal Owner QA	x			
Owner Final Design Control			x	
Need for Checks and Balances		x		
Existing System Compatibility	x			
SCHEDULE		**X**		
Contractor Proven Performance		x		
Contractor Work Plan Vital			x	
Capacity to Accelerate		x		
Duration/Milestone Certainty/Meet Critical Path		x		
Shortest Design-Construct Duration			x	
SAFETY			**X**	
Top Notch Program			x	
Unique Safety Conditions			x	
Attention to Public Safety			x	YES
COMMUNITY/PUBLIC BENEFITS			**X**	YES
Utilize DBE			x	
Minimal Disruption to Businesses/Residences			N/A	
Maintain Access to Properties			N/A	
Minimal Traffic Flow Impact			N/A	
Minimal Noise/Vibration			x	
Minimal Utility Disruption			N/A	
Early Completion			x	

acquired land south of the existing site for the expansion. Existing run-around tracks must be relocated, yet daily operations cannot be adversely impacted.

Critical Factors for Success

Sequencing or staging of the construction work and coordination with operations are critical. Construction impacts or disruptions to existing LRV daily revenue service operations must be kept to an absolute minimum.

Evaluation of Options

Table 2 reflects TriMet's evaluation of options for the Ruby Junction expansion. TriMet must develop a construction staging approach that is compatible with service operations. Construction contractor input during design is a key in developing a realistic, cost effective, and executable construction staging plan. TriMet operations will demand that the contractor focus on the expansion work and get it done quickly, safely, and in accordance with TriMet track access procedures.

Also, the civil and systems improvements must be technically compatible with existing yard and facility systems at Ruby Junction. Design must accommodate the critical need to minimize revenue service disruptions.

Neither low bid nor RFP involve the construction contractor during design. Not having construction contractor input during design will increase the risk that the construction staging plan will not be realistic or cost effective. Additionally, TriMet desires that the contractor fully understand TriMet's operational needs so adverse service impacts are avoided.

DB shortens process time for planning and design. In this instance, TriMet must deliberate over and approve the final plan for construction. Shorter process time is not advantageous to TriMet. Design choices are limited in that compatibility with existing systems is critical. TriMet will require that the design does not compromise its operational requirements.

TriMet should retain control over the final design and the contract documents that specify the construction staging. Construction contractor input during design and document review will help TriMet develop contract requirements that meet the needs of both TriMet operations and efficient construction. The CM/GC method will put TriMet in the best position to succeed with this work.

The preferred contracting method is CM/GC.

Rose Quarter to North Argyle, In-Street Civil and Utilities Construction

Work Description

Interstate MAX will interconnect with the existing Banfield–Westside system near the Rose Quarter, then head north on Interstate Avenue for 4.4 mi. The interconnection includes special track work, signalization, and switching to accommodate merging vehicles. The Rose Quarter work will likely be done while maintaining existing east-west light rail service, or during pre-approved service disruption periods.

The 4.4 mi of civil construction includes relocation of utilities, followed by roadway and sidewalk demolition and reconstruction, then new curb and trackway work. One lane for vehicular traffic in each direction must be maintained at all times.

TABLE 2 Criteria for Selection of Construction Contracting Method: Ruby Junction Expansion

Key Criteria	Extremely Important	Very Important	Important	Legal Finding Required
COST SAVINGS/CONTROL		**X**		YES
Lowest Bid			x	
Technical Complexity Risks	x			YES
Funding Source Impact on Costs		x		YES
Scope Certainty/Scope Clearly Defined			x	
Must Meet Tight Budget	x			
No Follow-On Delay/Impacts			x	
Shortest Duration to Avoid Market Increases			x	YES
Maximum VE Savings		x		YES
SPECIAL EXPERTISE REQUIRED		**X**		YES
Hazardous Materials/Environmental Impacts		x		
Railroad Coordination/Impacts			x	
Utility Conflicts/Relocation		x		
Permit/Jurisdictional Relationships/Requirements			x	
Access/Site/ROW Constraints	x			
Minimize Light Rail Operational Impacts	x			
Engineering/Technology Knowledge		x		
Subsurface Conditions			x	
QUALITY ASSURANCE		**X**		
3rd Party/Public Approval			x	
Minimal Defective Work			x	
Effective Contractor QC/Minimal Owner QA			x	
Owner Final Design Control	x			
Need for Checks and Balances		x		
Existing system compatibility	x			
SCHEDULE		**X**		
Contractor Proven Performance	x			
Contractor Work Plan Vital	x			
Capacity to Accelerate			x	
Duration/Milestone Certainty/Meet Critical Path		x		
Shortest Design-Construct Duration			x	
SAFETY		**X**		
Top Notch Program		x		
Unique Safety Conditions	x			
Attention to Public Safety			x	YES
COMMUNITY/PUBLIC BENEFITS			**X**	YES
Utilize DBE			x	
Minimal Disruption to Businesses/Residences			x	
Maintain Access to Properties			x	
Minimal Traffic Flow Impact			x	
Minimal Noise/Vibration			x	
Minimal Utility Disruption			x	
Early Completion			x	

Nearly all private and public utilities along Interstate Avenue must be relocated. The final roadway configuration requires that existing PGE power poles be moved. Other private utilities to be relocated include Qwest, Pacific Power, ELI, ODOT, Paragon, TCI, NW Natural Gas, and AT&T. Also, all city sewer and water mains and laterals along the alignment must be relocated.

Critical Factors for Success

Impacts to vehicular traffic on Interstate Avenue and to light rail traffic at the Rose Quarter should be minimized, as should impacts to large public events at the Rose Quarter and Coliseum. Access for residents and businesses should be maintained at all times. The project should be done quickly and safely, and utility relocations should be completed on time to avoid overall critical delays to the project.

Evaluation of Options

The construction will significantly impact the public on a daily basis. The construction work plan must be both realistic and cost effective. TriMet, working with the city of Portland and the community, must develop the plan. Contractor input during design will facilitate the development of realistic construction options in terms of schedule, cost, traffic flow, noise, and safety considerations. Table 3 shows the criteria for work on the Rose Quarter to North Argyle project.

CM/GC is the option that puts TriMet in the best position to accomplish the critical factors for success. TriMet must retain control of the planning and design in order to properly balance all of the considerations involved in the performance of construction on city streets and adjacent to the Rose Quarter and Coliseum. Public process must be adequate to properly assess options and to develop an acceptable approach. TriMet and city of Portland review and approval are critical.

DB reduces owner control over design and shortens process time. The nature of this work requires thorough planning, design, and coordination with the city and community. Shortening process time is likely to backfire; therefore, DB is not the preferred option.

Neither RFP nor low bid allows for construction contractor input during planning and design. Because efficient construction is critical, these options are not preferred. The preferred contracting method is CM/GC.

North Argyle to Expo, Structures, Tie and Ballast Civil Construction

Work Description

This portion of the alignment is 1.4 mi in length, inclusive of a 3,850-ft, light rail only structure. The structure crosses the Columbia Slough, Schmeer Road, and Victory Boulevard. The alignment runs through an environmentally sensitive zone and requires mitigation to wetland impacts. The existing roadway viaduct links businesses and communities on both sides of the Columbia Slough.

Tie and ballast track extends to the northern terminus at Expo Center. Coordination of work with major events at Expo and Portland International Raceway will be critical. Expo Road will be rebuilt. Park-and-ride facilities will be constructed at Expo and Portland International Raceway.

TABLE 3 Criteria for Selection of Construction Contracting Method: Rose Quarter to North Argyle, In-Street Civil and Utilities Work

Key Criteria	Extremely Important	Very Important	Important	Legal Finding Required
COST SAVINGS/CONTROL		**X**		YES
Lowest Bid			x	
Technical Complexity Risks	x			YES
Funding Source Impact on Costs		x		YES
Scope Certainty/Scope Clearly Defined		x		
Must Meet Tight Budget	x			
No Follow-On Delay/Impacts	x			
Shortest Duration to Avoid Market Increases			x	YES
Maximum VE Savings		x		YES
SPECIAL EXPERTISE REQUIRED	**X**			YES
Hazardous Materials/Environmental Impacts	x			
Railroad Coordination/Impacts	x			
Utility Conflicts/Relocation	x			
Permit/Jurisdictional Relationships/Req'ts	x			
Access/Site/ROW Constraints	x			
Minimize Light Rail Operational Impacts	x			
Engineering/Technology Knowledge			x	
Subsurface Conditions			x	
QUALITY ASSURANCE	**X**			
3rd Party/Public Approval	x			
Minimal Defective Work	x			
Effective Contractor QC/Minimal Owner QA			x	
Owner Final Design Control	x			
Need for Checks and Balances			x	
Existing System Compatibility	x			
SCHEDULE	**X**			
Contractor Proven Performance	x			
Contractor Work Plan Vital	x			
Capacity to Accelerate			x	
Duration/Milestone Certainty/Meet Critical Path	x			
Shortest Design-Construct Duration		x		
SAFETY	**X**			
Top Notch Program	x			
Unique Safety Conditions		x		
Attention to Public Safety	x			YES
COMMUNITY/PUBLIC BENEFITS	**X**			YES
Utilize DBE	x			
Minimal Disruption to Businesses/Residences	x			
Maintain Access to Properties	x			
Minimal Traffic Flow Impact	x			
Minimal Noise/Vibration	x			
Minimal Utility Disruption	x			
Early Completion		x		

Critical Factors

Construction of the new light rail only structure should be done in a manner that minimizes time for construction and that least impacts vehicular traffic on the existing roadway viaduct. Compliance with environmental zone regulations should be met, and impacts or disruptions to major events at Expo and Portland International Raceway should be minimized.

Evaluation of Options

Table 4 applies the selection criteria for a contracting method to the North Argyle to Expo section of the project. The most significant construction risk for this segment is the light rail only structure. The tie and ballast rail, road, and station work is straightforward and does not drive the critical schedule. Regardless of contracting method, the contractor must comply with fish window permits for in-water construction and strictly comply with environmental permits for Expo Road widening and wetland mitigation.

Lacking in-house expertise in structures, TriMet has no need to directly control the design of the structure. TriMet's design and operating criteria for a light rail only structure can be defined. Further, the local community whose access is impacted desires that the construction period be kept to an absolute minimum. For these reasons, DB is an advantageous choice for this work. DB will allow the contractor to develop and manage a design that incorporates cost and schedule efficiencies, and to address environmental permitting.

Neither the RFP nor the low bid methods allow the construction contractor to work with the designer of the structure. While CM/GC would provide this opportunity, TriMet has no need to retain direct control over the structure design. Additionally, TriMet desires that the contractor achieve cost and schedule efficiencies. DB will maximize these opportunities.

The preferred contracting method is design–build.

Rose Quarter to Expo Light Rail Systems Work

Work Description

Systems elements of Interstate MAX include traction electrification, signals, communications and fare collection. Traction electrification includes six substations, installation of all of the overhead catenary conductors and poles. Joint-use poles are planned for street lighting. Wayside signaling will control train movements at the Steel Bridge and Rose Quarter, and between Kenton and Expo stations. Between Rose Quarter and Kenton stations, train movement will be governed by traffic lights in conjunction with train-to-wayside communications. Fare collection equipment will be included at each of the new ten light rail stations.

To accommodate systems conductors, underground duct banks and vaults extend the full alignment. Wayside components interconnect with Ruby Junction central control facility. TriMet's existing communications system and equipment at Ruby Junction must be expanded to incorporate Interstate MAX. The communications system tracks vehicles, and controls and monitors certain components.

TABLE 4 Criteria for Selection of Construction Contracting Method: North Argyle to Expo, Structures, Tie and Ballast Civil Work

Key Criteria	Extremely Important	Very Important	Important	Legal Finding Required
COST SAVINGS/CONTROL		**X**		YES
Lowest Bid			x	
Technical Complexity Risks	x			YES
Funding Source Impact on Costs		x		YES
Scope Certainty/Scope Clearly Defined		x		
Must meet tight budget	x			
No follow-on Delay/Impacts			x	
Shortest Duration to Avoid Market Increases			x	YES
Maximum VE Savings	x			YES
SPECIAL EXPERTISE REQUIRED	**X**			YES
Hazardous Materials/Environmental Impacts	x			
Railroad Coordination/Impacts		x		
Utility Conflicts/Relocation		x		
Permit/Jurisdictional Relationships/Req'ts	x			
Access/Site/ROW Constraints	x			
Minimize light rail operational impacts			x	
Engineering/technology knowledge	x			
Subsurface conditions		x		
QUALITY ASSURANCE		**X**		
3rd Party/Public Approval	x			
Minimal Defective Work		x		
Effective Contractor QC/Minimal Owner QA		x		
Owner Final Design Control			x	
Need for Checks and Balances			x	
Existing system compatibility			x	
SCHEDULE	**X**			
Contractor Proven Performance	x			
Contractor Work Plan Vital	x			
Capacity to Accelerate			x	
Duration/Milestone Certainty/Meet Critical Path	x			
Shortest Design-Construct Duration		x		
SAFETY	**X**			
Top Notch Program	x			
Unique Safety Conditions	x			
Attention to Public Safety	x			YES
COMMUNITY/PUBLIC BENEFITS	**X**			YES
Utilize DBE			x	
Minimal Disruption to Businesses/Residences	x			
Maintain Access to Properties	x			
Minimal Traffic Flow Impact	x			
Minimal Noise/Vibration	x			
Minimal Utility Disruption		x		
Early Completion	x			

Critical Factors for Success

Design and component compatibility with existing TriMet light rail systems should be ensured.

Evaluation of Options

Quality control of light rail systems design, components, installation, and testing is important to ensure safe and proper functioning in revenue service. Contractor expertise in each systems discipline is critical. TriMet's experience is that in-house expertise must be utilized to ensure that TriMet's criteria are met. Accordingly, TriMet desires direct control over design and installation.

TriMet successfully completed light rail systems on the Westside–Hillsboro extension using a two-step, low bid process for separate traction electrification, signals, and communications contracts (see Table 5). TriMet developed preliminary engineering and final design documents to a level that ensured that fundamental light rail operating and systems criteria were met. TriMet developed these criteria after years of safe operating experience on the Banfield line. The criteria have been updated for Interstate MAX.

Except for fare collection, a similar two-step process is preferred for Interstate MAX. It allows TriMet to retain direct control over design and installation, and to evaluate contractor technical qualifications in step one. Following industry survey, TriMet decided on two separate contracts to maximize competition: traction electrification, and signals and communications.

The new fare collection equipment, ticket vending machines (TVMs), must be compatible with the existing system. TriMet market survey identified no feasible options other than to utilize the existing manufacturer's equipment. Consequently, a sole source procurement of the TVMs is recommended.

The preferred contracting method is two-step low bid for traction power, two-step low bid for signals and communications, and sole source for fare collection equipment procurement.

CONTRACTING PLAN SUMMARY

Identification of objectives and analysis of the major project elements provide a rationale for a contracting plan. In addition, there may be agency resource, political, or financial considerations that weigh in favor of one large contract rather than multiple contracts. TriMet was not constrained by these considerations on the $350 million Interstate MAX project. In fact, TriMet valued involvement of multiple contractors. TriMet also has retained experienced technical and project management personnel from the recently completed $960 million Westside–Hillsboro light rail extension project and relied heavily on its agency ability to manage the design and construction work.

Oregon law permits a variety of alternate construction contracting approaches. Other states may not provide similar flexibility. DB and CM/GC are popular options in Oregon.

TriMet's approach to the formulation of the Interstate MAX contracting plan is built upon lessons learned on previous projects, particularly the Westside–Hillsboro light rail extension. Currently, Interstate MAX is 75% complete overall. It is four months ahead of schedule and under budget. While multiple factors affect whether a project is successful, TriMet believes that the contracting plan for design and construction has been a key factor in the successful implementation of Interstate MAX.

TABLE 5 Criteria for Selection of Construction Contracting Method: Rose Quarter to Expo Light Rail Systems Work—Traction Electrification, Signals, and Communications

Key Criteria	Extremely Important	Very Important	Important	Legal Finding Required
COST SAVINGS/CONTROL		**X**		YES
Lowest Bid			x	
Technical Complexity Risks	x			YES
Funding Source Impact on Costs			x	YES
Scope Certainty/Scope Clearly Defined			x	
Must Meet Tight Budget			x	
No Follow-On Delay/Impacts			x	
Shortest Duration to Avoid Market Increases			x	YES
Maximum VE Savings			x	YES
SPECIAL EXPERTISE REQUIRED	**X**			YES
Hazardous Materials/Environmental Impacts			x	
Railroad Coordination/Impacts			x	
Utility Conflicts/Relocation			x	
Permit/Jurisdictional Relationships/Requirements			x	
Access/Site/ROW Constraints			x	
Minimize Light Rail Operational Impacts			x	
Engineering/Technology Knowledge	x			
Subsurface Conditions			x	
QUALITY ASSURANCE		**X**		
3rd Party/Public Approval			x	
Minimal Defective Work			x	
Effective Contractor QC/Minimal Owner QA			x	
Owner Final Design Control	x			
Need for Checks and Balances	x			
Existing System Compatibility	x			
SCHEDULE			**X**	
Contractor Proven Performance		x		
Contractor Work Plan Vital			x	
Capacity to Accelerate			x	
Duration/Milestone Certainty/Meet Critical Path		x		
Shortest Design-Construct Duration			x	
SAFETY			**X**	
Top Notch Program			x	
Unique Safety Conditions			x	
Attention to Public Safety		x		YES
COMMUNITY/PUBLIC BENEFITS			**X**	YES
Utilize DBE			x	
Minimal Disruption to Businesses/Residences			x	
Maintain Access to Properties			x	
Minimal Traffic Flow Impact			x	
Minimal Noise/Vibration			x	
Minimal Utility Disruption			x	
Early Completion			x	

Design-Build Contracts

Lessons Learned on the Gold Line Rail Project for APTA

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Design–build (DB) projects are on the rise within the United States due partly to the apparent ease of implementation for the owner. However, DB projects should not be taken lightly because appearances can be deceiving. Engineers and managers of such projects should share their knowledge and lessons learned in an effort to better understand the issues that make these projects either a success or a failure. Such areas of concern to be explored further are as follows:

- How do you write a performance-based contract that contains sufficient scope but is not too detailed? For example, how do you convey in the contract the owner's intent for the station's appearance and other subjective esthetics without detailed drawings or descriptions?
- What authority or responsibility should an owner relinquish to the DB contractor? What authority or responsibility should not be relinquished? For example, how does an owner oversee the DB contractor's quality assurance (QA) and quality control (QC) process without interfering?
- What comprises an effective Project Management Consultant that is able to successfully execute the contract on time and under budget?
- How do you keep stakeholders (third party agencies) involved throughout the process while maintaining the schedule and budget?

Some of the lessons learned and that continue to be learned on the 14-mi Los Angeles to Pasadena (California) Metro Gold Line Light Rail DB project are described, and an attempt is made to illustrate these issues with real life examples from the project.

PROJECT OVERVIEW

Over ten years in the making, the Gold Line has entered service in one of the most traffic-congested cities in the nation. Originally part of the Los Angeles County Metropolitan Transportation Authority's (LACMTA) 30-year plan, the Gold Line project was later given to a state-enacted Joint Powers Agency (JPA) created for one purpose: to build the 14-mi, 13-station light rail system within budget and on schedule. This goal was achieved on July 26, 2003, when the Gold Line opened ahead of schedule and under budget.

At one time during its development, the Gold Line was slated to directly connect to the preexisting Metro Blue Line; therefore, JPA was named the Los Angles to Pasadena Metro Blue Line Construction Authority (Authority). However, during the evolution of the project, this direct connection was eliminated, and in 2001 the Los Angeles to Pasadena Metro Blue Line was renamed the Gold Line to prevent confusion. It should be noted that the existing Red Line indirectly connects the Blue Line to the Gold Line. Furthermore, the Gold Line will extend in the near future to East Los Angeles via a new LACMTA project.

To help accomplish its goal, the Authority selected the Booz Allen Hamilton team to serve as the Program Management Consultant (PMC). The PMC is responsible for design and construction management, project controls, contract administration, and quality assurance. This role has continued from development of the bid documents through design and construction, system testing, and the start of revenue operations; the PMC will continue to contract closeout, which is scheduled to occur by the end of 2003.

Given the project's limited budget and aggressive schedule, a successful procurement strategy needed to be chosen. Taking lessons learned from similar projects in Southern New Jersey, Las Vegas, Nevada, and Australia, the PMC team recommended a Design-Build (DB) approach, which shifts traditional owner responsibilities of final design to the contractor. The schedule, therefore, is compressed as the contractor proceeds with construction while the design is in progress. Project costs are also reduced by defining and strategically allocating risk to the contractor.

As part of the procurement strategy, the project was divided into three DB contracts totaling over $300 million and a $14 million Joint Development project. The first DB is the Chinatown Aerial Structure contract that covers a half-mile of elevated track beginning at historic Union Station and ending north of Chinatown in Los Angeles. The second DB is the Sierra Madre Villa parking and bus facility contract that involves the construction of a 1,000-space parking structure at the terminus Sierra Madre Villa station in Pasadena. The third and final DB is the Arroyo-Seco contract that completes all remaining elements of work on the 14-mi alignment including 28 at-grade crossings, 2 tunnel sections, and 13 stations throughout Los Angeles, South Pasadena, and Pasadena. The Joint Development project was formed with Del Mar Station, LLC, to build a 1200-space parking structure beneath the Del Mar station in Pasadena, which will be surrounded by a future residential and commercial development.

LESSONS LEARNED

Developing a DB Contract

The first challenge for the PMC during the development of the Arroyo Seco contract was to sort through LACMTA's contractual documents and design drawings developed during the past attempts to complete the project. The PMC team decided to abandon the handed down contractual documents from LACMTA and to write a brand new contract. This decision was based on the significant amount of detail in the original contract documents that resulted from the traditional construction approach planned by LACMTA. The design drawings were in various stages of completeness, ranging from approximately 30% to 100%. Of course, this situation is unique to this project since most DB projects do not start with 13,000 drawings. Therefore, the Authority had to determine how to convey this massive amount of information while retaining the benefits of the DB model. Given the aggressive schedule and the limited manpower of the PMC, the prevailing concern was that all the LACMTA documents could not be thoroughly reviewed prior to incorporating into the contract. Therefore, the PMC selected only a small percentage of these drawings to thoroughly review, minimally modify as necessary to meet the scope of work, and incorporate into the baseline contract documents. The remaining drawings not selected were provided to the DB as reference documents. If no drawing existed for a critical portion of the scope of work, the PMC developed a new drawing. The Baseline gave the DB clear direction on what the Authority expected while the reference documents gave the contractor some ideas to explore further at its discretion.

The second challenge was to determine the level of detail that was to be incorporated in the scope of work and the baseline drawings. This challenge arose since the Authority wanted the DB to develop a design that was creative in both esthetics and in cost-savings initiatives, the main reason for choosing DB contracts. However, at the same time the Authority wanted to convey essential requirements without dictating how to accomplish these requirements, thus defeating a significant advantage of the Design-Build model. Unfortunately, there is no easy answer to this dilemma. The PMC attempted to provide adequate performance specifications while at the same time giving the DB freedom to choose the best method for achieving the desired outcome. A specific example of how this was done is the contract section for the thirteen stations. This section contained matrices that convey the overall intent of the stations such as amenities and material selection for each station. For the project's three landmark stations, the contract included more specific material selection information to ensure the DB understood the owner and the community's more specific requirements. The DB developed the specifications for the stations with the requirement that it conform to the intent of the MTA standard specification and design criteria in conjunction with the general terms and conditions of the contract. This methodology has produced a successful outcome based upon the stakeholders' satisfaction with the aesthetics and functionality of the stations.

Allocating Risk

In an effort to meet the challenging budget constraints and aggressive schedule, the PMC incorporated a number of innovative cost- and schedule-saving initiatives into the contract and into its management structure. These initiatives were intended to reduce the amount of risk and contingency money in the contractor's bids by shifting certain risks to the Authority. These risks were then mitigated through proactive management.

The first initiative was sharing the risk associated with differing site conditions between the DB and Authority. The Arroyo Seco DB contract represented the bulk of the work for the Gold Line project and included two tunnel structures that required significant excavation and tedious underpinning of adjacent older buildings. In an effort to reduce the contract price, the Authority took the responsibility for differing site conditions in the areas comprising the two tunnel structures. This greatly reduced the contractor's risk and therefore reduced the DB bid because the remainder of the project had a relatively small risk of a differing site condition. Conversely, the two tunnel sections had a significant amount of risk due to the fact that much of the work went through historic Old Town Pasadena. To mitigate this risk, the Authority had supplemental borings performed in these areas to better quantify the geotechncial conditions in these areas. These additional borings were then incorporated in the bid and contract documentation. In the end, this allocation of differing site conditions risk was successful for both the Authority and DB. To date there have only been two requests for a differing site condition Change Order totaling $450,000; at the time of this paper these requests were still under review.

The second initiative required that the Authority retain full responsibility for the environmental and hazardous waste mitigation for the Arroyo Seco DB. As with differing site conditions, supplemental investigative reports were performed prior to bid in an effort to further define the cost drivers associated with environmental and hazardous waste. This initiative was the largest cost saver of the entire project. To date, the Authority has spent only $750,000 (approximately 13% of its budget) on mitigation of hazardous material with only a slight chance of more to occur. Using this approach avoided a significant amount of risk and contingency money that would have been placed in the bids for the unknown quantity of hazardous material and environmental sites throughout the project.

From the perspective of the Authority, the most challenging initiative implemented by the PMC was the responsibility allocation of QC and QA. The Authority decided that the three DBs would be responsible for performing their own QC and that the Authority would perform quality compliance auditing of these contractors' QC programs. Strict contractual language was instituted to ensure that the DB's performed their QC programs in an unbiased manner in order to provide a quality product. In general, this approach has been successful. The amount of Authority personnel needed for field supervising the DBs is minimal. The DBs work closer with its QC people, and therefore issues are resolved in a timelier manner. However, the Authority has observed that the quality of the QC program is largely dependent on the DBs' own ethics and philosophy. Therefore, past performance in the quality arena should be a significant factor when selecting a DB that will also perform the all-important QC function.

Building the Oversight Team

For this project, the oversight team was a lean team comprised of people with diverse backgrounds. Some of the team members had experience on rail projects while others had none; this made for a large learning curve in the beginning. Furthermore, most of the oversight team had not worked together prior to this project.

The first year consisted of writing the contract, selecting the contractor, and the starting of the design process; most of this work was in the hands of upper management. However, as the design process began to pick up, upper management had to delegate more work to make the oversight manageable. To accomplish this, the engineering team, which was comprised of the engineering manager and four engineers, was broken into four specific areas: Stations, Structures, Civil, and Systems. Each of the four engineers was now a project engineer who was responsible and accountable for one specific area, while the engineering manager oversaw the complete project. This same type of breakdown occurred within the remainder of the oversight team, but the boundaries were selected by segments of the project instead of disciplines. However, as the construction began to comprise more specialized areas, such as Systems, people with this area of expertise were brought on board to oversee in addition to the segment managers.

Once a week, certain members of the oversight team members met to discuss work status and issues of concern. The participants consisted of the project manager, the entire engineering team, the construction manager, the contract administrator, and one of the third party coordinators. This meeting was crucial for dispersing information between different areas of the team.

Keeping Stakeholders Involved

The DB projects were broken down into three phases: 1) writing and awarding of the contract; 2) designing of the project; and 3) constructing the project. During each of these phases the Authority consistently strived to keep all stakeholders involved throughout the development.

Stakeholders included each of the three city agencies (City of Los Angeles, South Pasadena, and Pasadena), state agencies (Caltrans, etc.), and LACMTA. The reason for their involvement is obvious: the Authority was constructing in their jurisdiction.

Phase I: Writing and Awarding Contracts

During the writing of each contract, the Authority gave each stakeholder copies of the contracts for review and comment in an effort to ensure compatibility with the stakeholders' criteria and requirements. However, the Authority had an arduous task tracking the various comments and their resolutions. The solution was to develop a matrix for each stakeholder listing their comments, the Authority's response, and status. These matrices were then sent back to each stakeholder for review, and, if necessary, a meeting was held for final closure.

Phase II: Design of Projects

During the design phase, the DBs submitted to the Authority and the appropriate stakeholders various submittals for review and comment at specific stages. Again, due to the number of stakeholders, the Authority was faced with the task of tracking reviewers' comments and their resolutions. The Arroyo Seco DB tracked their submittal comments on matrices and issued their responses within the subsequent submittal for review. In addition, the Arroyo Seco DB would hold Joint Review Meetings (JRMs) with the appropriate parties in an effort to resolve more complicated matters.

The second challenge was the interface between the DB and the various city agencies that provided designs for the contractor to construct. Given the contractor's aggressive schedule, the Authority assertively managed the interface between the contractor and the city agencies. In general, the various city agencies were not used to the fast paced nature of the project nor were they used to working with a design that matured while construction progressed. The contractor faced much risk while the Authority had to ensure that the contractor provided the city with their requested information and that the city did the same in return for the contractor. To ensure this vital coordination between the DB and the third parties occurred, the Authority used third party coordinators dedicated to a specific functional specialty, held weekly meetings with staff level representatives of the stakeholders, held quarterly partnering sessions with senior level management from all involved parties, and maintained constant communication.

The third challenge concerned the communities and city design review committees. In addition to the contractual work, the Authority worked with the various cities to implement upgrades or additional work, known as betterments. The idea behind the betterments was to take advantage of the DBs' presence in these cities constructing the Gold Line. Therefore, the cities would not have to pay for mobilization, the annoyance of selecting a contractor, and other nuisances associated with construction work. For the most part, betterments were a win-win situation for all stakeholders. The total amount of betterments for the Arroyo Seco project was approximately $13 million.

Without a doubt, the most significant challenge faced by the Gold Line project was gaining regulatory approval of the at-grade crossing applications. As discussed earlier, the LACMTA completed a significant amount of design for the project prior to the Authority. The vast majority of the crossings were the standard two-gate system (i.e., entrance gates only) while on some rare occasions quad gates (i.e., entrance and exit gates) were used. Prior to the contract execution, extensive meetings were held with the project's stakeholders including the grade crossing regulatory agency to establish the baseline crossing requirements. These meetings resulted in significant changes to the LACMTA designs, most notably, quad gates were required at most of the crossings.

As the project progressed and crossing applications were submitted to the regulatory agency, community groups began to protest many of the applications. The main goal of the protesters was to grade separate many of the crossings. The regulatory agency conducted numerous public hearings that resulted in an injunction that temporarily prevented construction of many of the crossings. Meanwhile, the Authority continued at-risk construction of the other project elements. In an effort to gain approval, the Authority modified many of their original crossing applications to incorporate train speed adjustments, crossing layout modifications, and the addition of pedestrian and emergency exit gates at all but a few crossings. In a tight three to two vote, the regulatory agency approved the protested crossing applications.

There are two important actions that can be taken to mitigate a similar challenge in future projects. The first is to conduct extensive working sessions with the regulatory agency and all other stakeholders so that definitive grade crossing baseline requirements are established. The second is to submit the grade crossing applications as early as possible. By doing so, it provides the maximum amount of time to gain approval so at-risk construction doesn't have to take place, and it provides less time for small but vocal opposition groups to become established.

Phase III: Construction of Project

During the construction phase, the city agencies met once a week with the Authority and the contractor for status of the work and to address issues of concern. At these meetings, the cities were given an opportunity to discuss safety, design, construction, and scheduling issues.

The final lesson learned is to develop detailed requirements and proactively manage agencies and organizations that have a significant amount of leverage over the project such as occupancy or certificate-of-operations granting agencies. It is critical to develop and document well-defined, detailed requirements from these types of organizations prior to bidding the project. Once the project is under way, proactive management of these agencies is essential to prevent or limit scope creep.

CONCLUSION

The building of the Gold Line using the DB model has been an enriching experience to all the members of the PMC and the Design-Builders. There have been many lessons learned during the course of bringing LRT to the communities affected by the Gold Line. This paper has outlined the most successful and the most challenging of these lessons learned in an effort for others to learn from and apply these lessons to the next project. Do not hesitate to contact the authors at (213) 620-1900 to discuss this project or request public documents related to the Gold Line.

PORTLAND POSTER SESSION

MAX Light Rail Integration into the Community
Westside to Interstate MAX

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MAX Light Rail in Portland, Oregon, has evolved from the first Banfield project and has become an important contributor to the community's character, a catalyst for future urban form that is carefully coordinated with the neighborhood's private and public stakeholders. TriMet's approach to light rail planning, design, building, and the system's operating have changed from a top-down mentality to a more grass roots, context sensitive search for solutions. The Westside MAX project's design was the beginning. It was a transforming process for TriMet, and the community, when the project became a process for neighborhood self-determination. Subsequent light rail projects will try to repeat this lesson. Interstate MAX is a community involvement process where design elements are refined and standardized to fit this challenging alignment, and MAX's art program has become a reflection of the neighborhood's character.

A brief and succinct overview of light rail in the Portland downtown and metropolitan region will be provided, starting with Portland's first light rail effort, the Banfield project, in which a revolution turned into a regional evolution. While Westside MAX transformed the agency's view about transit, the death of the huge North/South Project then signaled a low point and forced a retrenchment. This led to a kind of resurrection with the Airport MAX extension, which in turned helped kick off the creation of Interstate MAX. Several key examples of the growth of community involvement will illustrate how urban design, station design, civil and traffic engineering, construction methodology, business support, and the art program can all work together to support the neighborhood's and community's goals. Specific examples of transit design coordination will be provided to show how the system has evolved to become more efficient, cost effective, safer, easier to maintain, while at the same time becoming a catalyst for community development and an attractive and enjoyable experience for all.

In conclusion: the story continues. All participants have learned a great deal about depending on one another and honoring the each other's needs, goals, and concerns. What TriMet builds today has to be responsive to each community, because that success will directly influence what TriMet may create in the future—whether it's north to Vancouver, Washington, east to Clackamas, Oregon, and south to Milwaukie, Oregon; whether it's Washington County Commuter Rail, Lake Oswego Historic Trolley, or extending light rail service in downtown Portland. There's more to be done in providing an efficient, economical, and attractive system throughout the region.

INTRODUCTION

Portland's MAX light rail system has evolved from the first Banfield project to become an important contributor to the community's character and a catalyst for future urban form. The

Westside MAX transformed the light rail project into a process for neighborhood self-determination. Subsequent light rail projects tried to repeat this lesson, but it was not until Interstate MAX that the community involvement process truly transformed the region's transit and planning agencies.

EARLY INTENTIONS

Banfield MAX

Westside MAX was an evolution of design from the first Banfield project. The Banfield line's concept used light rail to bring commuters from Gresham and East County into downtown Portland. Important connections were established using the Southeast Burnside Avenue vehicular traffic corridor, the Gateway/I-205 transfer node, the Banfield freeway corridor, the Lloyd district commercial center, and the Downtown with cross connections to the Transit Mall. Weekly commuters quickly realized that LRT offered a convenient and relatively quick way to come downtown. Since this line was well served by TriMet bus routes the only park and ride lots were provided at Gateway, 122nd, and later in Gresham.

Westside MAX

The Westside alignment required some very difficult choices early in the project. The key decision was whether to travel at grade over the West Hills or to tunnel through them. Numerous public meetings were held using visual simulations to illustrate the differences between the two choices. The other key choice was whether to travel west down the Sunset Highway and then swing over to Hillsboro along a relatively established vehicular transit corridor, or to turn south towards Beaverton along Highway 217 and then follow the existing Burlington Northern railroad corridor westward towards Hillsboro. After much public discussion, the route selected was through the West Hills, down 217, and west to Hillsboro. The public interaction that led to these decisions made a significant impact on TriMet's methodology for transit design, and led to a public process that is unparalleled in the United States. In short, this is the story of how community input influenced TriMet's approach to transit design, which in turn helped shape a community and a region.

Westside Story

To understand the change in TriMet's approach to the LRT's alignment design, one can study the evolution of the project in the Goose Hollow neighborhood. It is a case study of an early-engineered alignment that needed to change in order to win popular approval and support from the business community. Heading west from the original Banfield MAX turn-back in downtown Portland, the Westside LRT alignment began between the downtown business core and Portland's West Hills. This is an historic neighborhood with housing stock that dates to the late 1800s. The neighborhood was not happy when the original alignment showed only two stations on the edges of the neighborhood. They insisted another station was necessary to serve the heart of the Goose Hollow neighborhood. They reasoned that it would serve several important neighborhood institutions: Lincoln High School, the prestigious and influential Multnomah Athletic Club (MAC), and the historic Zion Lutheran Church. This neighborhood includes numerous influential, affluent, well-connected groups of citizens. The Goose Hollow Neighborhood Association is well organized and respected by the City of Portland. Its leader was a local activist, architect, and resident with over 20 years experience in city government. As such, the rest of the neighborhood group was savvy to the right of way and design review processes; they understood the local governmental bureaucracy, and how to apply political pressure. The group had learned in the 1960s how construction could negatively impact important civic monuments like the historic Vista Bridge. They feared that light rail would split the community both physically and psychologically.

Due to early and intense scrutiny during the selection of the tunnel alignment, the Goose Hollow neighborhood was galvanized to participate in the design of the LRT alignment in their neighborhood. The neighborhood is within a design zone requiring review by the city's Design Commission, and would require conditional use hearings for any portion of alignment outside the public right of way. Additionally, construction would be subject to the city's noise code, so the construction plan had to be reviewed in advance by the neighborhood association. TriMet also contacted private property and business owners at the 50% design stage. Through this effort individual property needs were accommodated and included in the construction contract. This input helped define the "Conduct of Construction" and "Public Information" plans.

Southwest 18th Avenue Case Study

Southwest (SW) 18th Avenue is an important historic street in the Goose Hollow neighborhood. Important civic institutions (such as PGE Park, Lincoln High School, Zion Lutheran Church, the MAC Club, and The Oregonian newspaper printing building) abut and use the road and sidewalks. SW18th Avenue was the dividing line in Goose Hollow between the urban "flatlands" and the residential West Hills. It also was the connecting arterial to SW Jefferson Street and the freeway (US-26). Buildings along SW 18th tended to have fewer stories than on SW Morrison and SW Yamhill Streets, and commercial developments often presented their "backsides" to the street. The road itself was part of the old plank road connecting with SW Canyon Road, and Tanner Creek Sewer "stream" runs underneath part of the street. During construction, portions of the old trolley tracks were unearthed, and the original road and stream bed, nearly 30 ft deep in some places, were discovered.

The SW 18th Avenue alignment is a very narrow 80 ft in width. It's like trying to cram ten gallons on water in an 8-gallon bucket. The LRT would need to use two trackways; vehicular traffic would be on two through lanes, as well as left turn lanes, bike lanes, on-street parking, and sidewalks. The neighborhood heavily influenced the actual design of the avenue. Cobblestone was used in the trackway up to the Vista Bridge. On-street parking along the avenue was restored in limited areas, and three parking lots were built near the alignment (to replace parking taken off the street on a one-to-one basis). A 100-year-old tree was preserved. Existing trees were re-located and planted as well. Finally, the project placed all the overhead utilities underground.

As the final design touches were implemented, TriMet's design engineers were horrified by the neighborhood's demand for another station just a block and a half away from the Civic stadium station (now called PGE Park). This was the ultimate demand of the neighborhood association, which desired to maximize access to light rail. In the end, we reached a funding solution created by a public–private partnership with the MAC Club, the City and TriMet. This spirit of cooperative problem solving continued when a Mercedes dealership, which had been relocated before (ironically for an earlier transportation project) was converted into mixed-use housing. At this location, a housing development sprung up on the south half of the block with the showpiece PGE Park station on the northern half. The light rail tracks diagonally bisected the block. Three other housing developments grew from other “left-over” pieces of property. Finally, Zion Lutheran Church (which was designed by the renowned Portland architect Pietro Belluschi, is on the National Historic Register, and has occupied its site for over 100 years) was outfitted with sound insulation for the beautiful stained glass windows.

Making a Place with Art

TriMet learned that it must acknowledge that sense of place and previous history is very important when doing a project like this. Public art became one way to connect and reflect community. Therefore artists were involved with the design team from the beginning of final engineering. Their charge was to listen to the hopes and goals of the community and reflect that back in their designs and artwork.

Lincoln High School Fence Case Study

The Fence related to both the neighborhood in its design (taken from window shapes found in Goose Hollow) and also its reflection of Lincoln High history (through bits of songs, ceramic silhouettes of hairstyles taken from old yearbooks, and reminders of momentous occasions in the school’s history). The neighborhood took a cue from the public art program and raised the money for a bronze statue of a goose at the SW 18th and SW Salmon station, a reminder of when the area was a farming community at the turn of the century.

Westside Corridor Conclusions

The Goose Hollow neighborhood had a tremendous impact on the design and construction of light rail in this area. The relationship wasn’t always smooth, but resulted in a better fit for light rail in this neighborhood.

This case provides important points to remember in planning:

- It is very important to cultivate a partnership between the project and the public.
- A team approach is necessary.
- Engineers, architects, artists, businesses, and community all have to be included in solving problems.
- Developing and nurturing long-term relationships helps the project run smoothly.
- Community memory or will should not be underestimated.
- Public art as a voice and context for the community can be a vital project element.

With the successes of the Westside project dancing in our heads, TriMet proposed the next big step—the first expansion from downtown Portland south to Milwaukie, Oregon, and north to the Columbia River.

South/North MAX

The proposed South/North project would have extended light rail from Downtown south to Milwaukie, and north along I-5 and to the Exposition Center. The 21-mi system would have created a springboard for expansion north to Vancouver, Washington. But when Washington voters defeated the local ballot measure to fund the initial efforts for light rail in southwest Washington, it made the North commuter extension less attractive to Oregon voters.

In the statewide vote of 1998 the huge, ambitious expansion failed to receive enough public and political support. The ballot measure, though supported in northeast and north Portland, did not have enough statewide votes to pass.

However, a new realization was born in the aftermath of South/North's defeat. In order to expand the system, transit supporters needed to craft projects that responded to a community's desire for transportation alternatives, and would support their urban renewal needs. The City of Portland, Metro, TriMet, the Portland Development Commission, and others would need to look for strategic partnerships that would mutually support each other's funding, community planning, and growth management realities.

There have been two ways TriMet has responded to this new understanding. The first was the extension of MAX to Portland International Airport. Light rail to the Portland International Airport has been part of regional and local master planning since the mid-1980s. The design of Interstate 205 (I-205) planned for a future bus-way in the median and a tunnel beneath the northbound lanes north of Rocky Butte. This expansion sidestepped the normal public approval process for funding by creating a unique public–private partnership. The project was organized to use only public agency and private development funds, rather than requiring a voter-approved tax or bond. Consequently, the alignment ran only through public right of way and private land owned by the development partners.

Airport MAX

The 5.5-mi Airport MAX Red Line operates between the Portland International Airport (PDX) and downtown Portland (with no transfers required). The Red Line runs every 15 min every day beginning at 5 a.m., with the last train leaving PDX at 11: 30 p.m. The trip from PDX to downtown Portland costs $1.55 and takes just 38 min. The extension is the result of an innovative public–private partnership between the Port of Portland, TriMet, the city of Portland, and a Bechtel Enterprises-led partnership with Trammel Crow Company, known as Cascade Station Development Company, LLC. As part of the project, Cascade Station Development Company will also develop Cascade Station, a 120-acre transit-oriented project featuring hospitality, retail, entertainment, and office space served by two light rail stations.

The Airport MAX Red Line was a specific response to a unique opportunity. The question remained: How could light rail be expanded where the community needed to be a full partner in funding and design? The answer would be a project far less expensive than South/North, which could use an existing public right-of-way, and which would help transform an old interstate highway, and greatly contribute to a community's desire for urban renewal and economic development.

Interstate MAX

Interstate MAX was the answer. Its funding partners and funding were a combination of TriMet's Capital Projects and Facilities Division in partnership with the City of Portland, the Portland Development Commission (PDC), Metro, FTA and the communities of North and Northeast Portland. The project's $350 million budget requires no additional property taxes. The federal government will provide $257.5 million, with local and regional funds making up the balance.

Local funding was committed in October 1999. The federal grant was signed in September 2000. The City of Portland is providing its $30 million share of Interstate MAX funding through the Interstate Corridor Urban Renewal Area.

When the 5.8-mi Interstate MAX light rail project emerged as a transportation option for this corridor, the community wanted some changes from the original South/North alignment. Those changes included

- A lower cost project;
- No businesses or homes displaced;
- No increase in property taxes to pay for it;
- A route that better serves the neighborhoods;
- Ensuring people who live in the community will benefit by helping to build it; and
- A final project that helps to revitalize the community.

These principles meant that MAX construction must fit within the existing street area, maintain one lane of traffic in each direction, keep parking available to support businesses, make it bike and pedestrian friendly, and increase the number of trees on the avenue. Impacts must also be minimized and businesses must be supported through construction. The design process for Interstate MAX has exploded the myth of public involvement. Everything has changed to become a process that takes seriously the involvement of citizen stakeholders. No more "blow and go." The local community and TriMet mutually test each other and understand how light rail should serve its neighborhoods, businesses, and institutions. Unique and exciting aspects of the total effort included those detailed in the following sections.

Interstate MAX Stakeholders Even though North/Northeast Portland voters were the strongest supporters of the failed South/North project there were still plenty of doubters that MAX would be a welcome addition to Interstate Avenue. Through a process of public meetings, presentations to neighborhood associations, focus groups, canvassing of business owners, and review of options with the various special interest contingencies, a design emerged that was unique to Interstate Avenue.

Alignment Character The Rose Quarter is a hub of multimodal movement and a center for entertainment activities. Lower Albina/Mississippi is an area of various industrial businesses, and a rail shipping center. At the same time it is reclaiming its mixed-use heritage as a unique center of retail, entertainment, and urban housing. In upper Interstate Avenue many of the businesses along the old interstate highway were motels and restaurants that reflected the character of the 1950s. Kaiser Permanente's Interstate Medical Center campus grew out of a close proximity to Swan Island shipping and other industrial employers. The avenue is both a north/south connector to Portland and Vancouver, and also gathers east/west connections to well-established neighborhoods and employment centers. The neighborhood of Kenton, on the northern edge of Portland, has a long history of residential, retail, and industrial use. Finally, the northern activities of Delta Park, Portland International Raceway, and the Expo Center experience periods of intense event activity. All of these areas have special needs that nevertheless needed to be carefully woven together by a common system.

Community Relations The programs created by the Community Relations team revolve around shared knowledge and understanding of the neighborhoods, businesses, schools, and other institutions. A broad database was created through formal surveys and countless personal interviews throughout the community. But it is equally important that the community members and leaders understand TriMet's methodology and purpose. TriMet representatives attended all the community and business association meetings, held regular public information forums, and called on other key community stakeholders. This resulted in an unprecedented sharing of knowledge for all parties, and ensured a very high level of trust and commitment to each other's goals.

Art Program The art program strives to establish a unique identity for each of the 10 stations along the new light rail line. Eighteen artists and writers have developed approximately 50 art elements that draw upon the history and culture of the individual station areas. The goal of the art treatment at each station is to establish a unique identity along the urban spine of the light rail line. Each station reveals layers of the urban landscape often overlooked, forgotten, or buried. Restoring those layers to public view enriches our appreciation of the character of the place and the complex forces that form our communities.

Design Decisions Stations were positioned to provide easy access to neighborhoods and support urban renewal planning. Each station, with the exception of the Interstate/Rose Quarter station, utilized a common set of materials and elements. However, since each station context was unique, the art program was utilized to reflect the individual character of each neighborhood and vicinity. The typical 100 ft right of way provided 10 ft sidewalk/planting areas, through travel and left-hand turn lanes with on-street parking. In transforming Interstate Avenue into a multimodal corridor, on-street parking was provided in order to maintain and enhance retail and commercial activity. The corridor's bike lanes are part of the regional bicycle route. Paved track was used in the Albina/Mississippi station area and all along Upper Interstate from Overlook to Kenton neighborhoods. Additionally a new joint use catenary support and street light pole was centered in the trackway throughout the Upper Interstate portion.

A mile-long elevated bridge connects Kenton to the Delta Park/Vanport station. Ballasted track extends north to the final station at the Expo Center.

The ten station areas have their own, special and unique character. The basic design concept was to provide a consistent and uniform light rail system that clearly belonged to the regional MAX system and yet could respond to local conditions and urban design opportunities. While regular street design and urban design strategies were employed , the art program was able to employ the broadest and most detailed strategies to create distinctive station areas.

Interstate/Rose Quarter station creates a transfer node between north/south and east/west travelers. Its platform includes glass canopy shelters that emulate the existing Rose Quarter station, although the paving will incorporate TriMet's new use of sand-set pavers. "The Silicon

Forest," a metaphor for displacement and change, is the theme of the artwork at Interstate/Rose Quarter Station. Concrete tree rings inset into the platform symbolize the forest that was once abundant at this site. The experience of standing in the dappled light of a forest canopy is simulated by the filtering effect of green and blue glass discs attached to the glass shelter roof. Two groups of 18 ft to 24 ft illuminated metal trees serve as station landmarks. Referencing both the forest industry of yesterday and the high-tech industry of today, the trees generate their own electricity through solar panels that branch out of the upper boughs. Beneath them, passengers can sit on stainless steel "stump" benches around a glowing-red "virtual campfire." Custom railing features branching tree limbs. The station artist is Brian Borrello.

Albina/Mississippi station provides access for the industrial employment center of Albina, and the emerging urban community along the Mississippi Avenue corridor. A center platform station, it utilizes the new Interstate MAX shelter and platform materials. The art program for the station is moved by its history of neglect, racism, and urban renewal; station artist Wayne Chabre developed a sculptural symbol for the indomitable spirit of the Albina/Mississippi community. At the north end of the station platform, a 12 ft high and 4 ft wide bronze vine bursts through the pavement and flowers with forms representing the local jazz scene and other arts and industries of the area. Cast-glass elements add color and light in a slow rhythm of various combinations. Additional art elements include a community map and two art benches.

The Upper Interstate Stations—Overlook, Prescott, Killingsworth, Portland, and Lombard—all utilize the new Interstate MAX shelter and platform materials. Typically the stations are a split platform arrangement in the middle of Interstate Avenue that facilitates left-turning traffic. Prescott is a center platform station with an adjacent bio-swale filtration pocket park and art features.

Two 9.5 ft by 2 ft square bronze light towers glow softly at each of the Overlook Park platforms, featuring colored glass "windows" printed with photos of community members and overlaid with images of nature. The concept for the towers was inspired by the station artist Fernanda D'Agostino's research on the healing power of light and nature. Modeled after traditional roadside shrines found in Poland, they also make indirect reference to the local Polish community. Imagery for the towers and for a windscreen on the east platform will be developed through meetings with the surrounding neighborhood. Additional art elements include a community map.

The Prescott station features a rainwater filtration demonstration project with references to the nearby Swan Island shipyards. A 14 ft tall sculpture suggestive of a ghostly ship's prow gathers rainwater and funnels it to a drain leading to a green space just east of the station. In the midst of the green space rises a Corten steel sculpture 8.5 ft by 16 ft modeled after a ship's propeller. Several basins of basalt collect water to support bird life in the newly created habitat. A map of local streams that have either been filled in or buried in culverts is inlaid into the platform. The station's artists are Brian Borrello and Valerie Otani.

Killingsworth station is characterized by a vibrant and colorful design inspired by the traditional arts of Africa, South America, and East India. Sparkling glass mosaic and handmade glass tiles add color to the shelter columns while triangular metal flags hang under the canopy. Geometric motifs found in South American textiles are laser cut into railing panels and custom benches reflect the influence of Ashanti tribal culture. Glass mosaic columns and custom benches at the nearby bus stops unify the transit area. Additional art includes a community map.

Artwork at this station was developed through a mentorship between a well-known textile artist and one of the three design team artists. Station artists are Adriene Cruz and Valerie Otani.

At the Portland station, a team of artists and writers drew on Native American culture and experience to develop artwork at the North Portland Boulevard Station. References to historic petroglyphs from the Columbia River Gorge appear on columns, custom benches, and railing panels. A traditional basketweave pattern is repeated in the pavement. Bronze sculptures look down from the shelter canopies and stand tall in a green space on Ainsworth Street. Inspired by trees that were removed from the Interstate MAX right of way, the Ainsworth sculptures integrate poetry written by students during poet Gail Tremblay's writing residency at Ockley Green Middle School. Station Artists are Lillian Pitt, Ken MacIntosh, and Rick Bartow, and the community map was created by Dawn Waldal and Elizabeth Woody.

The artist for the N. Lombard Transit Center has set up multiple workshops with neighborhood and community groups to engage the community in the development of imagery based on the theme of labor. The images will then be translated into brilliant glass mosaic tile that will appear in railing panels at the MAX platforms and trash cylinders at the bus stops. A colorful pattern of glass mosaic is wrapped around the shelter columns at both locations. Additional art includes a community map by Victor Moldonado, and the station artist is Linda Haworth.

Kenton station also utilizes the new Interstate MAX shelter and platform materials. The station's side platforms are positioned to the north side of Interstate Avenue, which will allow future redevelopment to directly coordinate with light rail. Neighborhood and connector streets, like Denver Avenue, were reconfigured to improve traffic safety and pedestrian access. Several "pocket parks" were thus created, thereby enhancing the pedestrian experience and creating on-street parking near the commercial hub of downtown Kenton. The most notable addition is the creation of Paul Bunyan Plaza, which is a combination of hardscape pedestrian areas and landscape backdrop. The artwork at the Kenton /North Denver Avenue Station reflects Kenton's rich history, with an emphasis on the cattle industry. Metal cutouts in the railing feature cowboys and cattle in diminishing perspective. Steel bands etched with an architectural motif wrap the shelter's columns. Custom benches highlight scenes from Kenton's past in mosaic tile. The community map features artifacts of daily life in Kenton imbedded in resin and surrounded by mosaic.

Salvaged architectural elements from the Portland Union Stockyard are featured at a nearby pocket park and sculptures inspired by Babe the Blue Ox offer seating across from the landmark statue of Paul Bunyan. The station artist is Tina Hoggatt , the community map was created by Mary Tapogna, and the seating sculpture is the work of Brian Borrello.

DeltaPark/Vanport and Expo stations both have a large park and ride component that will attract Washington commuters, and patrons of Portland International Raceway and the Expo Center's events. Located near wetland areas, and on the site of historic vanished city of Vanport, the stations emphasize environmental and cultural themes. The Delta Park/Vanport station will create two bio-swale planting areas that will filter both bridge and parking lot storm water. Both are side platforms that utilize the new Interstate MAX shelter and other materials.

The Delta Park/Vanport Transit Center features an integration of engineering, design, and art that provides an experience of nature while acknowledging the past. Michael Creger is using artifacts from the Chinook culture, the historic city of Vanport, and the Portland International Raceway to cast a bronze railing at the platform representing the three main chapters in the life of the area. Vintage prints of the life in Vanport are reproduced in enamel on steel and hung on the electrical cabinet. A mosaic paving insert depicts a map of the present (Delta Park) superimposed over a map of the past (Vanport). Roof-shaped sculptures below the platform emerges from the landscape recalling the disastrous flood of 1948. Down in the lower parking area the water quality pond features arcs of Corten steel and a glowing monolith suggesting the constantly changing relationship between man and nature in this historic wetland. The station artist is Linda Wysong.

Traditional Japanese timber gates mark the entrance to the Expo Center Station near the site of the assembly center where Japanese Americans were held in 1942 while the internment camps were hastily being constructed. Newspaper articles from the time are etched in metal and wrapped around the base of the timbers. Metal tags such as those worn by internees are strung across the gates representing each of the 3800 people incarcerated at the center. Seating is in the shape of the suitcases and trunks they used to store their belongings. A floor plan of the assembly center is inset into the platform paving. The station artist is Valerie Otani.

BUSINESS SUPPORT PROGRAM

One of the main concerns with any street reconstruction is the impact on businesses. TriMet is committed to minimizing construction impacts to local businesses along Interstate Avenue. This includes maintaining access to businesses, helping businesses by providing technical assistance, and marketing and advertising support.

TriMet supports Interstate Avenue businesses by:

- Maintaining at least one lane of traffic in each direction, and access to businesses and parking.
- Posting “Open for Business” signs along with directional signs to help customers access businesses.
- Creating a “Doing Business on Interstate Avenue” directory to make it easy for people to patronize companies.
- Working in partnership with PDC, U.S. Small Business Administration, Enterprise Foundation, Cascadia Revolving Fund, and Albina Community Bank to offer a low-interest loan and technical assistance program for small businesses on Interstate Ave.

As part of the “Interstate Ave. is Open for Business!” campaign, TriMet rolled out the Lunch Bus. The innovative program picks up employees from various partner agencies or neighborhood groups, give them a tour of the project, and then stops for lunch at an Interstate Avenue restaurant.

The Lunch Bus is a great way to inform people about the project while bringing customers to support the local restaurants.

By March 2002, the Lunch Bus had generated over $4,000 for Interstate restaurants including Playa Azul, Swan Garden, Dixon’s Rib Pit, Nite Hawk, Paul Bunyan’s Deli and Espresso, and U&I Restaurant.

THE STORY CONTINUES

What TriMet builds today will directly influence what TriMet is allowed to create in the future—whether north to Vancouver, east to Clackamas, through downtown Portland, or south to Milwaukie.

PORTLAND POSTER SESSION

Environmental and Sustainable Elements in Light Rail Transit Design and Construction

The GREEN Line—From High Tech to No Tech

SIMON COOPER
SEAN BATTY
Tri-County Metropolitan Transportation District of Oregon

The goal of the Tri-County Metropolitan Transportation District of Oregon (TriMet) is to be an environmental leader. TriMet aims to go beyond merely complying with environmental regulations by continually improving its environmental performance, preventing pollution, and reducing its impact on the environment. This policy was applied to the Interstate MAX project in Portland, Oregon, with excellent results. The final project was tangibly more "sustainable," allowing for the future implementation of additional sustainable elements, incurred no loss of system functionality, and was within the project budget and schedule constraints. The goals were accomplished by making extensive use of recycled materials and reused materials, by planting trees, and by using innovative storm water management techniques to clean storm water runoff. These sustainable project elements range from the very simple ("low tech") to the quite complex ("high tech").

It is concluded that

- Agency environmental philosophy begins at the top.
- Recycled elements and recycling often represent practical and cost effective solutions.
- Storm water elements are driven by City and Federal requirements and, in the case of Interstate MAX, required careful interpretation and application.
- Sustainable elements run the gamut from high tech to low tech, with the traditional precepts of "reduce, reuse, recycle" falling somewhere in the middle. Sustainability, in some cases, improves the bottom line over the life cycle of the system.

INTRODUCTION

TriMet is the first transit agency in the United States to utilize recycled materials extensively in a rail project. The Interstate MAX light rail alignment is an approximately 5.6-mi extension of the Portland area's regional light rail system from the centrally located Rose Quarter arena north to the edge of Portland (and Oregon State University), at the Expo Center. Recycled materials were used in response to internal agency policy, community desires for more sustainable construction, and, in part, due to regulatory requirements. The use of recycled materials and other sustainable elements were conscious responses to favorable engineering cost-benefit analysis that address the entire life cycle of the project.

These sustainability efforts save the agency money, streamline its operations, and make the project friendlier to the environment. For example, TriMet saved more than $500,000 in direct construction costs by focusing on opportunities to utilize recycled products.

Specific sustainable elements can be organized in a continuum of complexity. Sustainability proponents often focus on technologically complex elements; however, significant sustainability gains can be made by incorporating elements that are very low tech. For example, TriMet is tripling the number of street trees installed along the alignment, a "no-tech" project element. These trees will improve the environment by reducing air pollution, providing shade, and retaining storm water.

The Lower Albina and Upper Interstate reaches of Interstate MAX reduced the storm water impact of approximately 2.9 acres of impervious area through the use of a ballast trackway. This pervious track section reduces the amount of runoff from paved surfaces. This specific technology is definitely low tech.

The project also treats storm water runoff from 36 acres of industrial area that flows directly into the Willamette River. This runoff is treated through a specialized storm water treatment vault that could be considered to be in the mid-range of the technology continuum.

The future for light rail transit (LRT) may include the installation of regenerative braking energy storage capacitors—certainly a high tech solution. These capacitors act as batteries that store the energy that the trains generate when braking, and release it to the power grid for use by other trains.

Sustainability Somewhat Defined

The terms sustainability, "green," and environmentally friendly, have all been used to describe environmental initiatives. The current term of art is sustainability. What is sustainability? As stated by Oregon's former governor John Kitzhaber, the necessarily broad definition of sustainability is using, developing, and protecting resources at a rate and in a manner that enables people to meet their current needs and also provides that future generations can meet their own needs. Sustainability requires simultaneously meeting environmental, economic, and community needs.

In economic terms, the goal is to live on environmental interest, not on environmental capital.

Project Mandates

The sustainability of Interstate MAX is the result of two major factors. First is TriMet's commitment to being an environmental leader. TriMet's philosophy goes beyond simple compliance with environmental regulations to actively working on improving environmental performance, preventing pollution, and reducing the impact of TriMet's activities on the environment. This philosophy is largely attributable to TriMet's leadership. TriMet's General Manager Fred Hansen served as deputy administrator of the Environmental Protection Agency for 4 years, and he was the director of the Oregon Department of Environmental Quality (DEQ) for more than 10 years.

GREEN Environmental Policy

Through Mr. Hansen's leadership, TriMet has created a GREEN philosophy, described below.

Goal TriMet's goal is to be an environmental leader. TriMet is committed to not just being in compliance with environmental regulations, but to going beyond compliance by continually improving our environmental performance, preventing pollution, and reducing our impact on the environment.

Reduce, Reuse, and Recycle TriMet seeks to alleviate its negative impacts on the environment by reducing waste, reusing materials, and recycling waste, as well as by showing a preference for products made of recycled materials.

Educate TriMet educates employees to be environmentally responsible and achieve environmental goals. Furthermore, TriMet educates the public on the benefits of transit and how riding transit reduces pollution and helps meet the region's land use goals. TriMet also educates our business partners on the benefits of transit and employer commute options.

Efficiently Use Resources TriMet implements conservation measures that consume less energy including fuel, electricity, and time.

Nature TriMet seeks to conserve natural resources by working toward a long-term goal of sustainability using The Oregon Natural Step framework as guidance (www.ortns.org). TriMet works to minimize significant environmental impacts as identified in its environmental management system by setting and reviewing environmental objectives and targets.

The Natural Step was started in the 1980s by a Swedish medical doctor and cancer researcher Karl-Henrik Robert because he was concerned about rapidly increasing cancer rates for children. From his research, it had become clear to him that this increase in cancer was connected to environmental factors, not lifestyle. In talking with a fellow scientist, Dr. Robert was frustrated that there was endless debate that wasn't going anywhere. He felt something had to be done, so he began a consensus process in which he sent out a paper for comment from fellow researchers about conditions for planetary sustainability.

The Natural Step is a creative new approach for addressing environmental challenges based on consensus and systems thinking. Its purpose is to develop and share a common framework comprised of easily understood, scientifically based principles that can serve as a compass to guide society toward a just and sustainable future.

The second factor behind the sustainable elements of Interstate MAX is local and federal rules. A primary example is the City of Portland's Storm Water Manual, driven by Federal Clean Water Act requirements and specifically the National Pollutant Discharge Elimination System (NPDES) permitting system. The program was expanded in 1987 to target "non-point" source pollution, including pollution from diffuse sources, such as storm water runoff from urban and agricultural areas. (In Oregon, the Oregon DEQ enforces NPDES regulations.)

The City's NPDES permit requires a storm water management plan (i.e., storm water manual and regulations) to reduce pollution in surface runoff to the maximum extent practicable.

Yet another example is the generally high bar set by the City of Portland with regard to construction waste recycling. Portland City Council created the Office of Sustainable Development in the fall of 2000 to research and promote environmental, social, and economic health in Portland.

Criteria, Elements, Costs, and Benefits——Sustainability as a Balancing Act

Achieving sustainability will require the balance of several factors: economics, environmental needs, and community social needs. Elements that balance the needs of all three factors are sustainable. In business, this increasingly popular notion of three integrated sustainability goals is sometimes referred to as the "triple bottom line:" increasing profits, improving the environment, and improving people's lives.

The CEO of Electrolux once stated, "I'm convinced that we are seeing the birth of a new perspective of the world where ecology and economics are two sides of the same coin" (Sweden-based Electrolux adopted the The Next Step sustainability framework after it lost a multi-million-dollar deal because it did not offer a refrigeration system without chlorofluorocarbons).

In its final state, sustainability will always make economic sense. However, in the transition from now until this sustainable future, some sustainable elements will not survive cost-benefit analysis. Favorable cost-benefit analysis does not even strictly parallel the low to high technology continuum, nor are the results of cost-benefit analysis constant from place to place or project to project. Unfortunately, there are few "silver bullets" in sustainability. The way to decide which sustainable elements do make sense is through good old fashioned engineering analysis, keeping in mind three concepts: 1) make sure that life-cycle costs are included in the analysis; 2) account for all costs, even externalized costs; and 3) realize that balance, not maximization of one variable, is the goal.

In most basic terms, sustainability is just another project criteria to be balanced against all the others.

Project Specific Examples of Sustainable Elements

Reusing and Recycling Materials

The City of Portland is a leader in recycling policy. It currently requires building projects with a permit value of $50,000 or more to separate and recycle certain materials from the job site. City construction specifications for improvements to streets and sidewalks within the City right of way do not set specific performance standards but require projects to "recycle, reuse, or salvage whenever practical." TriMet's internal philosophy was compatible with the City's and the two agencies worked together to use recycled materials for use in roadway and sidewalk construction.

Recycled Concrete and Asphalt—Low Tech TriMet's contractor sorted demolished concrete and asphalt from other materials at the project site and then transported it to a crushing plant operated by Pacific Cascade Resources. The material was graded and mixed with some standard aggregate base to produce a material that met the engineering criteria for base rock suitable for roads, sidewalks, and concrete paved track slab. In all, 80,000 cubic yards of material was reused, saving TriMet $100,000 on the purchase of materials and on disposal fees.

Recycled Bollards—Moderate Tech Interstate MAX is the first project to make use of bollards and chain made from recycled plastic in paved track portions of the trackway. At the time of design, no bollards meeting TriMet's recycling goals and criteria were available, so the contractor was asked to fabricate them. The result was bollards made from recycled plastic, 20%

cheaper than steel, saving $100,000 in material costs. The use of plastic bollards also eliminated the need for grounding, yet another direct cost savings. Because LRT design criteria requires all conductive materials within 15 ft of the trackway to be electrically grounded, removing the grounding requirement saved an additional $150,000.

Recycled Plastic Track Ties—Moderate Tech The paved track portion of Interstate MAX uses 6,000 ties spaced every 6 ft, to maintain alignment, gauge, and grade, until the concrete track slab was poured. On previous light rail projects steel ties were used. Interstate MAX used ties made from recycled polyethylene automobile gas tanks. These ties have the added advantage of not affecting the signal system, unlike steel ties. Not having to shield the signal system from the steel ties offer yet another cost savings.

Storm Water Management

The design basis for the Interstate MAX project's storm water system is the City of Portland's Storm Water Management Manual. Project staff and engineers from the City's Bureau of Environmental Services formed a design task force to implement the City code. The team faced the challenge of applying rules intended for a typical city block development to a linear project 5.6 mi long, crossing 12 separate drainage basins, seven of which drain into the Columbia Slough, and five of which drain into the Willamette River. The task was also complicated because Interstate sewer system was in large part combined (sanitary and storm), with only the lower sections (those in Lower Albina, close to the Willamette River) being separated. The city's rules dictated that the project treat (i.e., clean) the storm water using one of a number of approved best management practices. The joint agency team weighed the factors and decided to install treatment manholes on key storm pipes, thereby treat a large percentage of storm water in the Lower Albina section of the project. When all of the project's total impervious area was calculated along Interstate Avenue, there was a net reduction. Although the road was widened to add the track, approximately 1.3 mi were constructed as open ballasted track. The replacement of asphalt paved roadway with ballasted track removed a 28-ft strip of impervious surface area.

Storm Water Treatment Manholes—Moderate Tech The team selected Continuous Deflection System water treatment manholes for the project. The manhole utilized a unique (high tech) deflection screen that reportedly removes 95% of solid pollutants.

This was one of several techniques that were approved by the City; however, it had some key advantages favored by the project:

1. Hydraulics advantages. This system did not require any head drop (differential between pipe inlet and pipe outlet) through the treatment structure. This meant money was focused on treatment structures and not on laying extra pipe chasing grade downstream to tie back into the sewer system.
2. High flow effectiveness. The manholes tolerated a wide range of flows. The first flush and flows were treated and the high flows were diverted without resuspending the captured pollutants.
3. Ease of maintenance. The City's bureaus were charged with maintenance, and with limited resources this was important. This is a good example of considering the life-cycle cost of a potential project element in selecting a particular design or facility.

Storm Water Infiltration—Moderate Tech Interstate MAX provided three retention facilities to mitigate the increase in impervious area in the upper reaches of the project. This served to decrease overall detention requirements in these reaches of the project. In addition, these facilities provide water quality benefits not strictly required. These facilities will infiltrate paved track drainage. Road drainage was not infiltrated because the City of Portland prohibits the use of sumps to handle storm water along main automobile transportation arterials like Interstate Avenue because of concerns about vehicle hydrocarbons and the risk of hazardous material. As the paved track way is dedicated to light rail vehicles (LRVs), it presents no such risk.

Water Quality Pond—Moderate Tech Interstate MAX constructed two significant, traditional planted water treatment facilities at the Delta Park–Vanport Station and at the adjacent park and ride. The TriMet–City of Portland storm water team wanted the project to provide a more natural treatment facility that would showcase how water quality treatment can be incorporated aesthetically into design (in contrast to the more common practice of hiding a well-engineered but ugly facility in the corner of the parking area). The resulting facility integrates engineering and design to provide an attractive natural appearance while the artwork recalls the history of the area. Roof-shaped sculptures below the platform emerge from the landscape recalling the disastrous flood of 1948. Down in the lower parking area, the water quality pond features arcs of Cor-ten steel and a glowing monolith made of stone, steel, and acrylic.

Landscaping

Tree Plantings—No Tech Trees provide valuable storm water retention, reduce air pollution, and provide cooling shade. Interstate MAX will plant over 1300 trees, tripling the number that previously existed along the LRT alignment.

Groundcovers—No Tech Use of groundcover plants in lieu of “tree lawns” in sidewalk planting areas reduces storm water runoff, irrigation water needs, and requirements for future petrochemical fertilizer and pesticides. In addition, this will eliminate the need for frequent mowing typically performed with gasoline burning equipment. When mature, these plantings will provide full ground coverage and total interception of rainfall to limit impact erosion.

Irrigation Systems—Moderate Tech Irrigation and plantings are designed based on an “irrigate-to-establish only” philosophy. Irrigation systems are a cost effective way to establish drought tolerant plantings in the Portland area. However, the irrigation systems will be decommissioned after two growing seasons. This approach netted some savings on the initial cost of these systems, and more savings will accrue when irrigation water is no longer necessary.

Certified Organic Soil Amendments—Low Tech TriMet is currently investigating use of soil amendments that are certified organic. Organic certification is better known as it relates to food production. Certified organic means less petrochemical use in production and less residual environmental chemicals. Typically, petrochemical based fertilizers and soil amendments are installed by landscaping contractors.

Light Rail Vehicle Propulsion

Storage Capacitors—High Tech The future for Portland LRT may include the installation of regenerative braking energy storage capacitors. These capacitors act as batteries that store the energy that operating trains generate when braking, and then release it to the power grid for use by other trains. Currently, all TriMet LRVs have regenerative braking capacity. That capacity is only realized as useable energy for propulsion in certain areas and when certain conditions occur on the system. The ability to store this energy for future use is the next step in fully capturing the potential of regenerative braking.

SUMMARY OF CONCLUSIONS

TriMet's policy of sustainability is based on the following conclusions:

- Agency Environmental philosophy begins at the top.
- Recycling and reuse often present practical and cost effective ways to improve sustainability, but there are no "silver bullets."
- Sustainability can be treated as another variable in traditional engineering and cost-benefit analysis, as long as lifecycle costs are considered, and project lifecycle is long enough to recoup investments in more sustainable elements.
- Elements that lead to system sustainability run the gamut from high tech to low tech with the traditional precepts of reduce, reuse, recycle falling somewhere in the middle.
- Sustainability, in some cases, improves the bottom line over the lifecycle of the system.

INTERNET RESOURCES

1. The Oregon Natural Step: http://www.ortns.org. Accessed Feb. 28, 2003.
2. The Alliance for Sustainability: http://www.mtn.org/iasa/tnssystemconditions.html. Accessed March 4, 2003.
3. Portland Office of Sustainable Development: http://www.sustainableportland.org. Accessed March 4, 2003.

Special Problems for Real Property Acquisition Valuations
Billboards and Parking Lots

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The construction of light rail alignments more often than not requires real property acquisitions. From time to time light rail projects impact income-producing properties such as paid parking lots and billboards. This raises the issue of the appropriateness of including "lost business revenue" and the "income approach" to valuation as part of an appraisal. The author suggests that it is a best practice to begin a project's acquisition process with these properties because they require more time and energy. This extra time allows the real property personnel to gather information and develop creative ways to minimize the impact of the income approach when good reason exists to believe that it would likely be the ultimate method used to determine value.

A fact scenario based on real property acquisition files involved in the Interstate MAX project will be utilized as backdrop to discussing the legal analysis involved in determining the relevance of the income approach to appraising paid parking lots and billboards taken under a government's eminent domain authority.

Where property generates rental income it would very likely be admissible in a condemnation action. Therefore, it is important to determine the appropriateness of including this in the appraisal at an early stage of the project and identify ways to minimize its impact.

INTRODUCTION

At the beginning of project planning, no one really knows the cost of the real property upon which the alignment will run. The simplest method is to determine an average per square foot value for the area based on market data and multiply this times the estimated square footage of the projects footprint. This process is fine and appropriate where the majority of property to be acquired is vacant land with no development potential. However, for light rail projects in developed areas, where people live, work, and enjoy their free time, this method may prove problematic for income-producing properties.

The owners of these income-producing properties will typically demand payment of their anticipated lost business revenues or profits, making negotiations contentious and lengthy. It is a best practice to begin the acquisition process with these potentially problematic acquisitions, thus allowing the agency a better opportunity to gather information and develop creative solutions to minimize the acquisition costs. When the issue is paying business losses, government is resistant because of the highly speculative nature of business profits; thus the issue is more likely to be resolved with a condemnation judgment.

Moreover, the cost of litigating condemnation proceedings themselves can be substantial. For the government, the situation is further complicated by the fact that many state condemnation statutes award the citizen their attorney fees and costs if the fair market value determined in the condemnation suit is higher than the government's highest offer, even if it is by only $1.00, or if the government's offer shows a lack of good faith (*1*). Therefore, it is important to understand when business losses are a proper basis for providing "just compensation."

This paper will look at acquisitions involving parking lots and billboards that took place as part of the Interstate MAX Light Rail Project in Portland, Oregon, as examples of dealing with these problematic acquisitions. We will begin with a brief overview of the Interstate MAX Light Rail Project and a description of the acquisitions. Next, we will look at the current state of the law respecting the acquisition of income-producing properties, particularly billboards and parking lots. This paper does not look at these properties as "special use" or "unique" properties, which is a different legal analysis. Finally, I will describe Tri-County Metropolitan's (TriMet's) acquisition process and discuss ways to minimize the impacts of the income approach to value for both parking lots and billboards.

INTERSTATE MAX LIGHT RAIL PROJECT

The Interstate MAX Light Rail Project is a 5.8-mi alignment going north and begins at the home of the Portland Trail Blazers, the Rose Garden, which is also adjacent to two other major event venues: the Portland Convention Center and the Memorial Coliseum. The alignment terminates at the Portland Exposition Center, which is frequented annually by more than 500,000 visitors for trade shows and other events.

It was a compromise project following the 1998 defeat of a bond measure proposed to fund a larger 25-mi project alignment. The scaled-down project was conceived and approved by the community within one year after defeat of the bond measure. Construction began in early 2001. It was financed in part with tax-increment financing generated by the creation of an urban renewal zone and federal funds under the Federal Transit Administration's New Starts Program.

The project runs along Interstate Avenue, which was the interstate connection between Oregon and Washington prior to the construction of Interstate 5. The new alignment connects with the existing system near the Rose Garden. Interstate Avenue is primarily a business area, industrial at the southern portion; and more retail in the center with single family units squeezed in between the major cross streets.

The area, one of the most diverse in the metropolitan area, has the highest concentration of African-Americans in the metropolitan area. Historically the city's record of having projects displace that population has not been good. TriMet and the City of Portland, recognizing the communities' sensitivities on the issue, made the commitment that there would be no displacements as a result of the project. Therefore, TriMet, instead of approving a condemnation resolution covering the entire project area, authorized condemnations for only particular properties where negotiations with the property owner were not progressing sufficiently to meet the project's accelerated schedule.

The design of the alignment required moving the curb line back in order to accommodate on-street parking, bicycle lanes, through traffic lanes, turning lanes, and the trackway. It also required widening the sidewalks in station areas to a pedestrian friendly 10 ft from the original average width of 6 ft. Such adjustments required obtaining "slivers" of property measuring between 2 and 11 ft in width along much of the alignment. These adjustments were also necessary to provide for truck turning movements and to accommodate safe pedestrian space at street intersections. Few structures were impacted by the acquisitions; the corner of one building was severed and rebuilt, but most often the project only required moving the back of sidewalks closer to the buildings. The construction did, however, require the acquisition of property upon which billboards were located. A paid parking lot was also impacted. The parking lot and billboards were two of our most problematic acquisitions.

The parking lot is located at the project's northern terminus, the Expo Center, which is owned by the Metro Regional Government (Metro). The acquisition consisted of acquiring fee title to over 100,000 ft^2 for a station platform, which eliminated between 110 and 212 parking spaces; the exact number of spaces was a hotly contested issue in the negotiations. The project also required the creation of a 300 space park and ride lot immediately adjacent to the station platform. Despite TriMet's efforts to acquire fee title to this area, Metro would only grant a long-term easement or lease. Because Metro is a government entity, TriMet has limited condemnation authority over them (*2, 3*).

Three separate billboard locations were substantially impacted by the project. The City of Portland has an ordinance that restricts the erection of new billboards within the city limits (*4*). The ordinance does not apply to billboards erected prior to a certain date; these billboards are "grandfathered," so long as they are not changed or modified (*5*). Only one of the billboards was impacted by the project in such a way that its existence was threatened.

In the case of these particular acquisitions, the values of these properties to their owners were alleged to be their income-producing ability, which raised the issue of compensating property owners for business losses—something that is generally not recoverable in condemnation. Nevertheless, the U.S. Constitution requires that these property owners be compensated for the value of what they lose. For parking lot and billboard acquisitions, the real question is what are the property owners losing? A look at the current legal background for these acquisitions gives us some guidance on this issue.

Just Compensation and Lost Business Revenue

The Fifth Amendment to the U. S. Constitution grants the government the right to take private property. Specifically, it requires that private property not be taken for public purposes, *except* upon payment of just compensation. Just compensation is normally interpreted to mean the "fair market value" or "market value" for the property taken (*6*). Jurisdictions differ as to the precise definition of either term (they are generally interchangeable), but the essence of the various definitions is the value that knowledgeable sellers and buyers would attribute to the property. The *Uniform Standards of Professional Appraisal Practice* (USPAP) states it this way:

> The most probable price which a property should bring in a competitive and open market under all conditions requisite to a fair sale, the buyer and seller each acting prudently and knowledgeable, and assuming the price is not affected by undue stimulus. (*7*)

The notion of just compensation, simply put, is to reimburse the owner for the property interest taken by the government, and to place them in as good a position as they had been prior to the taking (*8, 9*).

Fair market value is usually based on the property's "highest and best use." Highest and best use refers to the use of the property that will most likely produce "the highest market value, greatest financial return, or the most profit" (*10*). The highest and best use determination requires considering whether a reasonable probability exists that in the near future the property would be put to that use and the effect the prospective use will have on the market value at the time of the taking. Fair market value is generally based on the value attributable to the property itself, not the business conducted on the property (*11*). Whatever the highest and best use, there are various appraisal methods used to determine fair market value.

There are three principal methods used to determine the fair market value of property taken by eminent domain: 1) "market data approach," 2) "income approach," and 3) "cost approach" (*12*). The market data approach is the most popular. This method is based on an analysis of comparable sales in the area. The cost approach looks at the replacement or reproduction cost to acquire the land and build a structure similar to the one at issue, with an appropriate reduction given for any depreciation. Our focus is the income approach, which establishes fair market value based on capitalized net income.

Jurisdictions differ on the proper use of one method over the others, but the consensus suggests that all are relevant so long as sufficient evidence supports their usage (*13*). Unique factual circumstances typically determine which approach is more appropriate than another, but a jury ultimately makes the determination if the parties fail to agree (*14*). However, the use of the income approach is a relevant basis for valuation only when the property at issue generates revenue, particularly rental revenue. This is an important distinction between *rental revenue* and *business profits* generated from the business conducted on the property. In condemnation proceedings, the former is compensable, the latter is not.

In Oregon, as in most jurisdictions, the general rule is that evidence of profit derived from a business conducted on property "is too speculative, uncertain and remote" to be considered as a basis for determining fair market value in condemnation proceedings (*15*, *16*). One exception to this rule, however, is when the earnings depend chiefly upon the "location, soil, or character of the property itself." In that case, the rental value of commercial property can be considered "profit derived from the land itself" and, therefore, admissible as determinant of value in conjunction with the income approach (*17–19*).

To the extent that a taking eliminates rental income produced by income-producing parking lots or billboards, the owners of these properties will likely seek to recover their business losses as part of the fair market value determination. We now turn to a brief review of case law on this issue.

Paid Parking Lots

Parking in major metropolitan areas is a thriving industry. With the limitations on surface parking in many areas (*20*), and regular increases in the number of cars on the road, parking can be a major source of revenue for parking lot owners and other businesses that incorporate paid parking into their business model. In the City of Portland alone, with a population of just over 500,000, the average monthly parking fee in the downtown area is around $145.00. Daily parking fees average in the area of $10.00 per day. For special events, parking rates can surge as high as $15.00 at parking lots in the area of the Rose Garden, home of the Portland Trail Blazers professional basketball team. More importantly, the cost of operating these parking facilities is nominal given the limited labor and maintenance costs involved. Historically the demand for parking does not decrease, even with increased investments in transportation infrastructure. When condemning this type of property, the government should anticipate a claim that the business or a portion thereof has been taken. The question is whether that is an appropriate basis to determine fair market value given the particular facts of the acquisition.

Cases in jurisdictions across the United States have found such evidence at least relevant to market value, if not determinative (*21*). One court has held that there must be an exception to the general rule against admitting evidence of business profits to show the value of land in the situation "where the business is inextricably related to and connected with the land where it is located, so that an appropriation of the land means an appropriation of the business" (*22*). One clear reason for this conclusion is that, for income-producing property like paid parking lots, the prospective earning power is evidenced by past earnings, which would be a foremost factor between a buyer and seller (*23*, *24*). One of the earliest cases addressing this exception in valuing parking lots is *Trenton v. Lenzer* (*25*).

Lenzer arose when the City of Trenton adopted an ordinance creating a parking authority to determine the feasibility of creating off-street parking facilities to address the City's parking problems. As part of the process, it identified a private parking lot for condemnation to create a public parking lot. The lot owner argued that the acquisition was not only a taking of real property, but in effect the taking of their "parking yard business." Acknowledging that when land acquisitions result in the loss of the owner's business located thereon, an owner of property is *not* entitled to compensation for the value of the business, the New Jersey Supreme Court explained that the fair market value is, nevertheless, measured by the price which a hypothetical seller and buyer would agree. Although the compensation for the parking lot was not an issue for the court, the court writes,

> The property being taken under the terms of R.S. 40:60—25.1, N.J.S.A., is land which has been operated profitably by the appellants for many years as a parking lot. Its fair market value . . . would be fixed after due weighing of all the factors which customarily enter into [a willing seller and buyer's] purchase and sale negotiations. A foremost factor in the sale of the parking lot would be its prospective earning power evidenced in considerable part by past earnings.

The Supreme Court of Missouri considered the issue a few years later in *Municipal Court Facilities v. Kordes* and provided a more forceful statement in favor of considering business losses (*26*). There they stated the issue very succinctly:

> Are business profits derived from land used as a parking lot and operated by the owner of the land properly capitalized to determine fair market value even though such land can be used for other purposes and in spite of comparable rules of land in the area?

In *Kordes* the properties at issue were being used as surface parking lots, and were being condemned to build a new courthouse. At trial, a jury awarded $651,000.00 for a 38,000 ft^2 parcel and $256,000.00 for a 15,840 ft^2 parcel (*27*). The lot owner submitted and the trial court allowed the valuation evidence based on capitalized income from parking fees, over the objection of the government. On appeal, the government argued that the trial court erred in permitting the property owner to use "capitalized business profits" as evidence of fair market value, citing the speculative and conjectural nature of business profits. Affirming the trial court's judgment, the Missouri Supreme Court held that "the operation of the public parking lot was *related to and connected with* the land such that appropriation of the entire property appropriated the business," and therefore the trial court properly admitted the evidence (citations omitted, emphasis added). The issue was raised again in *Land Clearance Redevelopment Authority v. Kansas University and Endowment Association* (*28*).

In *Land Clearance Redevelopment*, the government appealed a $2,000,000.00 award for condemnation of a multi-story parking garage containing 325 spaces and consisting of 15,620 ft^2. At the time of the taking, the lessee, who had 40 years left on a 99-year lease, stood in the shoes of the owner. At trial the government's valuation based on comparable sales reflected a value of $1,000,000.00. The garage operator's evidence reflected a value as high as $2,775,000.00 based on income figures from the previous fifteen years, projected out for the remaining 40 years of the lease.

The court considered the issue of whether clear and reliable evidence of future profit of the lot owner is admissible if there is evidence of comparable land sales. Finding in the affirmative, they write:

> Any reasonably sophisticated buyer would have looked at PSI's use and business profits in capitalizing or researching a present value to put on the land in the form of an offer to purchasers. Here there was a taking of the whole property and with it the whole business which was interrelated with the property of operating a private downtown parking garage, the highest and best.

These cases provide compelling precedent and support for the use of the income approach when determining fair market value of paid parking lots.

Billboards

The outdoor advertising sign industry, commonly called billboards, has had difficult times since the 1950s and 1960s when they were seen as a nuisance and an eyesore on the burgeoning national highway system. So much so that the Federal Highway Beautification Act was passed at the insistence of then-First Lady Lady Bird Johnson, wife of former President Lyndon B. Johnson (*29*).

Billboards remain under fire in cities throughout the United States. Because of the restrictions on the erection of new billboards in the City of Portland, all the billboard locations in the Portland area are prized possessions, and the major sign owners are very protective of their franchise.

Billboards can pose a real threat to a project real property budget if they are substantially impacted by construction. Billboard locations have been called "unique"(*30*). Unlike buildings which may be reshaped to fit new boundary lines, this may not always be the case with a billboard. Negative attitudes towards billboards have made it difficult to relocate them when public works projects require their removal: "[I]nvoluntary termination of a nonconforming 'grandfathered' status by government compulsion has given rise to a compensable taking of private property" (*31*). Because billboards are in the business of leasing space for advertising, they are often valued in condemnation cases based on an income approach, as opposed to being valued as personalty. So the debate is typically whether to value the structures at their replacement cost, or based on their revenue.

The Uniform Relocation Assistance and Real Property Acquisition Act (Uniform Act, *32*) requires that any acquisition by a federal agency acquire an equal interest in "all buildings, structure or other improvements" located on the real property (*33*). Just compensation for that part of the acquisition must treat the building, structure, or other improvement as part of the real property (*34*). The problem is this, if billboards are anything other than personal property—which is what most states assert—then, under the Uniform Act, the owner or tenant must be compensated (*35*).

The Uniform Act gives a sign owner the option as a "displaced person" to either receive relocation benefits, or seek compensation for acquisition of the sign. The problem is that in some situations relocation, whether on the same parcel or within the same general area may not be an option, thus forcing the condemning authority to pay fair market value for the signs.

Like in the City of Portland, many local jurisdictions have outlawed or have placed serious restrictions on the erection of new billboards, making those that remain nonconforming uses of the property, permitted to remain so long as the use does not change. While many of these ordinances have survived First Amendment challenges, and are considered valid, content-neutral aesthetic and safety restrictions on speech, this does not mean the government has no obligation to compensate sign owners under the Fifth Amendment when a light rail project necessitates their removal (*36*, *37*). Several jurisdictions have looked at this issue and resolved that, when a billboard cannot be relocated, the sign owner is entitled to fair market value of the sign. From the government's perspective, compensation to the sign owner should be limited to the replacement cost of the structure. The Uniform Act, however, arguably eliminates that option. The case of *State of Washington v. Obie Outdoor Advertising, Inc*. considered the issue (*38*).

State of Washington v. Obie Outdoor Advertising, Inc. considered whether a sign owner was entitled to just compensation for their billboard beyond the mere value of the sign structure when the ability to relocate the sign was an issue. The case arose when the State of Washington brought an eminent domain action to acquire the advertising company's leasehold interest in a parcel of land that contained two billboards. At trial, the state only presented evidence of the billboard structures' value. The advertiser provided valuation evidence based on rental income from the billboard. They further presented evidence that state law prevented the relocation of the sign. The Washington Court of Appeals rejected the state's argument that the only relevant evidence was reproduction costs. They write,

> [In the cases cited by the state] [i]t was held that to capitalize the income over the unexpired term of the ground lease would amount to a windfall to the sign company, since the sign company would in all probability relocate the sign. That rationale is not applicable to this case.

Accordingly, they found that the trial court properly granted a new trial because the instructions eliminated the jury's consideration of the advertiser's income-approach evidence. A Florida court found a similar result.

A Florida Court of Appeals found it erroneous to limit the valuation of a billboard to replacement cost (*39*). In *National Advertising,* the sign owner held a leasehold interest in property being condemned by the State Department of Transportation (DOT) on which it erected a billboard. At trial, the state DOT submitted evidence of replacement value for the billboard at \$38,400.00. The state's appraiser acknowledged in his testimony that the sign could not be relocated anywhere in the county because of the county sign ordinances. The sign owner's appraiser testified that he valued the leasehold as improved by the billboard. He explained that the market approach for valuing billboards was known as the "gross income multiplier" method, which is a form of income approach. Applying this process and noting the lease term was extendable through 2006, the appraiser found a value of $81,000.

The trial court entered judgment solely for the value of the billboard structures. On appeal the Florida Court of Appeals held that, because the state DOT relied solely on replacement value of the billboard, it failed to meet its burden of producing evidence that it had provided full compensation for the value of the leasehold and reversed the trial court (*40*). Thus it is important to distinguish the value of the sign from the value of the leasehold, which generates income (*41*).

Given the distinction between compensation for the structures as opposed to compensation for the "leasehold" interest in the real property, there is a compelling argument for valuing billboards on the income approach. However, as shown, the application of the income approach has one important limitation: if the billboard can be relocated, "fair market value" is not the standard for compensation and the income approach becomes a nonissue.

Regardless of whether a billboard is considered personal property or a fixture, the underlying leasehold right is the property interest at issue in a condemnation suit (*42, 43*). The importance of the issue is seen by the range of values that may present themselves. For example, one court had the range for the fair market value for a billboard between $5,200.00 and $115,740.00 (*44*).

Income Approach Problem

Given the weight of authority supporting use of the income approach to valuing parking lots and billboards in appropriate cases, it is important to take steps at an early stage in the project to minimize that likelihood of its use and its impact. In both our cases, our problem was solved in large measure through intergovernmental cooperation.

Paid Parking Lots

TriMet resolved our acquisition of the parking lot through negotiations with Metro without resort to any formal dispute resolution process. Through negotiations and discussions that lasted over two years, the parties were able to minimize the impact of the appraiser's analysis under the income approach—which we acknowledged had some bearing on the issue. In a memorandum of understanding, TriMet and Metro agreed to perform a joint appraisal, although TriMet secured a separate appraisal as required by FTA regulations because of the high cost of the acquisition. The appraisers were given assumptions that to which the parties had agreed. First, the parties agreed to develop the "annual gross revenue" figure based solely on the number of days on which the Expo Center parking lot was filled to "capacity." Second, the parties agreed to give no consideration or adjustment for "churning," the word used to describe the process of selling a parking space several times during the day. These limiting factors resulted in the appraisal only determining the value of the fee based on the income approach; the park and ride value was ultimately based on the market approach.

The Expo Center acquisition was one of the first acquisition processes to begin and one of the last to be completed. Although the two-year negotiation period was unusually long, it did not substantially interfere with the project schedule because Metro granted TriMet construction easements and permits, which allowed the work on the property to proceed pending resolution of the compensation issue. If the acquisition activities for this parcel had begun later or took much longer, there would no doubt have been substantial delays to the project, especially if the construction easements and permits were not granted.

Billboards

For the billboard, the agency settled the matter after filing a condemnation suit. The crucial issue for the agency was whether the sign could in fact be relocated on the parcel. We were successful in ensuring the sign could be relocated on the site. The initial offer to the sign owner was for the replacement value of the structure given our understanding and expectation that the structures could be relocated on the same site. The sign owner argued that the structures could not be relocated on the site nor elsewhere in the area because of the city code. The project's resident engineers and project managers worked closely with the sign company providing them detailed drawings of this portion of the project. After a series of meetings and discussions that included TriMet, the sign owner and the City, the parties were able to confirm that the City would not apply its ordinance in such a way as to prevent the sign owner from rebuilding its billboard on site.

TriMet never saw any evidence of the signs annual net revenue. In this particular case, the sign owner was also the real property owner, thus there was no apparent term to cut off the damages. The expectation was that an income approach analysis of the sign could yield substantial damages. Lucky, the sign owner was more interested in maintaining the location than recovering a hefty condemnation judgment.

CONCLUSION

Problematic acquisitions, particularly those that involve income-producing property like parking lots and billboards, require more time to allow for creative problem-solving in order to minimize the possibility of paying property owners for their business losses. For parking lots it is important to start conversations early to help gather information that will help shrink the net revenue figure as much as possible. In the case of billboards, it is important to find ways to ensure the sign structure can be relocated. In both cases, our results turned on invaluable intergovernmental cooperation.

ACKNOWLEDGMENT

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NOTES

1. See e.g., ORS 35.346.
2. ORS 267.225.
3. *City of Keizer v. Lake Labish Water Control District,* --- P.3d ----, 2002 WL 31873575 (Or App Dec. 26, 2002), reinforces the fact that exercise of condemnation authority by a statutorily created agency like TriMet must be applied strictly in according with the statute. Id. at 4-5.
4. See City of Portland Code Title 32 (2003) generally, Portland City Code § 32.32.020 in particular.
5. Portland City Code § 32.36.020 (2003).
6. See *United States v. Miller,* 317 US 369, 374, 63 S Ct 276 (1942) (explaining that the more concise way to think of the concept is “market value fairly determined”).
7. *Uniform Standards of Professional Appraisal Practice,* The Appraisal Foundation (2003*),* glossary reference.
8. *San Diego Transit Development Board v. Cushman*, 53 Cal App 4th 918, 925, 62 Cal Rptr 2d 121 (CA App Dist 1997).
9. *New Jersey Transit Corporation v. Cat In the Hat, LLC,* 803 A2d 114 (New Jersey 2002) (explaining that the goal in condemnation cases is determining fair market value so the government can make citizens whole).
10. *Commission of Transportation v. Towpath Associates,* 767 A2d 1169, 1177 (Conn 2001); Uniform Appraisal Standards for Federal Land Acquisitions (Fifth Edition 2000), p. 17.
11. See *Kimball Laundry Co. v. United States,* 338 US 1, 5, 69 S Ct 1434 (1949).
12. See *State v. 3M National Advertising Company, Inc.,* 653 A2d 1092, 1094 (NH 1995).
13. See *Denver Urban Renewal Authority v. Berglund–Cherne Company,* 568 P2d 478, 481 (Colo 1977) (explaining that appraisers utilize all three approaches to test the validity of their conclusion as to the fair value of property to be condemned).
14. See also Cat In The Hat, supra at 121 (explaining that it is proper to consider all factors affecting value that willing buyers and sellers would consider).
15. See *State v. Cerruti,* 188 Or 103, 107, 214 P2d 346 (Or 1950).
16. *Board of Public Building v. GMT Corporation,* 580 SE 2d 519, 525 (Mo 1979).
17. *Denver Urban Renewal Agency v. Berglund–Cherne Company*, 193 Colo 562, 567, 568 P2d 478 (Colo 1977) (Citations omitted.).
18. *Land Clearance Authority v. Kansas University And Endowment,* 796 SW 2d 495, 499 (quoting that the capitalization of income method is utilized to value income-producing property when there is a complete taking).
19. *State By and Through State Highway Commission v. Nunes*, 233 Or. 547, 379 P.2d 579 (1963).
20. For example, Portland City Code §33.450.300 prohibits surface parking lots on the portion of a site within 500 ft of a light rail alignment to encourage transit use.
21. *City of Cincinnati v. Banks*, 757 NE 2d 1205, 1215 (Ohio App 1 Dist 2001).
22. *Land Clearance Development Authority v. Kansas University And Endowment Association,* 797 SW 2d 495, 498 (Mo App WD 1990).
23. *City of Trenton v. Lenzer*, 109 A 2d 409, 416 (N.J 1954).
24. *State v. Cerruti,* 188 Or 103, 108, 214 P 2d 346, 349 (Or 1950) (“The profits derived from the use of the property itself may be shown, whenever such profits would be an indication of value”).
25. *Trenton v. Lenzer,* 109 A 2d 409 (NJ 1954).

26. *Municipal Court Facilities v. Kordes*, 43 SW 2d 124 (Mo. 1968).
27. The second parcel was shown to have an annual income of $20,000.00.
28. *Land Clearance Redevelopment Authority v. Kansas University And Endowment Association*, 797 SW 2d 495 (Mo App WD 1990).
29. Sackman, J., V.B. Russel, P. Rohan, M. Reskin, T.P. Brigham, and G. Kanner *Nichols on Eminent Domain §23.03 (Mathew Bender & Co. Inc. 1999).*
30. See *City of Scottsdale v. Eller Outdoor Advertising Company of Arizona, Inc.,* 579 P2d 590, 597. The Eller court has noted that billboard locations as opposed to billboards are unique. They write depending upon the viewable distance in either direction, the amount of traffic passing the location, and the type of viewing public, a location of a particular billboard may have a value over and above its nuts and bolts value. In this sense, in the billboard industry, it is virtually impossible to separate location from structure. Id.
31. *National Advertising Company v. State of Florida*, 611 So 2d 566, 570 (Fla App 1 Dist 1992).
32. This paper will not take a comprehensive look at payment obligations under the Uniform Act.
33. 42 USC § 4652(a).
34. 42 USC § 4652 (b)(i).
35. See *also Lamar Corporation v. State Hwy. Commission* 684 So 2d 601, 604 (Florida 1996) ("The sign is clearly a structure under any ordinary meaning of that term").
36. See *Outdoor Systems, Inc. v. City of Mesa,* 997 F2d 604, 610 (9th Cir 1993) (explaining the analytical framework for anti-billboard ordinances).
37. *Red Roof Inns, Inc. v. City of Ridgeland*, 797 So. 2d 898, 900 (Miss 2001) (explaining that a zoning ordinance requiring removal of nonconforming billboards is a proper exercise of police power and does not constitute unconstitutional taking requiring payment of compensation.
38. *State of Washington v. Obie Outdoor Advertising, Inc.,* 516 P2d 233 (WA App 1973).
39. *National Advertising Company v. State of Florida*, 611 So 2d 566 (Fla App 1 Dist 1992).
40. The court noted that the sign owner sought a variance to relocate the sign on the remaining property, but was denied, thus losing the grandfathered status, and the sign was ultimately removed.
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Federal Davis-Bacon Prevailing Wage Law and Light Rail Construction

Streamlining Implementation and Playing by the Rules

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Throughout its history in light rail construction, TriMet has strived to streamline and simplify the application of complex prevailing wage requirements that tend to intimidate contractors. The agency's goals have included fairly interpreting prevailing wage laws and regulations and applying practical methods to disseminate understandable information, so that all stakeholders can comprehend these requirements, thereby making compliance and enforcement easier through hands-on resources and techniques.

Implementing practical instructions for stakeholders to understand and comply with the Davis-Bacon Act is achieved by building and sharing knowledge from national, regional, district and local sources, as well as from prior experience. This information can then be developed and packaged in a manner that will be most useful to various stakeholders, keeping them in compliance and on track.

Every light rail project presents unique situations and problems related to federal prevailing wage requirements. Resolution of such issues can provide important lessons learned on future projects. Through understanding the parameters of the Davis-Bacon Act, issues of contractor compliance and agency enforcement will be dealt with in an expedient and decisive manner. Applying methods that enable understanding the complexities of prevailing wage requirements is an opportunity for establishing continuing partnering techniques. Contractors learning the process today can grow to be mentors of subcontractors tomorrow.

FEDERAL PREVAILING WAGE HISTORY

Whatever you may think of prevailing wage law, it remains the current law that affects all publicly funded on-site light rail construction labor. This law affects thousands of men and women employed in construction of light rail projects each year. Keeping informed is essential. Because there are gray areas in the law that are subject to interpretation, compliance is sometimes difficult, and it pays to keep educated and abreast of procedures, trends, and changes. The contracting agency and contractors alike need to be aware of precedents, and how rulings and interpretations of the applicable laws may affect them on current and future light rail projects.

Davis-Bacon Act

Enacted in 1931, the Davis-Bacon Act (DBA), 40 U.S.C. § 276a, is named for its sponsors, Senator James Davis and Representative Robert Bacon (*1*). The law was enacted as a result of the Depression and the fear that labor surpluses could allow contractors from outside communities to bring in low-wage labor and underbid local wage levels to win competitively-bid federal construction projects away from local firms. Because award was based on the lowest responsible bid, competition focused on wages and had the effect of depressing them.

The DBA applies to contracts in excess of $2,000, to which the United States or the District of Columbia is a party, for construction, alteration, or repair, including painting and decorating, of public buildings or public works. It also applies to federally funded and federally assisted construction projects, in which a public agency other than the federal government (or the District of Columbia) is a party to the construction contract.

TriMet has traditionally received federal funds, in the form of grants, for its light rail construction projects. As a result of this federal funding, TriMet's light rail construction projects are generally governed by the DBA, and therefore subject to DBA prevailing wage requirements. (*2*).

Copeland "Anti-Kickback" Act

The Copeland "Anti-Kickback Act," 18 U.S.C.§ 874, was originally enacted in 1934 and amended in 1948. This Act makes it a Federal crime to "induce . . . any person employed in the construction, prosecution, completion or repair of any public building, public work, or building or work financed in whole or in part by loans or grants from the United States, to give up any part of the compensation to which he is entitled under his contract of employment."

The Department of Labor's regulations implementing the Copeland Act require every employer (contractor or subcontractor) on a covered project to submit weekly, certified payroll reports (CPR) to the contracting agency. Through review of CPRs, the contracting agency is able to monitor contractor and subcontractor compliance with prevailing wage requirements.

Federal and State Prevailing Wage Requirements

The general requirement of the DBA is that contractors and subcontractors on covered projects must pay workers employed directly upon the site of work not less than the locally prevailing wages and fringe benefits paid on projects of a similar character. The Secretary of Labor determines what rates are locally prevailing in the community and publishes the rates for public contracts governed by the DBA in periodically issued "wage determinations."

Many states have adopted "Little Davis-Bacon Acts," which are generally modeled after DBA, and require payment of prevailing wages on state-funded construction projects. A majority of states have these laws. Coverage, provisions, and implementation may differ from the DBA, and from one state to another. For example, the Oregon "Little Davis-Bacon Act," ORS 279.348 *et seq.*, applies to publicly funded projects of $25,000 or more, compared with the Federal Davis-Bacon threshold of $2,000.

LIGHT RAIL CONSTRUCTION AND PREVAILING WAGE

Throughout its history in light rail construction, TriMet has strived to streamline and simplify the application of complex prevailing wage requirements that tend to intimidate contractors. The sheer number and variety of subcontractors on a light rail construction project makes this a critical feature of the project in its entirety. Failure to comply with federal regulations, such as prevailing wage, may jeopardize the budget and opening date of a light rail endeavor. TriMet believes this risk can be avoided through planning, clear understanding, training, mentoring, and partnering with contractors, and enforcement of the applicable regulations. In addition, understanding the DBA is critical to contractors because the act may increase project and contractor costs.

Multiple layers of laws, rules, regulations, and requirements govern federally funded or federally assisted light rail construction. The DBA and its implementing regulations set forth the federal prevailing wage laws which have been and will continue to play a key role in all federally funded light rail transit projects. Federally funded light rail construction infuses the community with an enormous amount of construction jobs and dollars that positively impact the local economy. Prevailing wage evens the playing field in bidding for contracts, ideally reflects local wages for experienced workers, and provides a training ground for apprentice workers. Large contractors have the opportunity to hone their expertise in dealing with prevailing wage issues. Small contractors have a unique opportunity to participate in building large public works projects, such as LRT. The experience they gain from participating in one federally funded or federally assisted construction project may benefit them on future projects, and enable them to grow their businesses so that they can continue to participate in rail expansion projects.

Some of TriMet's goals relating to prevailing wage requirements have been the following:

1. To embrace the benefits of federal prevailing wage in light rail transit construction by:
   - Leveling the playing field for contractors to bid public works projects, and
   - Conveying to participants that payment of prevailing wage is *mandated by law*, while helping them to understand the complexities of compliance, including the need to consider the impact to their bottom line in accurately bidding a project (sometimes learned through experience and correcting past mistakes).
2. To fairly interpret complex laws and regulations by:
   - Spotting and resolving issues with the aid of contemporaneous contractor documentation (for example, reviewing trucker logs and truck tickets to monitor prevailing wage paid to truckers for on-site work in excess of the de minimis threshold); and
   - Avoiding getting bogged down in uncertainty, and finding an accurate decision path for tough issues.
3. To apply practical methods and disseminate understandable information, so that all stakeholders can comprehend prevailing wage requirements, thereby making compliance and enforcement easier through hands-on resources and techniques (such as printed guidelines, checklists and other resources). See Table 1.

TABLE 1 Standard Resources for Prevailing Wage—TriMet

Document	Description	Used By
Process Chart	Flow chart of procedures	Contracting Agency, Contractor
Davis-Bacon Information Guidelines	Single topic procedure guidelines or general information	Contractor/Subcontractor
Davis-Bacon Contractor Checklist and Reference	General guidelines for contractors—a reference sheet	Contractors, subcontractors
Labor Compliance Manual	Contract document on labor requirements	Contractors, subcontractors
Wage Determination	Specific wage determination for a contract	Contracting Agency, Contractor, subcontractors
Sample Certified Payroll Form	WH-347—US Dept. of Labor (DOL) form and Statement of Compliance	Contractors, subcontractors
Project Rate Sheet	Single sheet of trades and rates used on a project—as described by DOL – HUD "Making Bacon"	Contracting Agency, Contractor, Subcontractor [does not replace full wage determination]
Federal Poster	Resource on Davis-Bacon posted on site with wage rates	Employees of all contractors/subcontractors
Trucking Log Form	Resource to document on site activity more accurately	Trucking employees of all contractors/subcontractors who perform work on site

Using a Prevailing Wage Information Base

TriMet has assembled a base of information concerning prevailing wage by building knowledge from national, regional, and local sources. In the information age, a contracting agency such as TriMet has many resources that it can use to keep current and refine its internal processes for monitoring prevailing wage compliance by contractors and subcontractors. TriMet's objective is to disseminate this information to project participants in a streamlined, straightforward manner.

Examples of sources for readily available information include:

- U.S. Department of Labor (DOL) (*1*, *3*–*6*);
- U.S. Department of Housing and Urban Development (HUD) (*7*);
- Local DOL representative; and
- Periodically scheduled DOL conferences addressing DBA and prevailing wage.

Compliance Training—Streamlining and Removing Barriers

Training and dissemination of information regarding prevailing wage requirements begins in the contract document itself, with accurate prevailing wage language and wage rates, and continues throughout the course of the light rail project. Figure 1 illustrates the types of contracting methods and variations in application of DBA.

By compiling relevant, practical data that can be easily understood and passed on, the agency's oversight role is more easily accomplished. TriMet's goal is to develop and package the information in a manner that will be most useful to various stakeholders, keeping them in compliance and on track.

The importance of communicating accurate data cannot be stressed enough. TriMet views training as a mentoring opportunity, in which the agency educates contractors, so they, in turn, can train their subcontractors. The preconstruction meeting offers a great first opportunity for contractors and subcontractors to obtain a package of relevant "how-to" prevailing wage data from the contracting agency.

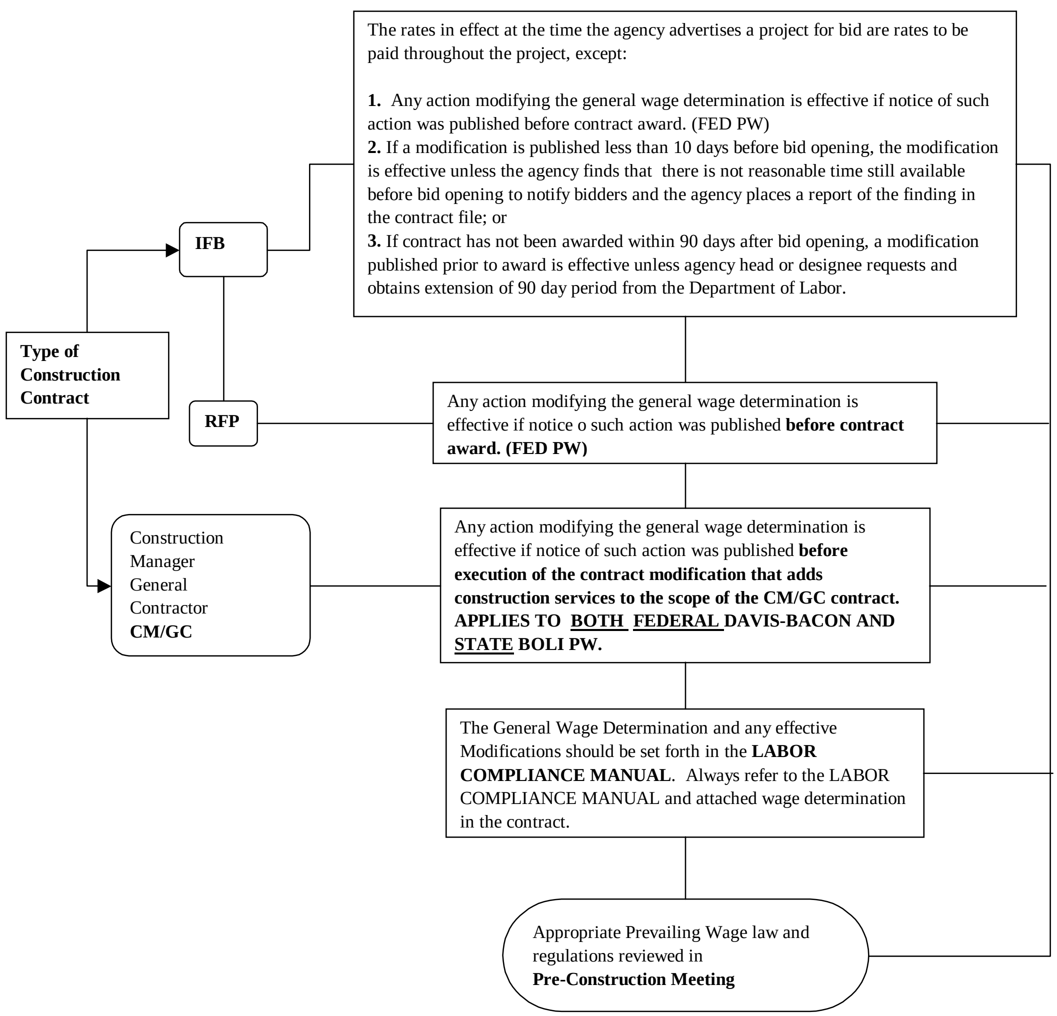

FIGURE 1 Prevailing wage requirements—type of contract.

TriMet has developed a package of resource tools for distribution at the pre-construction meeting, including the following:

- Labor Compliance Manual (specific to each contract);
- Wage Determination (specific to each contract);
- Federal poster;
- Sample Certified Payroll Form (WH-347);
- Statement of Compliance—Certification;
- DBA Information Guideline on Completing a Payroll;
- Contractor's Checklist and Common Errors; and
- Truck Log Ticket Sample Form.

See Table 1 for a description of each item.

TriMet has found that when contract-specific documents, such as the wage determination, are combined with resource materials such as these, they serve as a useful aid and continuing resource for the contractor and subcontractors involved. This package also provides key contacts for responding to questions as they come up during the course of construction.

Completing the Certified Payroll Report

Contractors and subcontractors may view completion of the CPRs as a daunting exercise, but with guidance from the contracting agency, the process can be streamlined and simplified.

The public agency can assist contractors by providing detailed instructions on how to complete a CPR. Such instructions can be particularly helpful for emerging businesses or contractors that have limited or no prior experience with prevailing wage projects. The necessary information is readily available through the DOL (*7*).

Subcontractors are instructed to send all weekly CPRs to the prime contractor, who then forwards the documentation to TriMet's project manager and contracts compliance specialist for detailed review. When corrections or clarifications are needed, the contracts compliance specialist advises the project manager, who then informs the prime contractor. It is the prime contractor's responsibility to take action to resolve prevailing wage issues at the subcontractor level. TriMet's process keeps all necessary parties involved and informed. The process is illustrated in Figure 2.

Certified Payroll Compliance Can Affect the Contractor's Bottom Line

Certified payroll information must coincide with the contract wage determination. The federal wage determination may contain many worker classifications and descriptions that vary between state, union, and type of construction. This can lead to confusion and frustration among contractors, particularly those with limited or no experience on public works projects.

A contractor's misunderstanding of CPR requirements can become a dollar issue. For example, contractors often employ workers to perform more than a single type of work on a project. In such a case, the worker is considered to have a "split classification." DBA permits the contractor to pay the worker the wage rates specified for each classification only if the contractor maintains accurate time records showing the amount of time spent in each

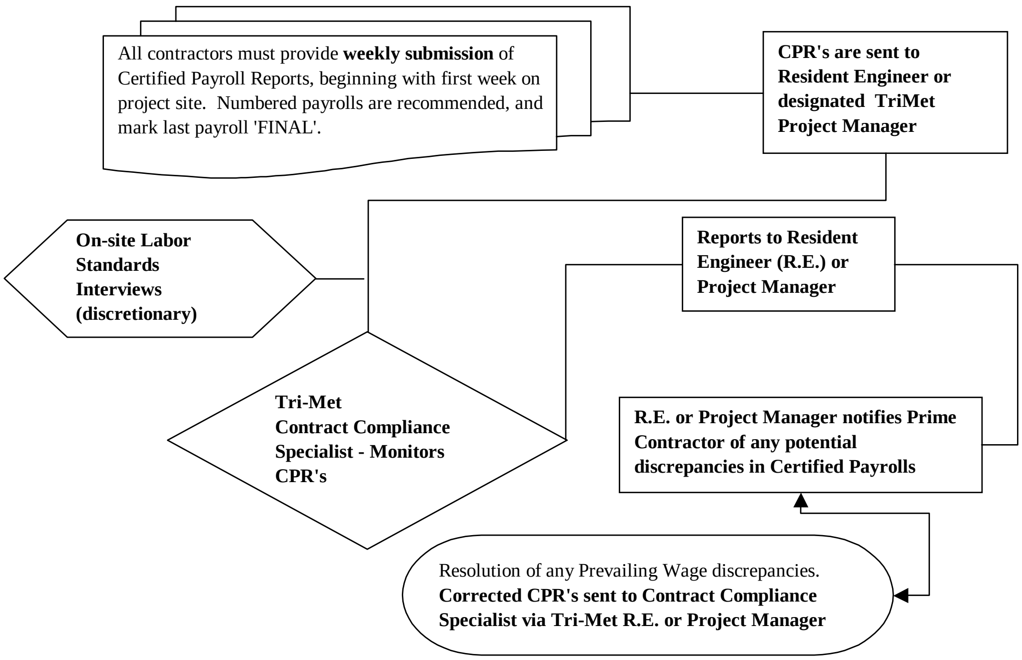

FIGURE 2 Certified payroll report monitoring process.

classification of work. If the contractor does not maintain such records, then the contractor is required to pay such employees the highest wage rate of all the classifications of work performed. As a result, it is to the contractor's benefit to keep accurate records and report all classifications of work performed on the CPR.

Skilled Workers—The Builders

Figures 3 through 6 depict a small variety of the worker classifications employed on TriMet's Interstate MAX light rail project. Workers in many other classifications participated and are participating in the construction of this light rail line, and the variety of work covers a vast array of skills.

COMPLIANCE WITH TOUGH ISSUES IN LIGHT RAIL CONSTRUCTION

Trucking

One of the most difficult prevailing wage issues that TriMet has encountered on the Interstate MAX light rail project is defining the circumstances under which truck drivers employed to haul dirt and other materials to and from the project are entitled to payment of prevailing wage.

No 0001

Prime Contractor
Official Trucking Ticket
Contract
Project Name

Name of 1st Tier Contractor
Address
City, State, Zip
Phone:
Fax:

Employee Time Ticket

Date

Odometer Start: _________

Company Name: ________________________
Truck Number: __________________________
Driver Name: ___________________________
Truck Type (Circle One): Solo / T&P / End Dump

Start Time: _____________________
End Time: ______________________
Total Time: _____________________
Downtime: ______________________

Odometer End: __________

Load Number	Crew Chief	Load Time: On Site, Time In	Load Time: On Site, Time Out	Load Time: Off Site	Hauled: To	Hauled: From	Prime Contractor Cost Code	Load Type

Driver Signature ____________________________

End of Day Inspection:

Foreman Signature _________________________

Yes ___ No ___

FIGURE 3 Sample truck log ticket.

FIGURE 4 Interstate MAX light rail construction workers—track work.

FIGURE 5 Interstate MAX light rail construction workers hoisting steel beam.

FIGURE 6 Interstate MAX light rail construction worker grinding string with profile grinder at Ruby Junction Maintenance Facility Expansion Project.

In December 2000, DOL published its "Final Rule" refining the definition of the term "construction" for DBA compliance purposes. [Final Rule concerning Labor Standards Provisions Applicable to Contracts Covering Federally Financed and Assisted Construction (65 Fed. Reg. 80268, Dec. 20, 2000)]. The Final Rule changed the regulatory definition of "construction" to provide that:

> the off-site transportation of materials, supplies, tools, etc., is not covered unless such transportation occurs between the construction work site and a dedicated facility located "adjacent or virtually adjacent" to the construction site. [65 Fed. Reg. at 80268.]

This language became critical on the Interstate MAX project, as discussed below.

On the Interstate MAX project, TriMet developed an overall contracting plan which broke the project into its major elements, identified overall objectives and critical factors for success, analyzed contracting options, and concluded with a recommended plan. As a result of the contracting plan, civil work for the Interstate Avenue alignment was broken down into two separate contracts, Line Section 10 A/B (LS 10 A/B) and Line Section 10 C (LS 10 C). The LS 10 A/B and LS 10 C contracts were awarded to two separate general contractors, and utilized two separate contracting methods: Construction Manager/General Contractor (CM/GC) and Design/Build.

LS 10 A/B extends from the south side of the Rose Garden to north of North Argyle Street, just south of the Columbia Slough. LS 10 C is generally located from Argyle Street to the Exposition Center near Marine Drive, and includes construction of a 4,000-ft span linking Kenton to Portland International Raceway.

As it turned out, both the LS 10 A/B CM/GC and the LS 10 C Design/Builder awarded excavation subcontracts to a single subcontractor. That subcontractor determined that it could save money on both subcontracts by hauling material required to be removed from LS 10 A/B, to LS 10 C, where fill was needed. The question arose whether the truck drivers employed by the subcontractor on LS 10 A/B were entitled to be paid prevailing wage when they were hauling material to LS 10 C. This inquiry involves the following difficult questions:

- Are LS 10 A/B and LS 10 C a single "site of work" for prevailing wage purposes, even though they are defined by two separate contracts?
- If they are not a single site of work, then is LS 10 A/B a "dedicated facility" located "adjacent or virtually adjacent" to LS 10 C, so that the off-site transportation of dirt from LS 10 A/B to LS 10 C is covered by prevailing wage requirements?

These are the kinds of questions that remain unresolved under the current state of the federal prevailing wage laws, and TriMet continues to grapple with them.

The other major issue involving truck drivers on the Interstate MAX project was capable of resolution. That issue involves the extent to which material delivery truck drivers are entitled to be compensated at prevailing wage rates for time spent waiting on site to be loaded or unloaded.

This issue is clarified in the Final Rule, which provides that material delivery truck drivers are not entitled to payment of prevailing wage for time spent off-site. DOL has chosen to use a "rule of reason," and "will not apply the Act's prevailing wage requirements with respect to the amount of time spent on-site, unless it is more than 'de minimis.'" [65 Fed. Reg. at 80276.] The Final Rule states:

> Pursuant to this policy, the Department does not assert coverage for material delivery truck drivers who come onto the site of the work for only a few minutes at a time merely to drop off construction materials. [65 Fed. Reg. at 80276.]

Applying advice received from our local DOL representatives, TriMet determined that prevailing wage would be paid to employee truck drivers who spent in excess of 20% of their workday or work week on the site of the work. We worked to verify the amount of hours spent on site by reviewing trucker logs and truck tickets, and performing labor interviews with truck drivers.

One of the greatest lessons learned is that the public agency should require its contractors and subcontractors who employ material delivery truck drivers to generate contemporaneous documentation. As the Interstate MAX project went forward, the general contractor on LS 10 A/B developed the "truck log" form, shown in Figure 3, that it required truck driver employees to complete while on the job. The truck log details when and for how long each employee truck driver was on site each day. Through accurate completion of this paperwork, compliance with prevailing wage requirements in this difficult area can be made substantially easier.

Which Wage Determination Applies?

As part of its responsibilities on a federally funded or federally assisted construction contract, the contracting agency is required to include in the construction contract the "wage determination" applicable to the work being performed. DOL issues wage determinations applicable to four basic categories of construction work: building, residential, highway, and heavy. In Oregon, the heavy and highway rates are usually combined into a single wage determination.

TriMet's light rail projects have traditionally included elements of heavy construction (civil construction work on the general alignment) as well as building construction (construction of substations and signal/communication buildings). Thus, the question often arises whether TriMet is required to include both the heavy/highway and the building wage determination in its contracts.

As a rule of thumb, it is not necessary to include both wage determinations if, for example, the building work is "incidental" to the heavy construction work. DOL generally considers anything less than 20% of the contract value to be "incidental." However, in determining what is incidental, DOL takes into account the size of the contract. Thus, building work that is 15% of a $1 million contract may be "incidental," while building work that is 15% of a $1 billion contract may be more than that. Where complexities arise, it is a good idea for the contracting agency to contact the DOL's Wage and Hour division for assistance in determining what wage determinations to include in the contract.

Are Acts Preparatory to Construction Covered by Prevailing Wage Requirements?

TriMet's contracts for light rail construction often require the contractor to perform tasks preparatory to construction, such as demolition and survey-related work. As a general rule, such work, with the exception of professional surveying, is subject to DBA prevailing wage requirements, so long as it will be followed by additional work that will result in the construction, alteration, or repair of a public building or public work at that site ([48 C.F.R. § 37.301).

Warranty Work

If a construction contract is covered by DBA, on-site warranty work required under the construction contract is likewise covered by DBA. This is important for project managers to keep in mind at the conclusion of a project.

GETTING CONTRACTORS INVOLVED

It is no secret that prevailing wage requirements do not hold high favor among various sectors of the contracting community. How can contractors become more comfortable with these requirements? The bottom line is: GET INVOLVED!

DOL's Wage and Hour Division determines regional prevailing wages through a survey process. The Wage and Hour Division administers the DBA and collects data from surveys on wages and fringe benefits. In the past, the General Accounting Office (GAO) has raised concerns that data from these surveys, in the form of wage determinations, may not accurately reflect wages for the local region. GAO has assessed the extent to which DOL is addressing weaknesses in its determination process (*8*).

In the March 31, 1997, issue of Engineering News Record, author William Krizan states, "it is hard to say whether labor costs on federally funded projects are higher than they should be, or lower." He summarizes the position of the Office of the Inspector General (OIG) as follows:

> The main problem with the survey process as a whole is the strictly voluntary nature of the submissions by contractors, says OIG. It recommends that the Labor Dept. select contractors for the survey using statistical or other independent means and that wage data be collected on site directly from contractors' records. That also would eliminate the need for third-part reporting, says OIG. If mail surveys are used, they should be verified through statistical sampling. Wage and Hour does not believe that using statistical or independent means to select survey participants is necessary to ensure accuracy (John R. Fraser, 1997). Since the study, the division has implemented new procedures for verifying data and will address other accuracy problems as part of an "ongoing reengineering initiative." (*9*)

What is DOL's position about these and similar concerns? They stress the importance of participating. They state that "[a]ccurate and comprehensive wage determinations are dependent *upon interested party participation in the survey process*" (emphasis added).

The U.S. Department of Labor Davis-Bacon Resource Book illustrates the current process:

- When a survey is started, the interested parties and identified contractors are contacted by a letter requesting their participation through the submission of wage data

- Contractors are identified initially from construction information provided on reports from F.W. Dodge (a provider of project news, plans, specifications and analysis services for construction companies in the United States and Canada);
- Wage and fringe benefit data are collected from construction contractors and other interested parties on WD-10 survey forms including an electronic version (*3*);
- Wage data submissions are verified as to area, time frame, construction type, and timeliness, and data are then compiled and analyzed; and
- Third party verification, contractor verification, and on-site verification are conducted (*10*).

At a DOL Davis-Bacon conference in November 2002, it was disclosed that a goal has been set to complete wage surveys every three years in all 50 states. All construction types will be surveyed, and the process is expected to take from 4 to 8 months to complete once initiated. DOL is making this survey plan available to interested parties through the Wage and Hour Division's website (*3*). The survey form, entitled "Report of Construction Contractor's Wage Rates" or "WD-10" may now be filed electronically (*11*).

MONITORING AND ENFORCEMENT

Enforcement is actually part of the partnering process. When contractors do not comply, measures must be used to give the requirements "teeth." Under Reorganization Plan No. 14 of 1950, the federal government has delegated authority to the contracting agency to investigate and enforce DBA compliance. This is usually done through payroll monitoring, documentation, and requesting and obtaining clarification or revisions to CPRs, including wage restitution to employees owed back wages.

Labor Compliance On-Site Interviews

On-site interviews are commonly conducted on large-scale prevailing wage projects. The contracting agency can use this tool to verify that the CPRs accurately reflect worker classification and payment. Ideally, the interviews should confirm the data reported in the CPRs.

This tip is offered: conduct on-site labor interviews with construction workers on Friday mornings when feasible, because most workers receive their paychecks on Fridays, so they may have their pay stub handy for easy reference.

Enforcement Options

DOL is a good resource in difficult cases, but more often than not, the contracting agency and the prime contractor can resolve issues of enforcement.

The prime contractor is responsible for disseminating information on prevailing wage to all subcontractors. The prime contractor is ultimately responsible for payment of DBA wages, including subcontractor violations if back wages are owed to employees and the subcontractor is unable to pay. Willful violations and falsified statements of compliance on the certified payroll report can subject the wrongdoer to criminal prosecution. For each false statement on a payroll, penalties of $1,000 and/or one year in prison may be imposed. In some circumstances, the violations can cause contractors to become ineligible for future participation in DBA contracts (debarred) for up to three years.

Available enforcement mechanisms include

- Withholding of contract funds or setoffs;
- Cancellation of contract (termination for default);
- Referral to DOL for investigation, hearing, or lawsuit; and
- Debarment (by DOL).

Again, coming to the table together to resolve difficult prevailing wage issues is far preferable to jeopardizing the timeline on a big-budget light rail project, although all reasonable options may be considered.

PARTNERING

In TriMet's experience, it pays to partner with contractors and subcontractors on prevailing wage issues. The contracting agency should use regulations, precedents, and experience to act firmly and quickly when a contractor is out of compliance. Delays in relaying information to the prime contractor, and from the prime contractor to the subcontractor, can slow the process down. This could result in continuing non-compliance, turning an initially manageable problem into an unmanageable one.

The public contracting agency should work with the contractors and subcontractors so that they realize the advantages to responding in a timely manner. The ultimate alternative could be the necessity to withhold payment – not a desirable choice on a light rail project where schedule delays can critically affect deadlines and opening dates. Providing resources to contractors and subcontractors gives them an understanding of requirements and consequences, and at the same time justifies a reasonable response time.

Applying prevailing wage requirements on a case-by-case basis is an opportunity for establishing partnering techniques that may also be built upon in the future. Most contractors and subcontractors are very willing to learn how to respond to DBA requirements in an expedient and professional manner. It is essential on a large-scale construction project such as light rail to develop a good working relationship regarding these requirements. Welcoming inquiries and questions provides a more relaxed approach to solving problems, and is well worth the time and effort. Telephone, mail, and meeting in person are all good ways to get to know the people who are involved in building the rail system. Many contractors and subcontractors may be working on future extensions of the light rail system, so it pays to educate them about federal requirements and correct documentation processes.

Contractors who become adept in these practices today can grow to be mentors of subcontractors tomorrow.

SUMMARY

Every light rail project presents unique situations and problems related to federal prevailing wage requirements. Resolution of such issues can provide important lessons learned on future projects, not only locally, but also nationally.

Key points to always keep in mind on prevailing wage issues are the following:

- Educating yourself: contracting agencies and contractors alike need to keep informed, and expand their knowledge base on DBA to resolve tough issues. Sharing information and resources helps everyone.
- Interpreting the law: Federal requirements may be argued from more than one point of view. How will this impact the light rail project?
- Making a case: Document, document, document. Anecdotal versions of what occurred, or reliance on memory alone, are in most cases insufficient. Do interviews, including field interviews.
- Setting a precedent: Experiences with similar cases and issues are good to document and keep on hand in a casebook or DBA file, for future light rail expansion projects. Don't expect *everything* to go smoothly on future projects. Remember that prevailing wage issues may be very complex. Some of the same issues may crop up. Being prepared will save time and money.

Through understanding the parameters of Davis-Bacon, issues of contractor compliance and agency enforcement can be dealt with in an expedient and decisive manner. This will benefit the contractor, the contracting agency and most importantly, the thousands of employees who build our light rail systems.

ACKNOWLEDGMENTS

Chris Fussell supplied the photographs for Figures 4 and 5 courtesy of TriMet. John Bokneckt of Stacy and Witbeck, Inc. (Prime Contractor), supplied the photograph for Figure 6.

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From the Ballot Ashes
Rebirth of Interstate MAX

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For transit properties that have had success planning and building light rail projects, there is the potential to disconnect the critical link between community value and project planning, and yet expect continued success. However, the Tri-County Metropolitan Transportation District of Oregon (Tri-Met) managed to take a failing project from the dregs of a failed local (regional) funding election and in its place create a project of value to the community it serves and the local and federal funding partners.

A review of the demise and resurgence of a light rail project is supported by interviews with key participants in planning, financing, communications, and engineering. Public transit projects must be good public policy as well. They must make technical sense, but more importantly have credibility with the community it serves and be fiscally responsible from inception to implementation.

The Interstate Metropolitan Area Express succeeded by fostering and maintaining a collaborative team from design through construction; aligning and maintaining project priorities; and focusing on value for the public and the transit system.

INTRODUCTION

The Interstate Metropolitan Area Express (MAX) Project literally arose from the ashes of the South/North Project after its narrow defeat in the November 1998 regional funding election. The South/North Project was quite dead, technically and politically. Months later, however, a community based effort brought a new project proposal to light that held three priorities paramount: serve north and northeast Portland with reliable transit; build a quality project with lower costs than the South/North proposal; and require no displacements along the alignment.

This paper attempts to detail the transition from what had been South/North Project to Interstate MAX from the perspectives of planning, engineering, financing, and communications staff involved with both projects. Interstate MAX construction is currently 75% complete overall—four months ahead of schedule and under budget. Service is scheduled to begin September 2004.

But it didn't start that way.

South/North Project

The South/North Transit Corridor was identified as the priority corridor for high capacity transit improvements through Metro's Region 2040 Growth Concept. Planning began in 1993 and culminated in the Locally Preferred Strategy selection of a light rail project from the Clackamas Regional Center to Rose Quarter Transit Center.

South/North included a new bridge over the Willamette River to carry light rail and pedestrians, reconstruction of the existing transit mall in downtown Portland to add light rail, and reconstruction of the Rose Quarter Transit Center. The planned alignment traveled through southeast Portland, creating exclusive right-of-way by acquiring properties adjacent to existing roadways, McLoughlin Boulevard in particular.

The South/North project, managed by Metro from the project inception until November 1998, included a complete public process with a Citizens Advisory Committee and a series of Public Open Houses to receive public comment on project specifics. Project staff worked diligently to incorporate comments into preliminary designs. And yet, public support waned with each public vote on funding measures.

The final blow came in November 1998 when a regional election to confirm local match funding failed by a 52-48 margin.

Not Dead Yet

Anyone who enjoys Monty Python's brand of callow humor can see the connection between South/North and the knight in "The Holy Grail" who continues to fight and doesn't give up although he loses limb after limb. After the 1998 election South/North, and the Knight, was officially dead. At the time, City Commissioner Charlie Hales stated that the project was "Dead, dead, dead." Project architect Michael Fisher described the weeks after the election as a grieving process. Dick Feeney likened it to yet another Monty Python scene, in "The Meaning of Life" where an old woman succumbing to the plague calls out, "I'm not dead yet!"

REBIRTH OF PROJECT AS INTERSTATE MAX

An analysis by Davis & Hibbitts, Inc., of voting trends in the 1998 election showed that support for light rail was strong in Multnomah County, but failed within Clackamas and Washington Counties. A difficult fact was that the project failed in the Clackamas County precincts through which the alignment ran. Support within precincts located along the North alignment was very strong in favor of light rail. A significant factor in the election results, however, was the effect of the lowest turnout in a general election, and the especially low turnout of younger voters more inclined to have voted in favor.

Leadership Strategy

The election analysis and public opinion survey provided the basis for what could be good public policy. People were interested in a regional network, with connections to Vancouver, that would provide transit to destinations and increase options for people dependent on transit. An alliance of business and public leaders developed a general proposal that met the key policy priorities.

While concerned about impacts and costs, the North/Northeast business and residential community and leaders wanted light rail in their neighborhood, a fact seen from the precinct-voting trend. Transit ridership is very high in north and northeast Portland. The Nos. 4, 5, 8, and 72 bus lines that serve the area are among the highest ridership in the entire TriMet system. Business leaders were also excited about potential revitalization along the Interstate corridor.

Funding Without New Taxes

Given the failure of the regional funding measure, the funding priority of a new project was to use local dollars to match available federal funding. There was absolutely no support for new taxes to create the local match, so a strategy had to be developed to find a source for the funds.

Discussion of possible funding partners and sources began when the business and residential community brought through a proposal to go to North Interstate. Metro had a potential $55 million in regional funds, TriMet $25 million, and the City of Portland pledged $30 million. The discussion was tied back into the technical aspects of the developing project. The question of how much the region could afford was tied back to the technical process of how to determine a project that could be built for that affordable price.

During the Intermodal Surface Transportation Efficiency Act (ISTEA) authorization period in 1995, Congress added TriMet to the list of large interrelated projects. The ISTEA statute was amended in the middle of its authorization period within the Appropriations Act. The amendment required the secretary to forward a project in Portland along the South/North corridor through to a Full Funding Grant Agreement. This provided motivation to continue forward to create a project that could work for the region.

Community Resolve

In December 1998 and January 1999, Metro held a series of listening posts to allow people to voice their opinions regarding the future of transit and transportation in the Portland Metropolitan Region and the South/North corridor. With no specific project on the table, Metro, the City of Portland, and TriMet wanted to bring people together just to listen. The slate was clean and the potential was open to hear what transportation options the public supported. Public comment paralleled the findings from the voting analysis in that the majority (75%) were supportive of light rail but had reservations about specific elements of the South/North project, such as:

- Build in segments;
- Too high a cost;
- Light rail necessary to achieve land use goals, economic development or redevelopment; and
- Build rail but use multiple transportation modes (e.g., expanded bus service, streetcar, high occupancy vehicle lanes, and car and van pools).

Additionally, those who supported building light rail suggested alignment variations that either use existing structures, or in other ways could reduce overall project costs:

- Use the eastside connector/Hawthorne Bridge;
- Go to North Portland;
- Use 1-205 [existing right-of-way (ROW) for transit];
- Avoid the transit mall; and
- Go to Clark County.

Project Goals

Through the community process, the project goals were defined as follows:

1. No displacements;
2. Reflect community values; and
3. Fiscal responsiveness.

Displacements

North and Northeast Portland were physically separated during the construction of the Interstate 5 freeway system. A section of residential neighborhood two blocks by 3.5 mi was removed through the imminent domain process to build the highway. Construction of Emanuel Hospital, in the Elliot Neighborhood, followed a decade later and removed more established neighborhood housing and businesses. The community wounds have never completely healed, and people were very concerned that a new federally funded project may have similar negative impacts. To eliminate displacements, the Project would need to utilize existing rights-of-way to the maximum extent feasible.

Two typical design cross-sections were developed that fit double-track LRT, through traffic lanes and left turns, bike lanes, and sidewalks within both an existing 80 ft and 100 ft ROW. Operationally, this changed Interstate Avenue from a four-lane arterial to a two-lane (one in each direction) with dedicated turn lanes at signalized intersections.

With minor exceptions, no additional ROW was required to fit Interstate MAX within the existing ROW. In the Lower Albina area, additional ROW was required at the entrance to the Union Pacific Railroad (UPRR) Albina Yard and near the Tillamook intersection where Interstate MAX tied into the construction of the Lower Albina Overcrossing, a new grade separated crossing of the UPRR main line. During final design, minor acquisitions were required at some corners to meet Americans with Disabilities Act guidelines at curb ramps.

Design to Reflect Community Values

The City of Portland's strong neighborhood structure enabled communities to be integrally involved in the new visioning. Three design review open houses were held in January 1999. Each session covered different issues: schools, neighborhoods, parks, traffic, station areas, and economic development. Key recommendations from the community included

- Preserve existing trees wherever feasible;
- Maintain on-street parking along Interstate Avenue;
- Maintain access to properties along Interstate with signalized left turns and permit U-turns at key intersections; and
- Provide safe pedestrian crossings at regular intervals.

As design progressed from conceptual engineering to preliminary engineering and then final design, these recommendations became firm design elements.

Public involvement stressed themes of maintaining community "ownership" of station areas. Each station went through a process to reflect and celebrate their adjacent community. While the structural and architectural elements of each station were standard, the selected artist for each station worked with the community to develop a theme that represented elements of each neighborhood's physical, social, and environmental history. The artist team created elements at each station that could be individualized by each station artist, including community maps, paving block outs, and benches. At a number of stations the shelter columns were part of the artists' treatment.

Track Treatment The initial assumption of ballast track was not fully accepted by the community. Through the Lower Albina Industrial Area ballast track was an acceptable treatment. However, the community resolved that paved track treatment was imperative for the section of Interstate between Fremont and Argyle. The concrete trackway met two objectives for the community: higher standard of treatment for the more residential and commercial area of Interstate, and ability for emergency access around stalled traffic. Other savings had to be found to offset the additional $2 million for the 2.7 mi of paved track treatment. This process serves as an example of the close commitment to match community objectives with project cost restrictions.

Commitment to Existing Uses Interstate Avenue travels through industrial, residential, and commercial districts. The community strongly valued the existing uses, and pressed the Project staff to assure that these uses would be maintained and strengthened with the addition of light rail.

The Lower Albina Industrial Area especially was concerned, as their businesses depend on access to and from Interstate Avenue for large trucks. This proved to be an area of intense technical analysis that included study of existing and proposed access and circulation for trucks, and allowance for future growth of the UPRR Albina Intermodal Yard. More than any area on Interstate, the Lower Albina area required concurrence that the single through auto lane would be sufficient for the peak demands for auto and truck access. The result of the Lower Albina Traffic Study was that a dual right-turn lane for SB Interstate would be required at Russell Street to provide adequate storage for UPRR Intermodal trucks during UPRR main line train moves across Russell Street. Additional ROW was required to build the double right turn. A successful negotiation between UPRR, the City of Portland, and TriMet provided benefit to both through-traffic access on Interstate and UPRR Intermodal traffic.

Residents along and directly adjacent to Interstate Avenue required sufficient access to existing properties. Maintenance of existing on-street parking was critical for properties with no existing off-street parking. On-street parking again was critical for existing business nodes, including areas near Skidmore, Killingsworth, Portland, Lombard, and Kenton.

The project team balanced the needs of businesses and residents with the transportation goals for light rail, autos, and bikes. The resulting reconstructed Interstate Avenue is tailored specifically for the needs of the adjacent community. The design team remained flexible to accommodate existing and future patterns of development, without sacrificing the goal of a successful transportation system.

Project Building with Local Community The activist community challenged the project to maintain a credible, active community involvement plan. The Community Involvement Compact, signed by TriMet in October 1999, set commitments to coordinated and collaborative outreach by TriMet for all aspects of the Interstate MAX activities from design through construction. For the first time, TriMet began a project with an explicit commitment to environmental justice ranging from specific environmental issues, to jobs and economic responsiveness to the community.

TriMet set a high goal on the Interstate MAX project for utilization of Disadvantaged Business Enterprises, minority- and women-owned business enterprises. Sixteen percent of all contracts was the project's goal. Utilization of alternative contracting methods including design/build and construction manager/general contractor enabled this goal to be met.

Fiscal Responsiveness

The Interstate MAX budget was $350 million and included all provisions for civil, track, and systems construction, additional light rail vehicles, and maintenance facility expansion. To meet the cost goals, the community engaged in discussion about what level of amenities was required to meet their objectives while maintaining cost control. The Interstate MAX line was not conceived to be "cheap" but to live within the $350 million budget and still provide the quality product expected by the community was the goal.

There was a clear break in process between the 1998 funding election and the reinvigoration of a new potential project. This break allowed staff to discard gathered assumptions and potential myths created about costs on the alignment. One of those myths was that an alignment adjacent to the freeway would result in a fast travel time and lower construction costs. However, the alignment that resulted from those assumptions required numerous grade separations with expensive walls and structures.

From an engineering perspective, the use of existing ROW and grade separations would prove to be the primary cost savings. The initial assumption that rebuilding an existing street was too expensive was not exactly a myth, but with hard consideration of design and operation requirements the costs of road reconstruction were brought under control.

Initial assumptions and recommendations for cost-saving measures included

- Tie and ballast track construction;
- Standard materials for stations; and
- Combined catenary and street lighting poles.

As discussion of design and construction continued, there was clear motivation from the project team and the community to design a project that would not destroy existing businesses with a long construction schedule and destructive construction methods. This led to the focus on using an overlay approach for the reconstructed roadway. By reducing excavation and full depth pavement construction the project saved time and money, but the community saved even more with speed of construction and easier traffic control during construction.

Station elements were standardized to use the same materials for shelters, handrails, surface finishes (e.g. concrete pavers), and so forth. Standardization was stressed for cost control, but this priority could not overshadow the responsibility to have high quality materials that reflect an investment in the community.

The focus on cost savings carried through the project from its inception through to final construction completion. As design progressed and new elements were introduced, the design team continually weighed the balance of new additional costs with required additional savings.

CONCLUSIONS

Public transit projects must be good public policy as well. They must make technical sense, but—more importantly—have credibility with the community it serves, and be fiscally responsible from inception to implementation.

Interstate MAX succeeded by fostering and maintaining a collaborative team from design through construction; aligning and maintaining project priorities; and focusing on value for the public and the transit system.

LIGHT RAIL ELECTRIFICATION

Feederless Traction Power Design Considerations for New Streetcar Lines

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The construction of streetcar and electric trolley bus lines in urban areas poses some unique challenges regarding the installation of overhead contact systems (OCS). These considerations range from the aesthetics of a catenary system to costs for land procurement, high voltage feeds required by a typical substation, and possible extensive buried conduit. An integrated solution of both the overhead contact system and the traction power supply substations can be used to address these issues without the need for expensive feeders along the track.

Feederless power distribution systems have been developed and implemented effectively in both Portland and Seattle using novel solutions. The systems were designed independently but have similarities, which can be used as a basis for the installation of electric traction systems in other cities. Issues which were considered include

- Restriction of the OCS to a single contact wire;
- Use of existing 480 Vac supply power systems;
- Minimizing property procurement requirements;
- Minimizing the need for underground conduit;
- Minimizing stray currents and utility relocations; and
- Providing adequate power to operate electric vehicles.

Each of these issues will be described with specific examples of the how the challenges were addressed.

INTRODUCTION

The installation of new streetcar and electric trolley bus (ETB) systems in dense urban areas poses some design challenges which are not usually seen in rapid transit or LRT systems. Streetcars and ETBs operate almost exclusively in dense urban areas, while rapid transit and light rail normally operate with long open route sections and brief forays into downtown areas. The usual strategies employed with LRT systems—namely, providing power from the fringes of the downtown area with a low impedance distribution system and relocation of all utilities in the affected streets—are difficult and very expensive to implement on an exclusively urban system. In the Northwest, the Portland (Oregon) Streetcar and Seattle (Washington) Metro ETB systems have used some innovative strategies to address these challenges.

The Portland Streetcar system design began in 1998 with an electrification system typical of a light rail line. The system was conceptualized as a 2.5-mi (4-km) line using two or three 1

MW DC traction substations and a contact wire with parallel feeders to deliver power to the vehicles and control the voltage drop in the lines. During the preliminary engineering phase the difficulty of implementing this strategy quickly became apparent. The difficulty in siting the substations, design prohibitions on using a catenary system instead of a single contact wire, and stray current levels impacting utilities over the entire alignment would prove very expensive and extremely unpopular. The task of downsizing this system without reducing capacity or performance resulted in a number of the ideas presented in this paper.

The Seattle Metro ETB system consists of 60 route-mi (96 km) of two way traffic using overhead contact wire and 37 traction power substations. The nominal system voltage is 700 V DC. The original 55-mi (88-km) system was designed and constructed between 1975 and 1981 as part of the Trolley Overhead System and Substations Rehabilitation and Expansion Project. An additional 5 mi (8 km) were added within the last 7 years. The new extensions use a feederless system consisting of 4/0 AWG copper contact wire with 500 kW substations spaced about 5,000 to 8,000 ft (1,500 to 2,400 m) apart.

Several techniques have been utilized to meet these challenges in both the Portland Streetcar and Seattle Metro Trolley Bus systems. The following six areas are discussed in this paper with examples:

- Restriction of the overhead design to a single contact wire;
- Use of existing utility power distribution systems;
- Minimization of property acquisition requirements;
- Minimization of underground conduit requirements;
- Minimization of stray currents and utility relocations; and
- Delivery of adequate power to the transit vehicles.

SINGLE CONTACT WIRE DESIGN

The single contact wire design seems to be every urban planner’s overhead contact systems (OCS) preference. (That is, if they have to have a wire at all.) While it can be argued that the general public will not notice the overhead conductors, the concept of a single contact wire seems to arise in every urban area as a matter of aesthetics. From an engineering viewpoint, the single wire design is attractive for its design simplicity and lower cost.

The main concern with using only a single contact wire is the higher impedance and subsequent voltage drops which result from moving large amounts of current. Doing so through a single wire over a long period of time may also result in overheating of the wire and annealing of the copper if the sizing is not correct.

LRT systems constructed with a single contact wire generally use along-track underground feeder cables typically sized from 500 to 750 kcmil. The other option is a full catenary, often with a reduced system height referred to as a low profile catenary. The difference in line resistance is significant. With a full catenary system (300 kcmil contact wire and a 500 kcmil messenger) the resulting resistance is 0.071 ohm per mi (0.044 ohm per km). The underground feeder systems (300 kcmil contact wire with a parallel underground 750 kcmil feeder) result in a resistance of 0.054 ohm per mi (0.034 ohm per km). By contrast, a single 300 kcmil contact wire yields a resistance of 0.188 ohm per mi (0.117 ohm per km), or three times the line resistance of a typical LRT system.

On the Portland Streetcar alignment this challenge was met by shrinking the distance between substations to 0.5 mi (0.8 km) instead of a typical LRT spacing of 1 mi (1.6 km). This effectively reduces the maximum distance from a substation to one half that seen on an LRT system, approximately 1320 ft (400 m), and consequently reduces the line resistance by half. Additionally, for the anticipated single-car operation the required current flow in the overhead line is also reduced compared to a typical LRT two-car consist. The operational voltages on the line are discussed further in a subsequent section.

In Seattle, 4/0 AWG overhead contact wire without parallel feeders in outlying area results in an impedance of 0.266 ohm per mi (0.162 ohm per km), almost one and a half times the impedance of the Portland Streetcar system. The lighter ETBs with a maximum current draw of 500 amps allow the system to be operated with a substation spacing of 5,000 to 8,000 ft (1,500 to 2,400 m).

The key to designing for a single contact wire is knowing what the loads are going to be and designing a system that will serve these loads within the limits of the wire.

MINIMIZING UNDERGROUND CONDUIT

Using the single wire concept instead of a parallel feeder system also greatly reduces the need for an underground conduit system to contain the feeder system. Generally, two 4-in. (100 mm) conduits are installed for along-track feeders with a manhole placed every 300 ft (90 m) and a lateral feeder run to a pole base and up to the contact wire on every block.

Underground conduit can also be required for transfer tripping substations as a back-up to the primary overcurrent protection. These wires require an additional 2-in. (50 mm) conduit. On both Portland Streetcar and Seattle Metro ETB systems the di/dt protection with reclosure relays is relied on to ensure an adjacent substation trips in the event of higher impedance faults where the primary overcurrent protection does not see the fault.

The cost of installing underground conduits for the power distribution feeders and transfer trip cables can be grossly estimated at $90/ft ($295/m), including the cost of manholes and lateral feeders at approximately 300 ft (100 m) intervals. With the tracks separated by a block on the Portland Streetcar system there are 5 linear track miles (8 km) to cover both tracks. The cost of the total underground distribution system can be estimated at about $2.5 million.

An additional benefit to eliminating an underground traction power conduit system is the avoidance of the problems that arise from trying to fit it into a street which is already crowded with the underground services of several local utilities. Relocating utilities is a task which is wise to avoid.

EXISTING UTILITY DISTRIBUTION SYSTEMS

Another challenge in urban areas is the supply of primary 60 Hz power to the traction power substations. Typical LRT substations are fed from dedicated medium voltage (12 to 25 kV) feeders run from the nearest utility substation. In dense urban areas these feeds can be very long, and the installation under existing streets can be very difficult and costly. The Portland Streetcar system was faced with an average cost of $25,000 per substation for the local utility to supply 13 kV power, with one location that may have approached $50,000. On the other hand, a 480 V distribution grid was easily accessible at all locations.

Low voltage service drops, such as 480 Vac, are not normally used for traction power substations because of the high power demands normally encountered. Typical LRT systems use 1 to 1.5 MW substations, while electrical utilities in general will not usually provide for loads above 500 kVA without installing a medium or high voltage feed. The ampacity requirements are too large.

It was Portland Streetcar's decision to keep the substations below 500 kVA to make use of the local 480 Vac distribution system. The power rating chosen was 300 kW at the output. All substations except for one are fed with a 480 Vac supply. The exception is a substation located in a City of Portland parking garage where the existing 208 Vac supply had sufficient capacity to handle the substation load.

An additional positive consequence of the low voltage supplies is the ability to use a standard industrial switchboard for the power supply instead of an incoming AC cubicle and a 15 kV AC breaker. This reduces the price of the primary power equipment by a factor of three and, of course, the footprint of the substation building is also reduced.

MINIMIZING PROPERTY ACQUISITION

The acquisition of real estate for the siting of traction power substations in central business districts is also a major cost element in the design of urban transit. The typical 1MW substation with a medium voltage primary will occupy a minimum of 650 sq ft (57 sq m), with a buried ground mat of 1,250 sq ft (116 sq m). Typical dimensions of the property acquisition are 60 ft by 30 ft (18.3 by 9.2 m).

By contrast, the smaller low voltage, low power substations used on the Portland Streetcar alignment require only 400 sq ft (37.2 sq m) of property for a stand-alone substation with a perimeter ground. The use of low voltage, 480 and 208 Vac, eliminates the need for large clearances in the AC incoming cubicle. These factors allow for much greater flexibility in the siting of the units.

Portland Streetcar took full advantage of this flexibility. Of the six substations on the line, two are stand-alone prefabricated package units, two are installed in vaults placed under the sidewalks, one is installed in a city parking garage, and one is installed in an unused basement extension under the sidewalk. One of the package units is installed on the maintenance facility property which is leased from the state of Oregon and located under a freeway overpass. The two units installed in vaults under the sidewalks are in the city of Portland right of way. The parking garage unit was constructed with the loss of only two parking spaces to the city of Portland. The location in the building basement extension was donated by the building owner and only required the installation of a fireproof door to the main basement and a personnel access door in the sidewalk. The final substation was located in the backyard of property owned by a major stakeholder and only required a credit on the local improvement district assessment. A route map showing the substation locations is included as Figure 1.

Seattle Metro has also been flexible in accommodating any available area for their substations. The majority of their 37 substations are located on properties which Seattle City Light (SCL), the local power utility, has granted easements. Only three substations are located on

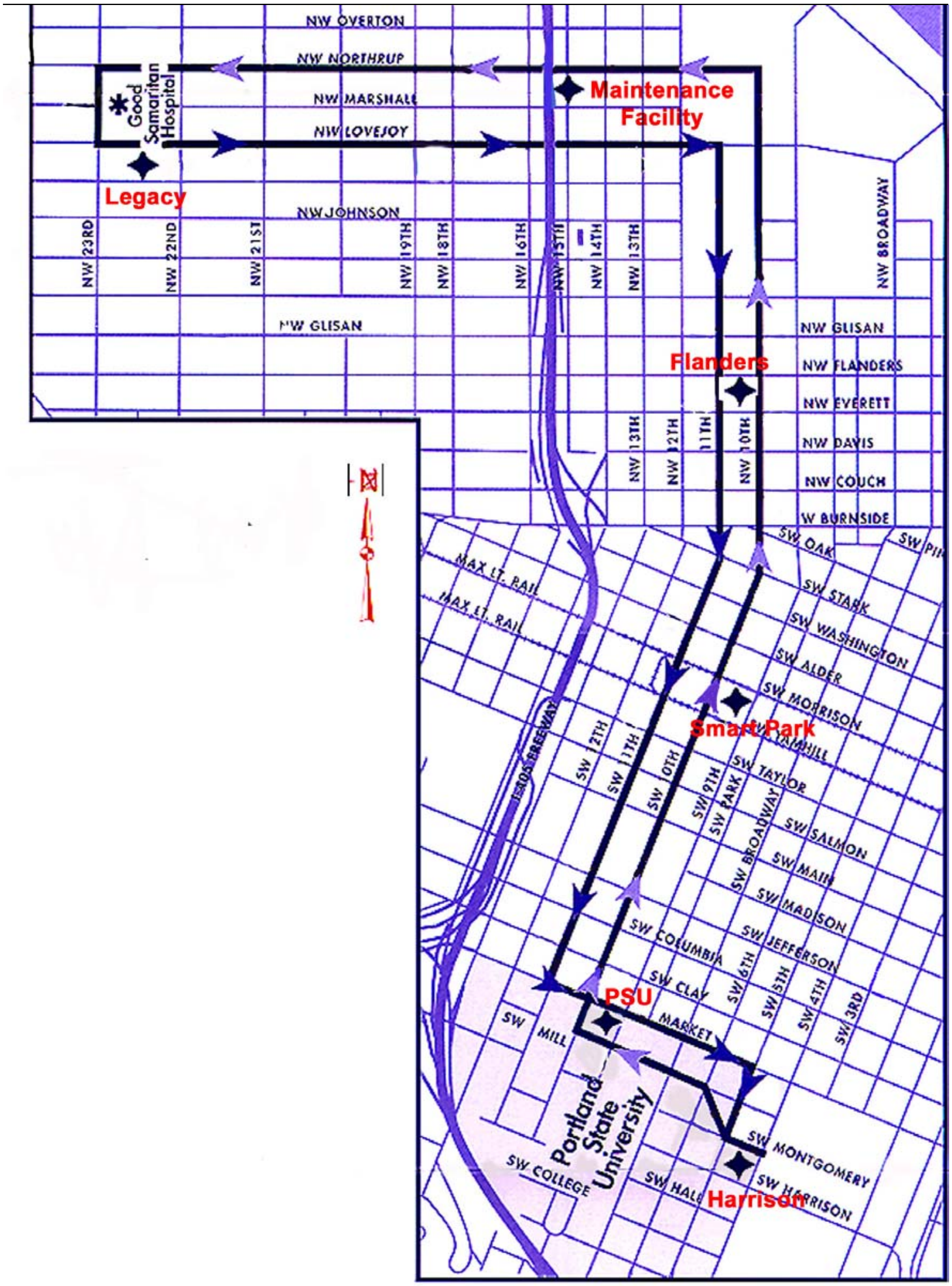

FIGURE 1 Portland Streetcar substation locations.

private, purchased properties. Three of the four newest substations were installed in Washington Department of Transportation right of way under Interstate 5 structures. The fourth substation was installed on SCL property. A route map showing the substation locations is included as Figure 2.

One of the major differences is in the grounding of the substations. As mentioned above, the Portland Streetcar substations use a perimeter ground instead of a full ground mat. A perimeter ground consists of four 15-ft (5-m) ground rods installed 3 ft (1 m) from each side of the substation at the four corners and electrically tied together. The ground rods are driven, without excavation, and tested to ensure a maximum resistance of five ohms-to-earth. The utility neutral is tied to the substation structure and the perimeter ground. This results in a considerable cost savings over the excavation and installation of a full ground mat under a substation serviced by medium or high voltage.

STRAY CURRENT CONTROL

The primary impact of stray current control on the construction of a transit system is the need to move underground utilities away from the track bed. Direct current stray, or leakage, currents will tend to corrode both underground metallic services and structures along the right-of-way. Thus there is the requirement to relocate all metallic elements where the level of stray currents may cause a reduced life. Needless to say, the relocation of underground utilities is an expensive proposition.

While it is not practical to totally prevent the leakage of current from the return rails to the earth, it is practical to control the currents to a level of about 50 mA per 1,000 ft (305 m) or less. A detailed metal loss analysis indicated this would not impact underground services located greater than 18 in. (457 mm) from the tracks. This is about one third of the level normally tolerated in LRT projects. To achieve these levels three major design strategies were used:

1. The distance between substations was kept as short as economically feasible,
2. The resistance from the rails-to-earth was maximized, and
3. The magnitudes of the vehicle currents were minimized.

As described in previous sections, a substation spacing of approximately 2,500 ft (760 m) was used. This spacing limits the maximum distance for return currents in the rails to approximately 1,250 ft (380 m) and results in maximum rail-to-earth potentials of 5.5 V under normal operating conditions and 8.7 V with a substation out of service. These low potentials translated to a maximum short-term leakage current of 50 mA per 1,000 ft (305 m) of track with soil resistivities found on the right-of-way and the rail-to-earth resistances described below.

The required rail-to-earth resistances were established by simulating the actual operation of the network. Initially five resistance levels were used; 25, 50, 100, 200, and 500 ohms per 1,000 ft (305 m). The lower ranges approximate rails directly embedded in concrete or asphalt and the upper values reflect rails electrically isolated from the track bed and the track bed electrically isolated from earth. The required value developed from the simulations was a minimum of 108 ohms per 1,000 ft (305 m) of track. This level of isolation was obtained using a high density polymer rail boot that completely encapsulated the rail. Figure 3 shows a section of the rail with the boot installed.

The magnitude of the vehicle current was constrained with the 66-ft (20-m) vehicles

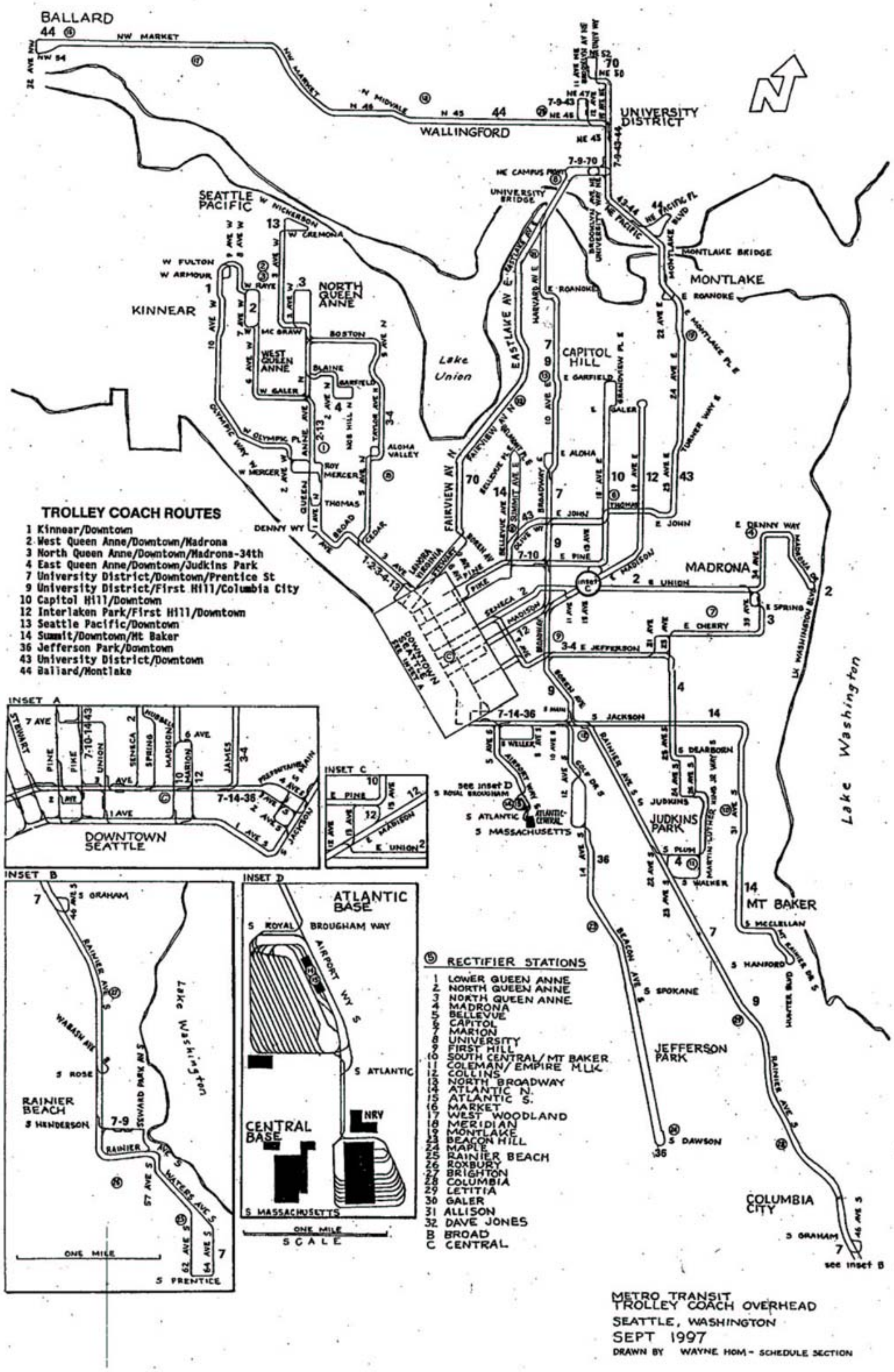

FIGURE 2 Seattle METRO substation locations.

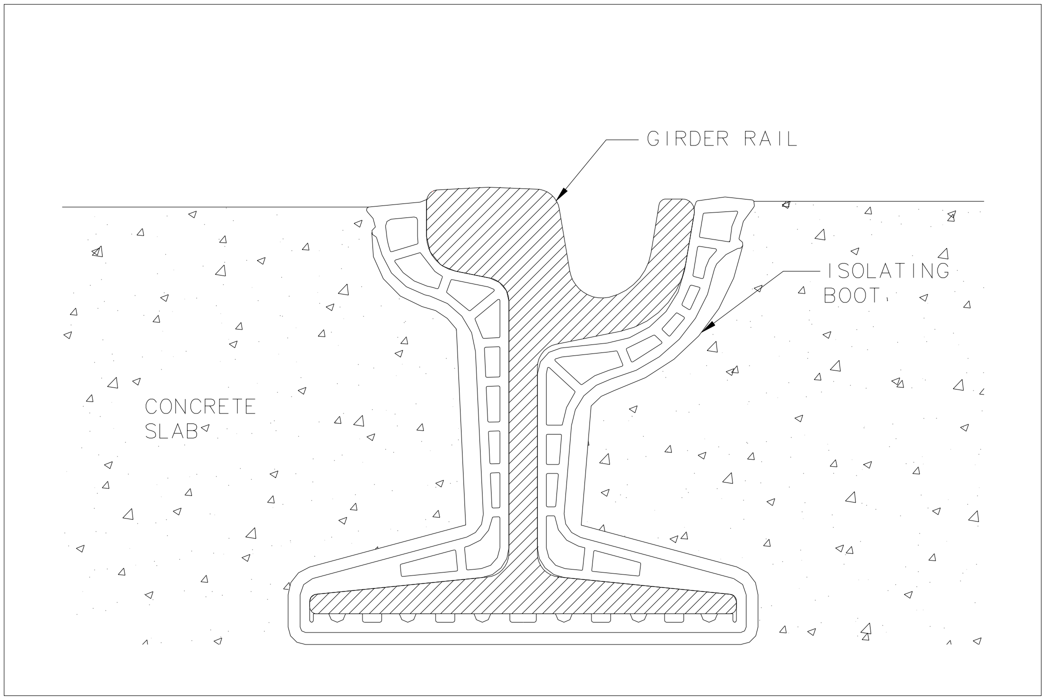

FIGURE 3 Cross section of rail with isolating boot.

operating only as single units. Typical acceleration currents are less than 1,000 amps. In contrast, a two-car light rail vehicle consist will draw over twice this level of current.

While not all three of these methods can be implemented on every transit system, the use of the applicable strategies described above can reduce stray current levels and limit the amount of utility relocation that needs to be undertaken. The fewer relocations, the lower the cost.

ADEQUATE POWER TO VEHICLES

The last point is also the most important. The DC supply and distribution system must be capable of supplying adequate power at an acceptable voltage to the transit vehicles at all times. Substation sizing, spacing, and the cross-sectional area of the distribution system all have a direct impact on the ability to operate transit vehicles, especially when operation needs to be assured even with a substation out of service. The verification of this capacity is performed using computer programs which model the performance of the vehicles and the power demand on the distribution system.

The simulations focused on three elements which were judged to be controlling factors in the design—the voltage supplied at the vehicle's pantograph, the power required from the substations, and the heating effects of the rms currents on the copper conductors. These elements were evaluated during a simulated operation of the vehicles at 10-min headways, 20-s station dwell times, and a load weight of AW2. The vehicle accelerations and decelerations were set to the maximum rate and regeneration during braking was disabled to produce worst case conditions. All simulations were run with the Carnegie Mellon Energy Management Model (EMM) program.

The voltages at the pantograph were recorded during simulated runs in both directions while maintaining the required headways. The criteria for the voltage was to keep the voltage at the vehicle above a minimum 525 Vdc—the level at which the propulsion and auxiliary inverters on the vehicles would shutdown. Sample plots of the line voltages with all substations operational and with one substation (Legacy) off line are included as Figures 4 and 5. Since the streetcar system is a starter system that may be significantly expanded in the future and also has the maintenance facility on the route, a large margin was desired for future headways decreasing to 5 min or less.

The RMS power delivered by the substation was also simulated with the EMM program. Figures 6 and 7 show the RMS power demands on each substation for revenue operation. The substation power demand is far below the sustainable levels for a 300 kW substation, and no short-term overloads were observed. However, no significant cost savings could be anticipated by lowering the capacity, and room for future growth of the system capacity is assured.

Heating of the copper conductors was also calculated with a 10-min headway. The highest temperature found was 50ºC including a 40ºC ambient and a wind speed of only 0.5 ft/s (0.15 m/s). The annealing temperature for the copper wire is 75ºC. Room for future growth is again assured.

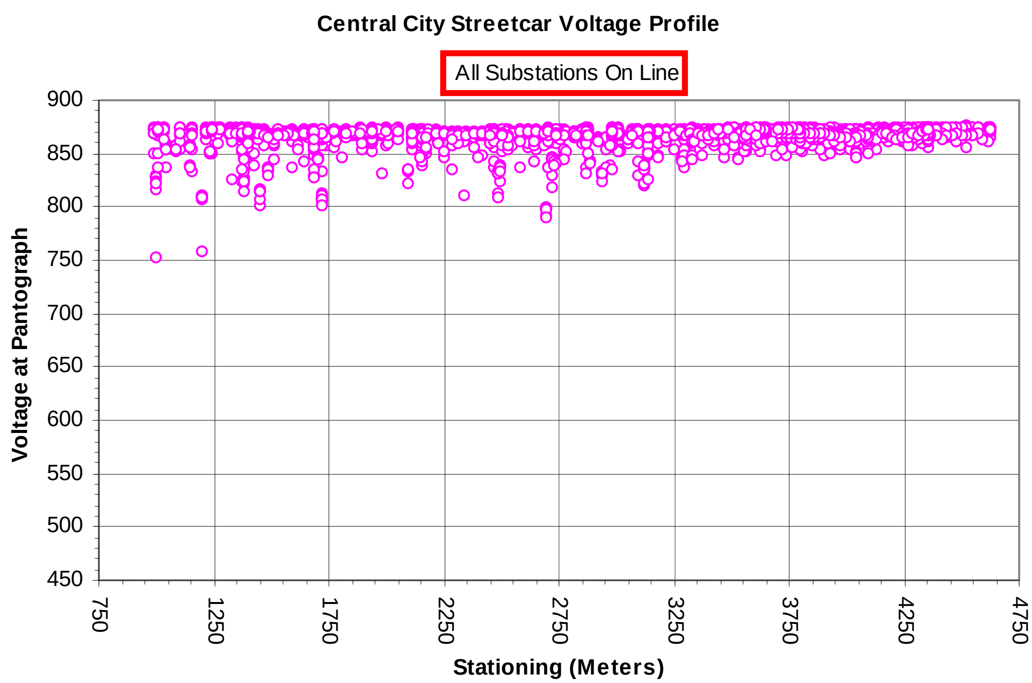

FIGURE 4 Voltage profile with all substations on line (normal operation at design capacity).

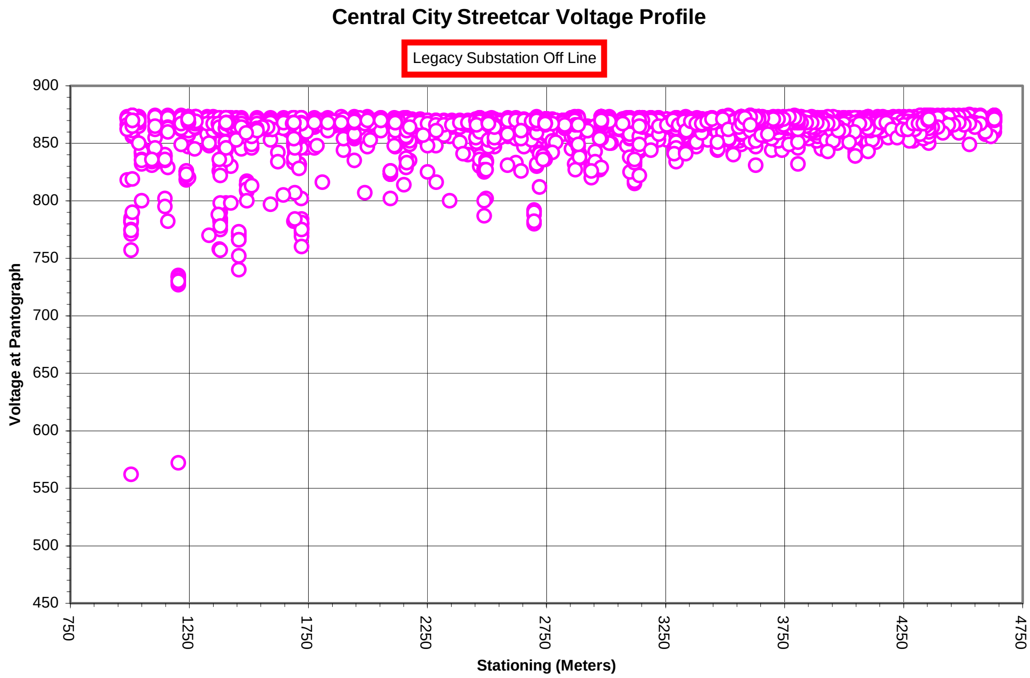

FIGURE 5 Voltage profile with Legacy substation off line (abnormal operation at design capacity).

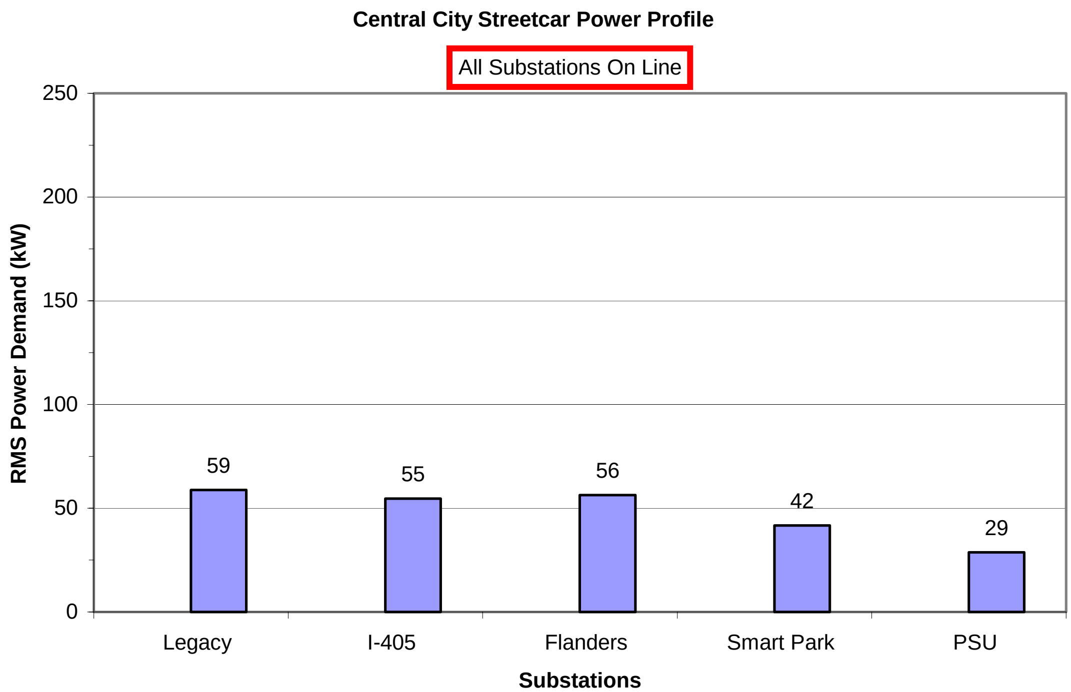

FIGURE 6 Power profile with all substations on line (normal operation at design capacity).

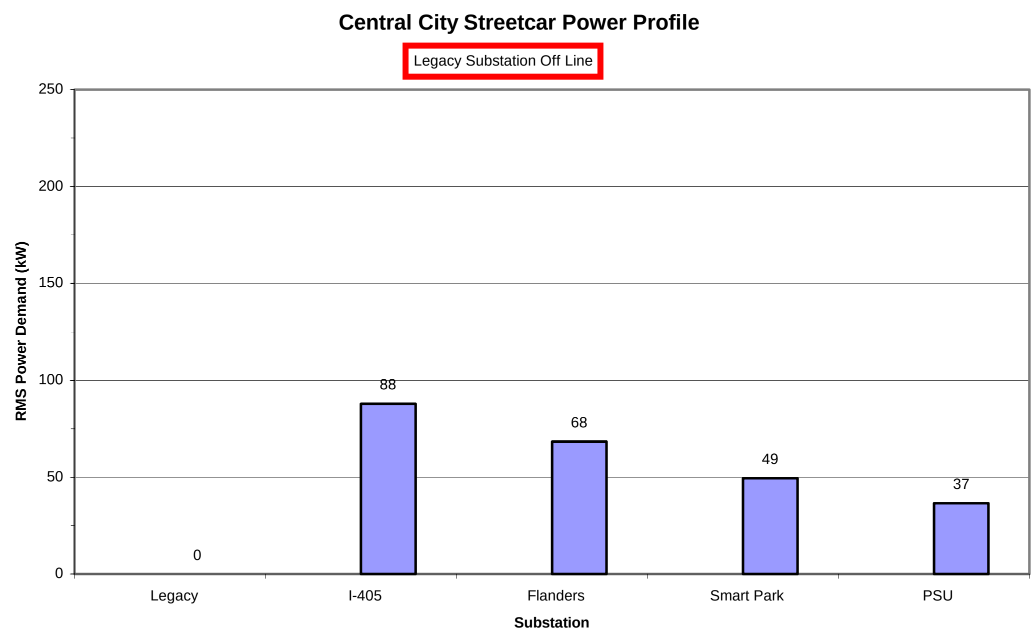

FIGURE 7 Power profile with Legacy substation off line (abnormal operation at design capacity).

Seattle Metro also used simulations to verify the operation of their 60-ft articulated and 40-ft ETBs. Similar criteria for operation with all substations operational or a single outage condition were used. The system uses a no-load voltage of 700 Vdc and both ETBs have vehicle drop-out voltage of 450 Vdc. A minimum operational ETB voltage of 500 V is used.

The other substation spacing criteria is a minimum DC fault current of 700 A or greater. This criterion insures that in case of a single outage condition a fault in the end of the line could be detected and cleared by the di/dt relay.

SUMMARY

Several techniques that can be implemented to reduce construction costs of rail transit systems in urban areas have been discussed. All or part of these can be used depending on the requirements of the transit system. Each technique needs to be evaluated independently although there is interaction between the different techniques and often two techniques can be used together for one benefit. For example, both the rail-to-earth isolation and the close spacing of substations act to reduce utility relocation costs.

Perhaps the most interesting aspect is the resiliency of the feederless systems designed. Both have sufficient capacity for the addition of more vehicles to the line in the future. Operation of two-car trains with peak currents of 1300 A per vehicle, typical of LRT lines, is feasible using the concept of smaller, low-powered, closely spaced substations, and the construction cost savings are significant.

Operational and Safety Considerations for Light Rail DC Traction Electrification System Design

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An overview is presented of an integrated approach to operational and safety issues when designing a DC traction electrification system (TES) for modern light rail and streetcar systems.

First, the human body electrical circuit model is developed, and tolerable step and touch potentials derived from IEEE Standard 80 are defined. Touch voltages that are commonly present around the rails, at station platforms, at traction power substations are identified and analyzed.

Operational and safety topics discussed include

- Applicable codes and standards for electrical safety;
- Traction power substation (TPS) grounding;
- Detection of ground faults;
- DC protective relaying schemes including rail-to-earth voltage sensing and nuisance tripping, and transfer tripping of adjacent substations;
- TES system surge protection;
- Electromagnetic and induced voltage problems that could cause disturbances in the signaling system;
- DC stray currents that can cause corrosion and damage to the negative return system, underground utilities, telecommunication cables, and other metallic structures; and
- Emergency shutdown trip stations (ETS).

To ensure safety of the project personnel and the public, extensive testing and proper and safe equipment operation, are required. The testing includes factory testing of the DC protection system, first article inspection of critical TES components, inspection and field testing during commissioning. In addition, safety certification must be accomplished before the TES system is energized and put into operation.

INTRODUCTION AND OVERVIEW

The TES for a typical modern light rail or street car system includes an overhead contact system (OCS), traction power substations and feeder cables, together with associated substation protective devices, and may include supervisory control and data acquisition. The feeder cables include both the substation DC feeder cables and possible supplementary parallel dc feeders. It is important to recognize that there are fundamental differences in safety and operation between LRT and street car systems that may run on city streets, and third rail or heavy rail systems which run on a dedicated right of way where the public is well isolated from the rails and the TES. For many LRT and streetcar systems, the rails are embedded in public streets where the public can walk on the rails. Occasionally, an OCS contact wire may break and contact an OCS pole, or fall on a metallic fence, or contact and energize other metallic objects such as station shelters. Ground faults in DC feeder conductors can result in energized OCS poles or manhole lids, yet there is no common method that we know of which is capable of detecting OCS ground faults on the system, and safely isolating these faults. Indeed, we could have fault currents resulting from a very high impedance ground fault that are extremely hard to distinguish from train accelerating currents. Since the rails are purposely insulated from earth to minimize stray currents, rail-to-earth voltage must be limited to a safe level due to the touch voltages present around the rails which could be a danger to passengers and personnel.

APPLICABLE CODES AND STANDARDS

At present, the following electrical safety standards are available for use as a basis for design:

- IEEE Standard 80, Guide for Safety in Ac Substation Grounding, which defines methods for calculating safe touch and step potential, and is widely used in the transportation industry for traction power substation grounding.
- The National Electrical Code.
- NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems.
- AREMA, Chapter 12, “Rail Transit.”
- The National Electrical Safety Code.

IEEE Standard 80 (*1*) deals with the recommended practice for safety grounding in high voltage AC substations, but it was never specifically intended to apply to situations outside of AC substations such as we might find in a light rail environment. For example, tolerable limits for children in bare feet, for guide dogs for the blind, or tolerable limits for people with medical conditions or implanted electronic devices such as pacemakers are not considered.

The National Electrical Code prescribes a minimum standard for electrical design that should be incorporated into the design of the TES wherever possible.

HUMAN BODY CURRENT—ELECTRICAL CIRCUIT MODEL

As shown in Figure 1, the human body electrical circuit includes the feet contact resistance, R_1, and the internal body resistance, R_B. A bare foot contact resistance is equal to $3\rho_S$ ohms, where ρ_S is the surface resistivity in ohm-meters underneath the foot.

For the touch potential circuit, we have two feet in parallel, the contact resistance R_1 is, therefore, equal to $1.5\rho_S$.

The *touch potential* is:

$$E_{TOUCH} = I(R_B + 1.5\rho_S) \tag{1}$$

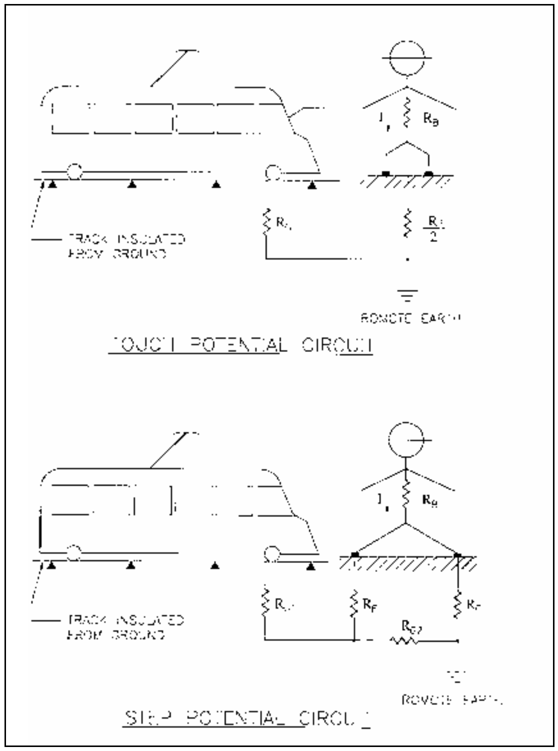

FIGURE 1 Human body current electrical model.

For the step potential circuit, we have two feet in series, the contact resistance R_1 is, therefore, equal to $6\rho_S$.

And the *step potential* is:

$$E_{STEP} = I(R_B + 6\rho_S) \tag{2}$$

For the *touch potential*, consider:

$R_1 = 1.5\rho_S = 1.5 \times 100$ ohms = 150 ohms, based upon $\rho_S = 100$ ohm-meters for surface resistivity of wet concrete floor.

$R_B = 1000$ ohms (internal body resistance for an average person, per IEEE Standard 80)

The touch potential Equation 1 becomes:

$$E_{TOUCH} = I(1000 + 150) = 1150 \times I \tag{3}$$

The current passing through the body is:

$$I = E_{TOUCH} \text{ amperes} \tag{4}$$

$I = 2.0$ ma (minimum perception)[2], $E_{TOUCH} = 2.3V$

I = 60.0 ma (maximum threshold)[2], $E_{TOUCH} = 69.0V$

I = 80.0 ma (maximum allowable)[2], $E_{TOUCH} = 92.0V$

Limiting the electric current passing through the human body can enhance personnel safety. There are two ways to achieve this: a) reduce the touch potential, E, to the lowest practical values such as 70 V or less; and b) increase contact resistance for foot and hand.

It should be mentioned that the human body current obtained from the above equation depends on the surface resistivity (ρ_S). If the person is standing on an insulating pad with much higher resistivity, then the body current will be much less. It has been shown that ventricular fibrillation is not only a function of the current magnitude but also the duration of the exposure. It has been shown experimentally that ventricular fibrillation which appears in animals comparable in size to human beings invariably leads to death (*3*). It was concluded that ventricular fibrillation could be regarded as the only cause of death from electric shock.

There are several equations developed by researchers to calculate maximum allowable non-fibrillating AC current. However, the most acceptable at this time is the Dalziel's equation for a body weight of 50 kg (*1*):

$$I_{NFac} = \frac{116}{\sqrt{t}} \tag{5}$$

where t is the shock duration in seconds and I is the AC current in milliamperes.

Recently, the IEEE Standard 80-2000 recommends the following equation for a body weight of 70 kg:

$$I_{NFac} = \frac{157}{\sqrt{t}} \tag{6}$$

It is interesting to note that for DC systems, the maximum allowable non-fibrillating DC current is about three times that for AC current and is given by the following equation (*4*):

$$I_{NFdc} = \frac{348}{\sqrt{t}} \tag{7}$$

For a modern LRT system, t is in the range of 5 s for train accelerating conditions and about 5 cycles (0.08 s) for high speed DC feeder breaker tripping time under short circuit condition. Thus, using Equation 7, the tolerable body current under DC fault condition is

$$I_{NFdc} = \frac{348}{\sqrt{t}} = \frac{348}{\sqrt{0.08}} = 1.2\ A$$

STRAY CURRENT AND TRACK-TO-EARTH POTENTIAL

To illustrate the basic components affecting the levels of stray currents generated by a dc traction power system, a simple radial feed circuit model is shown in Figure 2. This model assumes that the resistance of the OCS to ground is very high and there is no coupling between the positive circuit and earth.

From this model, the three basic components which control the level of leakage stray currents to ground are (*5*)

I_T	the train current,
V_N	the voltage developed across the negative circuit resistance (R_N), and
R_L & R_S	the effective resistance between the negative circuit and earth.

Although these three items are interrelated as described later in subsequent parts of this paper, each item must be considered separately.

The magnitude of current required to operate the train *(I_T)* is power dependent; for example, for a stated power requirement to provide for a certain acceleration under a given set of conditions, the current required will vary depending on the voltage. Hence, an increase in operating voltage would allow a proportional decrease in the current, and would be a benefit to stray current limitation. Most modern DC transit systems are designed for the 600 to 800 Vdc range. One consideration in maintaining train operating voltage within acceptable limits and minimizing the generation of stray currents as the vehicle moves away from the power source is to keep the substation as close to the point of maximum load as possible. This may require the use of more substations than otherwise would be necessary.

The second factor requiring consideration is the resistance of the negative return circuit, referred to as R_N in Figure 2. Stray current is a function of the track circuit potential or negative

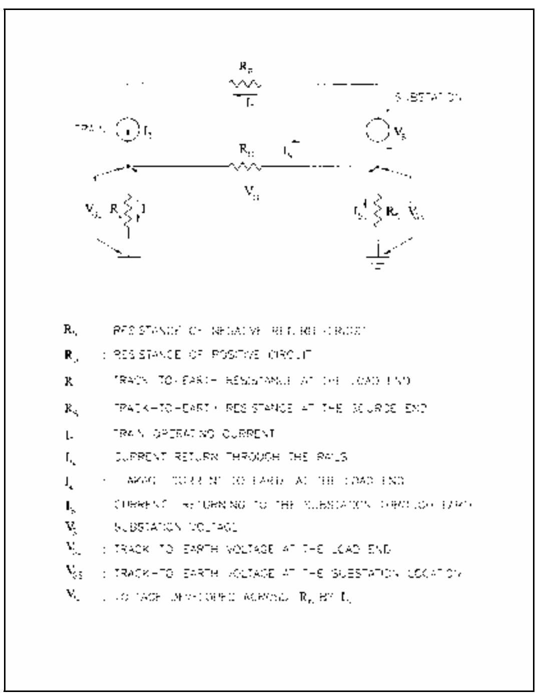

FIGURE 2 Basic stray current model.

rail potential rise. This potential, V_N, is the voltage developed across the negative return rail from the substation to the train and it depends on the train current (I_T) and R_N. There are two basic approaches to maintain the voltage developed across the negative return system within the desired limits, assuming a given propulsion power requirement: a) increase the conductance of the negative return circuit; and b) reduce the maximum distance between the load and power source as also noted above, which means spacing between traction power substations would need to be reduced, which again may result in an increase of the number of substations.

The third factor affecting the stray current magnitudes in the model of Figure 2 is the negative circuit to earth resistance, referred to as R_L & R_S. Theoretically, we could reduce the stray current by increasing R_L &R_S to very high values.

Stray Current Control

The following accepted rail industry methods have been used in recent rail transit system designs to control stray currents:

- Insulating pads and clips on concrete ties.
- Insulating direct fixation fasteners on aerial structures.
- Coating the rails and encasing the track slab with an insulating membrane where the rails are embedded in the roadway areas.
- Minimizing the stray current leakage path through rail/ballast contact by maintaining the ballast at a minimum of 1 in. below the bottom of the rails.
- Bonding rail jumpers at mechanical rail connections for special trackwork.
- Cross-bonding between rails and between tracks to maintain equal potentials of all rails.
- Insulating the impedance bond tap connections from the housing case.
- Insulating switch machines at the switch rods.
- Utilizing separate traction power substations for the main line, yard, and shop. Shop tracks are solidly grounded for maintenance personnel safety.
- Installing rail insulators to electrically isolate the mainline from the yard and the yard from the shop.
- Placing substations near points of maximum train acceleration.
- Maintaining as close substation spacing as practicable.
- Increasing system nominal voltage from 600 Vdc to 750 Vdc and higher.
- Maintaining electrical continuity in tunnel liners and reinforcing steel.
- Maintaining an on-going maintenance program that monitors rail-to-earth resistance values, keeps track-bed areas clean and well-drained.

Track-to-Earth Voltages

As mentioned earlier, stray currents can be controlled effectively by increasing the track-to-earth resistance values. However, a well-insulated negative return system may also cause the increased track-to-earth voltages depending upon other system characteristics.

The relationships between the voltages, V_N, V_{GL}, and V_{GS} as shown in the basic circuit model of Figure 2 are summarized below (*4*, *5*):

$$V_{GL} = \frac{R_L}{(R_L + R_S)} \times V_N$$

$$V_{GS} = \frac{R_S}{(R_L + R_S)} \times V_N \qquad (9)$$

where: $V_N = I_N \times R_N$ (10)

The main concern that relates to this voltage is the human body's safety from touch potential. A voltage relay (device 164N) is recommended to be connected between the negative bus and ground. This relay would trip the DC feeder breakers when the negative rail-to-earth potential becomes high to avoid a dangerous situation. As an alternate, the substation negative bus could be clamped to ground temporarily when excessive rail-to-earth voltage occurs. The rail transit industry has not standardized the acceptable limits of negative return rail potential with respect to ground. Each transit agency has set its own limits. Based on our past experiences, the maximum trip setting ranges from 60 Vdc to 90 Vdc.

TRACTION POWER SUBSTATION AC GROUNDING

Two basic approaches to designing grounding systems are used worldwide (*3*): a) In some countries, a grounding system is considered adequate when the grounding resistance is lower than a recommended value, and b) in some countries, such as the U.S., a grounding system is considered safe when step and touch potentials are lower than a permissible values. Of these two approaches, the second is more valid because magnitude of tolerable current flowing through the human body is taken into consideration.

AC Ground Mat

The traction power transformer, substation AC switchgear and other AC equipment enclosures including auxiliary power transformer, AC panel boards and prepackaged building frames should be connected to a substation AC ground mat designed per IEEE Standard 80-2000 with considerations for step and touch potentials. It should be mentioned that the intent of the IEEE Standard 80 is to provide guidance and information pertinent to safe grounding practices in high voltage AC outdoor substations. The following is quoted from the first page of IEEE Standard 80-2000,

> This guide is primarily concerned with outdoor substations, either conventional or gas insulated. Distribution, transmission, and generating plant substations are included. With proper caution, the methods described herein also applicable to indoor portions of such substations, or to substations that are wholly indoors. No attempt is made to cover the grounding problems peculiar to DC substations. A quantitative analysis of the effects of lightning surges is also beyond the scope of this guide.

In contrary to high voltage outdoor substations where most of the equipment such as buses, breakers, transmission towers, and so on are all exposed; all equipment inside the traction power substations such as 15 kV switchgear, 15 kV station service transformer, and AC panelboards are all enclosed and grounded, furthermore all this equipment is housed inside a grounded building. Hence, it is a very conservative design to follow the IEEE Standard 80 to design AC ground mats for traction power substation AC equipment.

Maximum Tolerable Step and Touch Potentials

By substituting Equation 6 into Equations 1 and 2, we obtain the following equations:

Tolerable touch potential for a human body of 70 kg:

$$E_{touch\ tolerable} = \frac{157 + 0.236 \times C_S \times \rho_S}{\sqrt{t}} \tag{11}$$

Tolerable step potential for a human body of 70 kg:

$$E_{step\ tolerable} = \frac{157 + 0.942 \times C_S \times \rho_S}{\sqrt{t}} \tag{12}$$

where

ρ_S = the surface resistivity in ohm-meters
C_S = the surface layer derating factor
t = the duration of fault in seconds

The surface resistivity and duration of fault are used to establish maximum tolerable step and touch potentials. High surface resistivity and fast fault clearing time will give high tolerable step and touch potentials.

Calculated Step and Touch Potentials

The worst possible touch potential (called the mesh potential) occurs at or near the center of a grid mesh. Industrial practice has made the mesh potentials the standard criteria for determining safe ground grid design.

The following equations are obtained from IEEE Standard 80-2000 (*1*).

$$E_{mesh} = \frac{Km \times Ki \times \rho \times I}{L} \tag{13}$$

$$E_{step} = \frac{Ks \times Ki \times \rho \times I}{L} \tag{14}$$

where

I = maximum ground fault current in amperes.
L = total length of ground grid conductors in meters.
Km = mesh coefficient which takes into account spacing, diameter and depth of burial of the ground grid conductors.
Ks = step coefficient which also takes into account the grid geometry.
Ki = irregularity factor.
ρ = soil resistivity in ohm-meters

After E-mesh and E-step of the grid are calculated, they shall be compared to the values of the tolerable touch voltage ($E_{touch\ tolerable}$) and tolerable step voltage ($E_{step\ tolerable}$) respectively to determine whether or not the designed grounding grid can be judged to be safe (*6*, *7*).

TRACTION POWER SUBSTATION DC GROUNDING

Rectifier and DC switchgear equipment enclosures should be insulated from ground and connected to a DC ground mat through either a high-resistance or a low-resistance grounding system. This paper will not discuss the advantages and disadvantages between the two grounding systems. Refer to Pham (*6*) for additional discussions on high versus low resistance grounding. Regardless of a high or low resistance grounding system, a positive fault to the enclosure must trip the main AC breaker and DC feeder breakers and lock-out the substation. Ample clearance should be provided between the grounded AC equipment enclosures and the ungrounded DC equipment, particularly when the high resistance grounding option is used.

Special consideration must be given to the load side of DC feeder breakers that may get energized from the adjacent substations via the OCS distribution system. Transfer trip is a very reliable method to ensure that DC power feed from the adjacent substations is removed.

The DC surge arrestor ground should be isolated from the AC ground mat and connected to a separate DC ground mat. The DC equipment and the surge arresters are rated 1000 Vdc maximum while the medium voltage equipment has a maximum design voltage of 15 kV (RMS) with a BIL of 95 kV. Connecting the DC surge arrester grounds to the AC ground mat could result in equipment failure; for example, an AC ground fault of 3500 A will raise the AC ground mat (1.0 ohm) potential to 3500 V (1.0 ohm × 3500 A = 3500 V). This voltage rise of 3500 Vdc far exceeds the MCOV of a 1000 Vdc rated surge arrester.

The AC ground mat and dc ground mat should be kept physically separated to limit the voltage on the DC ground mat due to transfer of potential from the ac ground mat.

DETECTION OF OCS GROUND FAULTS

When there is a ground fault between the OCS and ground, the area in the vicinity of the fault could be subject to a high voltage of 750 Vdc. The return circuit back to the traction power substation will be closed via the earth to track if the substation negative bus is isolated; hence, the ground fault current could be relatively low and the time it takes for the DC feeder breakers to clear the fault would be unduly long. One approach to detect the OCS to ground fault is to connect the substation negative bus to a separate ground mat such as the DC ground mat through a grounding diode. The diode-grounding device will provide a return path from the ground to the substation negative bus and thus enable faster fault clearing. The grounding diode will also allow leakage current to return to the substation and thus create a lower resistance path for stray current leaving the rails. However, the return stray current can be monitored, and if excessive leakage currents are detected, the grounding diode can be temporarily disconnected between the negative bus and the DC ground mat, and the source of the leakage current determined and corrected.

LIGHTNING AND OVERVOLTAGE PROTECTION

Lightning intensity within a specific area is generally based upon the ground flash density, N_g, in flashes per km^2. However, at present within the United States this data, N_g is not generally available and the lightning severity must be based upon the isokeraunic level, or the number of thunderstorms per year, T_d. The value of N_g can be approximated by using the following expression (*8*, *9*):

$$N_g = 0.04\ T_d^{1.25} \text{ flashes/km}^2\text{/year} \quad (15)$$

For example, the average number of flashes/km^2/year in the Portland, Oregon, area is 0.1, while the average number of flashes/km^2/year in Florida is 8. This discussion is intended to establish the lightning intensity to the OCS system components—especially the contact wire, which is protected by DC surge arresters. The various components of the OCS system, messenger wire, contact wire, supporting structure which consists of metallic poles, cross-arms, and the running rails are relatively close to each other. There are equal chances that the lightning stroke may hit any of the OCS components described above.

The cross-arms and grounded metallic poles may provide some measure of shielding of the OCS contact wire from a direct lightning stroke. In rare circumstances, if the lightning strikes the OCS wire directly, flash over is almost certain since the dry and wet flashover values of the OCS insulators are normally relatively low as compared to the direct hit lightning stroke peak voltage which could be as high as 200 kV.

The following equation has been used in power distribution overhead lines and can be used to calculate the discharge current and energy for the OCS surge arresters (*8*):

$$I_A = (E_S - E_A)/Z \quad (16)$$

where

E_A = arrester switching impulse discharge voltage (kV) for current I_A
E_S = prospective switching surge voltage (kV)
Z = surge impedance of the OCS wire (Ω), and
I_A = switching impulse current (kA)

Energy discharged by the arrester, J, in kJ, may be conservatively estimated by the following expression (*8*):

$J = 2\, D_L\, E_A\, I_A / v$

where

E_A = arrester switching impulse discharge voltage (kV)
I_A = switching impulse current (kA)
D_L = line length (miles or feet) or (km)
v = the speed of light (190 mi/ms) or (300 km/ms) or 1000 ft/µs

The expression assumes that the entire line is charged to a prospective switching surge voltage and is discharged through the arrester during twice the travel time of the line. DC surge arrester data including energy discharge capability, peak voltages, and currents should be reviewed carefully and compared with the analysis results. The numbers and locations of the surge arresters can be recommended based on the above analysis. As a minimum, surge arresters should be provided at each substation or OCS feed point connection and in low OCS clearance areas.

INDUCED VOLTAGE

An energized overhead power line that carries current produces an electric field and a magnetic field around the conductor and into the surrounding spaces. These electromagnetic fields may induce voltages and currents onto the metallic track rails and other nearby conductors. The electromagnetic fields are non-uniform near the power lines. The electric field intensity is dependent upon (proportional to) the power line operating voltage, while the magnetic field strength is dependent upon (proportional to) the power line current. Because the electric field is stronger and non-uniform near the power line, different voltages will exist at different points within this region. Conductors within this region will perturb the electric field and develop a voltage gradient of their own. In AC power line installations where the magnetic field is time varying, that is, it is continually expanding and collapsing, a longitudinal electromotive force (LEF) will be induced in nearby conductors.

In this discussion, we will distinguish between induced voltages, which are a result of electric fields, and induced voltages (and currents), which result from the magnetic field interaction. In a DC distribution system, the voltage induced in the region near the conductor is time independent except for the noise component and the longer time varying DC load component. The correct term for the DC case is electric potential difference or electrostatic potential difference. In an AC distribution system, the electric and magnetic fields are alternating, as are the induced voltages and currents in the conductors. The correct term for the AC case is electromagnetic field induction or electromagnetic coupling.

Power wires, signal wires, track rails, and conduits that are located near overhead power lines, are considered to be “disturbed conductors” and will develop different voltages with respect to each other and with respect to reference ground.

The electric field, which exists along a disturbed conductor, is directed perpendicular to the conductor. The strength of the electric field at any point varies inversely with the distance from that point to the conductor. This effect in the low voltage circuit wires can be minimized if these wires have simple coaxial shields with drains to ground, or are buried.

The magnetic field, which exists along an overhead power line, can cause a longitudinal voltage to be induced into a parallel power line or signal conductor. Ferromagnetic materials, such as iron or steel, provide for effective shielding against magnetic fields. Such materials, when used in the conduits that carry insulated conductors inside, will reduce the strength of the magnetic field and thus its induction effect. Steel conduit provides a high degree of shielding against magnetic fields.

Magnetically induced voltages can be attenuated by the development of a counter-electromotive force (EMF). Counter-EMF can be generated and introduced onto a conductor in a manner that will tend to cancel the effect of the disturbing electromagnetic field. Coupling energy from the source of counter-EMF may be accomplished with transformers known as neutralizing transformers or by direct coupling between the "shield wire" and the disturbed wire.

The close presence of an overhead power line provides some shielding effect from direct lightning strikes in the immediate vicinity of the line. However, surge voltages can be induced onto the signal circuits from the power line as a result of switching and lighting strikes occurring at a distant location perhaps many miles from the light rail facilities. Surge arrestors should be used to reduce these unwanted effects. Also, utility fault currents will cause voltages to be induced in nearby light rail circuits. The magnitude of these voltages will be much larger than what the normal induced voltages are along the light rail circuits.

Normal induced voltages exist at 60 Hz and higher harmonics. Low and medium voltage (up to 34 kV) line faults are also 60 Hz. High voltage transmission line faults have components in the 40 to 400 kHz range. Switching surges develop frequencies up to 1.5 MHz. Lighting generates surges with steep wave fronts with frequencies around 1.5 MHz.

Induced voltages and currents that are found on signal circuits may create a safety hazard to personnel, equipment, and service.

Induced voltages may cause equipment to malfunction. Equipment operations may happen when they should not, or equipment may be inhibited from operation when it should operate. Equipment damage may also occur from fused electrical contacts or from punctured insulation. Any of these situations may result in the impairment of safe train movement and costly inconvenient service interruption.

The following LEF objectives are recommended for the protection of personnel (*10–12*):

1. According to the National Electrical Safety Code, electrostatic voltage must be limited such that a short circuit current between a disturbed circuit and ground will not exceed 5 mA.
2. The following LEF objectives are generally accepted by the electric power utilities and the railroads for the protection of personnel as established by the Association of American Railroads and the Edison Electric Institute Joint Committee. For coordinating the location of the light rail facilities with the electric power utilities, the following maximum voltages apply to the light rail (disturbed line) circuits:
    - 60 V RMS residual is acceptable for normal operating conditions.
    - 150 V RMS is acceptable to exposed sections where special instructions are given to the personnel authorized to have access to the exposed sections and special markings appear on all equipment connected to the exposed sections.
    - 430 V RMS is acceptable for usual power line equipment and maintenance.
    - 650 V RMS is acceptable for highly reliable power lines where high-speed relaying and fault clearing is provided.

These voltage objectives originate from the international telecommunications field and are presented here for personnel safety, not for equipment environment. The voltage objectives for equipment must be developed through the exercise of engineering judgment.

A personnel safety hazard is created when there is a complete circuit path developed and any of the following conditions occur:

- A person comes into contact with a conductor having an induced voltage sufficient to cause a dangerous current to flow through his body.
- A person comes into contact with a high voltage conductor and the duration of the high voltage-causing event is sufficiently long in duration to be physiologically dangerous.
- A person comes into contact with a ground-return circuit.
- A person comes into contact with a circuit that is accidentally grounded.
- A person comes into contact with a circuit that is effectively grounded through a capacitance.

The disturbed conductors and circuits could fall into one or more of the following general categories:

- Rails and contact wire.
- Railroad signal and communications circuits.
- Railroad conduit.

Because the signal circuits are meant to be isolated from earth potential, a shock hazard will be present only if the conductor capacitance to ground is large enough to allow a voltage to be built-up or if one side of the circuit becomes accidentally grounded.

The danger to personnel is related to the amount of current through the human body, which depends upon the total resistance of the path between the conductor and reference ground. The total resistance includes the contact resistance between the ground contact to reference ground (resistance of earth), resistance of the human body, and contact resistance between the human body and conductor. The danger increases when the resistance of the human body becomes a large fraction of the total resistance of the ground return path.

The amplitude of voltage a person will experience will depend on whether the contacted circuit is grounded or not and where the point of contact is. Electrostatic induced voltage is usually a low energy phenomenon and can be controlled with nominal cable shields. The duration of an electrostatic discharge current through the human body is likely to be below the danger level.

The recommended safety measures to be taken by construction and maintenance personnel are as follows:

- All personnel should be instructed concerning the hazard voltages present at all times and should be required to follow safe working practices.
- The rails and OCS are long metallic conductors and a significant voltage may be developed on them when paralleling an overhead power line. Personnel performing work on them should be made aware of the potential danger and should be cautious with respect to electric shock.

- The track rails are unshielded and present day practice is to attempt to isolate rails from earth to minimize stray currents. Although the OCS provides some shielding, significant voltage may still be developed along the tracks under an electrical fault condition.
- Safety grounding practices should be employed when working on OCS and insulated protective gear used when working on track. The rails must not be connected to ground, which would compromise signaling and stray current measures.

It is important to recognize that the OCS will have an induced voltage present at all times, even if all power sources are disconnected. Construction and maintenance personnel must exercise caution whenever working on a section of the OCS. Safety grounds should be used at the location where work is being performed. If workmen must come into contact with the OCS involving a continuous section of more than one span, safety grounds should be applied at each end of the work area and at all points of catenary support within the work area. Grounding both sides of the work area is a necessary requirement for personnel safety.

SUBSTATION PROTECTIVE DEVICES AND CONTROLS

As a minimum, the following substation protective devices should be provided.

Medium Voltage Switchgear

Phase over-current relays, residual ground over-current relay, phase balance current relay, and under voltage relays should be provided with medium voltage switchgear.

Rectifier Transformer

Transformer winding temperature devices should be provided.

Power Rectifier

Rectifier diode temperature device, diode fuse, rectifier diode fuse monitoring device, and rectifier enclosure fault detection relays should be provided.

DC Switchgear

Protective relays associated with DC switchgear should include reverse current trip device, over-current trip and rate-of-rise relays, reclosing and load measuring devices, transfer trip, rail-to-earth over-voltage and DC switchgear enclosure fault detection relays.

Transfer Trip Protection

Transfer trip protection is highly recommended for the DC feeder breakers since this will be a reliable additional protection to ensure that faults in the DC traction power system are completely isolated and fault currents are not fed from the adjacent substations.

EMERGENCY SHUTDOWN SWITCH AND BLUE LIGHT STATIONS

History

NFPA 130, “Standard for Fixed Guideway Transit and Passenger Rail Systems,” was initially developed by the National Fire Protection Association in 1975. The purpose of the standard is to minimize “the potential for entrapment and injury of large numbers of people who routinely utilize …mass transit facilities.”

Applicability

NFPA 130 applies to all fixed guideway systems, including at-grade, tunnels, and aerial structures. The degree of applicability and interpretation is decided by the transit agency in partnership with local fire and emergency or rescue authorities in accordance with NFPA 130, Chapter 7 (2000), which states in part:

> General. The authority that is responsible for the safe and efficient operation of a fixed guideway transit or passenger rail system shall anticipate and plan for emergencies that could involve the system. Participating agencies shall be invited to assist with the preparation of the emergency procedure plan.

Ideally, the emergency plan has been developed and incorporated into the design criteria before the beginning of the Civil/Systems final design since the emergency procedures plan may mandate design requirements. If the plan is not in place, or is being developed concurrently with the design, interpretation of NFPA 130 may be left to the designers.

NFPA 130 Requirements for Blue Light Stations

The 2000 edition of the NFPA 130 3-1.5 reads (in part) as follows:

> 3.1.5 Blue Light Station
> 3-1.5.1 A location along the trainway, indicated by a blue light, where emergency service or authorized personnel can communicate with the central supervising stations and disconnect traction power.
> Traction power disconnect devices shall allow quick removal of power from power zones. Emergency shutoff of traction power shall be achieved by activation of remote manual-control devices, which, in turn, cause the operation of substation circuit breakers and associated trackway disconnect devices.
> 3-1.5.3 Blue light stations shall be provided at the following locations: (1) Ends of station platforms (2) Cross passages (3) Emergency access points (4) Traction power substations

NFPA 130 A3-1.5.3 reads as follows:

> A3-1.5.3 The placement of blue light stations at the ends of station platforms should be governed on actual need. For instance, an at-grade system that has

stations in dedicated streets and overhead power supply would not need blue light stations at the ends of platforms.

The traction power disconnect devices referenced by NFPA 130, above, are commonly referred to as ETS or Emergency Shutdown Stations (ESS).

Industry Experience

In an attempt to categorize industry experience in how they interpreted the NFPA 130 requirements for blue light stations, and in particular where agencies were providing hard wired traction power emergency disconnect devices, we surveyed all LTK TES engineers, and contacted several transit agencies. Our findings are summarized as follows:

- With some exceptions, blue light stations with a manually actuated hard-wired TES ETS are provided for third rail systems at passenger stations. This appears to be true both in the USA and foreign countries. These stations are usually accessible to the general public, and may be of the “break-glass” types. NFPA 130 does not state the reason, but it appears to be related to the urgency to shut down the third rail should a passenger fall into the pit at a station.
- With some exceptions, blue light stations with either a manually actuated hard-wired TES ETS or an emergency communications telephone are provided in tunnels and on aerial structures for both third rail systems and OCS LRT systems.
- With very few exceptions, hard-wired TES ESS are not provided for at-grade OCS systems for LRT or electric trolley systems either along the alignment or at station platforms. Indeed, most agencies do not provide blue light stations for OCS systems. From a practical standpoint, central control may be contacted directly by emergency personnel using cellular telephone or radio. The need for a direct line from a station platform to central control is greatly reduced. Also, it is difficult to conceive of a situation where the general public would need to shut down the system in the event of an emergency.
- With no exceptions, ESS is installed at each traction power substation location for both light rail and heavy rail systems.

SUBSTATION VENTILATION

We know that substations contain arcing devices such as circuit breakers and switches that produce ionized gas and batteries which can produce hydrogen. Some electrical insulation can produce explosive gas when burned. An adequate ventilation system for the inside of the substation building is therefore very essential. Ventilation ductwork and fans must be sized to handle the heat losses generated by the substation equipment. Filters and louvers should be provided to filter outside air.

Mechanical cooling (air-conditioning) may be used to cool substations in warmer climates and to supplement ventilation, but should not be used exclusively, since some ventilation is required to remove explosive gases.

SUBSTATION OPERATION AND MAINTENANCE

From the perspective of traction power substation maintainers, convenient access to equipment for servicing and maintaining, sufficient working space around equipment, protection from the weather, and adequate lighting are essential for maintaining and operating the substations. Equipment rear access should be taken into consideration. For built-in-place substations, an aisle should be provided behind the equipment with two means of egress and with panic hardware on the man doors. For packaged units, rear access to equipment may involve the removal of access panels using heavy equipment, and access needs to be provided accordingly.

Many electric utilities now require significant space behind their utility incoming cubicle for rear access and cable maintenance, and the attachment of grounds to the equipment bus using a “hot stick.” This may necessitate a door and access to the rear of the cubicle from the outside of the substation.

Substation maintenance may involve taking the traction power substation out of service. A means to over-ride SCADA (remote substation control and data acquisition) should be provided. Consideration needs to be given to the function of substation protective devices such as transfer trip when the substation is off line and the OCS tie switches are closed.

RECOMMENDATIONS

Development of a TES must be approached in a fully integrated manner. All of the concepts discussed in this paper must be considered as they relate to each other. The goals for the TES must be both determined and accepted early in the design of a total project.

The following should be included in the integration effort:

- Car propulsion system design that minimizes rail rise and line current draw under abnormal conditions.
- Early and often use of comprehensive computer simulation to optimize TPS size, number, and location, and OCS sizing when it is possible to influence these elements.
- Coordination among corrosion mitigation requirements, step and touch potential, sensing and clearing of remote ground faults, inductive interference effects, and railway signaling requirements.
- Track, grounding, and ground system configuration and parameters.
- Operational requirements, track configuration, OCS sectioning, and sectioning methodology.

Design Recommendations

- Provide a means of OCS remote ground fault detection and tripping;
- Minimize rail potential rise by decreasing substations spacing and reducing the size of substations and by increasing system voltage as appropriate;
- Adopt and follow the National Electric Code as closely as possible, especially for minimum working clearances; and
- Provide adequate ventilation to remove explosive gases from the substation.

The following testing recommendations are made:

- Include design demonstration and thorough qualification testing of the critical TES components and the TPS control system, including DC protective relays;
- Installation, commissioning, field testing and inspection should include ground fault testing, short circuit testing, and testing and setting of each substation protective system;
- Attain safety certification before the TES system is put into operation;
- Consider safety for step and touch potentials at the substations, around the rails, and at the station platforms; and
- Forensic data is needed to understand how TES systems fail in service in order to make design improvements; perhaps even legislation is needed that requires agencies to report more serious failures (IEEE Traction Power Substation Standards Sub-committee is presently working on this).

ACKNOWLEDGMENT

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BIOGRAPHICAL SKETCHES

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Traction Power Supply for the Portland Interstate MAX Light Rail Extension

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Interstate MAX is a 5.8-mi extension of the 39-mi MAX light rail system serving Portland, Oregon. The line will connect downtown Portland to neighborhoods and other major destinations in North Portland. Ten passenger stations are provided and located approximately every half-mile. Trains will provide direct service from Expo Center through downtown and back. The project is currently under construction and scheduled for revenue operation in May 2004.

A general description of the traction power supply system is presented. Primary power is provided by the local utility companies at 13.2 kV and 11 kV and rectified by six mainline traction power substations to deliver DC power to the light rail vehicles. The major items discussed are computer loadflow simulation, regeneration studies and the selection of 825 Vdc versus 750 Vdc as traction voltage, built-in place substations, substation PLC controls, grounding, way-side electrical distribution, testing, and energization.

INTRODUCTION TO TRIMET'S MAX LINE

TriMet's Metropolitan Area Express (MAX) is a 39-mi light rail system connecting the cities of Portland, Gresham, Beaverton, and Hillsboro. The first 15-mi Banfield Eastside MAX Line opened on September 5, 1986. The 18-mi Westside and Hillsboro MAX extension opened on September 12, 1998. The 6-mi Portland International Airport extension opened on September 10, 2001. The 5.8-mi Interstate MAX extension to the Portland Expo Center is scheduled to open in May 2004.

The MAX line now features 50 stations, 16 park-and-ride lots which provide spaces for 6900 cars, and 78 cars, including ultimately 52 new, air conditioned, low-floor cars. The Washington Park (Zoo) Station is the only stop in the dual-bore, 3-mi tunnel. At 260 ft underground, it is the deepest transit station in North America.

The low floor cars for the Westside Light Rail are the first of their kind in North America (*1*). They make boarding easier, especially for people who use mobility devices. Each 92-ft low floor car is capable of speeds up to 55 mph carrying 166 passengers, and costs $3.1 million each.

Average weekday ridership of the MAX system is expected to exceed 90,000 passengers by the year 2004.

TRACTION POWER SYSTEM

Overview

The Interstate MAX extension is powered by six built-in-place substations located along the system route spaced approximately one mile apart. The nominal (full-load) voltage is 825 Vdc. The nominal voltage was chosen to be the same as the Eastside Banfield Line in order to minimize voltage drop, maximize the vehicle propulsion system performance, and still maintain the benefits of train regeneration. Each substation is rated at 1MW and is connected to a three-phase nominal 12.47–13.2 kV distribution circuit from Portland General Electric, except the Graham traction power substation is connected to a 11kV distribution circuit from Pacific Power.

The overhead contact system (OCS) is similar in conductor sizes to the existing line with the 500 kcmil underground supplementary parallel feeder in the Rose Quarter area to sustain voltage levels at the east end of the line with the Rose Quarter substation out of service. The substations are designed to comply with National Electrical Code wherever possible, except for the DC portion of the substation equipment. The substations were built-in-place, and the equipment was installed by licensed electricians. Each substation building is required to be inspected by the State of Oregon electrical inspectors.

Equipment Arrangement

The equipment arrangement of the Interstate Max line substations is similar to the Westside substations, except that the traction power transformer was placed in the equipment line up between the AC switchgear and the rectifier and the building width dimension was increased to allow for rear access to the utility incoming cubicle, AC and DC switchgear equipment.

AC Switchgear

The AC switchgear assemblies are indoor, metal clad vacuum circuit type breaker. The switchgear is rated at 15 kV, 500 MVA. The following relaying protections are provided with the AC switchgear:

- Phase overcurrent protection (50/51);
- Ground overcurrent protection (50/51N);
- Negative sequence voltage relay (47);
- Rectifier overload relay (51A); and
- AC lock-out relay (86).

Siemens SIPROTEC 4 7SJ61 digital multifunction relay is used for overcurrent protection. Siemens 4700 AC meter is used for power monitoring.

Traction Power Transformer

The traction power transformers are vacuum pressure impregnated dry type. All transformers are rated 1110 kVA 65°C rise at 100% load, three phase, 60 Hz. The traction power transformers and the power rectifiers are matched assemblies capable of providing a twelve pulse, 825 Vdc output at rated 100% load using ANCI circuit no. 31. Primary windings are connected in delta and have six taps, except the Graham traction power transformer has two additional lower taps to accommodate the incoming voltage of 11,300 Vac. These taps are used to accommodate the utility's voltage variations and to provide limited control of the DC output voltage. The two secondary windings are connected in delta and wye with 30-degree phase shift to obtain 12-pulse rectification which reduces the harmonics in the utility power lines and the interference voltages due to residual ripple. The transformers are built in accordance with ANSI and NEMA standards for extra heavy-duty service. Transformer winding temperature devices furnished with the traction power transformers are used for annunciating or tripping upon pre-set high coil temperatures.

Power Rectifiers

The rectifiers are naturally ventilated silicon traction power rectifiers with silicon disc-type diodes. There are two three-phase bridges connected in parallel with two diodes per arm of one of the three-phase bridge. This configuration results in a total of 24 diodes per power rectifier. The two three phase bridges are connected in accordance with ANSI circuit 31 configuration. The nominal rated DC output is 825 Vdc. The rectifiers are rated at 1000 kW continuous load with the overload capabilities as specified in NEMA RI-9 for extra heavy-duty traction service.

DC Switchgear

The DC switchgear consists of a positive cubicle, which houses the motor operated disconnect switch connected to the positive bus, two DC feeder breakers and a negative cubicle. The negative cubicle includes a 2000A manual disconnect switch, keyed interlock with the positive switch, DC shunt current measurement, an interphase transformer, and a low resistance frame fault protection device with current and voltage tripping. Each feeder cubicle includes a 2000A high speed circuit breaker, solenoid operated with direct acting overcurrent trip device, 2000A/60mV Shunt and a Digital Protection Unit for incomplete sequence, over-current trip and rate-of-rise relays, reclosing, load measuring devices, and transfer trip protection.

Programmable Logic Controller

A Programmable Logic Controller (PLC) system was programmed to integrate and control all intercubicle functions and provide control, monitoring, and data logging at each substation. Auto-reclosing relays and logic, auxiliary relays, timers, and relaying logic were done through the PLC system. Considerable internal cubicle spacing was realized and interconnecting cabling between cubicles was virtually eliminated.

The PLC control system consists of the following components:

- Siemens "SIMATIC" S7-300, consisting of CPU, signal modules, and interface board; and
- Siemens SIMATIC Operator Panel OP3.

Station Service Cubicle Section

The station service cubicle includes a primary fused interrupter switch and a 25 kVA single phase, dry type, 115°C rise transformer. The transformer was built in accordance with ANSI C57.12 and was designed and tested in accordance with ANSI C57.12.91 inside the switchgear enclosure to determine maximum temperature rise. The transformer is mounted in the bottom rear of the compartment for easy access and maintenance. The access door to the rear transformer compartment is key interlocked with the fused interrupter switch to prevent access to the energized equipment.

Each substation is equipped with an AC and a DC distribution panelboard.

Grounding System

The substation grounding system is comprised of two separate ground mats referred to as the “AC” and “DC” mat, and one separate ground rod (*2*). The AC ground mat, designed to meet the requirements of IEEE 80 to limit step and touch potential to safe levels in the event of a fault on the AC system, is also used to ground the building metallic structure, conduits, and AC equipment, including switchgear. The AC ground mat is placed under the substation, and extends a minimum of 5 ft beyond the perimeter.

Another smaller ground mat called the “DC ground mat” is used exclusively for grounding of the DC equipment, including the negative bus through a diode for stray current monitoring or testing, and for grounding of the DC lightning arresters and protective relays.

A separation of 25 ft minimum between the AC and DC mat is used to reduce fault current contribution from the AC equipment to the DC equipment. It also provides for some reduction in DC stray current.

The 15 kV cable shields from the utility service 3 phase, 3 wire service conductors are isolated from the substation by termination on an isolated lug within the utility cubicle in the AC switchgear, and grounded to a single ground rod located a minimum of 25 ft from the AC and DC ground mat. This provides an effective grounding path through earth back to the utility supply in the event of a fault on the utility system, while significantly limiting the ground fault current contribution from the utility to the ground mats.

Ground mats are constructed from an assembly of driven rods and bare copper conductor. All joints are exothermically welded. The mats are typically located at a minimum of 3 ft below finished grade, and constructed before the substation building is built. The conductors are encased in native soil, which in most cases is clay with a resistivity between 50 and 100 ohm-meters, except at Delta Park substation where the soil resistivity is over 160 ohm-meters. At this particular substation location, four additional 50-ft ground rods encased in Bentonite material were used to achieve a lower value for the substation ground mat resistance. An insulating layer of 2 in. minus crushed rock, free of fines, is then placed over the ground mat, and a layer of “filter fabric” cloth is placed on top of the rock to prevent the contamination with the layers of soil surrounding it. The top layers may be comprised of asphalt, or soil, and this lends versatility to the design of the installation, since it permits planting, or landscaping.

Stray Current Monitoring

Each substation is equipped with provisions to monitor stray currents. Within the DC switchgear negative switch cubicle is a shunt and bolted bus link in series with the DC grounding conductor. By bolting the link in the closed position, the DC mat can be used to ground the negative return through a diode. In this position, the DC mat acts as a stray current collector and most stray currents will flow through the shunt. The shunt can be connected to a chart recorder or voltmeter to monitor and record stray currents over time.

An AstroDAQ data acquisition system is used for the monitoring, acquisition, storage, and review of real time data of the stray current monitoring system. The AstroDAQ utilizes a personal computer running the Windows operating system.

Emergency Shutdown

As a safety feature, each substation is equipped with two emergency shutdown stations. One button is recessed in a stainless steel enclosure mounted in an exterior wall and accessible by key only. The other button is readily accessible and located inside the substation by the access door. Actuation of either button will trip and lock out the 15 kV AC breaker of the substation, and transfer trip and lockout the DC breakers at the adjacent substations, thus completely isolating the fault or trouble.

Substation Field Acceptance and Commissioning Tests

In addition to factory tests, which include design verification and production tests for each type of major equipment, functional tests were performed to verify the correct installation of the equipment, and each protective device was tested and checked for correct settings.

The full voltage short circuit testing was performed after the functional testing has been completed. The purpose of the short circuit testing was to verify the correct operation of the substation protective relays and the fault-withstand capabilities of the substation equipment.

Two series of fault tests were performed at selected substations. The first test was to verify the successful interruption of maximum and minimum fault currents supplied by a substation. The second series of fault tests were carried on an OCS section fed by two substations to check for maximum energy fault and transfer tripping protection.

Computer Performance Simulation

The simulation was performed using the RR Model developed by LTK Engineering Services specifically to perform traction power simulation; the model is a comprehensive software tool used for the design and analysis of DC traction power system. The RR model consists of a group of programs capable of simulating the entire electrification system from the power utility interface point to the vehicles. The information used by the simulator includes track alignment and grades, traction power substation type and characteristics, DC distribution systems including the OCS, DC feeders, and return rails, and the power characteristics of the vehicles to be used on the system. The programs are written in C++ and is Microsoft Windows based with many user definable settings. These settings allow the user to quickly and accurately enter the vast amount of input data required.

The vehicles were simulated to operate on the network according to a fixed schedule taking into account route geometry, speed limits, and passenger station stops. The RR simulator accurately models the tractive effort and current curves for the desired vehicle and automatically adjusts these curves as the traction power voltage varies over the prescribed route. This is accomplished through the use of direct matrix inversion techniques and the ability to iterate to a steady state voltage condition.

The computer simulation was used to verify that the RMS power demand on each substation was within the allowable limits, that the voltage delivered to the vehicles was within acceptable limits, and that the current draw in the substation underground feeder cables and the overhead contact wire would not create an unacceptable increase in conductor and insulation temperature under the above criteria.

The voltage at the pantograph is designed to remain above the minimum 525 Vdc requirement at all locations during the sustained 3-min headways with all substations operating, and during peak operation using the 2005 revenue service schedule. The TES system is not designed to support 3- min headways with one substation out of service. Under these conditions, voltages below 525 Vdc will occur when two trains simultaneously accelerate out of a passenger station where the nearest substation is off line and the adjacent substations are approximately a mile away in either direction. The result of the line voltage dropping below 525 Vdc will be a propulsion cut-out on the affected vehicle. The cut-out will automatically reset without damage to the vehicle when the line voltage returns to a level above 525 Vdc. Line voltage will immediately return when one of the two vehicles drops propulsion. In general, in order to avoid these occurrences with one substation out of service during the peak schedule, train acceleration rates must be reduced by direction from Central Control in the vicinity where the substation is out of service.

TRACTION POWER SUBSTATION BUILDINGS

The substation buildings, including low voltage substation AC auxiliary electrical system and facility electrical equipment such as AC panelboards, heating and ventilation systems, transformer partitions, all embedded conduit work, utility instrument enclosure, door intrusion switches, lighting, and substation ground mats were built in the “Civil” contracts in advance of the Traction Electrification contract.

The medium voltage electrical systems, traction electrification, and communications equipment were installed later in the follow-on TES/Communications contracts. Included in the Traction Electrification contract were cable trays, conduit systems, and cable for traction power, electrically insulated floor coating under the DC switchgear, AC and DC switchgear, traction power transformers, and the substation alarm panel. The Remote Transmitter Unit connected to the Supervisory Control and Data Acquisition system (SCADA) was installed by the Signals/Communications Contract.

Refer to Hastings et al. (*3*) for additional information on TriMet built-in-place traction power substation buildings.

OVERHEAD CONTACT SYSTEMS

Single Contact Wire Auto Tensioned

The Single Contact Wire Auto Tensioned (SCWAT) is installed from the existing MAX route at Rose Quarter Half Grand Union to the Interstate MAX Rose Quarter Station. The SCWAT system is auto-tensioned by using balance weight assemblies to maintain constant tension despite temperature variations. The SCWAT consists of a single contact wire (300 MCM) connected in parallel with an underground 500 MCM supplementary parallel feeder cable. The SCWAT system is supported by single-track cantilever, cross-spans by rollers and bridles mounted on steel poles. Two levels of electrical insulation are provided between the contact wire and a grounded pole or other grounded structure.

Simple Catenary Auto Tensioned

The Simple Catenary Auto Tensioned (SCAT) system is installed from the Rose Quarter Station to the Expo Center. The SCAT system consists of a single contact wire (300 MCM) suspended from a 500 MCM messenger wire. The SCAT is auto-tensioned by using balance weight assemblies so that the tension remains constant despite temperature variations. The SCAT support structure consists of either single-track cantilever, or headspan arrangements mounted on steel poles located between the two tracks. Two levels of electrical insulation are provided between the contact wire and a grounded pole or other grounded structure.

OCS Support Systems

Wide flange or tapered multifaceted tubular poles and all cantilever structures are made of galvanized steel. Cantilevers are mounted back to back on a common center pole located between the tracks. Where the clearance between tracks is not sufficient, side poles with head/cross span arrangements are used. At overlap sections and at turnouts where two cantilevers are required, both cantilevers are installed on the same poles for aesthetic appearance improvements.

Balanced Weight Anchor Assembly

The tensions for the contact wire and messenger wire are 3000 lb and 4500 lb at 60^{o}F respectively. Both the contact and messenger wires are combined tension and the forces are maintained by counterweight wheel with a ratio of 3:1 between wires and counterweight. The maximum distance between two tensioning points is about a mile and depending on the amount of curves and the individual track configuration, the distance would need to be reduced to ensure the auto tensioning effect of the wheel assembly. A mid-point anchor is installed approximately at the mid-distance between the weight assemblies to reduce the along-track movement of the OCS equipment and minimize the work in case of a conductor breakage.

Sectionalizing

OCS is sectionalized to provide isolation of the OCS section at each substation. Insulated overlaps are used for sectionalizing. Section insulators are installed at the crossover locations. To maintain electrical continuity, jumpers are used at overlaps and at crossover locations.

OCS Disconnect Switches

OCS Disconnect switches are of outdoor type, single-pole, single throw, non-load break, non-fusible, manual air–insulated switches.

CONCLUSION

The Interstate MAX light rail extension was designed and implemented to be safe, reliable, cost-effective, easily maintained and efficient. The TriMet MAX system has been in operation for over 16 years, the system has functioned quite well, and ridership has been increasing steadily and additional extensions of the system to Clackamas, Milwaukie, and to Clark County are imminent.

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BIOGRAPHICAL SKETCHES

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Built-in-Place Substations

Beauty and Brains at the Right Price— TriMet's Traction Power Substations Evolve to a Higher Level

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Light rail traction power substations (TPSs) do not have to be unsightly and hidden in the most remote recesses of the project. The large painted metal boxes surrounded by cyclone fence that have become the familiar norm for many projects are being replaced by built-in-place buildings in Portland, Oregon, where the Tri-County Metropolitan Transportation District of Oregon (TriMet) and the community are concerned with aesthetics and have made the TPS an important and prominent design element.

The general design, construction, costs, contract packaging, advantages and disadvantages, and features of the TriMet built-in-place substation buildings are discussed, and they are compared to similar packaged units.

Built-in-place TPSs are far more likely to be accepted by their neighboring community. This acceptance allows them to be an important part of the architectural design of the stations, platforms, and other design sensitive locations. Field constructed TPSs using built-in-place buildings are a cost effective alternative to packaged traction power substations. Built-in-place TPS substations can offer more working space around equipment and better access to equipment, compared to packaged substations.

INTRODUCTION

The Portland TriMet light rail system is comprised of approximately 39 mi of line serving the greater Portland Area, with another 6 mi currently under construction. The original Banfield line has operated since 1986; the Westside and Hillsboro extensions have operated since 1998; and the Airport Extension began service late in 2001. The Interstate line will open in 2004.

Supporting the load are 38 mainline traction power substations (TPSs), one yard TPS at Elmonica Maintenance Facility, and two small TPSs feeding the overhead catenary system (OCS) inside the operation and maintenance buildings. Six additional mainline TPSs and one new yard TPS at Ruby Junction Maintenance Facility will be added by the Interstate project. Characteristics of the TPSs are summarized in Table 1.

TABLE 1 TriMet Substations

	Banfield	**Westside**	**Airport**	**Interstate MAX**
Length of Line (mi)	15	18	6	6
Number of TPS (mainline)	15	18	5	6
TPS Full Load Voltage (Vdc)	825	750	825	825
TPSS Rated 100% Output Power (kW)	750	750	1000	1000

HISTORY

The Banfield substations were factory "packaged" units, featuring traction electrification equipment installed in prefabricated gray metal boxes at the factory. The packaged units were then installed on concrete foundations with crawl spaces for cable installation. The Westside and Airport substations were constructed in place. The Westside buildings used either brick or concrete masonry unit (CMU) construction. The Airport line substations were constructed from precast concrete panels. The Interstate MAX (IMAX) substations are the latest CMU design with glass block lights and metal roof, and are presently under construction. Installation of traction power equipment at the new Ruby Yard TPS is nearly completed.

After using typical prefabricated traction power substations on its first LRT project in the 1980s, at the beginning of the design of the Westside Light Rail (*1*), TriMet decided to locate many of the substations at passenger station platforms with the intention of building a brick façade around a packaged TPS. Additionally, several TPS were intended to be constructed in place within larger structures. The architectural treatment was in response to community desires for more aesthetically pleasing structures and to support urban design goals.

Preliminary cost analysis indicated that the cost for constructing a building and installing the traction electrification equipment in a follow-on contract was economical and feasible, and to be preferred over the alternative of attempting to construct a façade after the installation of the prefabricated TPS. The engineers managing the design and construction of the traction electrification contract, since all the substations would be constructed in the same manner, also favored this approach and the location at stations generally provided the best electrical performance.

Thus, beginning with the Westside LRT and continuing to the present, TPS buildings have been integrated with the station platforms wherever permitted by right of way or property availability. Otherwise TPS buildings have to be carefully integrated within the surrounding neighborhood. This consolidation of real estate reduces initial cost, and gives the urban designers and local artists enhanced opportunities for design and artwork. This approach has been well endorsed by the community, project architects, urban designers, and systems engineers. The larger working space and rear access to equipment incorporated into the latest IMAX design have been well received by TriMet operation and maintenance staff.

ARCHITECTURAL PERSPECTIVE

Building Features

In order to maximize the benefits of site built substations, it is important to address the scope of the total building.

Building Location and Context

In order to maximize energy efficiencies and reduce costs, it is imperative to locate the TPS as close to the LRT station as possible. When the station area is limited, a well-designed TPS can be successfully integrated into the neighborhood, or be an attractive feature along the alignment. In the Portland metropolitan area the typical off-station site is a 50 by 100 ft plot. The building will need to comply with each city's urban design guidelines and community aesthetic concerns. The IMAX TPS building form is a response to local neighborhood and adjacent property owner requests to fit into the scale of residential and urban streets. In either at-station or off-station site locations, the site plan needs to be carefully considered and carefully situated for its specific location.

Building Design and Materials

The new TriMet standard for TPS buildings features include a clearly recognizable triangle roof form, which is carefully detailed at the gable ends and eave lines. The building's design and materials were chosen to harmonize the scale of the substation in relation to its neighbors. By using careful, quality design, modest yet durable materials can be utilized. The interior floor plan is 19 ft 1 in. by 41 ft 10 in. by 13 ft 3.5 in. high. This incorporates a narrow access space along the rear of the traction power equipment. This layout allows for easily access to all the equipment round the clock, and in all seasons. All materials are noncombustible. Some of the substation building attributes are

- Metal galvanized roof coating that is a muted silver or gray over a waterproof sheathing and fire treated plywood diaphragm.
- Roof structure is premanufactured light gauge trusses anchored to wall plates.
- Exterior walls are a honed face, load bearing, concrete masonry system in a stack bond.
- Ballistic rated clear glass bricks are interspersed under the roof line, and along the street facing elevation.
- Antigraffiti coating is applied to CMU.
- Exterior paint is an abrasion resistant coating system.
- Interior walls are gypsum wall board with 4 in. metal studs, rigid insulation, and vertical metal framing channels at 4 ft on center.
- Gutters are deleted to minimize maintenance and allow storm water to recharge the local groundwater.
- Landscaping is provided to blend into the neighborhood vernacular.

Mechanical and Electrical Systems

TriMet's goal was to use cost effective, durable, low energy use, and easily maintained ventilation, heating, and lighting systems. The lighting is positioned to enhance security and safety during the evenings. A modest amount of interior illumination radiates through the glass bricks to give the appearance of the building being occupied. Fluorescent lighting is used inside and outside. Exterior light fixtures are located at each door and on the gable roof ends for security and safety. Heating is provided by a ceiling mounted, 10 kW electric heater. The cooling system utilizes two 4100 CFM attic ventilation fan units with back-draft dampers that draw filtered air through door louvers. The attic space is insulated.

Table 2 provides building specifications for IMAX TPS.

Contracting Methodology

TriMet has learned that the contractor that constructs the TPS building must be experienced in *building* construction. A *civil* contractor that coordinates packaged TPS building site requirements might be satisfactory, but in our experience, utilizing the knowledge and skills of a builder subcontractor can help overcome many concerns of site, mechanical elements, codes, and material coordination. A building contractor tends to monitor the construction process more closely, and understands how to manage the coordination of equipment, materials and products, and schedule. We also encourage the use of local subcontractors, trades, and product suppliers. It builds local capacity in the community, and reduces transportation costs and environmental impacts.

Built-In-Place Versus Prefabricated Buildings and Packaged TPS

When the TriMet IMAX built-in-place TPS buildings are compared with Airport MAX prefabricated buildings or the Banfield packaged units, there are a number of similar features:

- Weatherproof enclosures,
- Site built foundations,
- Ground mats,
- Site fence enclosures, and
- Landscaping.

However, there are also many significant differences that the prefabricated Airport building design or Banfield packaged units did not provide. They had

- No interior rear equipment access aisle.
- No interior to exterior security illumination.
- No exterior form or materials that would meet city requirements.

TABLE 2 IMAX TPS Building Specifications

Architectural Specifications	
Building Dimensions	Interior: 19 ft, 1 in. by 41 ft, 10 in. by 13 ft, 3.5 in. high
Walls	Load bearing, honed-faced CMU, with 4-in. metal studs, vapor barrier, R-19 rigid insulation, and 5/8 in. Type X sheetrock. 1 5/8 in. x 1 5/8 in. 'Super-strut' metal framing channels. Interior Latex paint.
Ceiling	5/8 in. Type X sheetrock, insulated R-30 batt insulation. 1 5/8 in. by 1 5/8 in. Super-strut metal framing channels
Ceiling Trusses	Prefabricated and engineered light gage steel trusses
Roof System	Pre-finished 'Zincalume' 24 gage metal roofing, over 30# felt, fireproofed plywood
Floor	Reinforced concrete slab-on-grade, 6 in. minimum, with polyethylene membrane. Sealed with acrylic, dustproof liquid membrane.
Doors	Steel, insulated, with stainless hardware and panic bars
Mechanical Specifications	
Cooling	Filtered exhaust air ventilation only (no air conditioning) designed for interior temperature using actual equipment full load losses. Two stage thermostat controlling both fans and unit heater. Heater will come on at 40° falling and off at 50° rising. One fan shall turn on at 85° rising, the second fan shall come on at 95° rising. Fans will turn off at 80° falling.
Heating	Chromolux 10 kW unit heater
Motors	(2) 1 H.P. Propeller Sidewall Exhaust Fans; drip proof, open type, with back draft dampers.
Control	Two stage, automatic/manual
Filters and Dampers	Door mounted
Electrical Specifications	
Interior Lighting	Fixtures are 4 ft length with 4 F32T8 fluorescent lamps, designed to provide adequate illumination for detailed maintenance; Emergency lighting provided by battery back-up "wall packs" for emergency egress only
Exterior	Fluorescent, 39 W wall packs, designed for each installation with automatic control (photocell or time clock)
Receptacles	120-V receptacles provided for maintenance only
Power	120/240 Vac panel installed prior to the Traction Electrification contract and temporary service provided by the utility (Converted in the TE contract)
Provisions for TE	Exterior NEMA 4x Emergency Shutdown Enclosures, ground mats, and substation ground buses, ductbank

Traction Electrification Design Parameters

- National Electrical Code compliance; inspected by local and state of Oregon electrical authority
- Building sized to accommodate all potential suppliers
- DC feeder trench allows versatility in suppliers' equipment arrangement
- Equipment doors and access allows for quick equipment removal and replacement if necessary
- Ventilation system designed for optimum cooling while removing ionized or potentially explosive gases from inside the substation.

- Not easily incorporated into station design.

Other factors that make a built-in-place building desirable over a prefabricated building or a packaged TPS building are

- Easy incorporation of art features.
- Floor plan flexibility that can respond to a variety of site conditions.
- The option to incorporate into the station, which reduces real estate costs.
- The ease of conduit, duct bank, and cable installations.
- The ease of operation and maintenance, which means low agency costs.
- Q assurance and quality control inspections that are local versus factory visits.
- Project dollars that stay in the local economy.

ENGINEERING PERSPECTIVE

The advantages and disadvantages of built-in-place traction power substations buildings will be discussed from the perspective of the traction power engineer for the three separate phases of the project: 1) preliminary design; 2) final design and procurement; and 3) construction.

Preliminary Design

Ideally, when the preliminary alignment and preliminary design criteria for the light rail line have first been decided, the traction power engineer will be involved in the process of determining the locations of TPSs, and will have the opportunity to run multiple train simulations to assist in the process of deciding the locations. Past experience has shown that in order to minimize voltage drop and hence the cost of the OCS and parallel feeders, as well as minimize the number of substations required to meet the criteria, the substations should be located near the points of maximum acceleration—which is usually at passenger stations and major grades. The community and project acceptance of architecturally pleasing buildings allows integration of the buildings into the stations where the placement is electrically optimum. In contrast, on projects where prefabricated buildings or packaged TPSs have been used, community acceptance was much less forthcoming, and the project strategy was to conceal the substations and place them at a distance from areas of architectural sensitivity. Therefore, acceptance of the appearance of the substations by the community creates restrictions upon the electrical performance of the system to some degree by determining substation placement. In this respect, the use of built-in-place buildings over prefabricated or packaged TPSs affords the design engineer the opportunity to place the substations optimally.

During preliminary design, opportunities should be identified for co-location of the TPS with other facilities such as parking lots for park and ride facilities, where the land use and cost can be minimized—for example, locating the substation ground mat under an asphalt parking lot.

Consideration should also be given during preliminary design to the number of substations that will have to be constructed in place, sometimes in existing structures or buildings. The administration of the traction electrification (TE) construction contract is easier if all the substations are of one kind—either all built-in-place, or all packaged units. Table 3 compares built-in-place TPS buildings to prefabricated substations.

TABLE 3 Built-in-Place TPS Buildings Versus Prefabricated Steel TPS Building Used for Packaged TPS

	Built-in-Place Building	Prefabricated TPS Steel Building
Initial Cost	Higher	Lower
Transportation/ Install Costs	None	May be high
Community Acceptance	Can be integrated with platform design and made architecturally pleasing	Poor, especially in central business district
Watertight Integrity	Few seams, water intrusion is normally not a problem even under maximum ventilation	Metal buildings are constructed with many seams which may not be waterproof. Water intrusion a possible problem, especially with maximum ventilation
Thermal Insulation and Sweating	Easy to achieve, and nonmetallic surfaces typically do not sweat	Difficult to achieve thermal insulation since interior walls are metal
Maintenance	CMU exterior does not require maintenance	Painting required to preserve metal
Design Limitations	Typically None	Shipping dimensions limit design and equipment arrangement; difficulty in obtaining NEC working clearances (Art 110 and 250-110)
Access to Equipment for Maintenance	All equipment maintenance can be performed indoors in any weather	Rear of the equipment is usually accessible by removing outside panels or opening doors
Site Restrictions	Vehicle and forklift access must be allowed to equipment, double doors only	Vehicle access must be allowed to entire rear wall of substation to remove panels and maintain equipment
Future Modification of Equipment or Building	Space for future expansion be provided without great expense	Space is at a premium
NEC Compliance	On-site building inspection ensures compliance prior to installation of TE equipment	Not inspected until after installation of TE equipment and installed on site
TE Equipment Installers	NEC qualified State Licensed Electricians	Factory workers

Final Design and Procurement

Final design marks the beginning of a process of design refinement and property procurement that will affect the substation placement and ultimately, can affect the decision of whether to build the substations in place, or procure packaged units. At the beginning of TE final design, the TPSs are placed in electrically ideal locations, with performance assured by running a computer simulation. We have found that built-in-place substations that have been placed as a part of an architectural design will remain in place, at least on the same site, and this stability is of benefit to the designer since it minimizes design changes. Packaged TPSs may move as the project attempts to hide them, or move them into less architecturally sensitive locations and this can destabilize the design effort.

To complicate the design process, the TE design involves both provisions in multiple "civil" contracts for the traction electrification, and the installation of the TPS equipment and OCS in the TE contract itself. Usually, the design schedule is organized so that the designs run concurrently, with the civil designs preceding the TE design. Generally, the work in the civil contract entails all underground work, or work in tunnels or on structures, including all underground conduit work and ground mat construction. The civil contracts also include either a foundation for a packaged TPS or a complete TPS building. It is absolutely essential from the TE design standpoint that the TPSs be located and stable at the beginning of final design, because TE designers may be involved in every civil contract. Changes in substation location are very difficult to accommodate at this stage and involve a second simulation; they may involve extensive changes to both the TE package and the civil contract packages. These factors favor the built-in-place buildings over the packaged TPS buildings.

Other design considerations include compliance of the finished TPS with the National Electrical Code (NEC), organization of the TE construction contract and contract interfaces, and cost.

Construction

Whether substations are packaged, built-in-place, or prefabricated, the TE work will extend to the civil contracts as noted above.

The construction phase of the project is when the electrical inspection authority will become involved in the project for the first time. The State of Oregon has written into law that TPSs and TPS buildings are subject to electrical inspection up to the DC equipment. For built-in-place buildings, the first inspection occurs before the TE equipment is installed, and includes all AC low voltage lighting and power, heat, and motor starters for the ventilation. The buildings pass inspection without a problem since the wiring is done by Oregon-state licensed electricians and contractors knowledgeable in the NEC. A second and final inspection then takes place after installation of the TE equipment.

In contrast, for packaged buildings, maximum shipping dimensions determine the maximum allowable width which can lead to working clearances about equipment less than those recommended by Article 110 of the NEC, and therefore, issues with the electrical inspection authority arise. There has also been a misconception by manufacturers that they are exempt from the NEC requirements as stated in Article 90, which can conflict with state law. Construction contracts now require that all field wiring be done by licensed electricians and conform to the NEC. These requirements are easily met by building in place, but may not be easily met with packaged substations. It is important to recognize that dealing with the inspection issues during construction can be taxing on both the project budget and manpower resources, and so there is an indirect cost savings by minimizing inspection issues. For TriMet, part of the solution to minimizing inspection issues is to build the TPSs in place.

Another factor affecting both quality and cost is contract organization. If the choice is made to procure packaged TPSs, then agency oversight should be established at the factory, which usually involves one inspector at the factory during installation of the TE equipment in the prefabricated buildings. In addition, another inspector will be required to oversee the installation of the packaged units on the foundations, and witness start-up and field tests. These tasks may overlap. If the choice is made to construct buildings in place, the administration of the TE contract is simplified by the elimination of the ongoing factory inspection. After approval of shop drawings and submittals, witnessing of design tests, and first article inspections, the need for factory inspection is greatly reduced, and only one TE substation inspector is required. However, it is essential that the manufacturer provide an on-site engineer to supervise installation every step of the way so the completed product is to the satisfaction of both the agency and the manufacturer.

OPERATION AND MAINTENANCE PERSPECTIVE

The decision whether to procure packaged substations or build the substations in place determines to a large extent how easily and successful the follow-on operation and maintenance program can be executed during revenue service. Maintenance-of-way has set several priorities for maintenance, which we attempt to accommodate in the design:

- Easy and ready access to the traction power transformer coils, and bolted bus connections;
- Maintenance not dependent upon weather;
- Adequate working space around switchgear; and
- Adequate floor space to accommodate and work on circuit breaker trucks.

These considerations are easily accommodated in the design of substation buildings. For example, all maintenance is performed from the inside of the substations, except when a component must be removed and replaced. Packaged substations, in contrast, are much more compact and the traction power transformers and switchgear are usually accessed through panels and openings in the building from the outside, where weather is a factor. Also, packaged substations may have bolt-on removable steel access panels that require a forklift or heavy piece of equipment to remove, which complicates the maintenance process.

COST COMPARISONS

Overview

The TriMet buildings can be categorized into the following types with the associated costs:

- Banfield—Packaged TPS with metal buildings and factory installed equipment, cost undetermined.
- Westside MAX—Brick exterior veneer steel frame building, constructed in place, $274,000.
- Airport MAX—Precast concrete building, constructed in place, $217,000.
- IMAX—CMU building, constructed in place, $240,000.

The above building costs are expressed in 2002 U.S. dollars and include costs to transport materials and equipment to the site, site work, foundation slab, ground mat, and complete building electrical and mechanical systems. (An itemized cost breakdown is not available for the Banfield packaged substations.)

Built-in-Place Substation Cost

The average building cost for a substation building is about $240,000. This average figure is based on the recent bid for the TriMet IMAX Civil Construction Contract LS-10A/B, May 14, 2001 (*2*). This building cost includes site preparation, ground mat, foundation slabs, wall systems, concrete unit masonry, doors, coatings, and complete building electrical and mechanical systems. Cost for the transporting, furnishing, installation, and testing of the TE equipment for a typical 1MW substation is about $328,000. The installation cost includes 2 kV outgoing DC feeder and negative return cables. This is the average cost obtained from the recent bid on the IMAX Traction Electrification Contract, November 6, 2001 (*3*). Since the site work, substation foundation slab, and ground mat are also required for prefabricated or packaged substation building, this cost(estimated at about $50,000) will be deducted from the unit cost for built-in-place substation building. The average cost for a completed, furnished, installed, and tested of a built-in-place substation is, therefore, equal to $518,000.

Prefabricated Built-in-Place Substation Cost

At first glance, it appears that a slight savings may be realized by using precast concrete construction. However, numerous disadvantages in precast construction—such as restrictions on size and placement of door openings, and the absence of an attic space for ventilation—favor other methods of construction. Also, the Airport MAX substations were approximately 15 ft by 39 ft, or 585 sq ft. The IMAX TPS, by comparison, were 20 ft by 42 ft, or 840 sq ft, so on a square foot basis the Airport MAX TPS building cost $370 per square foot, whereas the IMAX TPS building cost $285 per square foot—a significant savings.

Packaged Substation Cost

Cost for furnishing, installing and testing of a typical packaged substation building is itemized below:

Items	*Cost*
TPS	$450,000
Field Install	$25,000
Field Testing	$10,000
TPS Field Engineer	$10,000
Factory inspections	$10,000
Architectural Treatment	$5,000
Total Cost	**$510,000**

The installation cost includes receiving, off-loading, installing the TPS onto the slab, connecting AC service and outgoing positive feeder and negative return cables, and field testing. A representative from the TPS manufacturer is required at the site during the installation of the substation. Assume that four factory visits are needed for quality assurance inspection during the manufacturing of the substation equipment and building. The cost for the architectural treatment to the building enclosure varies, and a figure of $5,000 was used for this estimate.

Cost for a complete, furnished, installed, and tested built-in-place substation is only about 5% higher than that of a packaged unit. If savings in real estate cost and shorter conduit/ductbank runs for built-in-place substations are included in the total TPS cost, the costs appear to equalize, or favor the built-in-place over other methods of construction. Furthermore, the built-in place substation building clearly offers more advantages. Table 4 compares the costs of built-in-place substations to prefabricated substations.

Comparison of Total TPS Costs

In summary, the total costs for a 1 MW TPS, installed, complete, are

- IMAX CMU built-in-place, $518,000;
- Airport MAX prefabricated built-in-place, $495,000; and
- Typical Packaged TPS, $510,000.

SUMMARY AND RECOMMENDATIONS

- Built-in-place TPSs are far more likely to be accepted by their neighboring community. This acceptance allows them to be an important part of the architectural design of the stations, platforms, and other design sensitive locations.
- Field constructed TPSs using built-in-place buildings are a cost effective alternative to packaged traction power substations.
- Built-in-place TPSs can offer more working space about equipment and better access to equipment when compared with packaged substations.

TABLE 4 Cost Comparison of Built-in-Place TE Substations Versus Packaged TE Substations

	Built-in-Place	Packaged
Land	Real estate cost savings with TPS building integrated with station platform	No Saving
Inspection	Organize TE contract for continuous on-site inspection	Organize TE contract for continuous at-factory inspection
NEC Compliance Issues	None	Possible expense of dealing with electrical authority
Architectural Treatment	No extra cost	Extra cost is required
Off-loading, Handling with Cranes	Not required	Required
Ductbank/Cable Installation	Cost savings due to shorter ductbank runs	Extra cost for longer ductbank runs

The following are recommended TE design parameters:

- NEC compliant, and inspected by local and State of Oregon electrical authority.
- Building sized to accommodate all potential suppliers.
- DC feeder trench included that allows versatility in suppliers' equipment arrangement.
- Equipment doors and access allows for quick equipment removal and replacement if necessary.
- Ventilation system designed for optimum cooling while removing ionized or potentially explosive gases from inside the substation.

Figures 1 through 10 provide photographs of IMAX substations throughout Portland. Tables 2 and 3 compare the elements and cost of built-in-place TPSs and prefabricated substations.

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FIGURE 1 TriMet Banfield LRT Project Lloyd Center Substation, 1986.

FIGURE 2 TriMet Westside LRT Expansion Millikan Substation, 1998.

FIGURE 3 TriMet Westside LRT Expansion Civic Stadium Substation, 1998.

FIGURE 4 TriMet Westside LRT Expansion 170th Street Substation, 1998.

FIGURE 5 TriMet Hillsboro LRT Extension Government Center Substation, 1998.

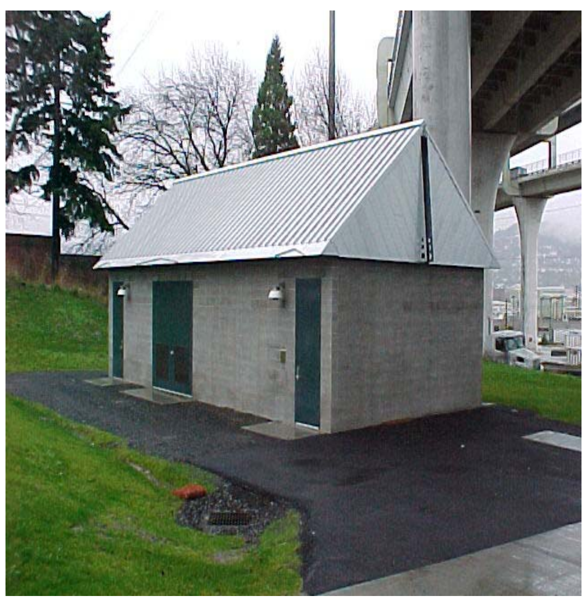

FIGURE 6 TriMet Interstate MAX LRT Graham Street Substation, 2003.

FIGURE 7 TriMet Interstate MAX LRT Killingsworth Station Substation, 2003.

FIGURE 8 TriMet Interstate MAX LRT Failing Street Substation, 2003.

FIGURE 9 TriMet Interstate MAX LRT Expo Substation, 2003.

FIGURE 10 TriMet Interstate MAX LRT Expo Substation, 2003.

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BIOGRAPHICAL SKETCHES

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One Break Point Is Enough
Traction Power Simulation in Portland

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Traction power computer simulation software has changed in the last 20 years. The tool has evolved from simpler, DOS-based, energy management software to detailed, Windows-based, user friendly, analytical software that can accurately model train performance, predict train voltages, and produce a train voltage profile for an entire rail system. Traction power computer simulation software is now used as a comprehensive design and analysis tool in the development and upgrade of the traction electrification system (TES) for modern rail systems. The software allows the designer to analyze the existing or proposed traction power system under various operating conditions including contingency outage conditions. The designer can also optimize the size and location of the traction power substations as well as the number and size of important components of the overhead contact system (OCS) such as wire, feeder cable, and parallel conductors.

As part of the Interstate MAX Light Rail Project in Portland, Oregon, a number of simulation scenarios were performed for the Tri-County Metropolitan Transportation District of Oregon (TriMet). In TriMet's case, in addition to developing the TES design for the Interstate MAX Project, the simulations were used to assess whether or not to relocate a major electrical break point within the existing TriMet OCS where the nominal voltage changes from 825 VDC to 750 VDC.

Results from analysis of the simulations led to the basic conclusion not to relocate the breakpoint. Also, the simulations demonstrated the effects that the added operation of the proposed Interstate MAX line would have on the electrical equipment and voltage profiles of the existing system. This type of software makes practical an accurate analysis of the impacts of additional line segments and changes in operating schedules.

INTRODUCTION AND OVERVIEW

Light Rail in Portland

TriMet and the Portland metropolitan area have a 25-year history of involvement with light rail transit (LRT). In the mid-1970s, public officials in Oregon, led by then-Mayor Neil Goldschmidt of Portland, formally withdrew an unbuilt segment of the Interstate Highway System, the Mt Hood Freeway, and, using the provisions of the 1976 Highway Act, substituted proposed transit projects in its place.

The first transit project to be developed using the Interstate transfer funds was a joint light rail-highway project that ran from downtown Portland 15 mi east to the suburban community of Gresham, generally in a parallel alignment to the deleted Mt. Hood Freeway. This project, known as the Eastside or Banfield Project, included rebuilding the Banfield freeway, an older urban freeway, and re-designating it as Interstate 84. Environmental, planning, and preliminary engineering work was completed in 1980, final design started in 1981, construction commenced in 1982, and the Eastside light rail line opened for revenue service in 1986.

Planning for the second line, the Westside Line, was begun before start of Eastside construction but was placed on hold due to the recession of the early 1980s and the need to successfully complete and demonstrate viability of the first line. The success of the Eastside Line buoyed the resumption of the Westside Line, but it took the region over 4 years to reach consensus on the characteristics of the line and to assure federal funding. Westside final design started in the early 1990s, the Hillsboro extension was added to the project in 1995, and the line opened for revenue service in 1998. The Westside Project was a more complicated line with a 3-mi tunnel and deep station and the introduction of the first, modern low-floor light rail vehicles (LRVs) in North America.

The third project, the Airport line, was a design-build project led by Bechtel in partnership with TriMet, the city of Portland, and the Port of Portland. The airport line opened in 2001.

The most recent project, the Interstate MAX project in north Portland, has its origins in a major funding referendum for a North-South line that failed at the polls in 1998 and was subsequently reconstituted in its current and substantially reduced form. The Interstate MAX line is scheduled to open in 2004.

The major characteristics of the TriMet system are summarized in Table 1. The system has grown to almost 45 mi in length (Figure 1), 60 passenger stations, and 105 LRVs, and it exhibits a wide diversity in alignment and station types. The majority of the system is signalized

TABLE 1 TriMet Light Rail System Overview

	Eastside (Blue Line)	**Westside** (Blue Line)	**Airport** (Red Line)	**Interstate** (Yellow Line)	**Total**
Start of Revenue Service	1986	1998	2001	2004	N/A
Alignment Length (mi)					
Shared trackway	0.1	0	0	0	0.1
Reserved trackway with at-grade crossings and traffic signals	6.9	2.1	0	4.2	13.2
Reserved trackway with at-grade crossings and gated protection	2.3	9.8	1.4	0.0	13.5
Grade separated trackway	5.8	5.6	4.3	1.6	17.3
Total	**15.1**	**17.5**	**5.7**	**5.8**	**44.1**
Single Track Sections (mi)	0	0	1.5	0	1.5
Extent of Automatic Block Signals	55%	90%	100%	35%	70%
Peak Hour Headway (min)	6	6	15	10	N/A
Typical Consist Length	2	2	1	2	N/A

FIGURE 1 Light rail in Portland.

with automatic block signals and magnetic trip stop enforcement. Consist length is limited to two-car trains due to Portland's short downtown blocks, and rush hour headways range from just under 6 min to 15 min with combined headways as low as 3 min. Service is approximately 21 h a day, 7 days a week, and ridership, prior to introduction of the Interstate MAX line, has increased to over 80,000 boardings a day.

Traction Power Substations

General Arrangement

TriMet has four generations of substations, all slightly different from each other, that are the result of the sequential construction of the four LRT lines discussed above.

The Banfield Line featured compact, packaged traction power substations (TPSSs), and all successive TPSSs have been built-in-place. For the last three projects, the TPSS enclosure has been built under TriMet's Civil contracts and traction power equipment installed on-site by the TES contractor using licensed electricians.

The physical sizes of the TriMet substations have undergone changes as the light rail system has evolved. The TPSS footprint has grown from approximately 24 ft x 11 ft for the first packaged units to 42 ft x 19 ft for the latest built-in-place unit. Equipment access, arrangement, rating, and conformance to National Electrical Code (NEC) requirements have all played a part in the increased girth of the TPSS.

The AC switchgear in the Banfield and Westside lines is unusual for metal clad switchgear in that it requires access from the front only, thereby permitting the equipment to be installed against the wall, without the need for removable or hinged access panels in the building walls. Similarly, the DC switchgear requires access from the front only and is mounted against the wall. The Interstate MAX substations permit both front and rear access and provide the extra space required. The traction power transformer is located at one end of the substation in the Banfield and Westside arrangement and is located in the line-up between the AC and DC switchgear in the Airport and Interstate MAX substations.

Each TPSS contains an auxiliary power transformer. This transformer always provides auxiliary power to serve the TPSS itself, for lighting, ventilation, battery charger, and other substation auxiliary loads. Additionally, the auxiliary transformer is used to feed hotel power for adjacent passenger stations and other facility loads on most of the Westside line and the Airport line. For Interstate MAX and a few unique locations on the Westside, auxiliary power serves only the TPSS. The auxiliary transformer size and service location vary from project to project. On the original Banfield line, the auxiliary transformer uses a separate feed directly from the utility while all other lines use a separate feed from the AC switchgear.

Grounding System

While the original Banfield substations use a single ground mat, the substation grounding system of the subsequent three lines is comprised of two separate ground mats and one separate utility ground rod. The main ground mat, designed to meet the requirements of IEEE 80 to limit step and touch potential to safe levels in the event of a fault on the AC system, is also used to ground the building metallic structure, conduits, and AC equipment, including switchgear. The main ground mat is usually placed under the substation, and extends a minimum of 5 ft beyond the perimeter. Another smaller ground mat referred to as the DC ground mat is used exclusively for grounding of the DC equipment, including the negative bus through a diode for stray current monitoring or testing, and for grounding of the DC lightning arresters and protective relays. A separation of 25 ft minimum between the AC and DC mat is used to reduce fault current contribution from the ac equipment to the DC equipment. It also provides for some reduction in DC stray current, when compared to the single ground mat arrangement on the Banfield line.

Stray Current Monitoring

Each substation is equipped with provisions to monitor stray currents. Within the DC switchgear negative switch cubicle is a measurement shunt and removable bolted bus link in series with the DC grounding conductor. By bolting the link in the closed position, the DC ground mat can be used to ground the negative return through a diode. In this position, the DC ground mat acts as a stray current collector and most stray currents will flow through the shunt. The shunt can be connected to a chart recorder or voltmeter to monitor and record stray currents over time.

In the Westside and Airport substations, a padlocked utility monitoring enclosure is also provided for the purpose of remote monitoring. It is equipped with a 120 Vac receptacle and terminals which TriMet maintenance personnel can connect to the shunt, thereby permitting utilities to remotely monitor stray currents. In the Interstate MAX substations, stray current data is transmitted and recorded using SCADA.

Emergency Shutdown

As a safety feature, each substation is equipped with two emergency shutdown stations. One button is recessed in a stainless steel enclosure mounted in an exterior wall of the TPSS, and accessible by key only. The other button is readily accessible and located inside the substation by the access door. Actuation of either button will trip and lock out the 15 kV AC breaker of the substation, and transfer trip and lockout the DC breakers at the adjacent substations, thus completely isolating the fault or trouble.

Ratings

The TriMet system is served by two local utilities with three-phase AC at 12.5 to 13.8 kV, depending on location. Taps on the traction transformers seek to provide sufficient adjustment to maintain electrical balance in the system.

The 100% full load voltage of the initial Banfield line was set at 825 Vdc. This determination was made in the early 1980s before regenerative braking was commonplace on LRVs—TriMet's first vehicles did not have regenerative braking capability—and to provide sufficient voltage margin in anticipation of future heavy loads on the system. Subsequently the Westside line, operating through a hilly environment with extended grades, was set at a 100% full voltage of 750 Vdc to provide greater opportunity to capture the benefits of regenerative braking, and the Westside vehicles and subsequent orders have all included a regenerative braking capability.

The traction power substations for the first three lines are all rated at 750 kW, while the Interstate MAX substations are rated at 1 MW (Table 2). TriMet has been very consistent in maintaining an average TPSS spacing of very close to 1 mi, resulting in installed power values from about 0.66 MW per mi on the more lightly loaded Airport line to 1.03 MW per mi on the latest Interstate MAX line.

Overhead Contact System

The TriMet OCS is predominantly catenary (messenger and contact wire) with balance weight tensioning. In downtown Portland and downtown Hillsboro, a simple contact wire system with variable tension, cross spans, and parallel underground feeder cable is used. The West Hills tunnel uses a reduced height catenary that is not weight tensioned due to the uniformity of the ambient temperature and lack of space for weights underground.

Contact wire on the TriMet system is 300 kcmil, and the messenger wire size ranges from 250 kcmil on the first lines to 500 kcmil on the Interstate MAX line, with the larger wire intended to mitigate against future voltage drop problems from expanded future service, particularly in the event the line crosses the Columbia River into Vancouver some day. These parameters are summarized in Table 2.

LOAD FLOW SIMULATION

Introduction

This paper describes a conceptual load flow study undertaken as an aid to the design of the TES for the Interstate MAX project. This study was also intended to assist TriMet in deciding whether to keep the system "break point" in its present location at Southwest 11th Avenue and Southwest Yamhill and SW Morrison Streets in downtown Portland, or move it to Northeast 9th Avenue and Northeast Holladay Street, just outside of the downtown on the near east side. The break point as used in this document is defined to be the boundary between the Westside system nominal voltage of 750 Vdc, and the Eastside system nominal voltage of 825 Vdc. As part of this effort, the entire TriMet system, including the Interstate MAX, Eastside, Westside, and Airport lines, was modeled, which allowed evaluation of the impact of train loadings and headways for the Interstate MAX project on the entire system, as well as evaluation of the proposed move of the break point.

The Interstate MAX line physically connects to the Eastside line just to the east of downtown Portland and thus approximately in the middle of the combined Eastside-Westside (East-West) line. TriMet had the choice of electrically connecting the Interstate MAX line to the Eastside line or introducing another break point such that the Interstate MAX line would be stand-alone. Given the characteristics of the line, TriMet decided that one hard break point in the system was enough and that the Interstate Max line should not be stand-alone. However, electrically connecting the Interstate MAX line, through the OCS, meant that the OCS voltage levels of the new and the existing should be similar (i.e. at 825 Vdc nominal), thereby reducing the opportunity for regenerative breaking on the new line. Accordingly, an alternative was developed which moved the existing break point between the Eastside line (at 825 Vdc) from the downtown to east of the junction point with the Interstate MAX line. By changing the transformers from (825 Vdc to 750 Vdc) in the four existing TPSSs between the two break points, effectively the Westside line was "extended" eastward, and the Interstate MAX line could be configured as a 750 Vdc system and capitalize on the increased propensity for regeneration.

The computer program used for this study is proprietary software developed by LTK Engineering Services.

TABLE 2 TriMet Traction Electrification System (TES) Overview

	Eastside	**Westside**	**Airport**	**Interstate**	**Total**
Length of line (route miles)	15.1	17.5	5.7	5.8	44.1
Number of TPSSs					
— mainline	15	18	5	6	44
— yard	1	1	0	0	2
— shop building	1	1	0	0	2
Average TPSS Spacing on Mainline (miles)	1.0	1.0	1.1	1.0	1.0
100% Full Load Voltage (Vdc)	825	750	825	825	N/A
TPSS Nominal Power (kW)	750	750	750	1,000	N/A
Total Installed Power on Mainline (MW)	11.250	13.125	3.750	6.000	34.125
Average Installed Power on Mainline (MW per mile)	0.75	0.75	0.66	1.03	0.77
TPSS Enclosure Type	Packaged	Built-in-place	Built-in-place	Built-in-place	N/A
TPSS Enclosure Size (ft)	26 x 14	38 x 14	39 x 16	42 x 19	N/A
Catenary					
With Weight Tensioning (miles)	13.8	12.3	5.7	5.8	37.6
Without Weight Tensioning (miles)	0.0	3.1	0.0	0.0	3.1
Simple Contact Wire					
With Weight Tensioning (miles)	1.3	2.1	0	0	3.4
Without Weight Tensioning (miles)	Yard only	Yard only	0	0	0
Messenger Wire Size (kcmil)	250	250	250	500	N/A

Notes: For Eastside, 1 mainline TPSS added, 1 mainline TPSS re-configured, and 1 yard TPSS upgraded since opening. Parallel underground feeders added in simple contact wire sections.

Methodology and Input Assumptions

General

Modeling of the TriMet system began with development of a network schematic, which is essentially a single line diagram of the TES. In this schematic, the traction power substations are shown in relation to the overhead contact system, return system, and passenger stations. The network schematic serves as the basis for development of the electrical characterization of the TES.

A number of data files describe the track geometry, the permissible speeds, the electrical characteristics of the network, the traction and braking capabilities of the LRVs, and the operating scenarios under investigation.

Description and Assumptions

The following parameters were used in this study ("Series" refers to the groupings of computer runs described below):

- The Interstate MAX TPSSs were modeled as 1 MW, 750 Vdc nominal for Series 1 through 4, and 825 Vdc for Series 5 and 6.
- The Westside, Airport, and Banfield TPSSs were modeled as indicated in Table 2. Four of the downtown (Banfield) TPSSs were modeled as 1 MW, 750 Vdc nominal for Series 1 through 4, and 0.75 MW, 825 Vdc full load for Series 5 and 6.
- In general, OCS was modeled as indicated in Table 2, with some exceptions in special cases.
- TPSS feeder cables were modeled as installed, with Interstate MAX using 3—500 kcmil for each positive feeder breaker, which represents an increase in feeder capacity compared to the East-West and Airport lines.
- Rail was taken as 115 RE tee rail (equivalent to Ri 59 girder rail electrically).
- All runs used an average contact wire wear of 20%.
- All electrical conductor characteristics were taken at approximately 60°C.
- Six new Interstate MAX TPSSs [Graham, Overlook, Killingsworth, Buffalo, Portland International Raceway (PIR), and Expo Center] were modeled.
- Track files were constructed using the alignment and profile data available from the civil design contracts.
- Runs were made using the following headways:

East-West	5 min (slight improvement over 2003 service levels)
Airport	15 min (average)
Interstate MAX	5, 7.5 , and 10 min

- Passenger station dwell time was modeled as 30 s except downtown stations and major transit centers which were modeled as 60 s, and end of line dwells were set as required to provide the necessary headway and proper operational sequencing.
- All runs were made using a full 60-min electrical simulation, which was delayed until all trains were correctly positioned on the system, thus representing the "peak of the peak."

Car Data

Passenger loadings for rail vehicles are typically defined as AW0 (maximum empty vehicle operating weight), AW1 (full seated load, plus operator, plus AW0), AW2 (standees at 4 persons per meter squared of suitable standing area, plus AW1 loading), and higher loadings representing crush conditions rarely encountered in most U.S. transit systems.

The vehicle used for all simulation runs was the Siemens Type 2 Low Floor LRV, which forms the majority of the TriMet fleet. The AW0 weight of the Siemens car was 109,000, and with a full AW2 load of 188 passengers at 154 lbs each, the AW2 weight used for simulation was 138,000 lbs.

The car weight in the model was uniformly set to the AW2 weight, which was a conservative assumption (i.e. representing a higher average load than normally achieved), since in actual operations, all trains, especially those in the off-peak direction, do not operate at crowded, AW2 levels along the entire lines.

The car auxiliary load was set at 42 kW, which represents a normal full usage of all vehicle systems, including the HVAC units.

All propulsion and brake rates were assumed to be maximum service rates, and regenerative braking was not modeled since its effects can mask low voltage areas, even though the vehicles have that capability. Actual tractive effort and current curves versus speed for the Siemens cars were used for simulating vehicle performance. The minimum permissible voltage for normal train operation was 525 Vdc, the low voltage set point for the Siemens' cars.

Consists of two-car trains were used for all simulations, except for the Airport line which was modeled as one car trains.

Series of Runs

A total of 54 separate runs were made to evaluate not only the performance of the Interstate MAX TES, but also to evaluate the effects of electrically connecting it to the existing TriMet system and to evaluate the two OCS break points described earlier. To rationalize this approach, the runs have been grouped into six Series as described below. The first four Series are based on the new break point at Northeast 9th and Holladay, while the last two Series are based on the existing break in the downtown area just west of Southwest 11th.

Series 1—Interstate MAX Only, with New Break This is one of two Series of Interstate MAX-only runs and contains the standard set of runs first with all Interstate MAX TPSS operational, then with each TPSS respectively dropped out of service one at a time, at headways of both 10 min and 5 min. A TPSS out of service is defined as the AC breaker being open. The substation does not supply power but acts as a tie station utilizing the DC switchgear and cable only.

Series 2—Entire System, with New Break, 10 min Interstate MAX Headway This Series adds Interstate MAX at 10-min headways to the existing system and respectively drops out various key substations in the downtown area and on Holladay Street. Two runs simulate bridging the break point at Northeast 9th in an emergency situation when either of the TPSS adjacent to the break point is out of service.

Series 3—Entire System, with New Break, 7.5-min Interstate MAX Headway This Series is similar to Series 2 except that Interstate MAX headways are 7.5 min instead of 10 min and there are no runs with the break point bridged.

Series 4—Entire System, with New Break, with Parallel Feeder This Series simulates the addition of a new, additional feeder cable along Holladay Street between Rose Quarter and the break at Northeast 9th to mitigate potential "single end feed" problems.

Series 5—Entire System with Existing Break, 10-min Interstate MAX Headway This Series is similar to Series 2 except that the OCS break point remains as the existing location at Southwest 11th and the four downtown (Banfield) TPSSs remain as is at 0.75 MW and 825 Vdc nominal. Two runs simulate bridging the existing break point at Southwest 11th in an emergency situation when either of the TPSSs adjacent to the break point is out of service.

Series 6—Interstate MAX Only, with Existing Break This Series is similar to Series 1 (Interstate MAX only) except that the OCS break point is the existing location at Southwest 11th and the four downtown (Banfield) TPSSs remain as is at 0.75 MW and 825 Vdc nominal.

Results

Voltage Results

A brief summary of preliminary voltage results is organized below by Series. The data pertaining to voltages lower than 525 Vdc has been summarized for each Series and presented below. Figure 2 provides a sample output or voltage profile for the East-West line.

Series 1—Interstate MAX Only, with New Break No low voltages were detected for all 10-min headway runs and for the 5-min headway run with all TPSSs in service. However, low voltage conditions were predicted when any one of four TPSSs were out of service.

The Series 1 data indicated that considering only the Interstate MAX line and with the break point at the new location of Northeast 9th, the TES will support 10-min headways with all substations in service, and with each individual Interstate MAX substation out of service. The TES will also support 5-min headways with all substations in service. However, the Interstate MAX TES will not support sustained 5-min headways with any specific single substation out of service. This series of runs did not simulate any existing TPSS—for example, from Rose Quarter TPSS to Pioneer Square TPSS—off line.

Series 2—Entire System, with New Break, 10-min Interstate MAX Headway No low voltages were predicted for Interstate MAX, but several instances of low voltage were predicted on the East-West line when any one of several East-West TPSSs was out of service. Voltages along Holladay Street near Rose Quarter were quite low for the one run with the emergency tie connected and Rose Quarter TPSS out.

Series 2 took into consideration the entire TriMet system, and showed slightly below minimum acceptable voltages between the Rose Quarter substation and Lloyd Center substation with all substations in service for 10-min Interstate MAX headways. However, it appears that the influence of the Interstate MAX line on this situation was negligible, and that the low voltages on Holladay Street were due to the combination of the East-West and Airport service levels and the single-end feeding as a result of the new break point. When Rose Quarter substation or Lloyd Center substation was taken out of service, severe low voltages were indicated between these locations. Conversely, the strength of the downtown TES, with the existing break moved to Northeast 9th, was demonstrated by the results showing no low voltages in the downtown when downtown substations were individually taken out of service. Of course, this last result is aided by the removal of any single end feeding in the downtown when the breakpoint was moved to Northeast 9th.

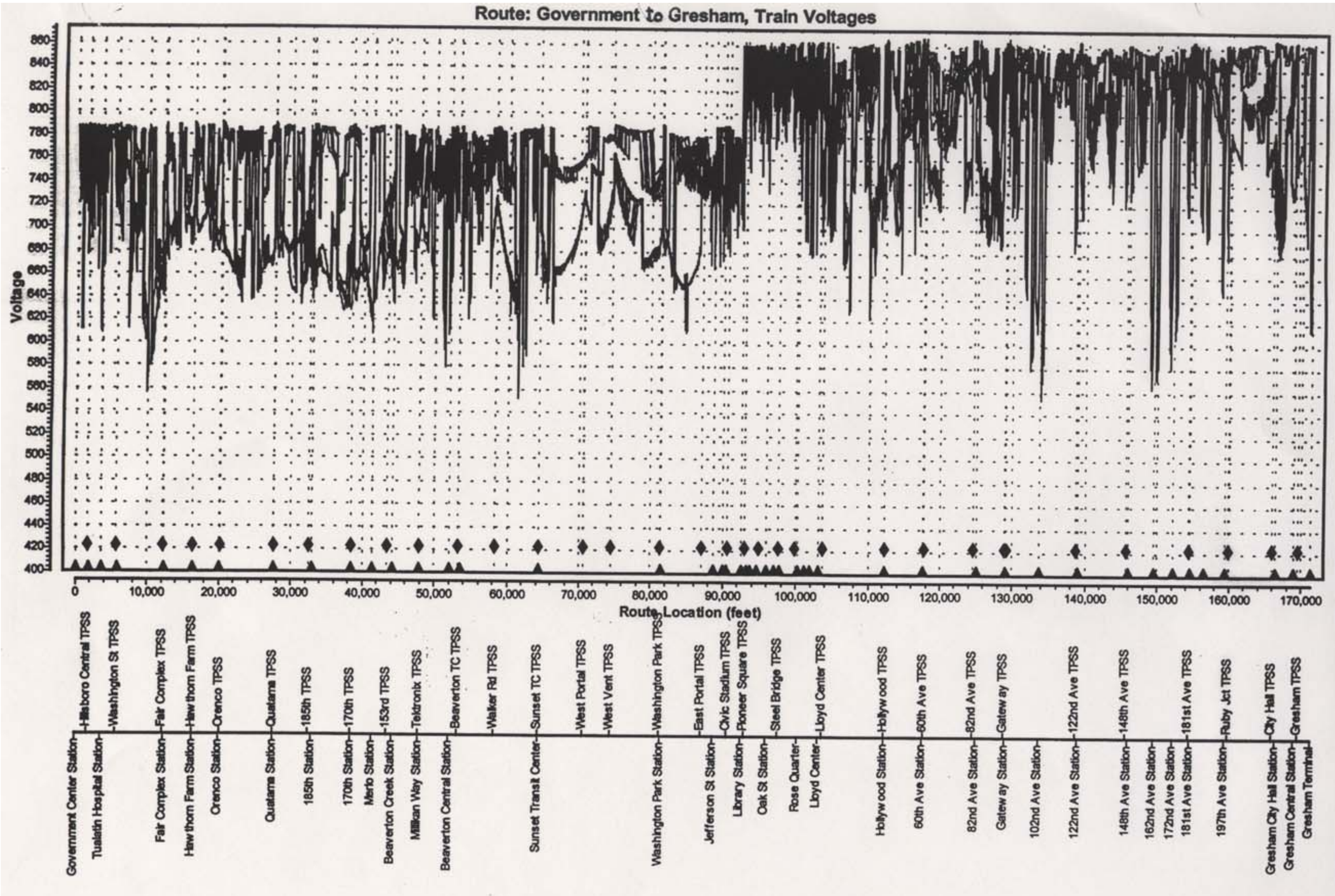

FIGURE 2 Voltage profile.

Two runs provided a simulation of an emergency tie that bridged the break at Northeast 9th and connected the two sections with differing voltages together in the event of loss of either Rose Quarter TPSS or Lloyd Center TPSS. In both cases, low voltages were significantly improved, as there was no longer a single-end feed. With the former (i.e., Rose Quarter TPSS out of service), the low voltages rose above the 525 Vdc level, but with the latter, Lloyd Center TPSS out of service, the low voltages remained below 525 Vdc.

Series 3—Entire System, with New Break, 7.5-min Interstate MAX headway Similar but slightly worse results than those for Series 2 were predicted. Voltages in the vicinity of the Rose Quarter were quite low.

Series 3 modeled 7.5-min Interstate MAX headways as part of the overall system and showed only very slightly worse voltage conditions than Series 2. Again, there were numerous low voltages along Holladay Street, but no low voltages in the downtown with any one or two substations out of service and no low voltages along the Interstate alignment with all Interstate substations in service.

Series 4—Entire System, with New Break, with Parallel Feeder Along Holladay Street No low voltages were detected for the two runs, at 10-min and 7.5-min headways for Interstate MAX, with all TPSS in service, but low voltages along Holladay persisted when the Rose Quarter TPSS was out.

Series 4 investigated using a parallel feeder between the Rose Quarter substation and Northeast 9th to attempt to improve the low voltage condition in that area. Very low voltages still remained at Rose Quarter substation and Northeast 9th with Rose Quarter TPSS out of service even at 10-min Interstate MAX headways (5-min headway East-West and 15-min average headway on the Airport Line).

Series 5—Entire System, with Existing Break, 10-min Interstate MAX headway No low voltages were detected for the run at 10-min headways for Interstate MAX with all TPSSs in service or for the runs with Rose Quarter or Lloyd Center not in service or for the emergency ties. Only one low voltage far removed from Interstate MAX was observed.

Series 5 investigated keeping the system break at its present location at Southwest 11th. With all substations in service, (and headways of 10 min, 5 min, and 15 min for Interstate MAX, East-West, and Airport) no low voltage conditions were encountered on the system. The low voltages along Holladay Street in the Series 2 runs were not present in the Series 5 runs since there is no single end feeding on Holladay Street with the Series 5 runs. With Civic substation out of service, low voltage conditions are encountered at Civic substation. This situation for the existing break was analogous to the single-end feed problem associated with the new break, except that the downtown TES, east of the existing break, is robust enough to maintain acceptable voltages with Pioneer Square out. The emergency tie simulations both resulted in no low voltages below 525 Vdc.

Series 6—Interstate MAX Only, with Existing Break No low voltages were detected on any runs.

Series 6 investigated only the Interstate MAX system with the present break location at Southwest 11th, and shows that when considering the Interstate MAX line alone, the system will support 10-min or 5-min headways with any one substation out of service. This result is due to the additional 75 Vdc margin when using an 825 Vdc TPSS instead of a 750 Vdc TPSS. Note that this run did not include any of the existing TPSS (i.e., Rose Quarter to Pioneer Square) off line.

TPSS Power Results

TriMet"s existing substations are all rated at 750 kW at either 750 Vdc (Westside) or 825 Vdc (Eastside and Airport) nominal. This rating is a continuous rating and the contributing current load can be increased for shorter time intervals, e.g. 150% of full load for 2 h such that effectively the existing TPSS can operate at 1,125 kW for 2 h and somewhat in excess of 1,125 kW for 1 h, but with accompanying temperature rise and potentially transformer and cable insulation degradation. The Interstate MAX TPSS will be rated at 1,000 kW continuous and up to 1,500 kW for 2 h.

The highest estimated TPSS power for each run was tabulated, and in all but one case the highest estimated TPSS power is below 1000 kW. The typical TPSS power is approximately 40% to 50% of rated power. With the Lloyd TPSS out of service, the Hollywood TPSS power is 1,051 kW, still within the rating for a 1-h period, although this is obviously a marginal situation.

Except in one run (full System, new break, Lloyd TPSS out of service), there were no TPSS power problems identified in any of the simulations, at least with the peak loads on a short term basis (1 to 2 h). The results from the marginal run indicate marginally high power levels at Hollywood TPSS that could be sustained only for short durations in an emergency situation.

These results lead to the conclusion that there are no power problems within any of the TriMet TES, including the Interstate MAX line, for any of the conditions simulated.

Feeder Current Results

Throughout the TriMet TES, there is considerable diversity in the feeder cable arrangement that connects each TPSS to the OCS. Feeder cables are either 350 kcmil or 500 kcmil or, in a few instances, 750 kcmil. The existing system typically has either two 350 kcmil or two 500 kcmil cables per feeder breaker, while Interstate MAX uses three 500 kcmil cables per feeder breaker. In many cases, particularly in the existing TES, a combination of cables is used. Also, of course the length of feeder cable varies significantly depending on site conditions and is only approximated in most simulations.

Complicating the analysis is the relation of short-term current rating to continuous current rating. The simulation develops a RMS value of current for each feeder connection for the timeframe of the electrical run, i.e. 1 h for all runs in this study. Continuous (3 h) current ratings for cables are readily available from NEC, but short term current levels and durations were not recorded by the model for this report. Therefore, the subsequent heating effects and temperature rises or drops from the varying current loads during the 1-h time frame have not been calculated for each feeder. For this study, to account for high short term currents, a feeder current was considered marginal or worthy of further investigation if the estimated 1-h RMS current approached or exceeded the feeder ampacity rating. Excluding fault current levels, high short term current levels likely contribute to wire fatigue and insulation degradation rather than catastrophic failure—a long term concern rather than a short term one.

High feeder current values for each run were also tabulated. Although there were numerous cases of estimated feeder current exceeding two-thirds of the applicable ampacity rating, the results were divided into three categories.

First, for Interstate MAX only at 10-min headways, if either the PIR TPSS or Buffalo TPSS is out of service, marginally high RMS feeder currents approaching 75% of applicable continuous criteria are seen at the other (Buffalo or PIR) TPSS. A similar result is seen at Graham TPSS in Series 2 and 3 when Rose Quarter TPSS is out of service.

Second, for Interstate MAX Only at 5-min headways, all runs show high RMS feeder currents, some in excess of continuous ampacity, at PIR TPSS and Buffalo TPSS. This situation would likely constrain Interstate MAX headways to 7.5 min, but the addition of a new TPSS at Kenton would likely ease or solve this feeder current problem and the voltage problems for Series 1 at 5-min headways identified above.

Third, analysis of marginal feeder conditions for the remainder of the system was beyond the scope of this paper, but it does appear that there are several locations where some marginality is present.

The simulations suggest that marginal or even overloaded conditions exist throughout the system under various TES configurations particularly on lines when headways are at 5 min and substations are taken out of service. These results need to be juxtaposed against some of the conservative assumptions input to the simulations before any general conclusion of inadequate feeder ampacity can be reached.

CONCLUSIONS AND RECOMMENDATIONS

Interstate MAX Only

- The data show that the Interstate MAX TES as originally configured (with substations at 750 Vdc nominal) would acceptably support 10-min Interstate MAX headways with all substations in service or with any single Interstate MAX substation out of service. Voltages should be well above the 525 Vdc level in most cases but would approach 525 Vdc if either the PIR TPSS or particularly the Buffalo TPSS were out of service. Estimated power is below the substation short term rating in all cases, and estimated RMS feeder currents are below the ampacity ratings.
- Similarly, Interstate MAX headways of 7.5 min and 5 min are achievable with all Interstate MAX substations in service, but numerous voltage and feeder current problems are present at 5-min headways with one substation out of service.
- Addition of another 750 Vdc substation in the vicinity of Kenton will likely be necessary to achieve reliable 5-min Interstate MAX headways with any one substation out of service, and the voltage and feeder current problems with substations out of service should be substantially mitigated.

Full System and Break Points

- Moving the break point from Southwest 11th to Northeast 9th and Holladay creates marginally low voltage problems along Holladay St. for normal peak hour operations with all substations in service and very low voltages, well below 525 Vdc, if either Rose Quarter TPSS or Lloyd Center TPSS is out of service.
- Adding a 250 kcmil parallel feeder (per track) from Rose Quarter to Northeast 9th improves voltages such that none is below 525 Vdc with all TPSSs in service, but very low

voltages remain along Holladay St. if Rose Quarter TPSS is out of service or east of the new break point if Lloyd Center TPSS is out of service.

- An emergency tie across the existing break would raise the voltages to an acceptable level for the one case of Civic TPSS out of service.
- Keeping the break point where it is at present and thus having 825 Vdc nominal Interstate MAX substations also provides significant benefit to Interstate MAX operations, permitting 5-min future headways with any one substation out of service, primarily as a result of the higher nominal voltage of 825 Vdc.
- Results from a separate study demonstrated that savings from regeneration are not reduced significantly by having the higher line voltage on the Eastside. Based on these results and the demonstrated advantages of a higher line voltage from the load flow study, TriMet decided to leave the break point in its present location and build the Interstate Line at the higher Eastside line voltage.

General

- Other marginally low voltage conditions were noted on the full system, but were not investigated under this Interstate MAX-focused simulation. Further investigation in these areas has been underway as part of preparatory studies for a new line, the South Line.
- There are always operational responses to TPSS outages, such as slow train orders which limit propulsion rates in affected areas or staggered starts at passenger stations, that may be employed on a “work around” basis.
- Pantograph voltages below 525 Vdc are part of a self-correcting cycle. When a Type 2 LRV experiences a voltage below 525 Vdc, it will (temporarily) shut down propulsion, which removes the load from the TES, which in turn improves the voltage situation, which in turn allows trains to re-start. Thus it is likely that trains can limp out of low voltage areas, although the scenario may not be one to be relied upon as an operating solution.
- A load flow simulation is a valuable tool not only in planning, sizing, and scoping the TES for a new line, but it can also assist a transit agency in making design decisions regarding modifications to its existing system.

Continuing Developments in Light Rail Transit in Western Europe
United Kingdom, France, Spain, Portugal, and Italy

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The primary focus of this paper was to provide a brief but informative survey of new light rail transit applications in Western Europe, concentrating on developments and trends in the United Kingdom, France, Spain, Portugal, and Italy. Since the author's last update in November 2000 for the 8th National Light Rail Conference, a spirited amount of activity has been observed in the countries cited above. The trend toward constructing new light rail systems, which had its genesis in France, and which has continued at a high level in that country, has generally spread throughout Western Europe and the British Isles. Light rail also continues to be implemented in progressively smaller cities than previously noted with cities having populations as low as 150,000 choosing to make significant long-term capital investments in fixed rail facilities (and willing to tax themselves to do so).

The goals of all new cities implementing light rail projects in the countries examined in this paper have proven to be astonishingly similar to those of cities previously implementing light rail projects. The influence of the largely successful trailblazer systems in France cannot be underestimated [Nantes (1985) and Grenoble (1987)]. All cities expressed the urgent need to provide a viable, affordable alternative to the automobile, improve the quality of life, enhance mobility, address environmental concerns, and promote land use trends that produce energy efficient, traffic reducing development, and enhance the overall competitiveness of the city as a desirable place to live and work. Cities continually cited the flexibility of light rail in being able to meet such a diverse set of goals.

INTRODUCTION

The trend toward the adoption of light rail transit in cities of all sizes (large, medium and small, even as low 150,000 population) in Western Europe has continued unabated since the last National Light Rail Conference was held in Dallas, Texas, in November 2000. Indeed, since the first recognized new light rail system in Western Europe opened in Nantes, France, in 1985, an additional 15 systems have opened in France, the United Kingdom, Germany, and Italy[1].

Germany, it must be pointed out, possesses the most light rail systems of any country in Western Europe (exceeded in the world only by Russia and other parts of the former Soviet Union), having generally avoided the massive abandonments that prevailed in France, the United Kingdom, the United States, and Canada in the 1950s and 1960s. The Germans, in both the West and the East, chose to retain and, especially in the West, modernize street-based urban rail systems after World War II. In the West, the Germans systematically converted and expanded basic streetcar networks into model light rail systems (*stadtbahnen*). With the exception of Hamburg, all large and most medium-sized German cities maintain robust light rail networks. As a consequence, Germany has added only two new systems since World War II, in Saarbrücken and Oberhausen. Saarbrücken was conceived and implemented as a Tram-Train application and successfully developed and applied over a wide area surrounding Karlsruhe. The Tram-Train concept is making additional headway with the concept being implemented in suburban Paris (Aulnay-sous-Bois to Bondy) and Mulhouse, France, the RijnGouweLijn-Oost project in the Netherlands (in the testing phase) and Kassel, Germany. Other developing applications will be mentioned in the paper.

In France, where the current trend emerged, light rail continues as the mode of choice in a surprisingly large number of small and medium-sized cities. In the mid-1970s, the French Minister of Transport announced a new policy to encourage medium-sized cities in France to consider light rail transit as a viable alternative and promised to provide national funding to underline his commitment. This policy initiative has born fruit beyond anyone's wildest dreams, spawning the implementation of eight new light rail systems, and the building continues unabated. Three new systems are now under construction in Bordeaux, Valenciennes, and Mulhouse, and funding for new systems has been approved for systems in Le Mans and Nice. In Toulon, a new city administration has also reactivated plans for a light rail system and expects to receive final approval for a modified plan in early 2004. The city of Brest has advanced plans for a modest light rail system and is seeking approval for national funding. In Paris, where two routes were opened in the 1990s (T1-1992 and T2-1997), light rail has assumed an increasingly prominent role in expanding mobility options in the City of Light. Currently one extension is under construction, another has been approved, and two are in the public hearing process. Finally, of the three systems predating the light rail renaissance, Saint Etienne has accomplished some modernization with a further expansion in the works, Marseilles has launched ambitious plans to use the existing line as the nucleus of a three route, 16.4 km network, while Lille has already completed a thorough modernization of its two-route system (known locally as Le Mongy).

The United Kingdom has built on the successes achieved in Manchester (opened in 1992); Sheffield (1994); Birmingham (1999); and Croydon (London Borough-2000). One new system is under construction and is nearing completion (Nottingham) and the British Government has recently approved funding for new systems in Portsmouth (South Hampshire), Bristol, Leeds and Liverpool. The Scottish Government has also pledged funds toward a three-route system in Edinburgh. The Mayor of London, Ken Livingston, most famous at this juncture for his bold (and successful) pricing plan for reducing congestion in central London, has announced firm plans to construct light rail in two central London corridors (Cross River and West London). This will dramatically expand transit capacity in central London. A pioneering hybrid system opened in 1980 in Tyneside, serving the Newcastle-on-Tyne metropolitan area, featuring high platform operation with overhead power collection and light rail-type vehicles on a fully grade separated system. This system has recently expanded and whether or not future extensions might feature some reserved street running is being debated.

In Spain, one new system has opened in Bilbao to complement a brand new Metro and a two-route system (with spurs) is currently under construction in Barcelona. Barcelona abandoned its previous street railway system in 1971, a decision it reportedly came to regret. A Coruña, in the upper northwest part of the country on the Atlantic, and Alicante, on the Mediterranean Sea, are edging toward true light rail networks with incremental development. Additional proposals are being refined in Vitoria, Vigo and San Terife in the Canary Islands. The State of Andalusia has recently adopted plans to build light metros in Seville, Malaga and Granada and has budgeted one billion Euros for the projects, representing 75% of the total cost.

In Portugal, Porto has opened an initial segment of what will become a region-wide light rail system involving short subway segments, reserved rights-of-way, and the conversion of a previously existing meter gauge suburban railway service to light rail operation. A short segment was opened in November 2002. At the same time, Porto is proceeding to revitalize a small portion of the previous conventional tram network to provide a complementary, historic service to the light rail network. Already partially in operation, this small network is being worked by rebuilt vintage trams. Coimbra has also announced plans for a new light rail system and recently called for bids for the construction, financing, operation, and management of a future 40 km system. The first line would use an existing railway spur. A new system is also being built under a turnkey contract on the Setúbal peninsula on the south side of the Tagus River, opposite the capital city of Lisbon.

Italy, which has witnessed in the late 1990s the resurgence of existing tram networks in Roma, Milano, Napoli, and Genova, will see new light rail systems built in cities where traditional tram networks disappeared in the 1950s and 1960s. One system in Messina, on the island of Sicily, opened for service in April 2003. Other new systems are under construction in Firenze (Florence), Verona, Bergamo, and Sassari on the island of Sardinia. Additional systems are planned for Palermo and Cagliari.

Dublin, Ireland, will also initiate service next year on 24 km of an eventual combination of light rail and light metro services. The system is the city's answer to burgeoning traffic congestion and mobility issues. Although slowed recently, Dublin's local economy has experienced rapid growth and generated attendant pressure on the transport network.

FRANCE

The light rail renaissance maintains steady progress in this country, even in light of the emergence of competing concepts. Although recent guided bus installations in Nancy and Caen have opened with mixed results, additional systems in Clermont-Ferrand and those proposed for the Paris *banlieu* (inner suburbs) will have ample opportunities to show their value. Since Nantes opened in 1985, new light rail systems have been built in Grenoble (1987), Paris (1992 and 1997), Strasbourg (1994), Rouen (1994), and Montpellier, Lyon and Orlèans (all in 2000). All of these systems (except Rouen and possibly Orlèans) have either engaged in significant extensions or are planning to do so. Both Montpellier and Lyon, both in operation for less than three years, have experienced patronage growth that has far exceeded projections. Montpellier will add center sections to its existing tram fleet to expand capacity in the short term.

Bordeaux

Bordeaux has followed a tortuous path to securing the necessary public consensus to pursue a major fixed guideway solution. After initially selecting the automated VAL (Vehicule Automatique Leger) system (also selected and built in Lille, Toulouse and Rennes), the decision was reversed after extensive public discussion over the merits of a system requiring complete separation and extensive tunneling in central Bordeaux, versus a street-based system requiring less extensive disruption and infrastructure modifications and attendant traffic measures. Light rail was finally selected due to a number factors, including cost, unstable soil conditions (making subway construction expensive and difficult), proven ability to carry increasing volumes of patronage, ease of insertion into the city's historic core, and high visibility of the service. The system's Stage 1 consists of three routes totaling 24.5 km (14.7 mi) and 53 stations that coil through the downtown and close in suburbs of Bordeaux. The Stage 1 system will be served by 44 Alstom-built low floor trams. An additional 26 trams will be delivered for Stage 2. Stage 1 will cost 680 million Euros (US$598.5 million or $40.7 million/mi). The system will essentially be street-based but completely segregated from adjoining traffic except at intersections. All intersections will have priority signalization for trams. As with other new light rail systems in France, Bordeaux will see the extensive revitalization activities along the route of the trams. Tram rights-of-way will either be in grass-covered medians or appointed with distinctive surfaces clearly identifying the exclusive tram reservation. Trees are added where feasible, especially along the grassy medians. Bordeaux will also feature discrete sections powered by a unique ground-based power system (Alimentation par Sol-APS, literally surface current collection). This new system will obviate overhead wire installation in the sections that are located in the city's historic district and in other selected areas. About 10.5 km of Stage 1 track (44%) will be equipped with APS. Trams will draw power from a surface third rail located in the center of the trackway that is controlled electronically to activate (energize) only when a collector extending from beneath the tram passes overhead. The system was developed by INNORAIL and extensively tested on Marseilles' single tram route and on French tram-builder Alstom's test track in La Rochelle. The system is undergoing final testing for safety certification and has already logged 3,000 km (1,800 mi). Bordeaux also has applied one of three methods of track construction to mitigate noise depending upon the distance between the track structure and nearby buildings. Standard track on concrete sleepers chosen where buildings were more than 12 m from the track. Resilient supports were added to the track structure for distances from 7 to 12 m. For 7 m or less, tracks were laid on a floating roadbed with resilient supports. Full service on Stage 1 is now expected toward the end of 2003 or early 2004. The additional 18 km of Stage 2 will be fully operational by the end of 2006. As has been the practice for new French systems, 4 min headways will be maintained during peak periods, and an 8 min frequency in the off peak. Connex has been awarded a contract to maintain and operate the system.

Valenciennes

After a period of uncertainty, Valenciennes has affirmed its original decision to construct a light rail system. The first phase will total 9.5 km (5.7 mi) with 19 stations and represents the precursor of a three route 30 km network. Dubbed Transville (literally "through the city"), Valenciennes is seeking to duplicate the success achieved by other light rail applications in France. In common with the latest systems, Valenciennes has ordered 17 Alstom-built Citadis 100% low floor trams. This first phase will cost €242.75 million (US$212.4 million or US$37.3 million/mi). Construction is slated to begin in 2004 with the initial segment scheduled for a June 2006 opening. Valenciennes will apply the same track construction engineering specifications adopted by Bordeaux to mitigate noise.

Nice

France's fifth largest city, Nice (350,000), has reacted to a worsening traffic problem by adopting a public transport on reservation (Transport en Commune en Site Propre-TCSP) solution. For Nice, this translates into a modern light rail system as well as an east-west reserved bus line. The light rail system will initially consist of an 8.7-km (5.22-mi) U-shaped line serving the northeast and northern reaches of the city via central Nice. The reserved bus lanes will be built along a west–east axis and is designed for easy conversion to light rail when patronage levels so warrant. The reserved bus lanes will go into service in 2004 with the light rail line to follow by the end of 2006. Central Nice will be made over with the arrival of the tram. This project shows the same attention to detail so visible with other light rail projects in France. In fact, Nice even developed a *Plan Lumière* to ensure proper illumination of the street, the tram, and the urban surroundings all along the route. There will be eight types of lighting, designed and deployed to accentuate particular urban settings such as historic, cultural or work destinations. In conjunction with the coming of the tram, numerous streets will be become tram-only or auto-free pedestrian zones. The bus system will be extensively revised to feed into the tram line. The initial light rail line will cost €350 million (US$306.3 million or US$58.7 million/mi). The initial line will require 20 low floor articulated trams. A tender is expected shortly for this order. Nice has received a Declaration of Public Utility, the last hurdle before construction can begin.

Mulhouse

Track laying has begun in Mulhouse, a medium-sized city located near the convergence of the Swiss and German borders. Mulhouse has adopted an innovative two-pronged approach. The urban portion of the plan consists of two lines of which the first 12 km (7.2 mi) will be placed into service in the autumn of 2005. A further 7.7 km (4.62 mi) will be gradually placed into service between 2005 and 2010. Mulhouse has ordered 20 Alstom-built Citadis trams for the urban segment of the project, with an option for an additional four units. This first increment of the urban portion of the work will cost €340.2 million (US$297.7 million or US$41.3 million/mi). The second half of the project will see the employment of the Tram-Train concept (*Périurbain*), with the urban segment connecting to and utilizing French National Railway (SNCF) tracks to access the Thur valley northwest of Mulhouse. Seventeen Siemens dual voltage trams will be acquired for service on this segment, which is planned for opening in 2007. Four km of new track will be constructed from central Mulhouse to Lutterbach, where the line will connect with the SNCF main line tracks. The line will jointly use 36 km of main line trackage with SNCF trains to Kruth in the Thur valley. Although other systems have discussed this option, this is the first actual application of this concept in France[2]. The capital costs of the Mulhouse Tram-Train portion of the project is estimated at €89.6 million (US$78.4 million), highlighting the low cost nature of this approach.

Paris

Having achieved the status of new system in 1992 with the opening of an in-street but largely on reserved rights-of-way light rail line (T1) between Sainte Denis and Bobigny, two working class suburbs in the northeast portion of the city, Paris proceeded to add in 1997 the enormously successful second line (Val du Seine or T2) between the La Defense edge city and Issy-Plaine, a commuter rail transfer point west of central Paris. The latter line largely follows the contour of the Seine river. The Sainte Denis–Bobigny line, or T1, is currently being extended east to south from the Bobigny–Picasso terminus to Noisy Le Sec, a distance of 2.9 km (1.74 mi) with plans for further extensions to eventually linkup with T2 as part of a grand circle (*Roncade*) around the periphery of Paris. The Noisy Le Sec extension will open later this year. The Val du Seine line (T2) will also be extended northwest from the La Defence edge city to Pont de Bezons, a distance of 4.1 km (2.46 mi). The line will be placed in the median of a regional highway. The extension is expected to cost €215 million (US$ 188.1 million or US$76.4 million/mi) and attract 70,000 daily passengers. The line is projected to open in 2008. T2 will also be extended at its southern end to Porte de Versailles (2.3 km/1.4 mi). In anticipation of significant patronage increases generated by these extensions, Regie Autonome Transports Parisiens (RATP), the Paris regional transit operator and planner, has already taken delivery of 13 Citadis low floor trams capable of multiple unit operation for operation on T2. RATP has also ordered an additional 13 trams of this design for delivery in 2004. All of the new trams will be assigned to T2 with existing trams of the old Grenoble design shifted to T1. T1 is currently carrying 80,000 daily passengers and T2 has reached 58,000 a day. Both lines registered an aggregate 8% increase in patronage in 2002. Significantly, Paris has also embarked on a plan to establish a new 7.9-km, 17-station, street-based route from Porte du Garigliano along Boulevard de Maréchaux (and other names celebrating military leaders from the Napoleonic era) to Porte d'Ivry. Called the Tramway des Maréchaux Sud (TMS), the line will consolidate a number of bus lines and is expected to quickly become one of the city's strongest routes, carrying 95,000 passengers when opened in early 2006. The line will provide connections with five metro lines and two RER suburban lines. The line will run largely in grassy medians (*voies engazonnées*) and will be shaded by 400 additional trees to be planted as part of the project. The line, slated to cost €185.2 million (US$ 162.1 million or US$32.2 million/mi), is part of the aggressive transit first policy being pursued by the Socialist Mayor of Paris, Bertrand Delanoë, who has already inaugurated a comprehensive network of bus only lanes throughout the city. The Mayor is also planning an ambitious inner orbital light rail line connecting the main train stations of Paris. Not to be left out, the French National Railways (SNCF) is employing the Tram-Train (*Périurbain*) concept and has ordered 15 Avanto dual voltage low floor trams from Siemens to run on an 8 km section of electrified (25 kV) main line track between Aulnay-sous-Bois and Bondy in the inner suburbs (*banlieu*) east of Paris. The line will interface with three RER (Paris area commuter rail) services. SNCF plans to eventually extend the line at both ends of the line by utilizing space on existing roads for reserved light rail operation. The *Périurbain* service will replace an existing suburban line operated by SNCF push–pull trains in June 2005. The resounding success of T1 and T2 has demonstrated that light rail clearly deserves the prominent role assigned to it in recently adopted plans for expanding transit options throughout the Ile de France.

Toulon

After some introspection occasioned by a change in the city administration in 2001, the new Toulon municipal authorities have affirmed the original decision to construct a light rail line. While the project had secured a Declaration of Public Utility in 2000, some revisions to the original plan will now require that a modified procedure be followed to secure final approval for construction. It is assumed that the go-ahead will be received in mid-2004. The east–west line will be 18.3 km (10.98 mi) in length and require a fleet of 24 articulated low floor trams. The vehicle selection process, which had actually been completed under the original project (the AnsaldoBreda Sirio model has tentatively been selected), will now be re-started. The system will connect La Gard and Gare de la Seyne and include 37 stops, 5 of which will include park-and-ride facilities. The system is projected to open in 2009, assuming all approvals are secured as planned.

SPAIN

Spain has been a late arrival to the light rail party. Spanish light rail had shrunk to tourist operations in Barcelona and one modern system in Valencia. Now, A Coruña opened a tourist line in 1997 with the idea of conversion to a legitimate light rail operation in the future. Alicante has constructed a short section of tramway in the harbor area to demonstrate the light rail concept and is upgrading a long meter gauge commuter line to light rail. Bilbao has just opened the first line of a three route light rail network (December 2002) and Barcelona is constructing not one but two light rail lines (Trambaix and Trambesós), both scheduled to open initial lines in 2004. The Spanish Region of Andalusia has also announced plans to fund light metros in three cities.

Barcelona

Renewal and expansion are the key words to describe the work in Barcelona, the capital of the Catalunya region of Spain. While the extensive metro and commuter rail systems are being modernized and extended (including the construction of a 46 km driverless metro running the length of the conurbation), the region is also moving to create an efficient intermediate capacity mode serving major districts in the city. Although the city abandoned a conventional tram system in 1971, there has been a growing realization that additional capacity represented by an intermediate capacity mode such as light rail is vital for the surface network. After the success of a short 640-m LRT demonstration line (*Prueba Piloto*) built on Barcelona's famed Diagonal in 1997 (a progression of different tram designs were operated over the line), the resulting surge of support overcame the skepticism of light rail in some quarters and the region moved to plan its introduction into Barcelona. *Autoritat del Transport Metropolita* (ATM), the region's transit operator, is now overseeing a plan to introduce light rail serving the Baix Llobregat section of Barcelona. Known locally as Trambaix, the 15.5 km (9.3 mi) system features two branches and major stops at Sant Feliu, Cornella, and Sant Joan Despi. The line is being constructed and will be operated by a corsortium, TramMet, led by French carbuilder Alstom. The line will cost €240 million (US$210.0 million or US$22.9 million/mi). Alstom is providing 19 Citadis low floor trams for this project. The project will be opened in stages, with the full network operational by April 2004. Even as Trambaix construction got underway, ATM approved another 17.4 km (10.4 mi) network of four routes to serve the Besós area of Barcelona. The cost of this second tram project is valued at €213 million (US$186.4 million or US$17.9 million/mi). TramMet also won the contract to design, build, operate, and maintain this project, known as Trambesós. Alstom will deliver an additional 18 Citadis low-floor trams for Trambesós. The Trambesós lines will be opened progressively between April 2004 and January 2005. Both lines will be operated by the private consortium Alstom and Connex. The trams for both Trambaix and Trambesós will be maintained by Alstom under a 25-year contract. After an absence of only 33 years, the tram will again return to Barcelona in the modern form, as light rail.

Bilbao

Bilbao, the capital of the Basque region of Spain, recently opened (December 18, 2002), a 2.1-km segment of an eventual 5-km meter gauge light rail line. The line is a mix of double track (3.1 km/1.86 mi) and single track (1.9 km/1.14 mi) with passing loops. The single track segment was dictated by the narrow street alignment in the city center. The line (Eusko Tram) is being served by eight CAF-built articulated 75% low floor trams (€18 million or US$ 15.75 million or US$1.97 million/tram). Ridership has reached 8,000 but is expected to increase substantially when the full system is placed into operation in April 2004. When completely opened, the line will provide access to many of the city's main attractions, including the world acclaimed Guggenheim Museum, the city's new Metro, theaters, a meeting hall, and a major hospital.

Alicante

Alicante, located on Spain's eastern Mediterranean coast 330 mi south of Barcelona, is in the process of upgrading to light rail standards a meter gauge line that follows a northeastly direction from the outskirts of the city along the coast. The upgrade will include a short 3.6-km tunnel to access Alicante's main train station (Término). This tunnel will also provide access to Término for a second line to be built to the city's university. The local railroad operator has ordered nine dual voltage tram trains from Alstom for delivery in 2005 to work the intercity portion of the line. The new vehicles will cost €46 million and will operate on sections energized at 750 V dc and 1500V dc. An additional 10 low floor trams will be ordered in the future for the urban portion of the line. Initial operation on the 750 V ac portion of the line may be furnished by trams borrowed from Valencia. As part of the overall program to modernize the line, Alicante also built in 1999 a 700-m section of electrified tram line from the existing coastal line terminal at La Marina to Puerta del Mar, along the rim of the city's harbor. This section of track has been used to demonstrate different types of light rail equipment and build public support for Alicante's ambitious plans (a la Barcelona). Nearby Valencia, which has upgraded its light rail network and built the highly successful tram line (Route 4), is providing technical advice to Alicante during this process.

IRELAND

Dublin

After a decade of planning, significant revision and finally construction, Dublin is in the final leg toward the opening of two initial segments [Lines B-9 km (5.4 mi) and A/C-15 km (9 mi)] in June and August 2004 respectively. Known as *Luas*, or speed in Irish (Gaelic), the light rail network is one measure in Dublin's comprehensive vision to enhance the quality of city life, expand mobility options, and confront pollution concerns. The plan also calls for the modernization of the existing commuter rail network (DART) and expansion of bikeways throughout the city and suburbs. The initial segments cost €691 million (US$604.6 million or US$42.0 million/km). A total of 40 trams built by the French railcar builder Alstom are currently being delivered and will come in two versions. While both versions are 70% low floor, 26 trams will be 29 m in length and feature three section articulation while the balance of the order, 14 trams, will have five sections and measure 40 m in length. These latter vehicles will be employed on the upgraded Line B. From an initial plan to create a five route classic light rail system, the decision was made in mid-stream to construct Line B to light metro standards (complete grade separation). This conversion was facilitated by the route configuration which largely follows a railway alignment abandoned some years ago. Line A/C from suburban Tallaght to Connolly Station (terminus of Dublin's electrified commuter rail network) in central Dublin remains a conventional light rail application, utilizing a variety of surface rights-of-way, including a former section of canal (shades of the Newark Subway). Line B will have no physical connection with Line A/C and plans call for extending the line into the downtown core via a tunnel, eventually reaching the airport. Each line will have its own maintenance and storage facility. Operation of both lines has been contracted out to Connex, a subsidiary of the French Conglomerate, Vivendi. Connex will also be responsible for maintenance of rolling stock and two depots. The contract will run for 5 years with an option for an additional 5 years. Connex, Europe's largest private transport operator, also operates rail systems in Sydney and Stockholm and will run light rail systems in Bordeaux and Barcelona, both currently under construction (and described in this paper).

UNITED KINGDOM

The trend to light rail in the United Kingdom began slowly but was firmly established by the success of Manchester Metrolink system, opened in 1992. While there was a brief hiatus in the mid-1990s when the former Conservative government became disenchanted after operational problems were encountered in another brand new system in Sheffield, the Sheffield system, christened the South Yorkshire Supertram and opened in 1994, eventually solved those teething problems (including unregulated bus competition) and has since achieved solid ridership gains. Another light rail project was successfully implemented in Birmingham in 1999. Birmingham's Midland Metro consists of a single route linking a commuter rail station located on the periphery of the downtown with suburban Wolverhampton via an old railroad right of way abandoned some 30 years earlier. This project also experienced initial problems associated with vehicle reliability and catenary system design shortcomings but, like Sheffield, solved these problems and has emerged with steadily rising patronage and firm plans to extend the system. Although the new Labor government initially displayed some ambivalence toward light rail, that initial coolness turned to a warm embrace with adoption of an aggressive goal of doubling light rail use by 2010 and the promise of funding for up to 25 new LRT lines ("trams not jams"). This policy change was no doubt influenced by the success of a new Tramlink three route system opened in 2000 to rave reviews in the London borough of Croydon. The momentum has been building ever since. An artistic success (the system now carries over 65,000 daily weekday patrons), the financing for the Croydon system has proven problematic with the Public-Private Partnership (PPP) contract apportioning too much risk to the private sector. The terms of the agreement are currently being renegotiated to ensure a financially healthy collaboration over the long term.

Nottingham

At present, only one new system is under construction in the United Kingdom, in Nottingham. This industrial city (population 275,000) located north of London, broke ground for a light rail system in mid-2000. Dubbed Nottingham Express Transit (NET), the line is slated to open on November 11, 2003. As with other schemes throughout Europe, NET is a long-planned reaction to mushrooming congestion and spectacularly rising automobile travel in the region as a whole. Nottingham is determined to provide a viable and affordable alternative to the auto. The line under construction will serve as the initial component in an ultimate region-wide network. The 14 km (8.4 mi) line will furnish 3,040 parking spaces at key stations outside the urban core and is expected to carry 30,000 daily passengers in the initial months of operation. The private consortium selected to build, operate, and maintain the system, Arrow, Inc., is not expected to experience financial difficulties similar to Birmingham or Croydon. This is due to the contract being structured to distribute identified financial risk factors in an equitable fashion between the private and public partners. The trams being built by Bombardier are based on a design recently supplied to Nantes, France (the Incentro). The system is a blend of street-running and private rights-of-way, including a physically separate operation in the same corridor with existing main line rail operations. The line costs £220 million (US$362.4 million or US$43.1/mi). The Nottingham City Council and the Nottinghamshire County Council have already given the green light to begin serious planning for two additional routes.

Portsmouth

As part of the big bang announcement by the Labor Government supporting light rail initiatives in three cities, the city of Portsmouth and the Hampshire County Council are proceeding to implement phase one of a regional network. The system has been christened South Hampshire Rapid Transit (SHRT) and the initial line, 14 km (8.4 mi) in length, will connect Portsmouth with neighboring Gosport and Fareham. The line will also feature a short 1-km tunnel beneath Portsmouth harbor (Portsmouth is located in Southern England and the harbor opens into the English Channel and is situated opposite the Isle of Wight). As with other proposals in the United Kingdom, the system will be built with significant private financial participation (Public Private Partnership). Two consortia (including Siemens and Mitsubishi, respectively) have submitted bids to design, build, and operate and partly finance the system. Award is expected in the fall. The initial line is estimated to cost £190 million (US$311.1 million and US$37.03 million/mi). The line will have 16 stops of which 5 will be interchanges with railway stations and three with major bus stations. Approximately 70% of the mileage will be located on abandoned railroad alignments with the balance on reserved street space in Fareham town centre and Portsmouth. Travel time end to end is estimated at about 30 min with a frequency of 7½ min during the day and 15 min evenings. Weekday patronage is estimated to reach 32,000 in the first year of operation. With worsening congestion and the projection of ever increasing automobile use, the light rail line is part of the area’s answer to ensuring mobility without major road construction. The line is also expected to be a catalyst for revitalization in several disadvantaged areas served by the new service. Portions of the Gosport area are especially targeted for economic renewal. Construction is expected to take 3 years and the first trams are expected to be in operation in 2007.

Bristol

With government approval, Bristol is embarking on a program to construct an initial 16.7-km (10-mi) light rail route with 16 stops from central Bristol to the city’s northern suburbs.

Estimated to cost £194 million (US$319.6 million or US$31.96 million/mi), plans call for construction to begin in 2004, but some uncertainty over a portion of the alignment and the ultimate northern terminus could push this date back considerably.

Leeds

Leeds, one of three systems approved by the government, will construct a 28-km three-route network to be served by 40 articulated trams, bringing to fruition some 10 years of planning. The genesis of this effort traces back to 1993 when Leeds received parliamentary powers to proceed with a single route project. These powers briefly lapsed in 1998 but were renewed in 2000 with an additional two routes. The main impetus for the system came from the realization that a reliance on road building alone would not solve Leeds' transport needs. The plan developed and put forward contained a mixture of road improvements, commuter rail upgrades, bus priority measures, and a surface running light rail system (which was the number one priority). The adopted system, Leeds Supertram, is estimated to cost £500 million (US$823.7 or US$49.0 million/mi). After considering the bids submitted from two consortia (from an original four aspirants), the contract to design, build, maintain, operate, and partially fund the proposed system has been awarded to the EUROTRANS consortium (includes trambuilder Bombardier). In an effort to intercept automobile trips, 4 of the 49 stops will feature large park-and-ride facilities. Although taking advantage of existing road space to carve out most of the system mileage, fully 75% of the right-of-way will be separated from adjoining traffic. Approximately 50 intersections with vehicular traffic will require integration into the traffic control network. The main construction phase is expected to get underway in early 2004, although advance work involving road works and utility relocation has already begun, with completion projected in 2007.

Liverpool

Liverpool will construct a 19-km network, Merseytram, that includes a downtown loop serving key business, tourist and shopping destinations, and a terminal in suburban Kirkby Town Centre. Seven of the nine downtown stops would connect to other transport modes. The system is estimated to cost £225 million (US$370.6 million or US$32.5 million/mi). The full plan calls for an additional two routes to be built to complete the system. Total cost of the completed network is estimated at £400 (US$658.9 million). The initial route has received government approval and the promise of 75% of the cost.

London

After the success of the Croydon Tramlink system (19% of patrons abandoned their cars for the service), London's Lord Mayor, Ken Livingston, has authorized advanced planning for two light rail lines to be built on in-street reserved rights-of-way in central London. These are the West London line running from Shepherd's Bush to Uxbridge, a distance of 20 km (12 mi), and the Cross River line navigating a 15-km (9-mi) route through central London with two branches at each end. The West London line will intersect with four tube (subway) stations and four town centers. The West London line is estimated to cost £200 million (US$329.5 million or US$27.5 million/mi) while the Cross River line will total £300 million (US$494.2 million or US$54.9 million/mi). These initiatives seek to provide additional capacity to alleviate overcrowding in

London's subway lines and allocate scarce road space from automobiles to more efficient public transport vehicles. A final decision on West London is expected in January 2004 upon conclusion of the public consultation process. Assuming final approvals and taking into account planning, design, and construction time, the West London line is expected to open in 2009 and Cross River in 2011. Mayor Livingston has vowed to find ways to accelerate this process and bring these initiatives on line at an earlier date.

Edinburgh

After considering a diverse number of alternatives including a 5.9-km curb-guided bus route, Edinburgh has settled on a three-route, 31-km (18.6-mi) light rail system to be the cornerstone of the region's ambitious 10-year £1.0 billion transport improvement plan. As part of this plan, the city of Edinburgh has also developed a congestion-pricing component, similar in scope to the London's successful scheme, to manage congestion in Edinburgh central core. This scheme appears to have strong public support if the resulting revenues are used to improve transit. The Scottish Government has given its approval to Edinburgh's tram proposal and has pledged £375 million towards the estimated £487 million (US$802.2 million or US$43.1 million/mi) cost of implementation. The first line, the 15-km North Edinburgh loop, is on schedule for a 2009 opening as is the 8-km second line to the west toward the Edinburgh airport. The Edinburgh City Council created a company, Transport Initiatives Edinburgh, Ltd., to develop the three route concept and bring the plan to reality.

ITALY

The renaissance in transit across Italy continues as transit investments are being targeted not only to revitalize existing systems in Roma, Milano, and Napoli, but also to establish new systems in Sassari, Verona, Messina, and Firenze (Florence). Additional systems are also on the drawing boards in Palermo and Cagliari.

Firenze (Florence)

The jewel on the Arno has endured a number of false starts in its efforts to install a modern light rail system. The most recent travail involved the choice of a consortium to design, build, and operate the system. The original selection, a group led by the French rail-builder Alstom, was challenged by an Italian-led consortium, including the Italian railcar builder, AnsaldoBreda, which ultimately prevailed in court. The legal wrangling delayed the initiation of construction. With legal difficulties finally resolved, construction is underway and Firenze will soon enjoy the first 7.5-km segment of an eventual three-route network. The initial line will run from suburban Scandicci to a terminal opposite the main train station (Santa Maria Novella) and will not penetrate the medieval district of the city (Il Duomo, etc.). Except for intersections, the entire route will be on reserved rights-of-way. Trams will have priority at all signalized intersections. Underpasses for automobiles at two major squares (piazzas) are being built to leave the surface free for the light rail line and pedestrians. A new tram and pedestrian-only bridge will be built across the Arno river. With plans to operate on 3-min headways during peak periods, a total of 17 low-floor trams will be required. An order has been placed with AnsaldoBreda for the 100%

low-floor Sirio model (also being furnished to Milano, Sassari, and Athens, Greece). Travel time from end to end is estimated at 15 min. Two additional lines are already in the advanced planning stages and have received guarantees for funding from the Italian government and the municipality of Firenze. Significantly, Line 2 will penetrate the historic center of Firenze where local officials have called for a system similar to Bordeaux to eliminate overhead wires in this visually sensitive area. The exact technology has not been chosen although two competing approaches developed by French and Italian companies are being considered. The French technology (Alimentation par Sol-APS) has the advantage of being tested and operationally deployed in Bordeaux and will soon have a track record on which to evaluate its suitability. Firenze is also moving ahead on Lines 2 and 3, asking for expressions of interest for a contract to build and operate the two lines. Only one bid was forthcoming, which is being evaluated by the city. The city estimates that both lines could be built for €231.6 million (US$202.7 million). Firenze is creating this system to provide a viable alternative to the chaotic traffic congestion plaguing the city and other metropolitan areas across Italy.

Messina

The Sicilian city of Messina has joined the ranks of operating light rail systems with the opening of its initial 7.7-km line on April 3, 2003. The line connects the city's downtown center and harbor area with the main train station. The service is provided by 15 100% low-floor "Cityway" articulated trams built by Alstom Ferroviaria. Similar vehicles have been delivered to Roma.

Sassari

Construction of a small 6-km (3.6-mi) line from the main train station to Emicicio Garibaldi in this Sardinian city is now complete but initiation of service has been postponed until 2004. Once service commences, the 950-mm gauge line will be served by five AnsaldoBreda Sirio low-floor trams which have already been delivered. Sassari has investigated the feasibility of converting two lightly used railroad lines to light rail service.

Verona

The town of Verona has selected a consortium led by Siemens to construct the first two routes of a planned three-route light rail system for an estimated €126 million (US$110.3 million or US$12.3 million/mi). Both routes total 15 km (9 mi) and will be served by 22 Siemens-built Combino low-floor trams. The first route will run on an east–west axis from Stadio Bentegodi to a park-and-ride facility at suburban San Michele Extra. The second route will run south from the city center to Ospedale Borgo Roma. A planned second phase calls for a 4-km (2.4-mi) extension from the terminus at Ospedale Borgo Roma to a new park-and-ride facility and a new Route 3 connecting the center of the city with a suburban rail station at Parona. The first phase is projected to be ready for service in mid-2004.

Bergamo

A total of 14 low light rail vehicles of the Sirio design have been ordered from AnsaldoBreda for the 12.6 km (7.56 mi) Bergamo-Alzano line, scheduled for completion in July 2004.

Cagliari

The city is moving ahead on a 6.5-km (3.9-mi) line from Piazza Repubblica to Museo Monserrato including the electrification of an existing rail line.

PORTUGAL

Oporto

Porto, faced with a severe decline in public transit usage, decided to make substantial investments to stabilize and dramatically increase transit over the long term. Spanning an 8-year period from 1988 to 1996, transit's share of all trips declined from 65% to 37% while auto trips increased from 35% to 62%, a mirror reversal. Porto's city fathers saw a real threat to Porto's competitiveness and attractiveness as a business location in Europe. Porto's answer was the Metro do Porto embodying the light rail concept. A full metro was rejected on cost grounds and other modes were considered and rejected as ill-suited for Porto's topography and developmental patterns. Porto was also heavily influenced by the success of the Strasbourg system, and the smooth integration of Strasbourg's initial tram line into the public transit network. It is therefore probably no coincidence that Porto's Metro reflects many similarities with the Strasbourg system. Metro do Porto opened an initial segment of 9.3 km between Senora de Matosinhos and Trinidade in December 2002 of what will be an ultimate four-route, 70-km system connecting all quadrants of the city and surrounding suburban areas. The full system, expected to cost €900 million (US$787.5 million, or US$18.8 million/mi) is expected to carry 250,000 weekday passengers. The financing plan for the system contains an array of funding from the national government as well as regional and municipal authorities. The European Union has also provided additional funding. The initial segment is already carrying 18,000 weekday passengers. Bombardier is supplying 72 full low-floor seven-section trams (€265 million or US$231.9 million or US$3.0 million/vehicle) patterned after the successful Strasbourg Eurotram design (as mentioned above). The bi-directional Porto vehicles will be wider than the Strasbourg version (2.65 m versus 2.4 m) and are equipped for multiple unit operation.. This may be the last order for this type of vehicle as Bombardier has decided to concentrate on its own in-house models. The Eurotram was an Adtranz product, a firm recently acquired by Bombardier. Besides Strasbourg and Porto, Milano has also received a small order of Eurotrams. Metro do Porto will incrementally extend service with the next segment, a 2.7-km (1.62-mi) tunnel section between Trinidade and Campanhã, to open in early 2004. Also under construction is an 8-km north–south line which will connect Hospital Sao Joao in the north through central Porto via tunnel (with an underground interchange at Trinidade) before crossing the famed double-decked High Level bridge (built in 1886) to cross the Douro river and reach Santo Ovideo. The upper level of the bridge will be reserved exclusively for the Metro trams. The remainder of the system, two former long meter gauge suburban lines being converted to standard gauge Metro operation (Povoa–32 km/19.2 mi) and Trofa–23 km/13.8 mi), are expected to open for service before 2005. Porto has clearly tapped the flexibility of light rail, deploying the system on grassy medians, high viaducts, short tunnel segments, converted railroad rights-of-way and reserved space along existing streets.

South Tagus LRT

The Portuguese government is funding the construction of a light rail system to serve the communities located on the south bank (Setúbal peninsula) of the Tagus river (opposite the capital city of Lisbon). Dubbed the Metro Transportes do Sul, the system will ultimately grow to an ambitious 27.5-km (16.5-mi) network linking Almada, Seixal, and Barreiro but the initial phase consists of a 12-km (7.2-mi) segment. This initial phase will also include connections with the cross-Tagus rail link to Lisbon as well as to commuter ferries. A consortium of Siemens and local Portuguese partners has won the contract that will ultimately total €397.5 million (US$347.8 million or US$21.1 million/mi) at full buildout. A total of 24 Siemens Combino low-floor light rail vehicles have been ordered for the first phase. The first phase is projected to open in late 2005.

CONCLUSION

The trend of constructing new light rail systems in medium-sized and small cities in Western Europe has become progressively stronger since the first trailblazer system was opened in Nantes, France, in 1985. Significantly, the trend has not been confined to cities under 500,000 as London, Paris, and Barcelona are pursuing ambitious light rail programs in their respective cities. It should also be noted that firms in Western Europe have acquired a large body of knowledge and experience in successfully implementing light rail. This has been applied to subsequent projects but has not precluded innovations as the tram-train concept forges ahead and Bordeaux's new system will employ a unique system the obviates overhead wires. It, of course, remains to be seen if light rail will continue at the same pace through the rest of this decade. The trend may slow, if for no other reason than many of the most promising locations have now implemented or chosen light rail or a competing intermediate mode (various forms of guided bus, etc.). Unlike the United States, financing does not represent as formidable a barrier to implementation of major projects. The United Kingdom has employed a PPP financing mechanism grounded in legislation to transfer some portion of the risk of projects to the private sector. While this has resulted in some problems on the financial side for projects such as Croydon in the United Kingdom, other projects (Nottingham, for example) have learned from this experience and structured contracts to better reflect project financial realities and achieve a more realistic distribution of risk. Financing in France is reflective of that country's inclusive multimodal approach to finding long-term solutions to current mobility, congestion, air pollution, and land use disfunctionalities. Substantial national government financing is available and localities have a number of financing alternatives from which to choose. National, provincial, and localities are expected to contribute to the project, consistent with the benefits received. Similar circumstances exist in Italy (still benefiting from the special legislation passed in 1992 to better balance the funding mix for transit-based solutions) and Spain. In Spain, the devolution of political power to the regions (Basque, Andalusia, Catalunya) has resulted in a shift favoring transit as the decision-making level has been moved closer to the Spanish people and is more reflective of their opinions. It is clear that all of the countries surveyed recognize the long-term benefits of enhancing the transit infrastructure and uniformly exhibit the political will to deploy the necessary resources to capture those benefits.

NOTES

1. This is not to ignore the expanding role of light rail elsewhere in Europe but the limitations on the size of this paper preclude reporting on such developments as the reintroduction of light rail in Stockholm, Sweden, (in operation) and Athens, Greece (under construction), important developments in The Netherlands, Belgium, and Switzerland, the proliferation of light rail systems in Rumania, the introduction and expansion of light rail in Istanbul, Turkey, and other Turkish cities, and the extensive developments in Germany, the recognized world leader in light rail. Even tiny Luxembourg has gotten into the act, officially approving construction of a tram-train scheme.
2. SNCF has also ordered 15 LRVs for testing the concept between Aulnay-sois-Bois and Bondy in suburban Paris beginning in 2005.

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Light Rail Without Wires
A Dream Come True?

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Since the dawn of electrification over a century ago, overhead wires have been used to convey electrical power and communications to offices, factories, and homes. Transportation, too, in the form of streetcars, and 0more recently, light rail vehicles, has commonly used overhead wires to transfer power to vehicles. Many people consider these wires to be unsightly and undesirable, but reluctantly accept them as a necessary evil because of a lack of practical alternatives. Only a few cities have managed to run significant streetcar systems without overhead wires for any length of time and all such systems are now defunct. In recent years, new technological developments in hybrid vehicles and ground level switched contact systems are at last showing signs of offering some practical alternative solutions. For light rail applications, the most promising development is the INNORAIL ground level switched contact system now being applied to the new light rail system in Bordeaux, France, which will be examined in detail. Based on the significant progress being made there, it seems likely the dream of having a practical alternative to overhead wires will be coming true in the very near future.

WHY HAVE OVERHEAD WIRES?

Dislike of overhead wires in the urban environment is not a new phenomenon. From the introduction of electrically powered apparatus over a century ago, people have protested against the erection of overhead wires, especially in the more affluent sectors of the city. As far back as the 1890s, major established, affluent cities such New York City, Washington, D.C., London, and Paris garnered enough political support to enact city ordinances prohibiting the erection of any type of overhead wires in specifically designated areas. For most cities, however, financial and practical considerations usually ended up winning the argument and as a result, overhead wires were erected.

During the development of the fledgling streetcars, a wild flurry of new and often impractical electric power supply approaches were tried, from the first experimental battery powered passenger carrying cars of 1847, to the first successful electric streetcar system, built by Frank J. Sprague in 1888 for Richmond, Virginia. Sprague's system, which was the first to use both an overhead contact wire and trolley poles, demonstrated such a clear superiority over other approaches of the time that it soon became the industry standard for supplying power.

Later developments have mostly focused on refining this relatively simple, economical, and reliable direct electrical contact technology, known today as the overhead contact system (OCS). These systems have operated efficiently and mostly unchallenged until today, with the biggest design change being a gradual transition from using trolley poles on the streetcars to pantographs on the more modern version, the light rail vehicle. As a result, almost every streetcar/light rail system in operation or being planned today uses an overhead wire to supply power.

CHANGING URBAN LANDSCAPES

In recent years, with cost-effective improvements in cable insulation and burial techniques, there has been a renewed interest in improving the quality of the urban cityscape. New housing additions have sought to create attractive neighborhoods by burying all cables and concealing transformers. Cities have undertaken expensive area improvement programs to eliminate garish billboards and signs, and to place local power feeders and communications cables underground, greatly improving the appearance of the area and generating public pride.

As those who have undertaken the task of trying to add a new light rail system to an established neighborhood know well, the concept of erecting overhead wires for a new system is unpopular with the public. This is what happens to the urban landscape when overhead contact wire is erected (Figure 1).

Even with attempts to minimize the visual intrusion of the OCS system, the impact is still significant. However, the elimination of these wires and their supporting structures is a problem for light rail systems because up to now, there has been no practical alternative to OCS. The next section examines some ways in which this problem might be resolved.

ALTERNATIVE SOLUTIONS

There are a number of potential alternatives available, but most either pose extreme technological challenges or are fatally flawed in some basic characteristic. Over the years, through the process of development and elimination, three potential solutions stand out as being the most promising:

(a) (b)

FIGURE 1 Urban landscape (a) with OCS wires; and (b) without OCS wres.

- Conduit power (old, but proven technology);
- Hybrid vehicles (combination of power sources including fuel cells, super capacitors, flywheels, microturbines, batteries, and internal combustion engines); and
- Ground level switched contact systems (center running 'third rail').

To address these adequately would be beyond the scope of a single paper, although an attempt has been made to provide an overview in a earlier paper entitled *At Last, Light Rail Systems Without Overhead Wires* published in the proceedings of the APTA 2003 Rail Transit Conference. Since the publication of that paper, it has become clear that resurrection of the old conduit system remains impractical from both a cost and operational standpoint, while the hybrid vehicle development program appears to be stalled indefinitely. Therefore we will concentrate on the ground level switched contact systems, and in particular on the INNORAIL system currently being commissioned in Bordeaux, France.

GROUND LEVEL SWITCHED CONTACT SYSTEMS

Based on proven third rail power transfer systems, a promising approach might be to place the power supply rails directly between the running rails and pick up the power using third rail type shoegear. The basic concept will remind many of Lionel and Marklin model trains. The problem with this approach is, of course, the danger inherent in having ground level power rails energized at 750V/dc when the rails are accessible to the public. This problem can be solved by making the power rails a series of separate sections—the system can switch each section on or off individually so that a power rail section is energized only when the vehicle is directly over it.

There have been a number of recent attempts at making this approach work. These include the E-Tran bus system developed for Minnesota by Nick Musachio, (1986–1992), the STREAM bus system for Trieste, Italy developed by AnsaldoBreda, (1994–present), the ALISS Light Rail Vehicle (LRV) system for Bordeaux, France developed by Alstom, (1999–2002) and the INNORAIL LRV power system developed by Spie Rail, a subsidiary of Spie Entertrans (1999–present), also for Bordeaux, France. Only the ALISS and the INNORAIL systems were specifically designed with sufficient power capacity for application to a light rail system.

Out of all these, the INNORAIL system is currently the most advanced and well on its way to a significant LRV system application in Bordeaux.

Bordeaux's Light Rail Transit System as a Driver for New Technology

When the new Bordeaux light rail transit (LRT) system vehicle specification was released for tender to potential suppliers in 1999, it included a requirement to provide a power supply system that did not use overhead contact wires through an architecturally important and aesthetically sensitive section of the city adjacent to the Cathedral, some 1.8 mi (3 km) of the system route. Historically, it is important to note that even in their earlier streetcar days, Bordeaux never had overhead contact wire in the town center, as a conduit power system provided vehicle power until the system was dismantled. Potential suppliers experimented with various options to meet these requirements, including flywheel energy storage. Upon close evaluation, all existing technological solutions had significant drawbacks, including weight, cost, space requirements, and performance between stations when stopping was required.

Eventually, it was determined that a completely new development, the ground level switched contact system, known in France as the APS system, short for Alimentation par Sol, was required to provide the reliable system needed. Two competing versions of this system were subsequently developed and evaluated, the Alstom ALISS system and the Spie Rail INNORAIL system. In the summer of 2002, the INNORAIL system emerged as the final choice for implementation in Bordeaux.

More importantly, the requirement for INNORAIL equipped sections of the Bordeaux system is now to be increased to 6.3 mi (10.5 km), nearly half the total 15.5 mi (25 km) Phase 1 system length. This is more than twice the initial requirement, clearly a vote of confidence by the city of Bordeaux in the viability of the technology.

An important lesson to learn from this is that strong and unwavering political support for a new technological development required to meet a perceived public need, will produce the motivation needed to develop and adopt it.

INNORAIL Basics

As is common with all the earlier ground level contact system approaches, the INNORAIL system uses a series of switched contact rails installed between the running rails, separated by insulated rail sections to ensure complete electrical isolation of each section. Each individual section is only energized when its local power rail contactor receives and verifies a low power, specially coded signal coming from the vehicle transponder that can only be detected when the vehicle is directly over the section. At all other times, the power rail segment is automatically grounded.

Two sets of pickup shoes are provided on the vehicle to provide continuity of power as the vehicle crosses insulated sections. The basic elements of the system are illustrated in the following two diagrams (Figures 2 and 3).

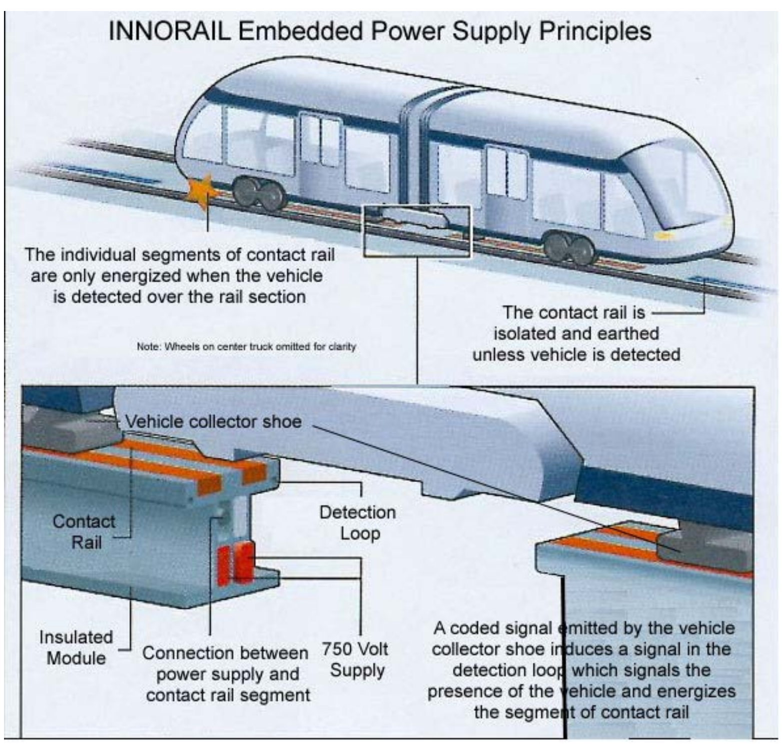


FIGURE 2

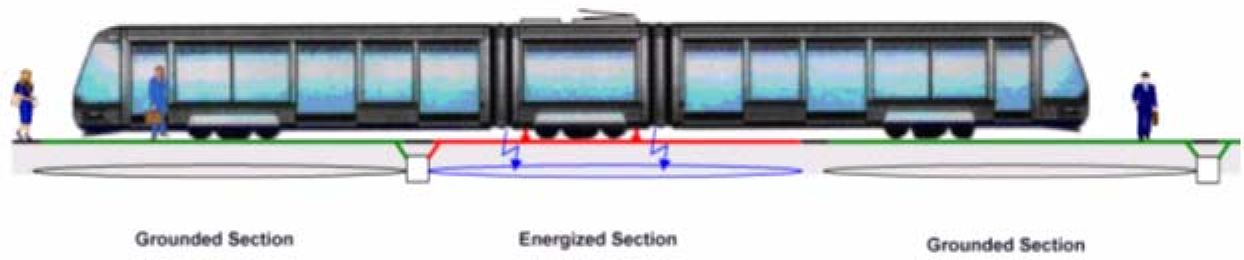


FIGURE 3 INNORAIL ground level switched contact system.

The INNORAIL power rail sections are designed with a very low profile, standing only 6.7 in. (17 cm) high. This allows them to be easily accommodated in virtually every type of track installation, including ballasted track. The INNORAIL system may also be retrofitted to many existing LRT systems (Figures 4 and 5).

Electrically dead zones caused by an occasional faulty power rail segment contactor are traversed using vehicle on-board emergency battery sets with automatic transition to battery power when needed (Figure 6).

All active elements of the system are fully modularized, easily accessible and quickly changed out in case of a fault.

In Bordeaux, transitions from INNORAIL to conventional OCS (and vice versa) are manually initiated by the vehicle operator with the vehicle stopped at a passenger platform. This transition is completed within normal station dwell times. According to the manufacturer, it is also possible for this process to be automated, allowing the transition to be accomplished with the vehicle moving.

The crossing of special track work such as turnouts and crossovers is made using special insulated sections, which allow the pick-up shoes to cross the running rails (Figure 7).

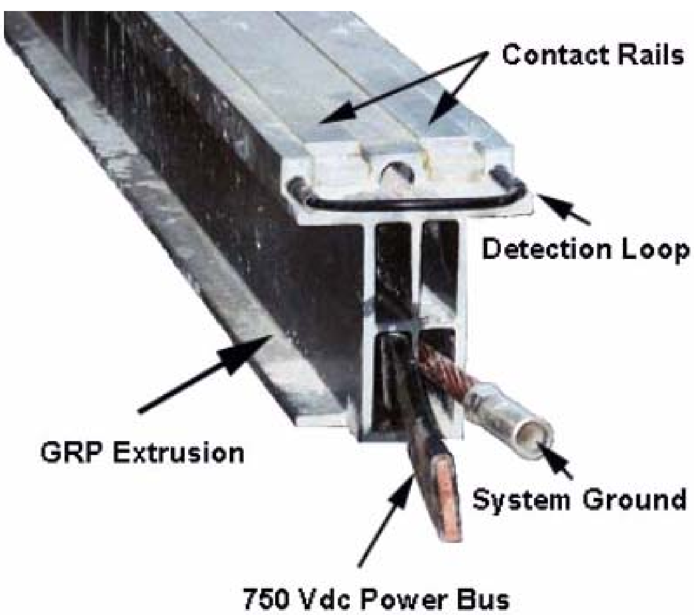


FIGURE 4 INNORAIL power rail cross section.

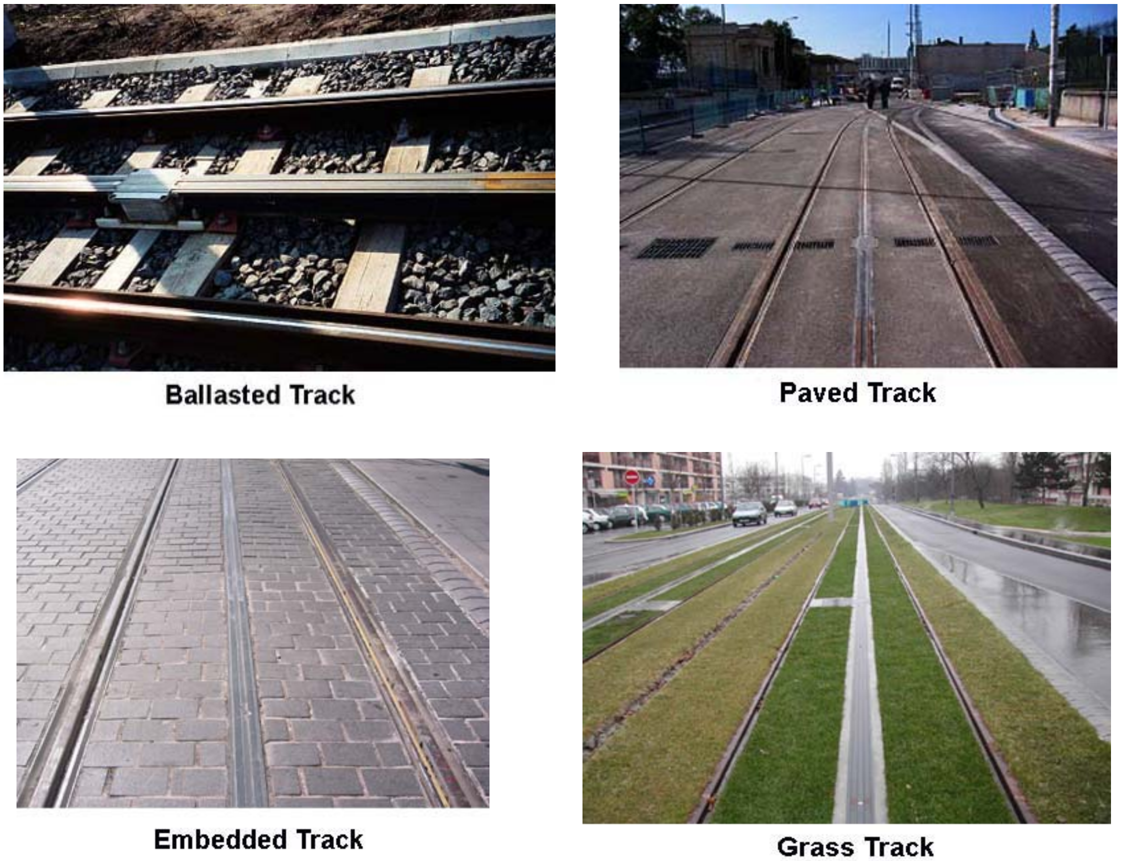


FIGURE 5

FIGURE 6 Station transition point.

FIGURE 7 Crossing special trackwork.

INNORAIL System Development

Development of INNORAIL began in the Spie Rail works in Vitrolles in the south of France in early 1999. Full size system component mockups were installed on streetcar Line 68 in nearby Marseille by December 1999, with fully functional prototype components installed by May 2001. This allowed the operation of a limited proof of concept installation using a modified 600V/dc high-floor vehicle and 1,968.5 ft (600 m) of sectional power rails, of which 492 ft (150 m) were in installed in city streets (Figure 8).

Meanwhile, in the north at Ollainville, track components in a variety of installation configurations were being subjected to a simulated 30 years of street traffic by the RATP Test Laboratories, being repeatedly crossed by 11 ton rubber tired vehicle loads (Figure 9).

By 2002, INNORAIL early production components had been installed on 2,296.6 ft (700 m) of LRV test track at the Alstom La Rochelle factory where the new Citadis LRVs for Bordeaux are being constructed. Extensive testing followed, using a state-of-the-art 100% low-floor Citadis vehicle operating at 750V/dc (Figure 10). To date, over 2,100 mi (3,500 km) of endurance running tests have been performed, including crossing special trackwork and automatic transition to emergency battery power.

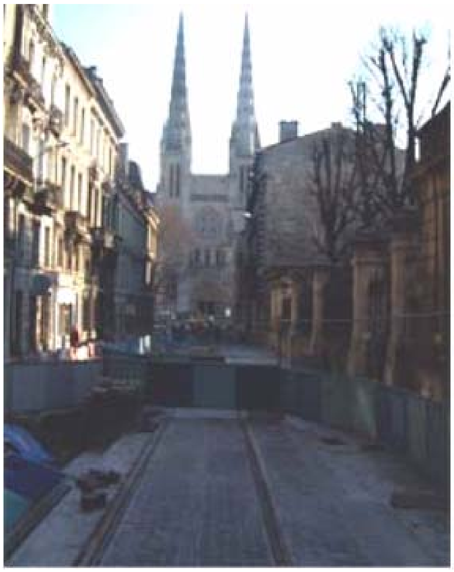
Bordeaux's LRT System

As was noted earlier, the Phase 1 Bordeaux system length (Lines A and B) totals 15.5 mi (25 km), of which 6.3 mi (10.5 km) or nearly half the system is INNORAIL equipped. The INNORAIL equipped sections are located in the old city center, on the historic stone bridge crossing the Garrone River, on Line B as far as Talence, and two short sections in Lormont and Cenon (Figure 11). The entire Phase 1 system is scheduled to be in revenue service by the end of 2003.

FIGURE 8 Proof of concept.

FIGURE 9 Endurance testing.

FIGURE 10 System testing.



(a)

(b)

FIGURE 11 (a) Old City Center; and (b) Garonne River Bridge.

Phase 2 of the development (Line C) will add another 11.6 mi (18.7 km) to the system. The percentage to be equipped with INNORAIL has yet to be finalized, but at least 3.1 mi (5 km) are expected.

The Bordeaux LRT system development produced one of the largest LRV orders in Europe, a total of 70 X 100% low-floor, air conditioned vehicles (Figure 12). The order breakdown is as follows:

- 6 X 107.93 ft (32.9 m) long, 213 passenger Citadis 302 and 38 X 144.36 ft (44 m) long, 300 passenger Citadis 402 100% low-floor vehicles in Phase 1.

FIGURE 12 Citadis LRV.

- 12 X 107.93 ft (32.9 m) long Citadis 302 and 14 X 144.36 ft (44 m) long Citadis 402 100% low-floor vehicles in Phase 2.

As is the norm for European LRV operations, they run only single car trains, adding more vehicles to the system as demand requires. The system typically runs trains at 4 min intervals (2 min at peak).

INNORAIL System Components

Fixed Installation

The fixed installation part of the INNORAIL system is made up of the following elements:

Sectional Power Rails (as mentioned earlier) These low profile sections are typically in 36 ft (11 m) lengths fitted with 26.25 ft (8 m) of conductor rail and 9.84 ft (3 m) of insulating rail. These FRP pultrusions contain integral duct banks that carry all power, ground and control cabling., as well as the vehicle detection loop for that section. These assemblies also have a spare cable duct that could potentially be leased to local fiber optic or coax cable service providers. The ratio of conducting rail to insulating rail is based on the vehicle operating speed, which in the case of Bordeaux, is 44.7 mph (20m/sec or 72 km/h).

Power Rail Control Contactor Units One is located every 72.2 ft (22 m), and controls two segments of power rail (Figure 13). These units are modular and can be replaced in less than 5 min. Although a solid state switching unit would logically be utilized, traditional contactor units were chosen for this application because the short duty cycles caused difficulties in semiconductor heat rejection at these current levels. It is still very likely that a solid state solution will eventually be applied.

(a) (b)

FIGURE 13 (a) Interior of power rail control unit; and (b) Installed power rail control unit.

Insulating Junction Boxes An insulating joint box is located every 72.2 ft (22 m) to mechanically and electrically join the ends of the power rails at all locations. These boxes are silicone sealed after all connections are made to keep out moisture (Figure 14).

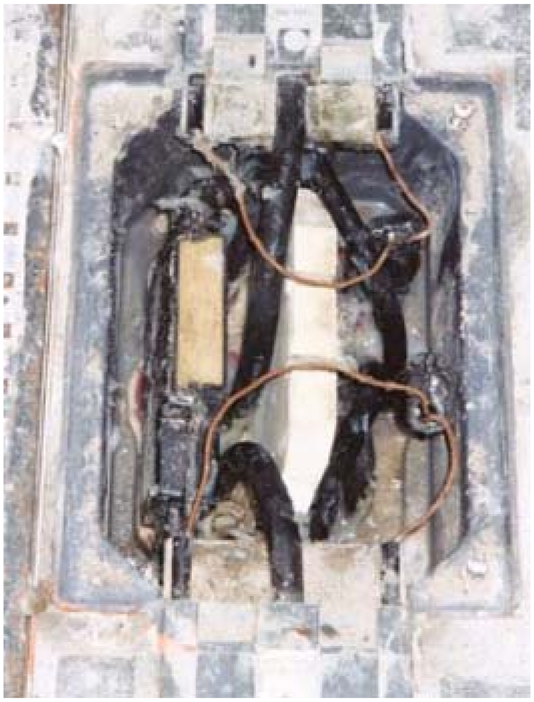
Grounding Contactor and System Monitoring Equipment For safety purposes, a cabinet containing a grounding contactor and system monitoring equipment is installed in each substation (Figure 15). The condition monitoring system is designed to detect faults in any power rail segment within 200 milliseconds, disconnect and ground the main 750 V/dc power feeder to all segments fed by that substation, automatically isolate the faulty segment and restore the system power to the remainder of the system in less than 2 seconds. These faults include, most importantly, a segment remaining live after the vehicle signal is lost and of course, short circuit or similar faults.

On the Vehicles

The INNORAIL system is capable of being installed on almost any type of light rail vehicle, including 100% low-floor vehicles. The following additional equipment is required to operate on an INNORAIL equipped system:

Emergency Battery Set One roof mounted unit is required on each vehicle to allow it to transition through any dead power segments (Figure 16). To save space, this unit is mounted under the pantograph frame on the vehicle center section. This battery set contains 63 x 12 volt sealed, aircraft certified, lead acid batteries and can provide approximately 1 min of vehicle movement at reduced speed [1.8 mph (3 km/h)]. This will move the vehicle a minimum of two failed power rail segments, although 500 ft (152 m) is routinely achieved.

Retractable Power Pickup Shoes Two sets of center truck mounted pickup shoes are necessary for current collection, mounted at the ends of the truck (Figure 17). The shoegear uses graphite shoes to keep the fixed installation wear to a minimum, although in the initial stages, soft iron shoes have been used to clean and polish all the contact surfaces.



(a)

(b)

(c)

FIGURE 14 Junction box (a) interior; (b) installed; and (c) with control unit.

FIGURE 15 System monitoring.

FIGURE 16 Battery box.

FIGURE 17 Shoegear installation.

Pickup Shoe Control Box Extra control components required to activate the pickup shoes and interlock with the pantograph controls.

Power Control Box This roof mounted box contains the additional contactors and controls needed to for switching 750V/dc power coming from the pickup shoes or the emergency battery set (Figure 18).

Cab Controls and Monitoring equipment Additional controls required to operate and monitor the vehicle's INNORAIL related equipment.

Safety Grounds Extra ground points installed under the low-floor section of the vehicle to suppress any possible fault conditions. These are shown in Figure 17.

Safety and Certification

With a readily accessible ground level power system, safety is clearly a key concern. A variety of safeguards are designed into the system to prevent any single point failure from causing a hazardous condition. Independent safety certification insures that the designs perform as expected.

The safety certification process has been and continues to be addressed by various well known and respected French certification authorities and independent assessors including CERTIFER and RATP. The process so far has been as follows:

- Independent system assessment in accordance with **EN 50126 –** Railway Applications – The Specification and Demonstration of Availability, Maintainability and Safety (RAMS) and **ENV50129 –** Safety Related Electronic Systems for Signaling .
- Approval of the Preliminary Safety Case – this was completed in January 2000.
- Approval of the Final System Safety Case – is currently more than 90% complete and with the current progress in energizing the Bordeaux system, it is expected to be fully completed and approved by the time of this conference.

As mentioned earlier, each section of INNORAIL power rail is solidly grounded unless a signal is received by its local power control unit, and separate substation monitoring circuits double check this by looking for voltage on the rail without a vehicle signal. This is to prevent any section from being inadvertently energized when not safely covered by an LRV.

FIGURE 18 Power control box.

Another major consideration is leakage from an energized power rail section when conditions are wet. Being on the Atlantic coast, Bordeaux is always humid and subject to frequent rain. Further, the streets are washed using salt water taken from the harbor, creating a very conductive and corrosive environment. Energized rail tests under standing salt water conditions have measured less than 5 volts leakage outside of the running rails which is considered acceptable.

Unfortunately copies of the Hazard Analysis used in the certification process and detailed design approach used to respond to these concerns are not yet readily available.

Adapting INNORAIL Technology to U.S. LRT Systems

A number of U.S.-specific issues must first be addressed before the INNORAIL system can be applied to a U.S. LRT system,. Following a technical assessment visit to Bordeaux in February of this year, the following observations were made regarding the suitability of the INNORAIL ground level contact system for U.S. applications:

- The INNORAIL ground level contact system is well developed and has applied sound engineering principles in its design and construction. All equipment is solidly constructed and is likely to survive in its operating environment.
- The system appears to mitigate all reasonable identifiable safety hazards, thus Safety Certification in the United States should be achievable. Such certification will require considerable preparation and documentation to be presented to U.S. local certifying authorities, but can build on the experience of the Bordeaux in its safety certification process.
- Adapting to multi-car operation may be achieved by increasing the size of the main power bus with no change to the basic INNORAIL installation as the ducts can accommodate a larger cross section power bus. Substation size and spacing should remain as is normal for typical U.S. OCS operation.
- Adapting for higher operating speeds is also said to be possible by the supplier. This would require relatively minor changes in the relative lengths of the conducting and insulating rail inserts to achieve the desired power rail switching.
- Sole sourcing is also a consideration. The INNORAIL system technology is proprietary and only available from one source, thus sole source procurement will currently be required. Fortunately, this may be allowable under Section 9.h.of FTA Circular C4220.1E *Third Party Contracting Requirements.*
- “Buy America” requirements are also an issue in U.S. procurements. However most, if not all, of the INNORAIL system components could be manufactured using 60% or more U.S.-manufactured components or possibly completely manufactured under license in the U.S.
- Adapting for higher gradient operation under section failure conditions has a higher impact as the Bordeaux LRT system profile is relatively flat. Should the U.S. LRT system being designed have any significant gradients involving INNORAIL operation, a larger set of batteries will be required for the Emergency Battery Set, adding to the vehicle cost and weight.
- Adapting the vehicle system components to U.S.-manufactured LRVs should be fairly straightforward due to the universal nature of the additional vehicle equipment required The biggest challenges would be the fitting of the retractable shoegear in the very confined area surrounding the center trailer truck and the space and weight distribution impacts on the vehicle roof area.
- Cost is always a critical issue. Currently the system is only operating in France and has yet to be “Americanized,” thus any cost projections are somewhat speculative. However, based on the

supplier's current estimates, the fixed installation should be within 5% of traditional OCS system costs, plus approximately 5% per LRV for the additional INNORAIL related vehicle mounted equipment. With series production, this could become no increase in cost over OCS.

- Operation in ice and snow conditions is currently not addressed. With its fully exposed conductor rails, icing is certain to occur. There are some potential solutions, such as electrical trace heating, but they will add cost, both in initial installation and energy wise.

Adapting INNORAIL for use on US LRT systems looks possible from a cost, safety, and engineering point of view as long as snow and ice are not a major factor. The author is aware of several U.S. cities that are actively considering this technology and the number is likely to grow as the system becomes fully operational at the end of this year.

The biggest single hurdle today is availability of the system. In March of this year, the Spie Rail INNORAIL technology was sold to Alstom who are currently showing no interest in the U.S. market for this very promising technology. It is hoped that if sufficient interest is shown here, we too may have the capability to operate without wires.

CONCLUSIONS

For the first time in many decades, the dream of having quiet, non-polluting, electric light rail vehicles running without any overhead wires is on the verge of becoming a reality.

The INNORAIL ground level switched contact system in Bordeaux is about to become a significant operational system, although more day-to-day operational experience is needed to fully prove system reliability over time. Nonetheless, this system is sufficiently developed enough that the author believes this to be a viable system and worthy of consideration for many new light rail systems.

One thing is certain, public opinion is very supportive of "wireless" systems and as this technology becomes more mature and available, widespread adoption is inevitable.

Light Rail Down Under
Three Strikes and You're Not Out !

PETER TURNER
Parsons Brinckerhoff

Queensland, Australia's "sunshine state," is typical of many sunbelts—it relies on tourism and has rapid population growth, continuing urban sprawl, falling transit modal shares, and a general community concern for the environmental consequences. These are trends familiar to many U.S. cities.

Light rail transit has been considered as a solution to these concerns, and has been the subject of a comprehensive planning and justification effort on a number of occasions for a Brisbane-based system. However, despite the many benefits offered by the light rail mode, none of the previous schemes have been able to garner sufficient support to allow implementation. State government is now preparing a planning and project justification for a light rail scheme in the region for the fourth time in a decade. This time, the proposed corridor is along Australia's premier tourist destination—Gold Coast City.

INTRODUCTION

The city of Brisbane is the administrative and commercial heart of Queensland. It forms part of a conurbation of some 1.5 million residents that includes four cities and two shires. From the turn of the century until 1969, the city was served by a network of tram lines which, in their heyday, operated a fleet of 425 trams and carried 170 million passengers per year.

As in other cities in Australia and overseas, 1960s Brisbane saw the demise of its local tram networks as community leaders sought to modernize municipal public transport systems. From the late 1950s until the mid 1980s, Brisbane experienced massive urban expansion as the municipal program of expanding the (then) limited sewer and water reticulation network to new development sites allowed developments to expand rapidly. The city changed from a corridor-based development focusing on tram lines to extensive urban sprawl. With the people's emerging love affair with the automobile, the future of public transport also favoured the road-based rubber tire mode—the bus. For Brisbane, the rest was history.

BACKGROUND INSTITUTIONAL LANDSCAPE

For the past 25 years, southeast Queensland's transportation network has been shaped by the region's institutional landscape. To this day, it remains a powerful influence on how planning is conducted, who drives projects and how the transport system evolves. This section provides a short background on the relevant historical aspects of transport in the region. Its purpose is to describe the institutional environment into which the concept of light rail was first introduced in the early 1990s.

Context

Brisbane is a municipality of nearly 700 km^2, with a city council headed by a popularly elected lord mayor. An Act of Parliament gives the Brisbane City Council (BCC) a degree of institutional independence on transportation matters within the region. Additionally, BCC has responsibility for much of the road network within its boundaries. In the context of light rail, this means it has overriding responsibility for curbside access, the provision of inner-city curbside parking facilities and the approval of all bus stops and bus layover facilities in the inner city area. A proposal that would have a material impact on the operations of traffic and access in Brisbane must therefore gain the support of BCC to proceed.

Brisbane's public transport is provided by the BCC municipal bus fleet and the state government's Citytrain operation. Both are heavily supported by the state government's department of transport in the form of operating subsidies and capital funding. The Minister for Transport, through the state department of transport, is ultimately responsible for the provision of all public transport services throughout Brisbane and the surrounding region. In practice, this involves medium- and long-range network planning; awarding, managing and funding public transport service contracts; and funding selected capital investments in supporting infrastructure and fleet and rolling stock enhancements. BCC also provides operating subsidies and capital injections into its municipal bus operation.

Consequently, the Lord Mayor of Brisbane is pivotal in all decisions affecting the functioning of the city. As BCC also operates the municipal bus service, the extent of its influence on road-based transportation investment and operation becomes readily apparent. With BCC's preference for undertaking transport planning activities within its boundaries, any unaligned overlap between state and BCC planning activities can require vigorous negotiations.

Early Development

Soon after the removal of the last Brisbane tram, the state government commissioned Queensland's first major study of public transport for the region. Key recommendations from that study included an upgraded heavy rail system with a comprehensive system of park-and-ride sites and a heavy emphasis on reorganizing the region's bus services to act as feeder services to a number of upgraded rail stations. The study also recommended establishing a single coordinating authority to oversee future government investment in the public transport network and to ensure the public transport network developed as an integrated system. In 1975, the Metropolitan Transit Authority Act was proclaimed and the Authority became a reality.

The Metropolitan Transit Authority (MTA) was effective in funding a comprehensive network of park-and-ride sites at a large number of stations on the heavy rail network, the electrification of the suburban rail system, limited bus priority treatments and some fleet acquisitions, and a number of other local public transport initiatives. The relationship between the MTA and the region's two major public transport operators was, for the most part, cordial, as long as MTA funding for system capital works continued. On the broader issues of network planning and integration, the setting of service levels and all operational aspects, both the rail operator and the municipal bus operator continued to maintain their independence from the MTA and from each other.

The MTA had a short life, and in 1978 the Act was repealed. Responsibility for planning and developing the rail and metropolitan bus system remained with the individual operators; however, the state government retained oversight of the number of private bus operators servicing the shires surrounding Brisbane. Thus from the beginning, the state government has provided funds for capital improvements, rolling-stock acquisitions and operating subsidies, but has had little success in developing a network which reflects an integrated system of bus and rail services, each working together.

In the early 1990s, the state government became concerned at the increasing levels of congestion and the inability of the current transport system to accommodate the needs of the traveling public. At the same time, BCCbecame aware of the reported successes of the "busway" concept in Ottawa. BCC saw the busways as a means of reigniting a declining public interest in the bus system while providing a much needed improvement in operational reliability and accessibility. Since the state government would, in all likelihood, fund the busway network, BCC lobbied strongly for this concept to take centre stage.

The state government subsequently prepared the Integrated Regional Transport Plan (IRTP). This plan sought to lay the blueprint for future development of the region's transportation systems until the year 2025. Key findings from this study included developing a 75 km busway network, heavy-rail enhancements and a raft of road network improvements. The key message from the IRTP was that the steady decline of public transport mode share—from some 13% in 1969 to 10% in 1980 to some 7.5% in 1992—was unsustainable in the long term. A $700 million busway network scheme became the centerpiece of the IRTP. Given the state government's previous funding emphasis on the heavy rail network, this shift in funding for buses was welcomed by BCC.

It was in the initial planning for the IRTP that the concept of light rail was first raised.

STRIKE 1—BRISBANE LIGHT RAIL TRANSIT PROPOSAL

Context

In the early 1990s, the central area of Brisbane was being earmarked for substantial development investment as demand for high-rise inner-city unit development gathered pace. In parallel with this, the development potential of a number of inner city precincts was also being recognized, and BCC's urban renewal task force teams were established to guide ongoing investment in these areas. One area in particular was well placed for urban renewal investment — the inner northern precincts of Fortitude Valley, Teneriffe and Newstead. As part of the planning for the urban renewal process, BCC undertook a number of investigations, which resulted in the recommendation that "A light rail transit (LRT) system should be installed as soon as feasibility is established and funding is available to connect Newstead, Teneriffe, and Fortitude Valley with the CBD (central business district)".

Proposal

Examined in detail in 1992, the proposal was for a light rail linkage between the Newstead urban renewal project and the CBD. The plan also provided for a link to the city-based University of Technology and a possible future link over the river to the redeveloping West End precinct. The route through the CBD sought to link the retailing, commercial, financial, and government-office precincts into a single inner-city loop. The route alignment proposed is shown in Figure 1.

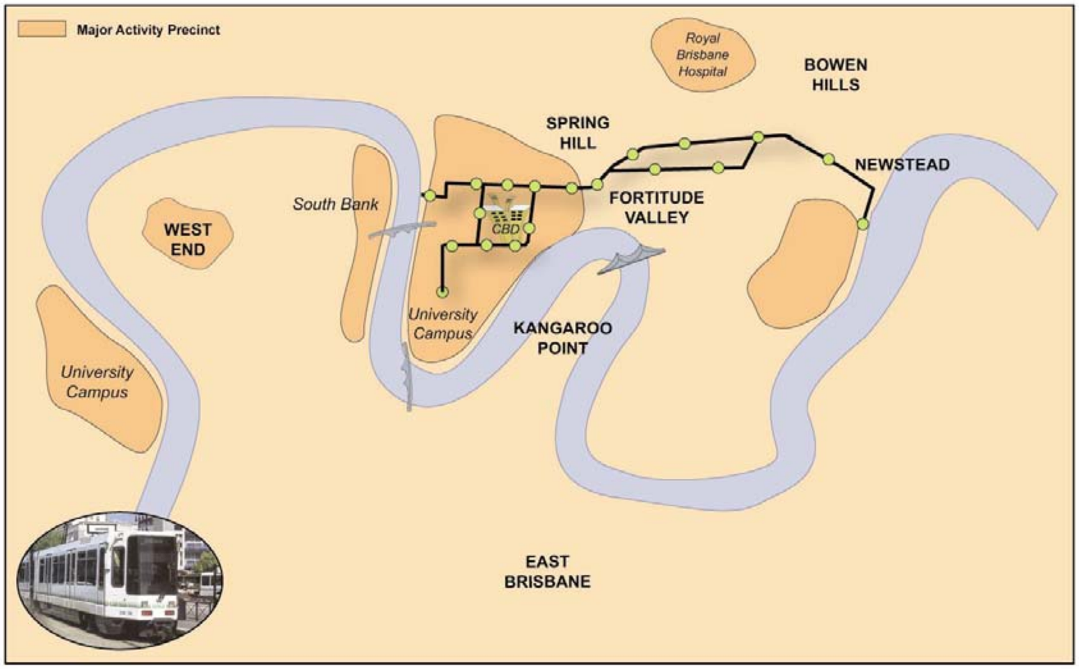


FIGURE 1 Brisbane LRT proposal

Technical Issues

The study examined the various modal options available as part of the selection of light rail as the preferred mode. It also addressed alignment planning criteria, elements of track design, and traffic impact issues. Detailed patronage forecasts were part of the study, as were estimates of construction and operating costs. At that time, BCC regarded the study as a major project, aimed at delivering a landmark transport system. During the study, the local tramways museum expressed interest in operating a heritage tram along a proposed route extension into New Farm, on the basis that council provided funding. The study also included an assessment of possible future extensions into the suburban corridors as part of a longer term, Brisbane-wide initiative.

The proposal was driven by BCC, although the state government continued to maintain legislative responsibility for any approval for a new mode operating in mixed traffic conditions. For council, the main game was urban renewal—not transit systems.

Institutional Issues

The project steering committee included representation from BCC, Queensland Rail (the heavy rail operator) and state treasury. Originally raised by council, the concept emerged as a low-profile proposal on the back of a substantial urban renewal agenda. The proposal failed to impress Queensland Rail, and Queensland Treasury remained unconvinced of the financial viability of the project, given the low patronage levels forecast for the project (10,000–15,000 passengers per peak hour per direction). Nor did it capture the imagination of those in the state department of transport who were preparing the regional transportation plans at that time. council didn't have the resources to fund the project, Queensland Rail was skeptical, and Treasury remained unconvinced of its worth. Despite considerable private sector interest in the proposal, the state government remained reluctant to offer the necessary funding. The Lord Mayor at that time was focused on urban renewal, urban liveability, and the development of local-area community development plans. With transport planning for the long term being progressed by the state government, BCC lost interest in the proposal.

Meanwhile, the state government was grappling with the prospect of a new regional busway (also being actively promoted by BCC) as a centerpiece of the emerging Integrated Regional Transport Plan. The prospect of introducing an entirely new mode into the equation at this time in the planning process failed to ignite the imagination of the state government. Since the proposal did not have a champion to push it, the Brisbane LRT proposal failed to see the light of day.

Lessons Learned

The influence of BCC and the personal imprimatur of the Lord Mayor are generally regarded as prerequisites for project approval in the city. This is particularly the case for projects affecting the inner-city area. In the case of the Brisbane LRT proposal, neither the state government nor the Lord Mayor were able to provide the necessary funds. Irrespective of the project’s merits or the level of private sector support for the proposal, the lack of mayoral and Treasury support meant it was effectively buried from the beginning. Council’s support for the eventually successful busways concept continued without the distraction of a possible inner-city light rail proposal.

Strike 1 – and the project failed to make an impact.

STRIKE 2—BRIZTRAM

Context

In 1997, the Queensland state government announced plans to develop a light rail system that would further revitalize inner Brisbane and deliver major benefits for business, tourism, the community and the environment. This announcement corresponded with the federal government’s announcement of a “federation fund” to provide start-up grants for successful projects of regional or historical significance. Given that the rebirth of Brisbane trams was an innovation that would capture the imagination of the public, provide a historical connection with the region’s past, and offer a sustainable transport solution for the future, the proposal was submitted for start-up funding.

The year 2001 was the centenary of federation of Australia. To celebrate this milestone event, numerous federal government grants became available to the state governments for the development of significant projects having a historical element. To be eligible for these funds, BRIZTRAM needed to become operational during 2001 and had to include an historical element, to be achieved by refurbishing a number of the old Brisbane trams from the local tram museum and including a local training program for tram refurbishment and maintenance. With state government commitments given for these two key requirements, the proposal was subsequently supported by the federal government and received a A$65 million start-up grant. Council was not involved in the proposal at this stage.

Proposal

The original proposal was to link the Royal Brisbane Hospital, CBD, and the University of Queensland St. Lucia campus with a modern, street-running light rail system operating on a line haul operation. These three precincts were, and remain, the largest, single-trip attractors in the greater metropolitan area. The proposal planning and impact assessment process was announced and proceeded with stakeholder workshops, community awareness programs and technical analysis. Alternative routes were explored, a preferred route alignment and operational plan was developed, and detailed community consultation commenced. The proposal was costed at approximately A$250 million; would carry some 45,000 passengers per day; and would be built, owned and operated by a private consortium under contract to government. The project was to help the IRTP achieve its aggressive mode share targets set some 5 years previously. The route alignment proposed is shown in Figure 2.

Thus, BRIZTRAM was a project with a dual purpose. It was being promoted as both a sustainable transport solution and a historical tramway which would provide the catalyst for returning tramway engineering skills to Brisbane through a project-sponsored training program for a local tramways historical society. Once again the local tramways historical society became involved in the proposal. The concept was marketed as a link with the past. This strategy aimed to capture the imagination and support of those residents who remembered the Brisbane trams of old.

Community reaction to the proposal was mixed. At the broader level, many residents supported the concept. However, for the residents of West End precinct where the alignment would pass through a commercial district, a degree of resident opposition emerged. The desire of the local

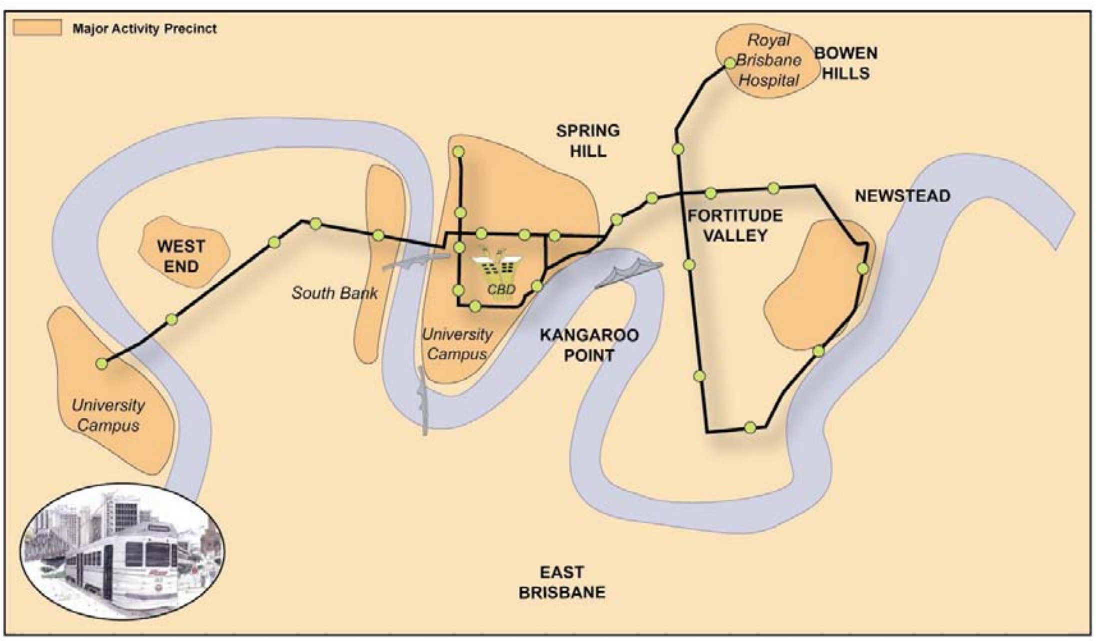


FIGURE 2 BRIZTRAM proposal

community was to maintain a local village ambience; the BRIZTRAM proposal was seen as destroying that atmosphere. Also at that time, the BCChad been championing the virtues of limiting the number of river crossings as a means of enhancing the river vistas of the city. As the BRIZTRAM included a bridge across the river to the university, local groups committed to the no bridge sentiment rallied in opposition. BCC did not become involved in the project, observing these developments from the sidelines.

Technical Issues

The vehicle fleet proposed was a combination of modern, low-floor and older, refurbished Phoenix trams from the local tramways museum.

Key technical issues in the debate during the study included:

- The use of old trams with a draw-down power requirement of 600vDC. The preferred arrangement from both the study consultants and a number of vehicle manufacturers was the common 750V/dc. Support for the former voltage came from the tramways historical group, keen to have the old trams back working the streets again.
- The pressure to resurrect some of the old trams and introduce them onto the system. There were vehicle safety concerns and the high floor was considered to be at odds with recent legislation that required barrier-free access to new transport infrastructure.
- The carrying capacity of the existing inner city Victoria Bridge. This bridge was originally designed for rubber-tired vehicular traffic, and there was doubt as to the rigidity and carrying capacity of the structure for the heavier light rail vehicles (LRVs).
- The difficulty in colocating a light rail alignment with a proposed busway in the Cultural Centre precinct in the South Bank area. At that time, the planning of a south-east busway was well advanced, and state government commitments had been given regarding its funding and delivery. BCC, as the municipal bus owner and operator, was anxious to see the opening of the busway in its original form and on time (Figure 3). The introduction of light rail into the project delivery phase was viewed as a distraction.
- The gauge. At the time of the study, the experiences of dual-mode operation in Karlsruhe and Zaarbrucken (Europe) were becoming more widely appreciated. There was a view that, in the longer term, some of the lightly loaded sections of the heavy rail network would be better served by a dual-mode light rail operation. Consequently, the debate over whether the old standard-gauge trams should dictate the future or whether the cape gauge of the metropolitan heavy-rail network should prevail continued throughout the study.
- The prospect of a river crossing from West End to the University of Queensland St. Lucia campus. This became a major project hurdle. During the mid-1990s, river crossings had become a politically emotive issue. Inner city communities opposed additional river crossings in order to protect local amenity from the unwanted incursions of through traffic. BCC supported these views. West End was one such community that made its views known very stridently. Furthermore, the University of Queensland and a local rowing club continued to express concerns over the effects of a bridge crossing in the area on the grounds of safety (rowers running into pylons), the visual impact, and station footprint requirements on campus. These three issues were central to the eventual failure of the project.

FIGURE 3 South–East busway at Southbank

- The effect of modal competition. BCC, which also operates a fleet of buses and river-based ferries between the city and the university, became concerned at the potential loss of revenue on the existing university services. Issues of compensation should the light rail project proceed were raised by BCC during the study.
- Traditional technical issues, such as alignment planning, utilities and plant relocations, clearances, traffic management, construction costs, and vehicle specifications. Reviewed as part of the detailed technical assessment process during the study, these issues were being considered in detail for the first time in some 40 years and the state government needed to be confident that it understood the detailed technical aspects of a new technology in an inner-city environment.

Institutional Issues

The state government was determined to deliver this project. This was partly a result of the "can do" attitude of the then state government, and partly due to a sense of urgency that, because it was a minority government (relying on the support of an independent member for a majority in Parliament), it had to deliver. There were also emerging concerns that, just having signed off on the IRTP, where busways were to be the dominant feature of Brisbane's future investment strategy, the government had suddenly decided to change tack to promote light rail. It needed to demonstrate achievement.

BCC was ambivalent about the concept of a comprehensive light rail network in the city centre and observed the emerging West End community battle over the proposed bridge to the university with interest. The broader community knew at the time that council opposed additional river crossings. Generally, the wider population supported this view, such had been the level of public debate and opposition to additional road building at that time. Convincing the local residents that cars would not be permitted to cross the bridge became the key issue.

The concept of a “green” light rail bridge then emerged. This concept, aimed at capturing the mood of an environmentally sustainable transport solution would only permit light rail, cyclists and pedestrians across the river. It quickly became the central focus of the entire project as the local community challenged the state government's commitment to guaranteeing cars and other road-based vehicular traffic would be excluded from the bridge.

Despite state government assurances that other road-based traffic would be excluded from the bridge, the community’s concerns were not satisfied. BCC’s subsequent requirement that the “green” bridge be authorized to carry the municipal bus fleet no doubt contributed to the community rejecting relevant state government assurances. This became a major project issue.

The second major issue that sealed the fate of the BRIZTRAM project was the influence of the busways proposals current at that time. Just prior to the release of the BRIZTRAM concept, the state government had been presented with the results of a council-managed study for an inner northern busway (INB) project. The INB was, at the time, considered essential to complement the operations of the South–East busway and continue the delivery of the 75-km regional busway system outlined earlier in the IRTP.

The significance of the INB in relation to the BRIZTRAM project was that the INB project proposed an underground alignment and supporting busway station through a council-run public car park. The loss of car-parking revenue should the INB proceed as planned was of concern to BCC who felt it should be compensated for loss of parking revenue. The issue of compensation was subsequently raised and relations between the state government and council were tested.

However, despite the progress being made on the proposal, a state election was suddenly held in 1998. The conservative government lost office and the incoming Labor Government was not prepared to continue with its predecessor’s BRIZTRAM proposal, particularly as one of the new Labor ministers represented the West End constituency and had (when in opposition), opposed the BRIZTRAM crossing the river to the university through the constituency.

Lessons Learned

Although the BRIZTRAM was fundamentally a sound proposal and had the support of a large number of Brisbane's residents, the lack of cohesive and unified support by both state and council leaders contributed to its delays, targeted community opposition and led ultimately to its demise.

Throughout the project, the state government sought to maintain tight control and to limit the involvement of other government bodies, particularly BCC. This was despite BCC’s initial pledge of some A$14 million for alignment enhancement and complementary measures at key locations. In the end, the lack of willingness to share jointly in what was a landmark project would emerge as a prime reason for the collective failure of the state government and BCC to champion the project. In the end, with the change of government, this all became academic.

Strike 2—and the project was shut down.

STRIKE 3—BRISBANE LIGHT RAIL

Context

After the 1998 election, the new state government took some 6 to 9 months before allowing the concept of an inner-city light rail to resurface. Once this occurred, it became clear that considerable work had been done to "rebadge" it as an entirely new concept. This was despite the mode servicing essentially the same inner city area.

The discussion paper prepared by the state government listed the following matters as the contributors to the failure of the BRIZTRAM proposal:

- The speed at which the project was being progressed and the limited time allowed for adequate planning and consultation, particularly with key stakeholders such as BCC;
- The plan to use the old heritage trams in the fleet;
- Lack of integration and coordination with other modes (the BRIZTRAM proposal was perceived to have been superimposed on existing highly patronized services without due regard to integration opportunities); and
- Failure to address the issues of LRV priority and impacts on traffic.

Based on the research carried out earlier on the BRIZTRAM project, the state government had the capacity to undertake some preliminary concept alignment and operations planning. For example, a route network had been set, the track alignment along most of the proposed network had been determined, and the operating strategy had largely been identified.

By the time the Brisbane Light Rail (BLR) proposal emerged, considerable progress had been made on the South–East busway (Figure 4) and indeed an inner northern busway. Together, these two busways would link the northern and southern Brisbane bus networks and provide a substantial benefit for municipal bus operation as well as the travelling public. BCC was keen to see the investment in busways continue, despite growing state government concern over the costs of such infrastructure.

Proposal

The pretext and differentiating feature of the BLR from the original BRIZTRAM proposal was that, unlike the latter which had a line haul function, the BLR was to be developed as a central-city distribution network. The BLR would service three inner-city railway stations (Brunswick Street, South Brisbane, and Roma Street) and three busway stations (Cultural Centre, Roma Street, and RBH). It would essentially act as an inner-city distribution mode for the growing number of CBD visitors coming into the city center by the busway and the region's heavy-rail networks.

From a network perspective, this proposal included an 11.5-km network with six terminals and 30 stations. It was indeed planned to operate as an inner-city distribution system. It was proposed to serve the key trip attractors of the city-based Queensland University of Technology, the Royal Brisbane Hospital, the emerging Newstead urban renewal project, the West End restaurant precinct, and the South Bank Cultural Centre. It was proposed as a street-running system, with a mixture of segregated and shared alignment sections. It was generally proposed to be a two-way operation throughout the city streets. And in the Fortitude Valley precinct, it was proposed to operate the network as a one-way couplet to complement the one-way street system operating through that area.

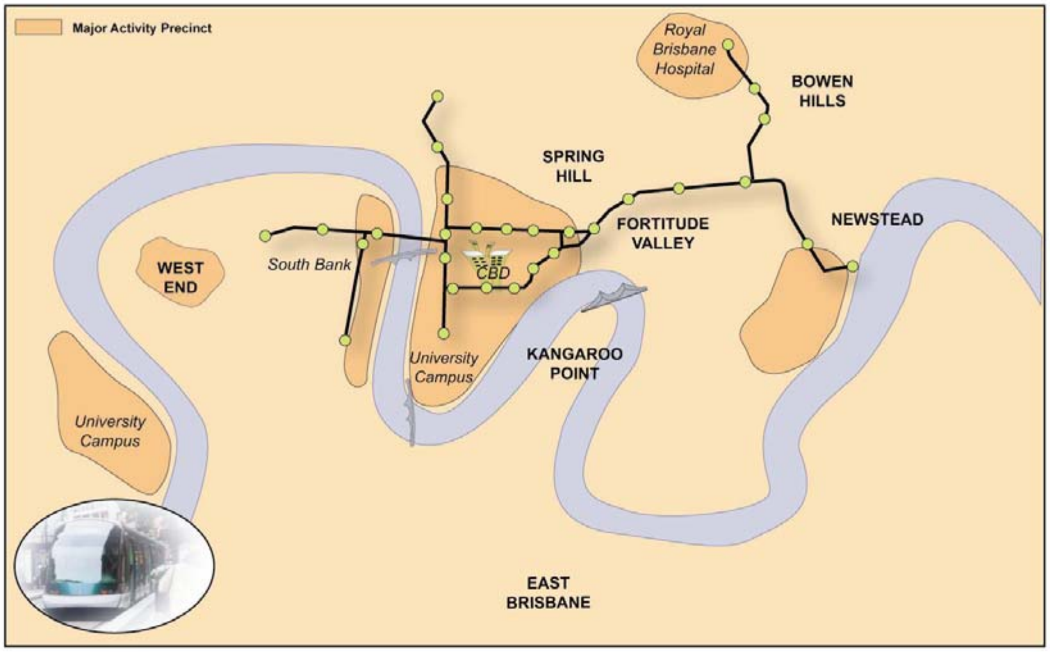


FIGURE 4 BLR proposal.

The stated objectives of the BLR were to:

- Enhance the inner city environment with improved urban design;
- Increase overall use of public transport and contribute to the IRTP mode share targets;
- Improve local air quality and reduce other environmental impacts of traffic in the city;
- Make public transport more permanent and increase its accessibility and understanding;
- Improve circulation of shoppers, workers, and tourists within the central city area;
- Stimulate development in the city, Valley, New Farm, and West End precincts; and
- Provide for extensions of the BLR on to the suburban rail network and into suburban environments.

At the outset, the impact of the West End community opposition to the BRIZTRAM was well noted. The initial discussion paper prepared by the state government noted the proposed new network does not pass through the West End area and therefore the concerns raised by the West End residents are removed.

Having undertaken a substantial amount of public consultation and having raised the concept of light rail in the public consciousness during the previous BRIZTRAM study, the BLR sought to concentrate on a range of technical issues, some of which remained unanswered due to the cutting short of the earlier study. These included:

- Wheel profiles—for possible future dual-gauge running in street and on the heavy-rail network;
- Modal integration—to connect the developing busway services and ferry network into the light rail system. In this case, the focus was more on the impact the light rail would have on the existing bus and ferry contracts held and funded by the state government;

- Detailed track and station design issues, such as structure gauges, signaling systems, design loads, and rail fixing techniques;
- Low-profile rail and rail-fixing options for the link over the Victoria Bridge;
- Operations plans, traffic impacts, environmental impacts, and construction schedules; and
- Revenue and cost estimates.

Once these and other technical issues had been addressed, expressions of interest were invited for the construction and operation of the system. The state government continued to lobby the federal government to provide the A$65 million federation grant for this proposal as it had done for the BRIZTRAM project.

Institutional Issues

The planning and assessment study for this project was managed by the state government. BCC's involvement was generally kept to a minimum and limited to consultation on technical issues where and as necessary. At state government level, there was a strong sense of wanting to have this project succeed, especially since the previous state government's BRIZTRAM proposal was unsuccessful.

While the study proceeded, the South–East busway was being built and planning for the inner northern busway proceeded along in readiness for future funding from the state government.

It was during this study that the notion of a colocation of light rail and busway operations emerged as a possibility for the future. This was a new twist from the earlier BRIZTRAM proposal which had identified opportunities to convert low-volume heavy-rail lines to light rail. BCC, as the owner of the municipal bus operation could see light rail becoming a preferred funding mode from a state government perspective, particularly as the South–East busway alignment was designed to accommodate light rail in the future. It seemed that another competitor for state government public transport infrastructure funds was emerging.

Council by this time was aware that the Property Council was expressing concerns over potential construction impacts on access to many of its members' inner-city properties. The Property Council, which was and remains an influential force in city development issues, saw the light rail as a "problem child" and proceeded to oppose it. The media ran with the story despite the state government's proclamations of it being a most worthy project. BCC continued to observe these developments with interest.

Notwithstanding this opposition, the project proceeded to the expression-of-interest stage. Four consortia expressions-of-interest were received. Detailed evaluation followed. However, the private sector felt the unresolved project risks (revenues, costs, public opposition, etc.) were high and the bids came in well in excess of government expectations. Unable to proceed further with the project because of these costs, the state government advised the consortia that it was withdrawing the expression- o- interest.

Lessons Learned

The BLR was a substantial project. It attempted to build on the curiosity and initial support garnered by the BRIZTRAM project. However, because of a lack of united approach and commitment at both the state government and city council level, the opportunity arose for a third party to rise in public opposition to the project (the Property Council).

While technically feasible, the BLR suffered from a financial feasibility perspective. All that was needed to place it out of reach of the state government's limited budget was to increase the perception of unresolved risks to the project. Bidding consortia would view these unresolved risks as costs and raise the contribution required from government accordingly. The Property Council opposition and BCC's non-involvement in the project contributed to the perception of unresolved risks. With the withdrawal of expression-of interest documentation by the state government, the consequence was inevitable.

Strike 3—and the project was abandoned.

STRIKE 4—GOLD COAST LIGHT RAIL

Context

The coastal resort city of Gold Coast lies approximately 50 mi south of Brisbane (see Figure 5). In 1998 Gold Coast City Council (GCCC) released its own Integrated Transport Plan (ITP). This plan built on the state government's IRTP but focused on the transport imperatives at the local government level. Part of GCCC's plan was to develop a line haul public transport system, linking with the heavy rail network which ran from the west of the main tourist and residential coastal strip to Brisbane. Out of this, the Gold Coast Light Rail was born.

The city of Gold Coast is Australia's premier tourist destination. The heart of the city, Surfers Paradise, contains high-density accommodation (Figure 6). Increasing urban sprawl to the west, combined with Surfers Paradise being the heart of the Gold Coast district, has led to severe traffic congestion in this constrained coastal strip.

Proposal

The proposal calls for a light rail alignment running from Pacific Fair, a major regional shopping complex at Broadbeach, northwards through the heart of the Surfers Paradise precinct, over the Nerang River to Southport, and westward via the Griffith University campus to the metropolitan rail network at Parkwood. The line is some 19 km in length, includes 17 stations and is generally street-running (Figure 7). At the time of writing this paper, early patronage estimates suggest a daily passenger demand exceeding 33,000.

Technical Issues

Due to the previous three attempts at light rail, there was a reasonable body of expertise capable of addressing any technical issues associated with this proposal. Major issues addressed early in the study included:

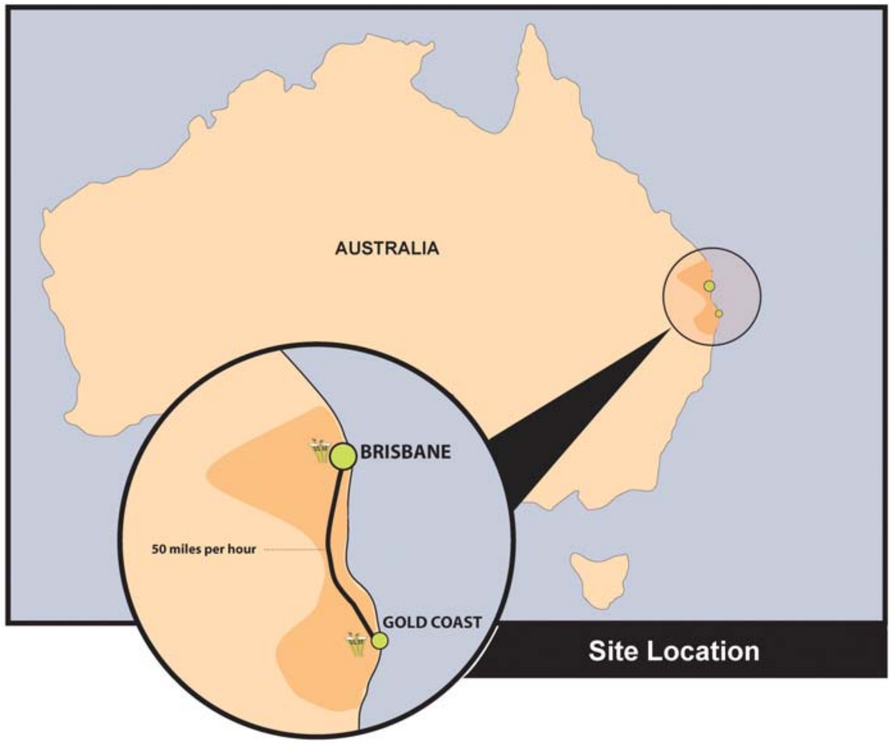


FIGURE 5 Gold Coast and Brisbane Regional Context

FIGURE 6 Surfers Paradise

- The interface with the Indy 300 track;
- Addressing of costs;
- Community alliances; and
- A strong emphasis on proving the financial viability of the proposal.

Institutional Issues

Funding for this project is being provided by a combination of local, state, and federal government. In Australia, this situation poses unique challenges. There is, however, tremendous local government support for the project, far greater than the degree of aligned political support seen at any level for the previous three proposals. At the same time, public–private partnerships (PPP) opportunities are being aggressively targeted by the state government, and a flagship transport PPP is being sought to spearhead this new method of infrastructure delivery. This comes at a time when the federal government is actively shying away from public transport and toward roads, rail, and freight in the transport portfolio. But light rail has proven to be about more than just transport, and opportunities exist for this project to be seen as a regional development and tourism catalyst from the federal government perspective.

It becomes apparent that institutional issues dissolve very quickly into funding issues. Who funds what and gets what back is likely to become a topic of much debate as the project evolves.

Initial Findings

The feasibility study has passed through its first stage and recommended that light rail is the most appropriate mode of line haul public transport for the coastal fringe. At a capital cost of A$300 million–A$400 million and expected patronage in excess of 50,000 trips per day in 2011, it was deemed that there was sufficient confidence to warrant more detailed investigations.

These more detailed cost estimates, patronage modeling and risk assessments are progressing.

FIGURE 7 Gold Coast light rail proposal.

Challenges of the Gold Coast Proposal

Based on the disappointing outcomes from earlier attempts at establishing light rail, the state government adopted a cautious approach to this latest proposal. For them, the essential question had to be proving the financial viability of the project. Having withdrawn the BLR from the tendering process after private sector interests had invested substantial monies into bid documentation, the state government was not prepared to have its light rail project credibility questioned further. On the other hand, the GCCC remains optimistic over the financial merits of the proposal. Based on these stakeholder views, the key challenges for the proposal, as implied in the project brief included:

- Financial feasibility of the project must be proven.
- Government is not willing to go to the private sector for funding without being sure that there is adequate private sector interest.
- The project must ensure local communities are supportive.
- The GCCC must actively support the project.
- The project must be able to demonstrate a capacity to act as an image maker while the GCCC continues to develop.
- Knowing that this time there might be a good chance of success, the financial impact on the local bus service contracts needs to be clearly established.
- The state government will settle for nothing less than a robust assessment of the true costs and revenues from the system.

As can be seen, these issues focus on essentially non-engineering and technical issues, and reflect the maturing of attitude towards establishing light rail as a viable mode in Queensland —a decade after it was first proposed.

Prospects for Success

Every new project has its own unique dynamic. In this case, while the community is well aligned and supportive of the project, the interagency issues remain. At the time of writing, there is some concern being expressed over the possible impact of light rail on the operations of the local bus service provider. This is probably a reflection that industry is taking this proposal seriously. In the end, government funding will be the key to the project's success. If the financial resources of the state government and GCCC are adequate, the project has a good chance of success. If federal funding is required, the future of the project may be less certain.

LESSONS LEARNED

These case studies have highlighted three key lessons:

Project Politics

Queensland's light rail project experiences over the past decade coincide with the view expressed by Hass-Klau et. al[1] that political decisions take center stage when transport decisions are being made. Technical considerations and project justification are often secondary considerations. In the Queensland case, the institutional and political contexts in which the various proposals were conceived, promoted, and dismissed clearly had an overriding influence on the proposal outcomes. If there is any major lesson to be learned from the proposals examined to date, it is that political leaders and relevant agencies all need to act as one, presenting a unified and proactive message about the project. While political support from stakeholders may vary according to individual agendas, this is not a concern as long as the project support and stakeholder relationships can be sustained over a number of years. For a light rail project, this partnership needs to be robust for at least 7 years to allow for the initial study, calling of expressions-of-interest, project construction, and through-commissioning. History has shown that the political landscape in Queensland presents major challenges in developing these long-term relationships.

Light rail is an expensive option and one that should be entered into with a deep commitment and pockets to match. Key political stakeholders will continue to support a project only if it supports their agenda for the future. This does not necessarily mean that each level of politics that is contributing will have the same agenda or needs from the project. In fact, they are very likely to be different because the motivators for each level are also different. What is needed is an understanding of what all potential contributors want to gain from the project and to tailor the light rail project specifically to achieve these needs.

Project Fundamentals

The proposal needs to have a unique and sustainable attribute, which “simply makes good sense.” The BRIZTRAM proposal had a substantial line haul component that offered a distinct travel advantage over existing travel options. In this case, the alignment linking the University of Queensland St. Lucia campus to the city centre would have provided a substantial travel-time benefit for this travel market. In contrast, the BLR, with its six terminals and 30 stations over an 11.5 km network failed to provide a viable addition to the transit network. The earlier Brisbane LRT proposal also failed to have a logical role in the network, given the costs involved. In the case of the latter two proposals, the market for an inner-city distribution network simply did not exist to the extent hoped for. For a project to withstand public scrutiny, it needs to have a simplicity and common sense about it.

Public Readiness

It is not unusual for initial light rail proposals to falter due to lack of public support. In many instances, it may be through a lack of appreciation of the nature of the mode. In other cases it reflects a concern over the perceived short-term impacts (e.g., construction) or the perceived consequences of a new light rail system in the network (e.g., during construction). It is important for a promoter to ensure the public is ready for the project. Public education, debate, and proactive involvement are essential. In the case of the BRIZTRAM proposal, it is doubtful that the public was ready for the new concept, in spite of sections of the community remembering the Brisbane trams of old.

The Gold Coast light rail project has attempted to address each of these key issues to promote and increase the likelihood of proposal success. Time will tell if this strategy is successful.

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CLOSING GENERAL SESSION

From Mule Tracks to Light Rail Transit Tracks

Integrating Modern Infrastructure into an Ancient City—Jerusalem, Israel

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In this article we will describe the Jerusalem, Israel, light rail project, its progress and prospects to date. Jerusalem is one of the world's oldest cities. The focus of three of the world's religions, the city has been a center of conflict for many years.

As a holy city for the three monotheistic faiths—Judaism, Christianity, and Islam—Jerusalem has always had a highly symbolic value. The stunning Dome of the Rock, built in the 7th century and decorated with beautiful geometric and floral motifs, is recognized by all three religions as the site of Abraham's sacrifice. To the Muslims, it is where the prophet Muhammad ascended to heaven. To the Christians, it is where the crucifixion and the resurrection of Jesus took place. The Wailing Wall is part of a remaining exterior wall surrounding the Ancient Temple of the Jewish people whilst the Resurrection Rotunda protects Christ's tomb.

The designers have succeeded in meeting the challenge of integrating state-of-the-art light rail transit (LRT) tracks into an historic city's mule tracks. The light rail line will replace existing automobile traffic lanes at street level and create a more aesthetic environment adjoining the Old City's walls. A new regional transportation plan, a revised and strengthened bus system, parking policies, downtown traffic management, and downtown revitalization all accompany this impressive effort at changing the way the public perceives their city.

Alongside the Old City, an international team of planners has outlined a network of LRT lines and focused on designing a first LRT line in Jerusalem. This is the story.

MULE TRACKS—FORCES SHAPING JERUSALEM'S DEVELOPMENT

Jerusalem—A Historical Review

Only in the 19th century did Jerusalem begin to expand beyond the walls of the Old City. Its growth was primarily along the ancient arterial roads to the west in the direction of the coastal plain (Jaffa Road), the watershed routes to Ramallah, Nablus, and Damascus (Ramallah/Damascus Road), to the north, and Bethlehem and Hebron (Bethlehem and Hebron Roads) to the south, and Jericho (Jericho Road) to the east. Expansion eastward was limited by the steep topography, large burial grounds, and less favorable climate. Thus most of the expansion was to the west, north and south of the Old City walls.

The British Mandate marked the beginning of planning in Jerusalem. Planners brought to the Holy Land by the British delineated boundaries, initiated zoning and created a vision for

Jerusalem's future. The plans emphasized expansion to the west in the form of a series of "garden cities" while preserving the valleys in their natural state.

Until the 1967 Six Day War, Jerusalem was an isolated backwater, linked to Israel's coastal plain by one major road and an old, slow intercity railroad. With reconnection to its hinterland, the city's isolation ended and Jerusalem developed into a metropolis with transportation, economic, and social links with the area around it. The Jewish population in the metropolitan area increased from 198,000 in 1967 to 455,000 in 2001; and the Arab population grew from 69,000 to 415,000. This reflects an Arab growth rate larger than the Jewish one. Today, in the year 2003, the city's municipal jurisdiction is home to 681,000 persons. Jerusalem is the largest city in Israel in population and in area with 126 km^2.

From a transportation perspective, it is essential to consider all areas adjoining the municipal boundaries irrespective of political or demographic composition. Surrounding the municipality are Arab communities to the north, south and east. Government housing policies have created large Israeli satellite communities around Jerusalem and other small agricultural settlements have developed into suburbs of single-family homes. Together, the metropolitan area contains about 1.3 million residents.

Despite the economic progress and growth of the city, motorization remains below the national average, resulting in a higher than average modal split in favor of public transportation.

Topography and Ancient Road System

Jerusalem's rich past is present in the architecture of the Old City's walls, streets, and structures. Still surrounded by the high stonewalls built by the Ottoman Turks in the 1500s; the Old City is the historic heart of Jerusalem. It covers a rectangular area of approximately 1 km^2. The city walls are about 12 m (40 ft) high and 4 km (2.5 mi) long. Eight gates, built in the 2nd century and reconstructed in the 16th century, serve as entrances to the city. Until the late 1800s, these gates were locked at night to protect the city's inhabitants. The improved security in the countryside, the overcrowding inside the walls, and the rising standard of living around the world persuaded the first pioneers to establish communities outside the walls in the early 19th century.

Since ancient times, Jerusalem's form has been dictated by its location atop the hills of Judea and Samaria. Jerusalem sits astride the crest between two watersheds. To the east, the topography descends to the Jordan Valley and the Dead Sea (Syrian–African rift); to the west, a descent of 60 km to the Mediterranean Sea. Jerusalem's altitude ranges from 520 m to 836 m (1,706 ft to 2,742 ft) above sea level. Although the center city of West Jerusalem sits on a relative plateau, the topography is such that even in the north–south direction the alignment of any transportation infrastructure is difficult (Figure 1).

Jerusalem was a central point on the ancient Kings Highway that traversed the mountain ridge. The primary roads leading into the city all lead to separate gates to the Old City. Jaffa Gate and Damascus Gate are named after the roads that begin at the Old City wall and proceed west and north respectively. Many of the villages surrounding Jerusalem were located on hills linked to the city by these original roads. These early roads and small villages are the nuclei of the city that exists today (Figure 2).

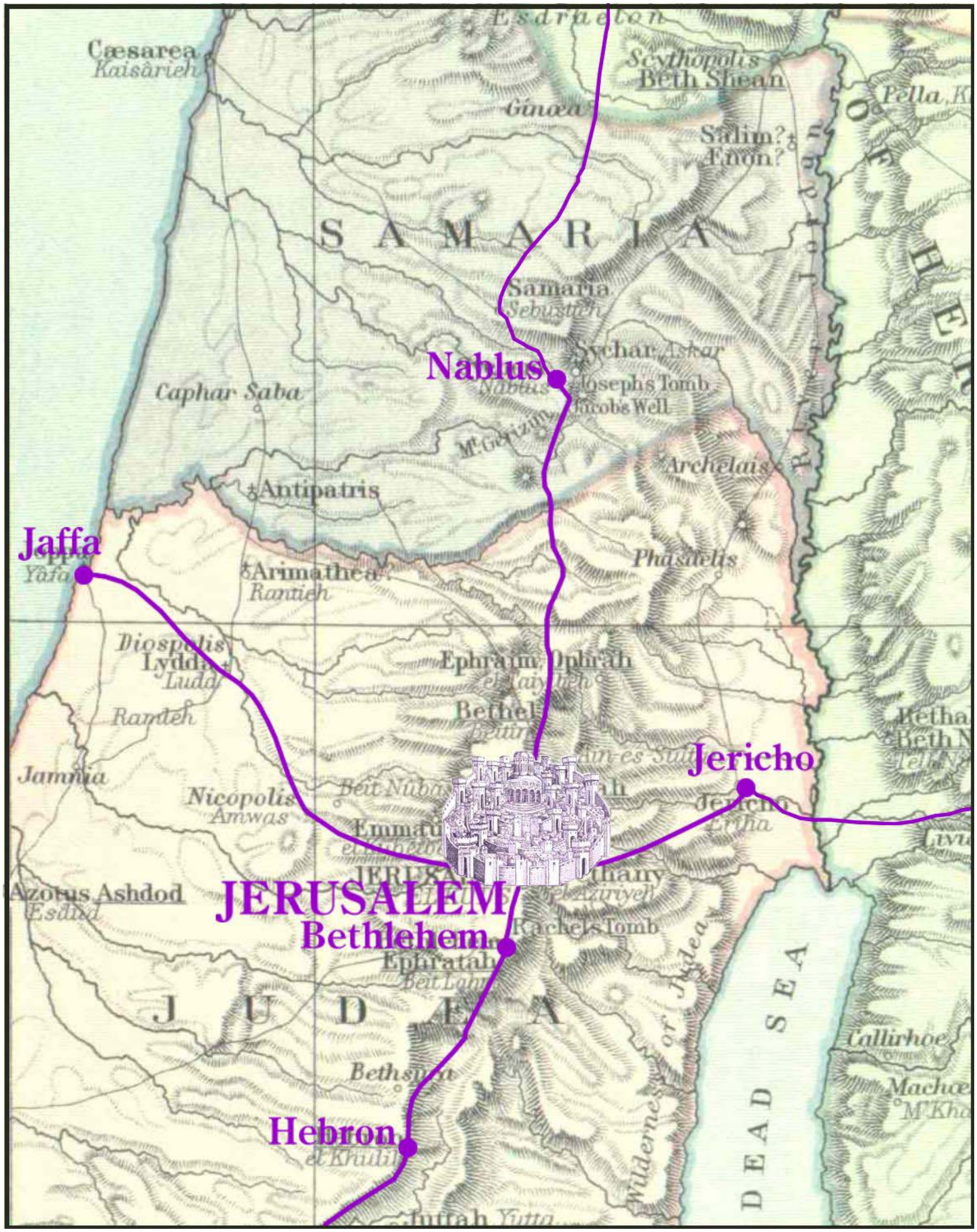

FIGURE 1 Jerusalem and its historic environs.

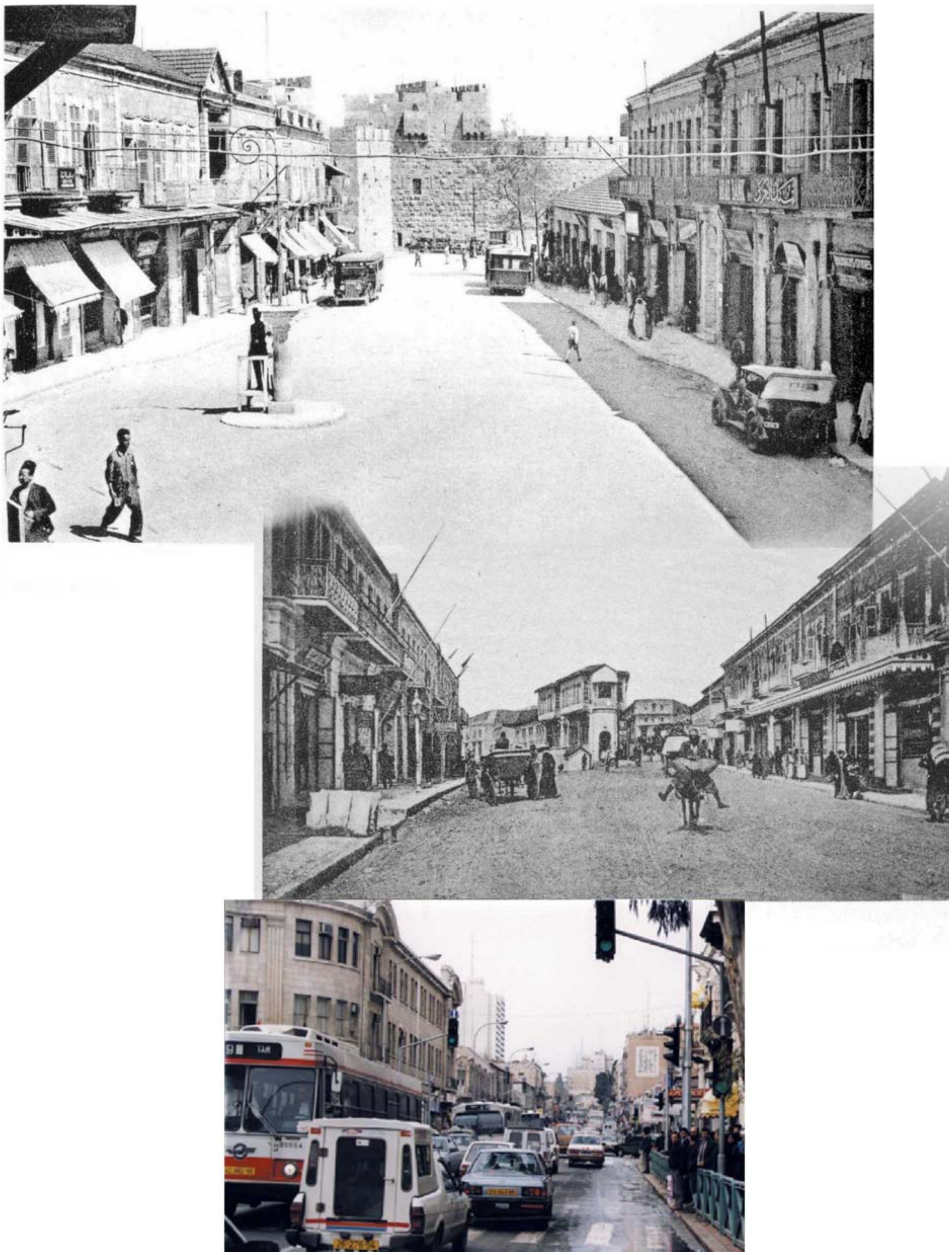

FIGURE 2 Jaffa Road – then and now.

The ancient form described above, with some additional roadways, is the skeleton of today's regional roadway system. The expanded and densely populated northern suburbs still link to Center City, Jerusalem through the Damascus–Ramallah Road. Jerusalem's urbanized area occupies the hilltops radiating from the Old City. In the sections where planning principles are implemented, the valleys are preserved as open space and the ridges and the upper part of the slopes are used for building. Thus, a unique urban form is achieved and preserved.

The population increase, economic development, and the increase in motorization necessitate much planning activity to answer the demand for roadway infrastructure in the city itself and its links to the rest of the country. In the past decade civil engineering projects that were without parallel in any period in Jerusalem's history have been constructed. New roads, tunnels, and long bridges have become part of Jerusalem's landscape, in an expensive effort to overcome the natural topography of the area.

URBAN CRISIS

Transportation Crisis

Jerusalem's present population generates 433,000 motorized trips per day, with approximately 46,000 in the peak morning rush hour. In 1996, the modal split was 55% private car, 39% public transport, and 6% other modes. This still relatively high public transport use represents a dramatic decline from the 60% public transport use of the early 1980s, and continues to decline. Only the growth of the city's population keeps absolute ridership relatively stable, preventing massive service cutbacks. The profile of the average public transport user has also changed. While among the ultra-orthodox Jewish population bus use is still the norm, in the general population users are increasingly limited to the elderly, young, and adults without a driver's license (often women).

Congestion in peak hours is the norm. Except for limited stretches, buses suffer in traffic jams along with general traffic. On the other hand, bus routes rarely use the new Road 4 freeway, which remains relatively free flowing.

The present security situation only exacerbates these trends, encouraging private vehicle purchase and riders to abandon the vulnerable bus system.

Land Use Crisis

While the city grew, Jerusalem's downtown continued to deteriorate. When examining statistics between 1988 and 1994 the following trends emerge:

- The total number of dwelling units in the city increased by 13.2% while the number of units in the city center decreased by 2.4%
- The city's population increased by 15.6% while the population of the city center increased by only 1.4%
- The number of businesses and offices in the entire city decreased by 0.8% in contrast with a decrease in downtown of 3.3%
- On the other hand, shopping and office centers outside of downtown began to emerge in areas with wider streets, more parking, and easier accessibility to the roads to Tel Aviv. These

trends underscored the need to improve the attractiveness of downtown. Like other cities, Jerusalem faces a series of problems that must be solved with a multipronged, long-term approach.

- The relative attractiveness of cosmopolitan Tel Aviv, and the ease of commuting to alternative employment centers.
- Drift of young, educated people to other places in Israel.
- Businesses and families abandoning the city to suburbs.
- Backward, unaesthetic condition of downtown Jerusalem and the rapid expansion of outlying commercial and employment areas.
- A vicious cycle of deteriorating conditions, declining tax revenues, and poor prospects for improvement.

Environmental Crisis

Among the several causes that contribute to the deterioration of the downtown is traffic. Congestion on the city's streets repels visitors. The noise, air pollution, crowding, lack of security, and narrow sidewalks all add to the unpleasant ambience. This is contrasted with modern, climate-controlled shopping malls in the new commercial areas.

TRANSPORTATION SOLUTIONS

Priority for Public Transport

The dramatic growth in private vehicle use in Jerusalem in the 1990s paralleled an unprecedented rise in the standard of living fueled by the high-tech phenomenon. Growing tax rolls allowed the implementation of long-dormant road projects, politically popular with the increasing ranks of car owners. Yet by the end of the 1990s, drivers remained frustrated with growing delay and congestion. Despite the ever-expanding road network, the Ministry of Transportation was forced to reevaluate its policies of favoring road investment and decreasing support for the subsidized bus system. In the Tel Aviv area, a fledgling suburban rail service met with dramatic success, with 30% to 35% ridership growth from year to year. The precedent had been set for government public transport infrastructure investment, especially in new urban rail systems.

Support for public transport investment came from other quarters as well. The growing environmental movement linked rail investment directly with environmental benefits such as reduced air and noise pollution, increased building densities and limits on urban sprawl. Growing awareness and support for groups with special accessibility needs led to the passing of regulations requiring handicapped access in all new public transport vehicles. Urban rail was seen as the ideal solution for seamless, level accessibility for these groups.

Finally, the urban planning establishment in Israel recognized in earnest the linkage between urban vitality and the quality and quantity of accessibility provided by modern urban rail systems; and the destructive nature of a preference for private vehicle accessibility on historic cities such as Jerusalem.

The last few years have not been kind to public transport patronage in Israel, as the security situation drives passengers from the urban and intercity bus network. Yet interestingly enough, the suburban Tel Aviv rail network continues to register dramatic yearly gains in patronage, attesting to the acceptance of this mode in a country with no historic tradition of rail use.

Integrated Transport Plan for Jerusalem

Since the reunification of the city in 1967, transport-planning policy for Jerusalem focused primarily on the development of new and widened urban arterial roads, allowing for the linking of newer, outlying areas of the city with the center in a radial pattern. Plans were prepared in the early 1970s to penetrate the historic core of the city with new roads requiring massive urban displacement, tunnels, and interchanges.

Public outcry and increasing political clout of neighborhood groups quashed these plans. Nevertheless, road development in the outer, newer areas continued unabated, culminating in the implementation of Road 4, a limited access north–south artery in the western part of the city. Road 4 broke the radial pattern, providing an alternative to the ancient north–south “Watershed” road, and allowing traffic to bypass the historic center. At the same time, and on a limited basis, bus lanes were implemented along some of the major radial corridors accessing center city.

The decision to expand the municipal boundaries of Jerusalem, center city decline, and the still mounting problems of congestion demanded a more comprehensive planning approach through the creation of an integrated transport strategy. The resulting plan has become widely accepted and is now awaiting formal approval in the framework of the new Jerusalem District Master Plan (Figure 3). Its major elements include:

- Creation of a ring road system around Jerusalem, consisting of a smaller, inner ring encompassing the contiguous built up area of the city and an outer ring including existing and planned outlying areas. The outer ring road will function to collect intercity and metropolitan traffic and distribute it to an urban arterial close to the trip destination, minimizing through traffic on city streets.
- Within the area encompassed by the outer ring road, clear priority will be given to the development of an extensive mass transit system, consisting of eight future light rail routes. Development of this system will include the appropriation of general traffic lanes for public transport; the lowering of geometric standards to slow traffic and allow LRT insertion; and increased areas for pedestrian and bicycle movements within the new traffic cross sections.
- At points where the mass transit system crosses the ring road or other outlying major arterial roads, a park and ride network is to be established allowing easy movement from private vehicle to mass transit. In the especially congested Tel Aviv–Jerusalem Route 1 Corridor, a high-occupancy toll (HOT) lane is to be established in the section inbound of a planned park-and-ride facility.
- The urban bus system is to be completely reoriented and integrated into the overall mass transit system. Radial routes are to be eliminated and replaced by the light rail network; local routes will be oriented to transit stops and circumferential routes. Thus, light rail stations will not only serve as transfer centers between the LRT and feeder buses, but also between the different feeder routes serving the same station (Figure 4).
- Bus penetration to the center city will be dramatically reduced, with a big savings in noise and air pollution.
- In the ancient and historic areas of the city, severe traffic restrictions and traffic calming measures are to be implemented.

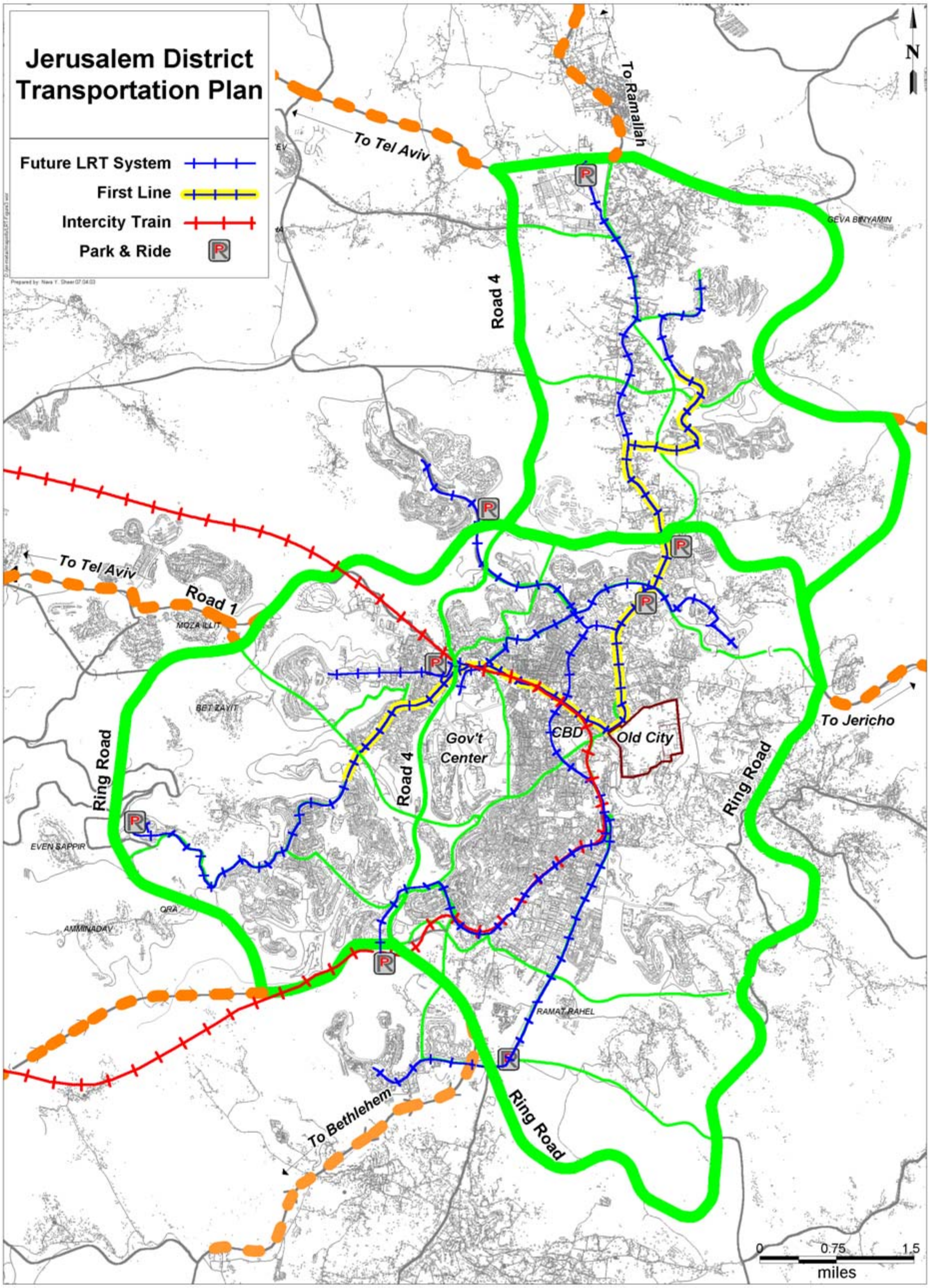

FIGURE 3 Jerusalem district transportation plan.

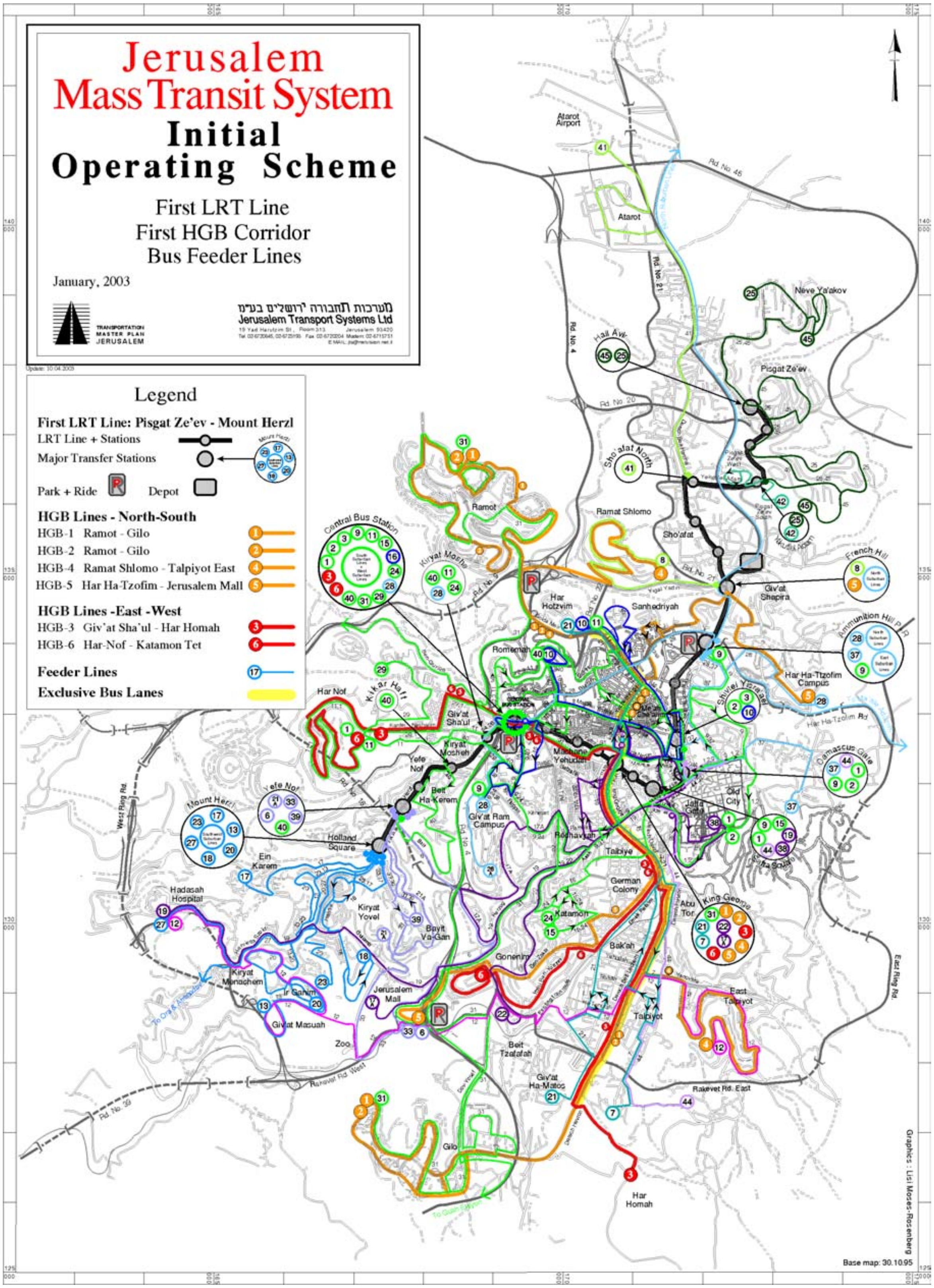

FIGURE 4 First LRT and busway system map.

The new transport policy is to be implemented in stages. Major parts of the inner ring road are currently under construction or have been completed. The first stage of the mass transit system, consisting of the first LRT line 13.8 km (8.6 mi) and a 7.5 km (4.6 mi) north–south busway in the alignment of a future LRT route are also in implementation. Park-and-ride facilities adjoining the first system are in advanced planning stages for construction. Most importantly, a clear mindset has been created in the entire planning community and in the public sees mass transit and transit-oriented land uses, including downtown revitalization, as the key to the quality of urban life.

Parking Policy

Nowhere has the revolution in transportation policy been felt more keenly than in the new parking code which has been adopted by the municipality of Jerusalem with the backing of the Ministry of Transportation.

The new code sets an upper limit on parking allowed in all areas of the city. In outlying areas not serviced by mass transit, these limits are similar to today's demanding requirements. But in projects within the central city area, or within 500 m (1,640 ft) of a mass transit line (light rail or busway), parking is restricted to between 10% and 20% of previous codes. In addition, planning authorities are increasingly using their power to regulate parking facilities by restricting employee-only parking and encouraging only higher cost, hourly parking for visitors to new and existing facilities.

Center City Traffic Changes

The Center City traffic plan is the last element of the new transport policy for Jerusalem to be put in place and is now in the implementation stage (Figure 5).

The plan creates a "Center City Ring" consisting of existing streets integrated into a continuous system. Within the area inside the Center City ring, through traffic is physically prevented, with only short loops leaving and rejoining the ring. Only the mass transit corridors penetrate and cross the center itself. The entire area within the ring has been defined as a traffic-calming (30 kmph–18 mph) zone. The existing highly successful pedestrian area is to be doubled in size; streets left open to traffic will see carriageways narrowed, parking restricted, and sidewalks widened. In combination with the traffic work, the project is upgrading the public domain with extensive tree planting, new street lighting, and expensive granite paving materials.

Mandate for Change

Seen together, the road and public transport policies, park-and-ride, parking policy, and Center City traffic changes form a unified whole which the city of Jerusalem is gambling will create a new transport paradigm for the city. With the current economic downturn and collapse of tourism (spring 2003), it is too early to judge what effects these policies will have on the long-term economic health of the city. But without a doubt, the relative calm with which businesses and residents have received the extensive public works disrupting the city at present is a result of the belief that just building more roads is not the solution to the quality of life issues most on people's minds.

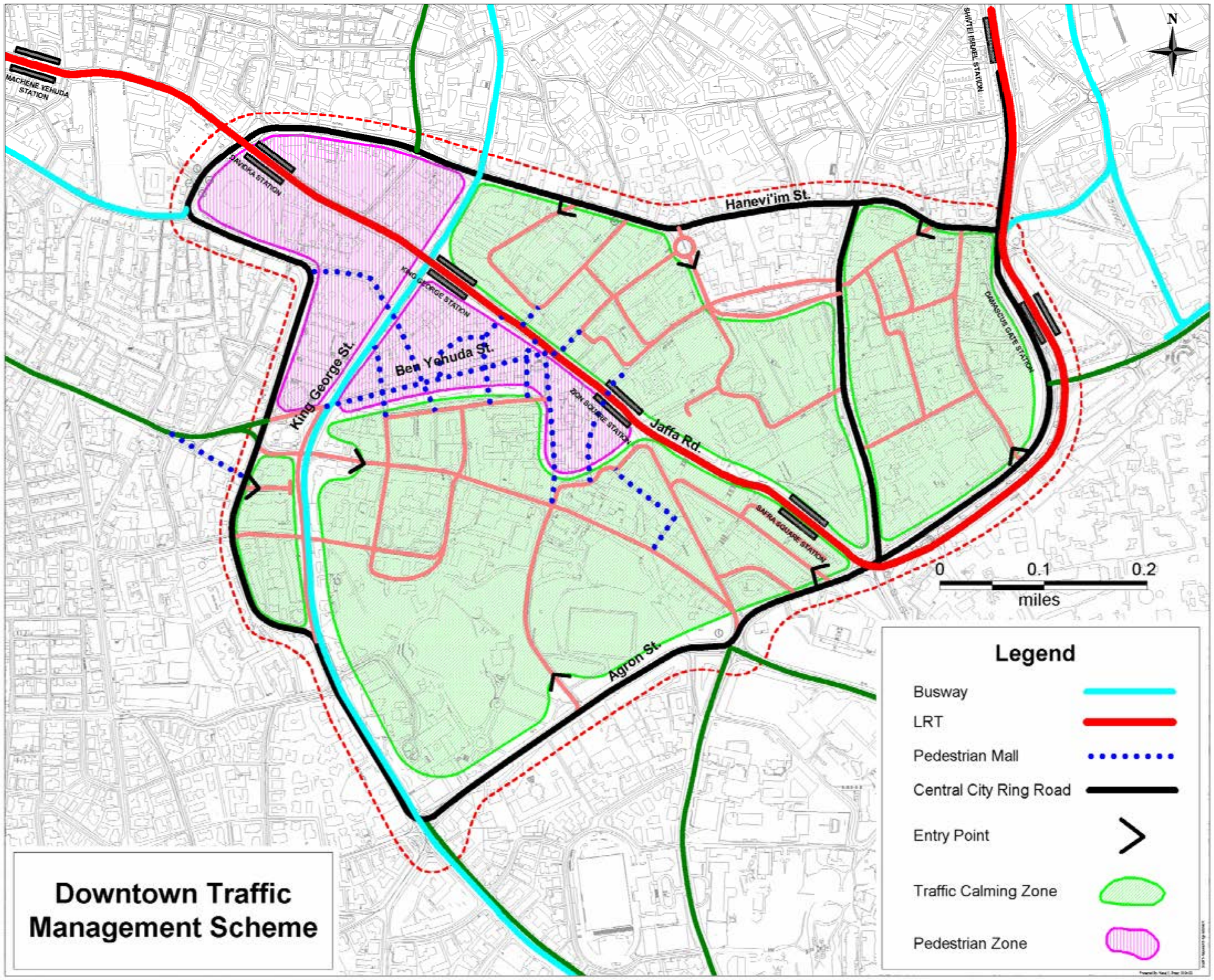

FIGURE 5 Downtown traffic management scheme.

TRAIN TRACKS—PLANNING A LIGHT RAIL LINE FOR JERUSALEM

This section will focus on how mule tracks are being physically translated into a plan for the city's first light rail corridor.

Why Not the Bus?

The decision to build a mass transit system based on light rail technology did not go unchallenged. In a city where 43 urban bus lines move 412,000 passenger boardings each day, the question was asked: Why invest $400,000,000 in a new technology when the existing system can be upgraded at a fraction of the cost?

The answer lies in a combination of physical constraints and the psychology of a rapidly motorizing public.

- Jaffa Road, the urban heart of Jerusalem, already serves almost exclusively as a public transport corridor. With over 250 buses crowding its narrow width in the peak hour, travel speeds are low (10 kmph—6.2 mph) and noise and air pollution unbearable. Of 43 bus routes, 38 use this section; yet bus utilization is low (along this section especially) due to overlapping direct services to almost every neighborhood of the city. Clearly a city poised to grow from 680,000 today to a master plan goal of 900,000 residents had outgrown this small town transit structure.
- The bus network serves primarily a captive population without access to private vehicles. New car owners are reluctant to go back to the bus, even when provided a busway that saves travel time. The Tel Aviv experience indicates that Israeli motorists will use rail, and in large numbers.
- Traffic planners have never succeeded in giving absolute priority to busses at signalized intersections when high bus volumes are present. This limits the effectiveness of busways as compared to high capacity, lower frequency LRT vehicles.
- The bus network is incremental by nature and has successfully resisted attempts at structural reform over the years. The new light rail system is conceived and being presented as an integrated new transport system involving major changes in road, rail, and bus arrangements.

In the end, the first phase of the mass transit system for the city includes 7.5 km (4.6 mi) busway in addition to the LRT line, accompanied by a restructuring of bus lines. Busway infrastructure is seen as a temporary phase before the implementation of a light rail line in its place in the future.

LRT Project Calling Card

The light rail line is planned to be dual track, 13.8 km (8.6 mi) in length. Twenty-three stations are planned, almost exclusively with side platforms. An overhead catenary system will supply electricity at 750V/dc. Traffic signalization and arrangements at 99 intersections will be adjusted and linked to a central system in order to give priority to approaching LRT vehicles. To eliminate conflicts with street traffic, a bridge will be constructed over the complex roadway intersection at the city's western entrance. This bridge, to be designed by the world renowned Santiago Calatrava, will be 260 m (853 ft) long, 135 m (443 ft) between abutments. The ramps sloping up over the bridge will have maximum gradient of 7º.

The LRT will operate exclusively in a right-of-way separated from parallel automobile traffic. Along Jaffa Road in Center City Jerusalem, the light rail line travels along a pedestrian mall. This will be the centerpiece of an urban upgrading of the downtown. A fleet of 23 trains, consisting of three LRVs each, will be needed to provide service for about 7,500 passengers in peak sections of the route. These low-floor vehicles will have a capacity of up to 155 passengers each, or up to 465 passengers per train.

The concessionaire will have sufficient vehicles to provide base service with headways of 3 to 5 min during the morning peak (and not exceeding the maximum density of passengers per square meter). The peak periods will be 1½ h in the morning and 1½ h in the afternoon. Maximum LRT speed will be 30 kmph (18.5 mph) in the city center and 70 kmph (43.5 mph) on other sections.

Design Dilemmas and Solutions

This section will describe the unique and challenging issues that continue to face the planners of the Jerusalem light rail project. Many of these issues are common with other projects in other places around the world but several of them are unique to Jerusalem. The alignment of the tracks adjacent to the Old City is certainly a unique feature of the Jerusalem project.

One of the major challenges in designing any light rail system is the macro planning of the alignments and locating fatal flaws as early as possible in the process. In Jerusalem, this process began in 1995 with Parsons Brinkerhoff of the United States; it continued with the German firm Lahmeyer International in a joint venture with Hamburg Consult and for the first line essentially ended with the value engineering report by French consultant Semaly in 1999. Further urban insertion improvements suggested by the French architect Alfred Pieter were incorporated in the final design drawings prepared in 2002. The topography of the city makes light rail planning especially difficult, as there are many roadways that have grades of 10º, making them infeasible for LRVs. These grades, acceptable as mule tracks, have to be modified or bypassed horizontally or vertically in order to create a viable LRT system.

The high travel demand projected between the northern suburbs and the city center required a connection to Jaffa Road. A macro-level evaluation of alignments indicated that all ways of linking north and south are flawed topographically and that an unusual solution is required. After exhausting the range of alternative north–south routes, it was initially decided that Jerusalem’s first line would run in a tunnel under Hatzanchanim Street, only 2 to 3 m (6.5 to 10 ft) at its closest point from the walls of the Old City. This solution presented an acceptable slope, based on the German criterion used in the planning process. The consultants judged an at-grade alignment as nonfeasible. This was later re-evaluated by the French (see following section).

Hatzanchanim Street is an extremely congested artery for many hours of the day (Figure 6). The project readily accepted the LRT below-grade alternative, which would allow the existing vehicular traffic to continue at street level without any negative impact on LRT operations. An underground alignment would neither be influenced by or improve this situation. In addition it was felt by some that the proximity of the light rail line, with its accompanying catenary system, would be an aesthetic blight on the Old City’s ancient walls. Keeping the status quo of five traffic lanes at street level with the light rail descending into a tunnel became a convenient

FIGURE 6 Old City walls—Hatzanchanim Street.

alternative. The choice of this alternative came with the price tag of an underground station next to the Safra (City Hall) Square.

A closer evaluation by project sponsors of planned alignments, cross-sections, and anticipated costs brought on a re-appraisal of this design. The Old City walls, built in the 1500s, are surrounded by a national park established in 1970. The notion of surrounding the Old City's walls with an open belt of green space was included in the very first plans prepared by planners of the British Mandate in the 1930s. Archaeological excavations were undertaken to expose the full height and grandeur of the walls and the city's gates. Today the Old City is surrounded by a "green belt" of parks.

The French Semaly reexamined the planning criterion and process that produced an LRT tunnel along the Old City. French criterion allows for a slope of 9º along short sections of a line while the German criterion only permitted a maximum grade 8º. Using new technologies to be specified for the Jerusalem system could solve safety and braking issues. If the LRT could be at-grade in the Hatzanchanim Street section, then the Safra Square station could also be at-grade. Thus the question of vertical alignment near the Old City was directly tied to the design of the nearby station, one of the most important and prominent stations along the first line.

All of the designers were pleased when the value engineering of the French consultants led to an at-grade solution. An environmental benefit was achieved by putting two traffic lanes in the tunnel instead of the LRT, greatly reducing noise and pollution next to the City Walls. The trackway, located in the vacated road space, can be designed and landscaped with much greater success than general traffic lanes. LRT riders will enjoy a view of one of the city's major attractions. This switch of alternatives produced significant cost savings due to the elimination of the underground station, estimated at about $15,000,000.

Center City Revitalization

Modern Jerusalem's central business district only began to develop outside the Old City Walls in the late 19th century, at the point where the road from the coastal port of Jaffa entered the old city. From this modest beginning, a thriving commercial area flourished in the British Mandate period (1920s–1930s), centered on the Triangle bounded by King George V Street, Jaffa Road, and Ben Yehudah Street. Jerusalem's first light rail line hopes to revive the glory and prosperity of Jaffa Road, which has served mostly as a passage for scores of diesel busses in an unflattering urban setting, despite lying on the natural path of thousands of tourists and city residents alike.

From the corner of the Old City and as far as the large Machaneh Yehudah Market, Jaffa Road will serve as a transit mall, with only the quiet light rail replacing a cacophony of busses, taxis, and private cars (Figure 7). Stations will be carefully integrated into the design of widened and renewed urban squares at three critical points: the Safra Square/Tzahal Square Station; the Zion Square Station; and the Davidka Square Station. The King George Street Station, adjacent to the oldest traffic light in the city, is the transfer station to the busway and future second light rail line. Jaffa Road itself will be lined with mature trees, creating a totally new and green image, integrated into the pedestrian precinct centered on Ben Yehudah Street. All these works are part of the Concessionaire's responsibilities and will open to the public along with the first line by 2006.

To the west of Machaneh Yehudah, the narrow and winding alignment of the street was inadequate even for LRT passage. Here a carefully planned and executed operation was carried

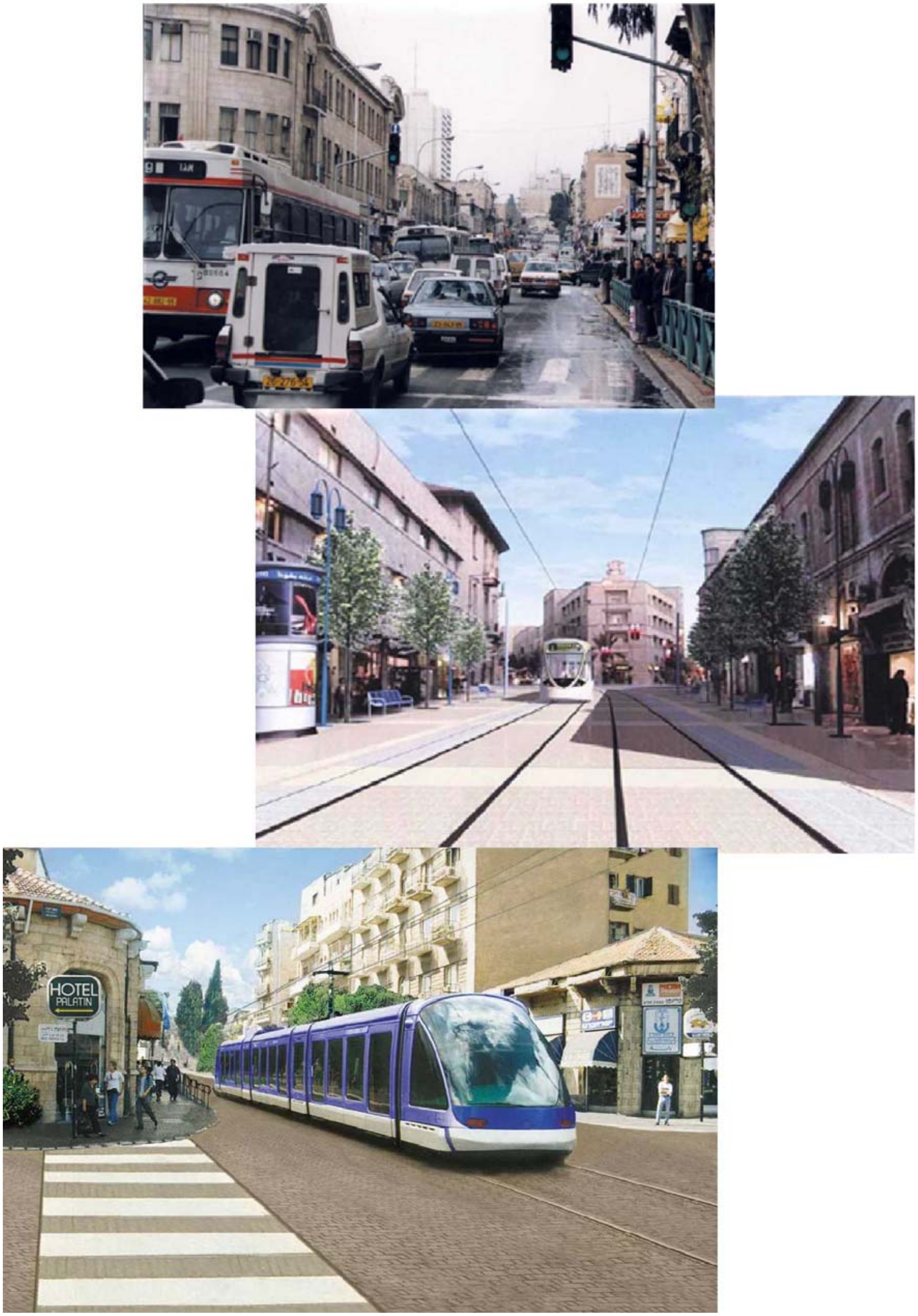

FIGURE 7 Jaffa Road–before and after.

out to preserve and relocate old building facades to a new street line. In this section, a wide boulevard will encourage the possibility of new high-density development along the north face of the street. The cumulative effect of these efforts is to elevate Jaffa Road to its previous status as the premiere commercial address in the city, with its immediate access to the light rail line and renewed, aesthetic appearance and ambience.

The city of Jerusalem has taken an added step in parallel to light rail development. It has created a new municipal corporation with the mission of renewing the remainder of downtown streets and public spaces, with joint funding of the Ministries of Transportation, Tourism, and the city of Jerusalem. To be finished in parallel to the light rail in 2006, the works will create a unified design palate for paving, street furniture, lighting, and plantings throughout the area enclosed by the Center City ring road.

Without a doubt, light rail implementation has been the impetus for these works, based on a synergy between renewed downtown activity, ridership on the light rail line, and vice versa.

Community Relations

Jerusalem is a patchwork of neighborhoods, ethnically and religiously, and often physically distinct. The magnetism, mystique, and beauty of the city drew its residents here; but in many ways there is little other common ground between them.

It is a welcome surprise that the light rail project has met with only minimal objections, and has garnered impressive support from all sides, down to the grass roots level.

This achievement did not come about by chance. A concerted community relations program, administered by the project's management, has accompanied all stages of the planning and execution of the project. The main elements of this effort include:

- The establishment of Neighborhood Transportation Committees in conjunction with community centers and other local institutions along the LRT route. All plans are presented and discussed in these local forums; residents bring their requests and complaints here for resolution.
- Establishment of a dedicated website, multimedia presentations, pamphlets, and exhibitions, all available in high profile at public events, museums, and festivals.
- Distribution of special explanatory materials to individual homes near work sites.
- Extensive meetings and presentations to community groups, schools, associations, business groups, etc.
- Press briefings, tours, and promotions that keep the light rail in the public mind well before the actual appearance of trains or tracks.
- Placement of explanatory construction signing at all work sites (Figure 8).
- Meetings with special needs groups such as the disabled to check designs.
- Thanks to these efforts, the optimism accompanying the development of the Jerusalem light rail project has weathered stormy times and remains strong. If the project succeeds in achieving the ambitious goals it has set for revitalization of the city and increasing the level of accessibility for the city's residents, it will be in no small part due to the efforts to include community relations and input as an integral part of the planning process.

FIGURE 8 A new transportation plan for Jerusalem–Public Relations.

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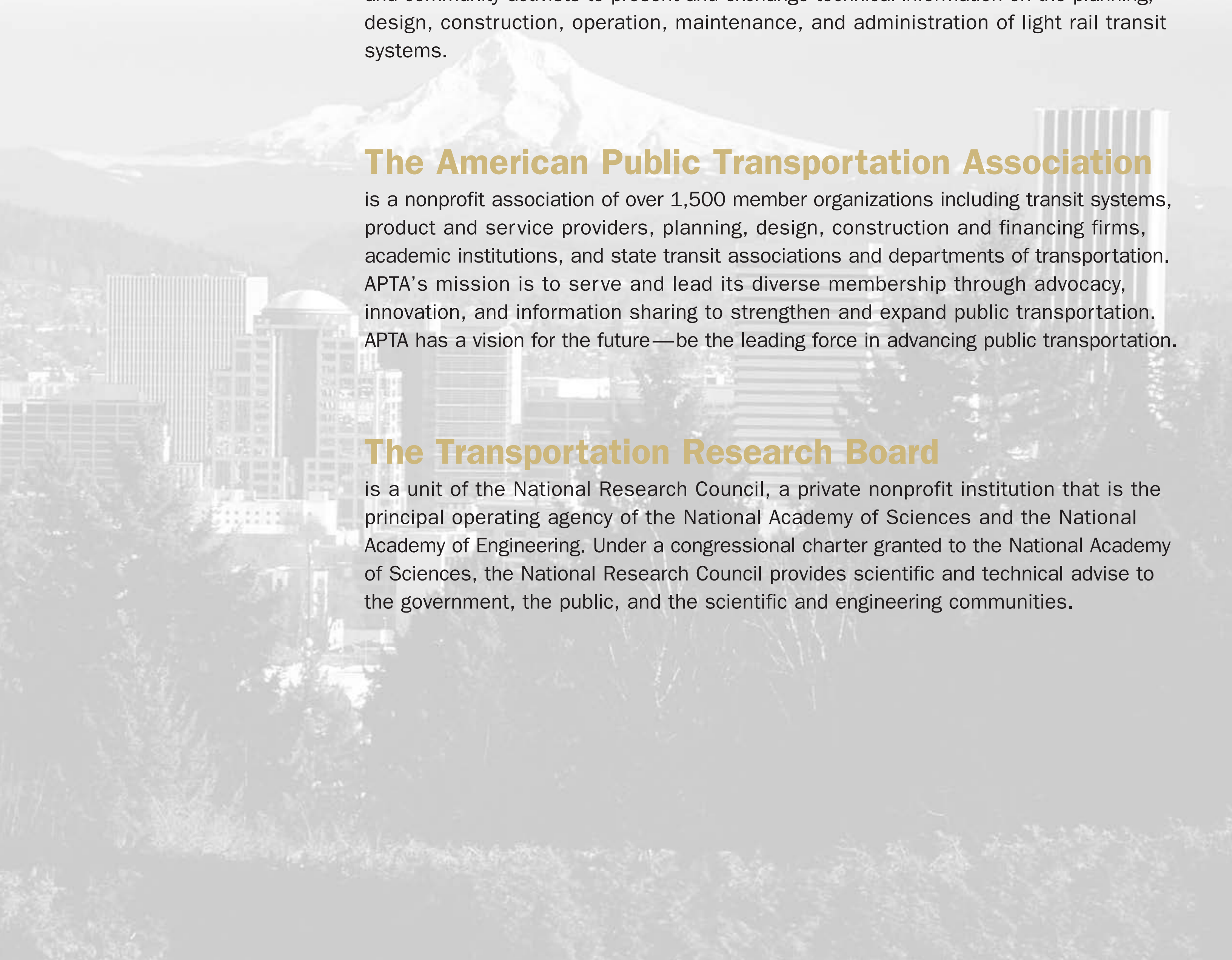

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