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Sustaining the Metropolis

LRT and Streetcars for Super Cities

12th International Light Rail Conference
November 11–13, 2012
Salt Lake City, Utah

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Foreword

The National Light Rail Conference: Sustaining the Metropolis: LRT and Streetcars for Super Cities is the 12th conference of the Transportation Research Board series on light rail that began in Philadelphia in 1975. The American Public Transportation Association became a cosponsor in 1995.

At the Philadelphia conference, the technical sessions focused on introducing the concept of light rail transit (LRT) in North America. Light rail had evolved from traditional streetcar systems in a number of northern European cities into intermediate capacity and performance rail transit systems sized for mid-sized urban agglomerations. The purpose of the first light rail conference was to show local decision makers in North America that the concept had great promise for application in North American cities. The Urban Mass Transit Administration jointly sponsored the first conference and offered financing for cities willing to implement light rail. At that time there were only eight legacy streetcar systems left in Canada and the United States. Now, 37 years later, the eight legacy systems have been rebuilt with many light rail characteristics and 22 additional completely new light rail systems have joined them. Many of the 22 new systems have steadily expanded through the years, and currently nine of the 22 new systems are in the process of further expansion. In addition, eight cities have built short circulator streetcar lines, mostly in downtown districts as part of urban revitalization efforts, four additional circulator streetcar lines are under construction, and at least a dozen circulator streetcar proposals are in the discussion stage.

The focus and related topics of the previous 11 national conferences have paralleled the development and reintroduction of LRT in North America:

- Introduction to LRT, 1st National Conference, Philadelphia, Pennsylvania, 1975;
- Light Rail Transit: Planning and Technology, 2nd National Conference, Boston, Massachusetts, 1978;
- Light Rail Transit: Planning, Design, and Implementation, 3rd National Conference, San Diego, California, 1982 (San Diego in July 1981 was the first all-bus urban agglomeration in the United States to open European-style light rail; Edmonton in 1978 was the first in North America);
- Light Rail Transit: System Design for Cost-Effectiveness, 4th National Conference, Pittsburgh, Pennsylvania, 1985;
- Light Rail Transit: New System Successes at Affordable Prices, 5th National Conference, San Jose, California, 1988;
- Light Rail Transit: Planning, Design, and Operating Experience, 6th National Conference, Calgary, Canada, 1992;
- Building on Success, Learning from Experience, 7th National Conference, Baltimore, Maryland, 1995;
- Light Rail: Investment for the Future, 8th National Conference, Dallas, Texas, 2000;
- Light Rail: Experience, Economics, and Evolution: From Starter Lines to Growing Systems, 9th National Conference, Portland, Oregon, 2003; and
- Light Rail Transit: A World of Applications and Opportunities, 10th National Conference and First Joint International Light Rail Conference, St. Louis, Missouri, 2006.

- Light Rail: Growth and Renewal, Los Angeles, California, 2009.

The technical information in the proceedings of these conferences (*1–11*) provides planners, designers, decision makers, and operators with a valuable collection of experiences and ingredients necessary for a successful transit development project.

More than 250 public transportation industry experts from across the country met at the Salt Lake City Grand America Hotel in downtown Salt Lake City for the 12 National Light Rail Conference, November 11–13, 2012. Sponsored by TRB and APTA and hosted by the Utah Transit Authority, the conference focused on the positive results being experienced in metropolitan areas that have embraced light rail and circulator streetcar and, similarly, show how other metropolitan areas that have rejected these modes of transportation have fared.

This conference was significant in that it returned to Europe for inspiration, both through papers and through a special plenary session highlighting the new French approach to insertion. Apparently, the old light rail dog indeed has new tricks. The new tricks center on techniques for inserting high-performance rail transit into the hearts of urban and suburban activity areas where transit infrastructure previously did not exist, in such a way as to reverse the declining role of transit while also developing transit-oriented urban forms. Just as in 1975, these exciting new European developments appear to have applicability to North American urban agglomerations.

With 14 sessions, eight tours, and a products and services showcase, the conference offered up-to-date information on new ways to plan, design, construct, maintain, and operate light rail and streetcar systems.

The objective of each conference in this series is to add to the growing body of knowledge and real-world experiences with modern LRT applications in order to continually improve new systems being planned, as well as those already in operation. This e-circular of 31 peer-reviewed research papers exemplifies the vibrancy of the fields.

Success can be fleeting, and we need to learn from past and current experience 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.

—Richard Krisak, *Chair*
Chair, APTA Light Rail Technical Forum

—Gregory L. Thompson, *Vice Chair*
Chair, TRB Light Rail Transit Committee

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Contents

Opening General Session

OPENING GENERAL SESSION

Status of North American LRT Systems
Year 2012 Update

JOHN SCHUMANN
LTK Engineering Services

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 2009. There were two completely new start-ups during this period: light diesel multiple-unit (DMU) lines in Austin (2010) and Denton County, Texas (2011), and an electric light rail line in Norfolk (2011). In addition, several systems extended existing lines: Dallas, Edmonton, Jersey City (Bayonne), Los Angeles, New Orleans, Pittsburgh, Portland (streetcar), Salt Lake City, Sacramento, and San Francisco. Beyond 2012, further LRT and streetcar extensions have been committed and will be completed in Calgary, Charlotte, Dallas, Denver, Edmonton, Houston, Los Angeles, Minneapolis–St. Paul, Ottawa (light DMU), Phoenix, Portland, Sacramento, Salt Lake City, San Diego, Seattle, and Tucson. New streetcar lines are under construction in Atlanta, Cincinnati, and Washington, D.C. These developments are discussed in the text and reflected in the accompanying data tables.

INTRODUCTION

Significant light rail transit (LRT) developments have occurred in North America since the last APTA–TRB National Conference on Light Rail Transit was held in 2009. Compared with the seven U.S., one Canadian, and one Mexican metropolitan areas operating legacy streetcar and proto-light rail systems in 1977 when the first version of this paper was presented, the succeeding 35 years have seen much progress in developing such systems. As of 2012, and considering only systems operated as part of a region's public transit system (i.e., excluding museums), there are the following systems:

- United States:
  - Seven legacy LRT–streetcar systems (Boston, Newark, Philadelphia, Pittsburgh, Cleveland, New Orleans, San Francisco);
  - Eighteen "new age" electric LRT systems (San Diego, Buffalo, Portland, Sacramento, San Jose, Los Angeles, Baltimore, St. Louis, Denver, Dallas, Salt Lake City, Jersey City, Houston, Minneapolis, Charlotte, Phoenix, Seattle, Norfolk);
  - Eight new streetcar systems [*Lowell*, *Memphis*, Portland, Tacoma, *Tampa*, *Little Rock*, *Kenosha*, Seattle (with italics indicating historic or replica vintage vehicles)]; and
  - Four new light diesel multiple unit (DMU) lines (Camden–Trenton, New Jersey; Oceanside, California; Austin and Denton County, Texas).
- Canada:
  - One legacy streetcar–LRT system (Toronto);

  - Two new age LRT systems (Edmonton, Calgary); and
  - One light DMU (Ottawa).
- Mexico:
  - One legacy (Mexico City) and
  - Two new age (Guadalajara, Monterrey) LRT systems.

Tables 1, 2, and 3 list basic quantitative parameters relating to the system in each U.S. and Canadian urban region—year first line opened, one-way kilometers/miles of line operating, number of revenue service vehicles, and weekday rides (boardings)—as well as statistics calculated therefrom—cars per kilometer/mile as a measure of service intensity, passengers per line kilometer/mile and per vehicle as measures of system and fleet productivity, respectively. Table 4 adds revenue passenger kilometer/mile for U.S. properties so that service productivity in terms of passenger kilometer/mile per vehicle kilometer/mile can be calculated. Data in Tables 1, 2, and 3 are for 2012, drawn from a variety of sources; while data in Table 4 are from the 2010 National Transit Database, the most recent and reliable aggregation of data on passenger kilometer/mile.

With the variety of projects now in service, the point has been reached where it has become useful to list systems in this paper alphabetically by city, along with the categories of light rail technology each city uses: post-1970 new age light rail, pre-1970 legacy LRT and streetcar systems, streetcar and trolley circulators, and light DMU lines.

OPERATING SYSTEMS

Austin (Light DMU)

Although regulated as commuter rail, Austin's MetroRail operates light DMUs in a shared-track arrangement essentially the same as other light DMU and LRT lines. Patronage has been improving since addition of some midday rail service. Weekend service began in 2012. Austin also is developing a plan for an urban LRT–streetcar system to serve the central city and adjacent neighborhoods.

Baltimore (New Age LRT)

The Central LRT system continues to operate with no significant changes. A planning study has recommended LRT for the proposed 19.3-km (12.0-mi) Red Line, which would operate east–west from the Johns Hopkins Bayview Medical Center through downtown Baltimore to Woodlawn.

Boston (Legacy LRT)

The Massachusetts Bay Transportation Authority (MBTA) continues to operate its four-branch Green Line LRT system, and the isolated Ashmont–Mattapan feeder to the Red Line rapid transit. Planning continues to relocate Lechmere Terminus at the north end of the Green Line, and extend LRT service along two branches through Somerville to Medford. In addition, the process has begun to procure new Type-9 low-floor light rail vehicles (LRVs) to supplement the fleet.

TABLE 1 Line Lengths, Car Fleets, and Productivity Indicators: LRT

City–System	Year Opened	One-Way Line km	One-Way Line mi	Fleet Cars	Cars per km	Cars per mi	Weekday Rides (000s)	Service Productivity, Passengers per Line km	Service Productivity, Passengers per Line mi	Service Productivity, Passengers per Car
Baltimore, Central Corridor	1992	46.7	29.0	53	1.1	1.8	27.2	583	938	513
Boston, Green Line and Mattapan	[a]	36.8	22.9	222	6.0	9.7	233.3	6,332	10,188	1,051
Buffalo, MetroRail	1985	10.3	6.4	27	2.6	4.2	24.5	2,379	3,828	907
Charlotte, Lynx	2007	15.4	9.6	20	1.3	2.1	14.6	945	1,521	730
Cleveland, Blue/Green	[a]	24.8	15.4	48	1.9	3.1	15.1	609	981	315
Dallas, DART LRT	1996	124.5	77.4	95	0.8	1.2	83.4	670	1,078	878
Denver, RTD LRT	1994	55.8	34.7	49	0.9	1.4	66.8	1,196	1,925	1,363
Houston, MTA	2004	12.1	7.5	18	1.5	2.4	36.1	2,992	4,813	2,006
Jersey City and Newark, N.J., Transit	[b]	34.4	21.4	73	2.1	3.4	41.9	1,217	1,958	574
Los Angeles, Blue/Green/Gold	1990	113.0	70.2	121	1.1	1.7	154.5	1,368	2,201	1,277
Minneapolis, Metro Transit	2004	19.8	12.3	24	1.2	2.0	30.3	1,531	2,463	1,263
New Orleans, streetcars	[a]	22.8	14.2	66	2.9	4.6	19.7	862	1,387	298
Norfolk, The Tide	2011	12.1	7.5	9	0.7	1.2	3.7	307	493	411
Philadelphia, city and suburban	[a]	68.4	42.5	159	2.3	3.7	110.1	1,610	2,591	692
Phoenix, METRO	2008	31.5	19.6	50	1.6	2.6	41.3	1,310	2,107	826
Pittsburgh, South Hills	a	40.2	25.0	83	2.1	3.3	24.2	602	968	292
Portland, MAX	1986	84.2	52.3	105	1.2	2.0	114.5	1,361	2,189	1,090
Sacramento, RT LRT	1987	62.3	38.7	76	1.2	2.0	45.6	732	1,178	600
St Louis, MetroLink	1993	73.2	45.5	83	1.1	1.8	52.3	714	1,149	630
Salt Lake City, UTA LRT	1999	57.4	35.7	40	0.7	1.1	59.1	1,029	1,655	1,478
San Diego Trolley	1981	84.5	52.5	134	1.6	2.6	103.4	1,224	1,970	772
San Francisco, Muni	[a, c]	49.4	30.7	175	3.5	5.7	162.4	3,288	5,290	928
San Jose, VTA LRT	1987	67.9	42.2	100	1.5	2.4	32.9	485	780	329
Seattle, ST, Central Link	[d]	25.1	15.6	65	2.6	4.2	27.8	1,108	1,782	428
Total U.S.		1,172.6	728.8	1,895	1.6	2.6	1524.7	1,300	2,092	805
Calgary, C-train	1981	44.6	27.7	156	3.5	5.6	263.9	5,921	9,527	1,692
Edmonton, LRT	1978	21.1	13.1	74	3.5	5.6	93.3	4,426	7,122	1,261
Toronto, streetcars	[a]	78.7	48.9	248	3.2	5.1	299.8	3,810	6,131	1,209
Total Canada		144.3	89.7	478	3.3	5.3	657.0	4,552	7,324	1,374

[a] Legacy system, major reconstruction or rehabilitation since 1977; [b] Jersey City: 2000; Newark, see [a]; [c] Upgraded from streetcar to LRT standards since 1977; [d] Tacoma: 2003; Seattle: 2009.

TABLE 2 Line Lengths, Car Fleets, and Productivity Indicators: Streetcar Circulators

City–System	Year Opened	One-Way Line		Fleet Cars	Cars per		Weekday Rides (000s)	Service Productivity, Passengers per		
		km	mi		km	mi		Line km	Line mi	Car
Kenosha, KT	2000	1.4	0.9							
Little Rock, River Rail	2004	5.5	3.4	5	0.9	1.5	0.4	73	118	80
Lowell, National Park Trolley	1983	1.9	1.2	3	1.6	2.5	—	—	—	—
Memphis, MATA Trolley	1993	11.3	7.0	16	1.4	2.3	3.1	275	443	194
Portland, Portland Streetcar	2001	6.8	4.2	7	1.0	1.7	12.0	1,776	2,857	1,714
Seattle, So Lake Union Stcar	2007	2.1	1.3	3	1.4	2.3	2.5	1,195	1,923	833
Tacoma, ST, Tacoma Link	2003	2.6	1.6	3	1.2	1.9	3.0	1,165	1,875	1,000
Tampa, TECO Trolley	2002	3.7	2.3	10	2.7	4.3	0.6	162	261	60

NOTE: — = unknown.

TABLE 3 Line Lengths, Car Fleets, and Productivity Indicators: Light DMU

City–System	Year Opened	One-Way Line		Fleet Cars	Cars per		Weekday Rides (000s)	Service Productivity, Passengers per		
		km	mi		km	mi		Line km	Line mi	Car
Austin, MetroRail	2010	51.5	32.0	6	0.1	0.2	1.8	35	56	300
Camden-Trenton, River Line	2004	54.7	34.0	20	0.4	0.6	9.0	165	265	450
Denton County, A-Train	2011	33.8	21.0	11	0.3	0.5	1.5	44	71	136
Oceanside, Sprinter	2008	35.4	22.0	12	0.3	0.5	8.3	234	377	692
Ottawa, O-Train	2001	8.0	5.0	3	0.4	0.6	14.2	1,765	2,840	4,733

TABLE 4 Line Lengths, Operating Statistics, and Productivity Indicators (Fiscal 2010 Figures, United States Only)

City–System	1-Way Line		Revenue Vehicle (000s)		Revenue Passenger (000s)		Service Productivity, Passenger km/mi per			
	km	mi	km	mi	km	mi	Line km	Line mi	Veh km	Veh mi
Regional Services										
Baltimore, Central Corridor	46.7	29.0	5,115.5	3,179.3	8,7718.7	54,517.5	1,168,374	1,879,914	17.1	17.1
Boston, Green Line and Mattapan	36.8	22.9	9,827.0	6,107.5	249,728.4	155,207.2	4,212,310	6,777,607	25.4	25.4
Buffalo, MetroRail	10.3	6.4	1,523.7	947.0	26,210.8	16,290.1	16,290	2,545,328	17.2	17.2
Charlotte, Lynx	15.4	9.6	1,304.7	810.9	27,550.7	17,122.9	1,108,537	1,783,635	21.1	21.1
Cleveland, Blue–Green	24.8	15.4	1,086.7	675.4	21,900.4	13,611.2	549,313	883,844	20.2	20.2
Dallas, DART LRT[a]	72.4	45.0	7,950.4	4,941.2	201,773.4	1,25,403.0	1,731,966	2,786,733	25.4	25.4
Denver, RTD LRT	55.8	34.7	12,823.2	7,969.7	224,321.5	139,416.7	2,497,062	4,017,772	17.5	17.5
Houston, MTA	12.1	7.5	1,448.9	900.5	38,885.5	24,167.5	2,002,693	3,222,333	26.8	26.8
New Jersey Transit: Newark	10.1	6.3	883.0	548.8	22,272.3	13,842.3	1,365,563	2,197,190	25.2	25.2
New Jersey Transit: Jersey City LRT and Camden DMU	79.0	49.1	5,362.2	3,332.6	140,070.0	87,054.1	1,101,924	1,772,996	26.1	26.1
Los Angeles, Blue, Green, Gold[a]	89.6	55.7	15,519.9	9,645.7	536,335.0	333,334.4	3,719,366	5,984,460	34.6	34.6
Minneapolis, Metro Transit	19.8	12.3	3,240.5	2,014.0	8,9045.4	55,342.1	2,796,369	4,499,358	27.5	27.5
New Orleans, Streetcars	22.8	14.2	1,525.0	947.8	2,4753.5	15,384.4	673,343	1,083,408	16.2	16.2
Norfolk, The Tide[b]	11.9	7.4	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]
Philadelphia, city and suburban	68.4	42.5	5,675.4	3,527.3	113,179.8	70,341.7	1,028,651	1,655,099	19.9	19.9
Phoenix, METRO	31.5	19.6	4,268.4	2,652.8	141,047.8	87,661.8	2,779,702	4,472,541	33.0	33.0
Pittsburgh, South Hills[a]	38.3	23.8	3,001.9	1,865.7	54,100.1	33,623.4	878,029	1,412,748	18.0	18.0
Portland, MAX	84.2	52.3	13,106.3	8,145.6	335,925.7	208,779.2	2,481,016	3,991,954	25.6	25.6
Sacramento, RT LRT[a]	59.7	37.1	6,554.6	4,073.7	132,743.3	82,500.5	1,382,059	2,223,733	20.3	20.3
St Louis, MetroLink	73.2	45.5	9,362.4	5,818.8	220,203.6	136,857.4	1,869,394	3,007,855	23.5	23.5
Salt Lake City, UTA LRT	32.2	20.0	5,227.2	3,248.7	92,080.8	57,228.6	1,778,390	2,861,430	17.6	17.6

continued on next page

TABLE 4 (*continued*) **Line Lengths, Operating Statistics, and Productivity Indicators (Fiscal 2010 Figures, United States Only)**

City–System		1-Way Line km	1-Way Line mi	Revenue Vehicle (000s) km	Revenue Vehicle (000s) mi	Revenue Passenger (000s) km	Revenue Passenger (000s) mi	Service Productivity, Passenger km/mi per Line km	Line mi	Veh km	Veh mi
Regional Services											
San Diego–Oceanside	San Diego Trolley (LRT)	84.5	52.5	12,458.8	7,743.2	300,093.5	186,509.3	2,207,929	3,552,558	24.1	24.1
	Oceanside–Escondido (DMU)	35.4	22.0	802.6	498.8	29,606.4	18,400.5	519,818	836,386	36.9	36.9
San Francisco, Muni		49.4	30.7	9,278.5	5,766.6	211,370.5	131,367.6	2,659,462	427,9075	22.8	22.8
San Jose, VTA LRT		67.9	42.2	4,859.0	3,019.9	80,450.5	50,000.3	736,384	1,184,841	16.6	16.6
Seattle, ST, Central Link		25.1	15.6	4,161.2	2,586.2	89,313.5	55,508.7	2,211,467	3,558,250	21.5	21.5
City Circulators											
Kenosha		1.4	0.9	27.5	17.1	95.6	59.4	43,432	69,882	3.5	3.5
Little Rock, River Rail		5.5	3.4	84.8	52.7	266.6	165.7	30,289	48,735	3.1	3.1
Memphis, MATA Trolley		11.3	7.0	555.7	345.4	1,476.7	917.8	81,488	131,114	2.7	2.7
Portland, Portland Streetcar		6.8	4.2	333.4	207.2	6,436.0	4,000.0	591,909	952,381	19.3	19.3
Seattle, So Lake Union Stcar		2.1	1.3	96.5	60.0	758.8	471.6	225,463	362,769	7.9	7.9
Seattle, ST, Tacoma Link		2.6	1.6	145.1	90.2	1,401.8	871.2	338,409	544,500	9.7	9.7
Tampa, TECO Trolley		3.7	2.3	114.9	71.4	1,269.8	789.2	213,257	343,130	11.1	11.1

[a] System miles expanded since FY 2010: Dallas now 77.4; Los Angeles now 70.2; Pittsburgh now 25.0; Sacramento now 38.7.
[b] System opened in 2011, so is not included in the 2010 National Transit Database tables.
Sources: 2010 National Transit Database (Table 19), except Portland Streetcar [www.portlandstreetcar.org (accessed August 22, 2012)] and author's estimates.

Buffalo (New Age LRT)

The 10.3-km (6.4-mi) Metro continues to link downtown and the State University of New York (SUNY) at Buffalo campus. Mid-life overhauls are being done on Buffalo's 27 LRVs, the only nonarticulated 4-axle cars built for a North American new age LRT project. Announced in 2012 was a project to integrate the current Allen–Medical Campus Metro Station into a new University at Buffalo medical school and Buffalo Niagara Medical Campus. Long-range plans remain to extend the line to SUNY at Amherst, as well as build other branches, if and when funding eventually becomes available.

Calgary (New Age LRT)

Three operating lines—South (1981), Northeast (1985), and Northwest (1987)—all have been extended, almost continuously. Now, the new West line is well advanced, scheduled to open in 2013. A fifth line, to the southeast, is being planned; it may run through a downtown subway, perpendicular to 7th Avenue. Since it will operate independently of the remainder of the system, it is planned to use low-floor cars for the Southeast line. However, detailed engineering has yet to begin. A North Central line is also in long-range planning, but would not be needed until the city grows about 25 percent more, which should take at least 20 years. If it branches off the Northeast line, there may be future capacity issues along 7th Avenue; but, a separate route north from the central business district (CBD) would enable use of low-floor cars.

Camden–Trenton (Light DMU)

Construction continues on the Pennsauken intermodal transfer facility, located at the crossing of the 54.7-km (34-mi) River Line and NJ Transit's Atlantic City commuter rail line. A planning study has commenced for a second line from Camden southeast to Woodbury and Glassboro.

Charlotte (New Age LRT, Future Streetcar Circulator)

This city's 15.4-km (9.6-mi) South Line continues to serve as the transit spine in that sector of the urban area. The initial 16-car fleet has been supplemented by four more LRVs of the same SD70 design. Under development is a 15.1-km (9.4-mi) Northeast Extension to link center city through the North Davidson and university areas and terminating on the Charlotte campus of the University of North Carolina. With construction scheduled to commence in 2013, revenue service is targeted to begin in late 2016 or early 2017. In addition, the city is moving ahead with a 2.4-km (1.5-mi) streetcar circulator in Uptown Charlotte, which will use the three Gomaco replica trolleys purchased circa 2000.

Cleveland (Legacy LRT)

The Blue and Green LRT Lines, including the Waterfront Extension of 1996 continue to serve the cities of Cleveland and Shaker Heights. A recent development is the selection of a locally preferred alternative for the Blue Line Corridor Extension Study: Realignment of the current intersection of Warrensville Center Road, Northfield Road (Ohio Rt. 8), Van Aken Boulevard and Chagrin Boulevard in Shaker Heights, a 0.5-km (0.3-mi) extension of the Blue Line across the realigned intersection to a new Shaker Intermodal Transit Center to facilitate transfers to the

Blue Line, express bus service to University Circle, and Park-N-Ride lots near the interchanges of Northfield Road and I-480 in Warrensville Heights, and Harvard Road and I-271, in Highland Hills.

Dallas (New Age LRT and Trolley Circulator)

DART's 45.1-km (28.0-mi) Green Line LRT was completed and opened in 2010. Now work is advancing on the Orange Line, with 16.6 km (10.3 mi) as far as Irvine opened in 2012, and the remaining 7.6 km (4.7 mi) on to the Dallas–Fort Worth airport, due to open in December 2013. Construction also continues on the 7.2-km (4.5-mi) Blue Line extension from Garland to Rowlett, with a late 2012 opening anticipated. Finally, a 4.9-km (3.0-mi) addition to extend the Blue Line south to the University of North Texas is targeted for completion in 2019. These additions will double the size of the LRT system of 2009, which itself was doubled from the original starter system of 1996. The McKinney Avenue Trolley now serves the DART light rail Cityplace station, reaching it over a short branch with a turntable to reverse single-ended streetcars. An extension on the downtown end of the line is under study, as is a separate new streetcar line from Union Station across the Trinity River to the Oak Cliff neighborhood.

Denton County (Light DMU)

In mid-2011, the Denton County Transportation Authority (DCTA) opened its 33.8-km (21.0-mi) line linking Denton with a DART LRT transfer station at Carrollton. Initially, 10 rail diesel cars (RDCs) were leased from Trinity Railway Express. Now these are being replaced with Stadler GTW 2/6 light DMUs. The transition, being completed in 2012 as the 11 new DMUs are delivered, tested, and accepted, has included a breakthrough agreement wherein FRA has approved a waiver allowing mixed operation of RDCs and DMUs during the transition.

Denver (New Age LRT)

The region's ambitious FasTracks program of LRT extensions and new commuter rail lines is moving forward. In 2013 the 19.5-km (12.5-mi) West LRT line will begin revenue service to Golden. Later LRT projects include an I-25 line from Parker Road up to a joint station with the East (airport) commuter rail route, extensions southeast to Lone Tree and southwest to Highland Ranch, and a short extension north to another of the East Corridor commuter rail stations from 30th and Downing. The latter may be built as either LRT or a streetcar line.

Edmonton (New Age LRT)

The 7.5-km (4.6-mi) South LRT extension was opened in two stages in 2009 and 2010 and was expected to raise weekday patronage by 26,000 to over 100,000. At present, a 3.1-km (1.9-mi) Northwest extension is under construction from Churchill to the Northern Alberta Institute of Technology campus, with a scheduled opening in 2014. Design is in progress for the 13.1-km (8.1-mi) Southeast to West LRT line, an urban LRT system using low-floor vehicles and operating on the surface, including through the CBD, to improve connections between the LRT and several of the city's major activity centers.

Houston (New Age LRT)

Construction on three Metropolitan Transit Authority of Harris County (METRO) light-rail lines is more than half finished and on-track to open in 2014, the agency has announced. METRO is building the 5.4-km (4.0-mi) East End line, which will run from the Magnolia Transit Center to downtown Houston; the North Line, which will extend the existing Red Line 8.5 km (5.3 mi) through Houston's north side; and the 9.7-km (6.0-mi) Southeast Line, which will run from downtown Houston to near Palm Center. METRO has ordered 19 S70 LRVs from Siemens and 39 low-floor LRVs from CAF to serve these extensions, which together will triple the length of LRT lines operating in Houston. Beyond these, another two lines are planned: East–West (University) and Uptown–West Loop.

Jersey City (New Age LRT)

The Hudson Bergen LRT is being extended 1.1 km (0.7 mi) along the West Side branch. The new track along the former Newark and New York Railroad route is being laid on an elevated viaduct from the West Side Avenue station across Route 440 to the northern end of the Bayfront redevelopment area, where a new island platform station is being constructed. In addition planning is in progress to extend the north end of the line up to 18.3 km (11.4 mi) into Bergen County along the former Erie Railroad Northern Branch, from Tonnelle Avenue at least to Englewood and, perhaps, Tenafly.

Kenosha (Streetcar Circulator)

Opened by Kenosha Transit in 2000 with five restored PCC streetcars, this 1.6-km (1.0-mi) line has 3.2 track km (2.0 track mi) in a loop layout linking a large lakeshore renewal area with downtown. At the start of 2012, another restored PCC was placed in service, and work continues on an additional PCC. A plan for extending the line further into the downtown area is under consideration.

Little Rock (Streetcar Circulator)

A 4.0-km (2.5-mi) extension to the airport is under development to double the system's mileage. The existing line between Little Rock and North Little Rock continues to operate using five Gomaco replica double-truck Birney streetcars.

Lowell (Streetcar Circulator)

A plan has been developed to expand the existing historic trolley service into a viable, modern system serving not only the Lowell National Historic Park but all of central Lowell. To do this, two extensions would lengthen the Lowell Trolley to 11.1 km (6.9 mi) from its current length of 1.9 km (1.2 mi), and six new replica vintage trolley cars would be acquired to increase the total fleet to nine. The larger system would serve three distinct groups of riders—visitors; commuters; and the students, faculty, and staff of the University of Massachusetts, Lowell. An environmental assessment has been completed, with completion anticipated to be six years after receiving authority and funding to proceed.

Los Angeles (New Age LRT)

The 13.2-km (8.2-mi) Expo Phase 1 line opened in April 2012. Work is advancing on the 10.8-km (6.7-mi) Phase 2 segment to complete the route to Santa Monica by 2015. Farther along in construction is the 18.5-km (11.5-mi) Foothills extension of the Gold Line to Azusa, expected to open in 2015. Design is advancing on the 13.7-km (8.5-mi) Crenshaw route that will create a north–south link between the Expo Line and the Green Line, bringing service close to the east entrance to Los Angeles International Airport. A 2018 completion date is targeted for this project. In planning are the 3.1-km (1.9-mi) Regional Connector under downtown Los Angeles to link Blue–Expo and Gold lines for through operation, and later extensions to both outer ends of the Gold Line. Completion of all these projects will result in over 160 km (100 mi) of LRT lines in the Los Angeles basin. In downtown Los Angeles, a 6.4-km (4.0-mi) streetcar circulator is being planned to provide a link between key spots of the ongoing downtown renaissance.

Memphis (Streetcar Circulator)

Vintage trolleys continue to carry riders along the Main Street, Waterfront, and Madison Avenue–Medical Center routes. Development of further extensions is not proceeding at this time.

Minneapolis–St. Paul (New Age LRT)

The 19.3-km (12.0-mi) Hiawatha Line continues to provide effective transportation between the business, government, sports and cultural concentrations of downtown Minneapolis; the airport; and the Mall of America. Construction continues toward completion in 2014 of the 17.7-km (11.0-mi) Central Corridor linking the downtowns of the two Twin Cities: Minneapolis and St. Paul. Design is advancing for a third line, the 24.1-km (15.0-mi) Southwest Line to Eden Prairie, which would connect with the north end of the Hiawatha Line, where passengers can transfer to and from the Northstar commuter rail service. Planning work also is considering LRT as a possible alternative for the 20.9-km (13.0-mi) Bottineau Corridor extending northwest from downtown Minneapolis, perhaps opening as soon as 2018.

Newark (Legacy LRT)

A station renovation project, expected to be completed by the end of next year, will bring the total number of accessible Newark Light Rail stations to 12, out of the total 17.

New Orleans (Legacy Streetcar)

Since 2009 reconstruction of the flooded Riverfront and Canal Street cars has progressed. A 2012 completion date is forecast for the 2.4-km (1.5-mi) Union Passenger Terminal–Loyola Loop addition to the three-line streetcar system. On the opposite side of Canal Street, a 4.0-km (2.5-mi) French Quarter extension is to be built to connect with the Riverfront Streetcar Line.

Norfolk (New Age LRT)

Norfolk's initial 12.1-km (7.5-mi) LRT line opened in August 2011. With nine S70 LRVs, *The Tide* serves 11 stations, including downtown Norfolk, the Eastern Virginia Medical Center, and

Norfolk State University. The line is attracting more riders than forecast, with patronage reported to be 60 percent higher than the pre-opening prediction. Being discussed is an eastward extension to Virginia Beach, which would more than double the length of the line. Also being considered is a northward extension to the Norfolk Navy Base.

Oceanside (Light DMU)

Veolia's contract to operate the 35.4-km (22-mi) line has been extended to the end of 2014.

Ottawa (Light DMU)

OC Transpo is renovating its *O-Train* facilities and acquiring new DMUs to increase the line's passenger carrying capacity. The C$59 million *O-Train* expansion will provide for the purchase of six new trains and the capital works required to increase peak service frequency from 15 minutes to eight minutes. This expanded *O-Train* service will begin in September 2014. An electric LRT project also is planned.

Philadelphia (Legacy LRT and Streetcar)

Streetcar service returned to Route 15–Girard after completion of $1.2 million in construction, part of which is a temporary rerouting to a new Northern Liberties loop to avoid major construction at the northeast end of the line.

Phoenix (New Age LRT, Future Streetcar)

Valley Metro's 31.5-km (19.6-mi) line through Phoenix and Tempe to Mesa is carrying about 45,000 weekday rides, accommodating a variety of regular and special-purpose tripmakers. Design and construction are advancing on a 5.0-km (3.1-mi) eastward extension into Central Mesa, expected to open in 2015. Planning also is moving forward for an additional 3.2 km (2.0 mi) of light rail farther east to Gilbert Road. Plans also are being finalized for a 4.2-km (2.6-mi) streetcar circulator line within the City of Tempe, targeted to open in 2016. In addition, work is being restarted on a 5.1-km (3.2-mi) northwest extension of the starter line, and planning is under way for the 17.7-km (11.0-mi) Phoenix West extension in the I-10 corridor, which the region hopes to complete in 2021.

Pittsburgh (Legacy LRT)

Opened in March 2012, the 1.9-km (1.2-mi) North Side Extension links the North Hills and the South Hills for the first time. The $523-million project starts at the new Gateway Station, dips in the tunnel under the Allegheny River and curves to line up with Stanwix Street and the North Side Station, then continues on an aerial structure to the Allegheny Station. The line emerges from the ground alongside Heinz Field and stops next to the stadium; from the elevated platform, riders also can see the science center and the casino, both of which are short walks away. On weekdays cars arrive at times ranging from four-minute intervals during peak periods to every 10 to 15 minutes during evening hours.

Portland, Oregon (New Age LRT and Streetcar Circulator)

In September 2009 TriMet completed 13.4 km (8.3 mi) of construction along I-205 and on downtown Portland's Transit Mall, and initiated its Green Line MAX service. The region's next LRT project is being built for the 11.7-km (7.3-mi) extension through southeast Portland to suburban Milwaukie. It is scheduled to open in 2015. Planning studies of alternatives are being conducted for future high-capacity transit in the southwest corridor. Service on the new 5.3-km (3.3-mi) Eastside loop began in September 2012, extending from the Pearl District connection with the existing line, through the Lloyd District and Central Eastside to OMSI, the Oregon Museum of Science and Industry. Five new streetcars, the first production cars from United Streetcar, will bolster the Portland Streetcar, Inc., fleet.

Sacramento (New Age LRT)

Regional Transit (RT) opened its 1.8-km (1.1-mi) extension to Richards Boulevard in summer 2012. This is the first segment of what ultimately will be a 19.3-km (12.0-mi) line to Sacramento International Airport. Before that, however, RT is building the 6.9-km (4.3-mi) extension of the South Line to Cosumnes River College, which is expected to open in the summer of 2015.

Saint Louis (New Age LRT, Future Streetcar Circulator)

There have been no further extensions to the 73.2-km (45.5-mi) LRT system, but design is proceeding for a 3.5-km (2.2-mi) streetcar line linking University City with the Delmar and Forest Park MetroLink stations, and with Forest Park itself. In September 2012 FTA gave final approval to the release of a $25-million grant for the line. Construction will begin in autumn 2013, and completion is expected by mid-2014. A regional plan, Moving Transit Forward, would add eight new LRT extensions, as well as two regional rail (commuter rail) services to the metro area.

Salt Lake City (New Age LRT, Future Streetcar Circulator)

Trains of 1–4 LRVs are being operated on the expanded system whose 57.5-km (35.7-mi) network now includes lines linking downtown Salt Lake City and the University of Utah with Sandy, West Jordan, and West Valley City. Most of the 77 Siemens S70 low-floor LRVs have entered service, supplementing the fleet of SD100s, SD160s, and former Santa Clara cars. Extensions to the airport (9.7 km/6.0 mi) and south from Sandy to West Draper (6.1 km/3.8 mi) are scheduled to open in 2013 and by 2015, respectively. A 4.4-km (2.7-mi) Sugar House streetcar line also is under construction, to start feeding passengers to TRAX at Central Pointe in 2014.

San Diego (New Age LRT, Limited Streetcar Circulator)

On the Blue Line, the United States's first new age LRT line, over $600 million is being invested to replace rail, ties, and catenary, as well as to add a fiber-optic communications systems and "Next Train" boards at stations. A total of 57 S70 low-floor cars will replace the last of the original 1981 LRVs. In 2011 a rebuilt PCC car began operating on the Silver Line, a one-way loop through downtown San Diego.

San Francisco (Legacy LRT and Streetcar)

The LRT system operated by the San Francisco Municipal Transportation Agency (SFMTA) continues to grow. After the 2007 opening of the 8.7-km (5.4-mi) line along Third Street through the southeast section of the city to Bayshore, SFMTA turned its attention to the north from 4th and King toward Market Street and Chinatown. This 2.6-km (1.6-mi) extension will be mostly in a new subway that will cross under Market Street and continue north beneath Chinatown's congested Stockton Street. Construction is to begin in 2012, with revenue service targeted for 2019. At the same time, activity has continued for a 2012 start of E-Line vintage streetcar service along the existing LRT route between the Ferry Terminal and Caltrain Depot.

San Jose–Santa Clara County (New Age LRT)

Valley Transit Authority continues to operate its 67.9-km (42.2-mi) LRT network. In recent years, studies have been commissioned to improve service and attract more riders to the system. An early action of the recommended program has been introduction of peak-period express service from the south end of the system through downtown San Jose and along North First Street to the Baypointe station. Construction of a new major league football stadium near the Great America theme park will bring new riders to LRT starting in 2014. There is a proposal in the AA/EIS (alternatives analysis/environmental impact statement) phase to extend light rail 3.7 km (2.3 mi) along Capitol Expressway between the existing Alum Rock Station and Eastridge Transit Center.

Seattle–Tacoma (New Age LRT and Streetcar Circulator)

The Central Puget Sound region operates *Central Link* LRT over the 25.1-km (15.6-mi) route south from downtown Seattle's Westlake Center to Sea-Tac International Airport. Under construction is a 5.0-km (3.1-mi) extension in tunnel north to the University of Washington's (UW) main campus. Work continues on further LRT extensions: from UW to the Northgate Transit Center, from Sea-Tac to a transit center and park-ride at South 200th Street and beyond to Federal Way, and across Lake Washington to Bellevue and Redmond. Tacoma's modern streetcar line and the similar South Lake Union route in Seattle continue to operate and attract growing passenger numbers. In Seattle, Sound Transit is funding a second streetcar line on Broadway to connect Capitol Hill and First Hill to *Link* LRT and *Sounder* commuter rail at the International District. The $134-million line will be 3.5 km (2.2 mi) in length.

Tampa (Streetcar Circulator)

The 4.3-km (2.7-mi) TECO Trolley Line continues to be operated by HART. Although Tampa and Hillsborough County have discontinued planning for future LRT lines after failure of a 2010 sales tax measure, Pinellas County across Tampa Bay has completed a plan identifying a 38.6-km (24-mi) LRT line that would link Clearwater and Saint Petersburg.

Toronto (Legacy LRT and Streetcar)

In 2010 Toronto Transit Commission's (TTC's) rebuilding of Route 512 St. Clair was completed with a separated right-of-way similar to that of Route 100 on Spadina Avenue, to increase service reliability. Replacements for the CLRVs and ALRVs are being manufactured by Bombardier. These 204 vehicles will be the first fleet of 100 percent low-floor cars to operate in revenue service in North America. Outside the TTC service area, the Province of Ontario's Metrolinx program anticipates building additional LRT lines in the newer parts of the greater Toronto metro area, and in Hamilton.

FUTURE OPENINGS (NEW STARTS)

Atlanta (Streetcar Circulator)

A 4.2-km (2.6-mi) city center streetcar circulator is under construction, with an anticipated opening to occur in 2013. It will extend generally west from the Martin Luther King, Jr. National Historic Site through the heart of downtown and on to Centennial Park and the Atlanta Aquarium. Four short S70 vehicles have been ordered from Siemens to operate the line. Potential future extensions, development of which is subject to future funding decisions, are streetcar–LRT plans for Peachtree Street (up to 19 km/12 mi), the Atlanta Belt Line (ultimately 35 km/22 mi), and the Clifton Corridor (14.2 km/8.8 mi).

Cincinnati (Streetcar Circulator)

A February groundbreaking marked the start of construction on a 6.0-km (3.7-mi) loop streetcar line to provide downtown circulation from Government Square through the Over-the-Rhine neighborhood to the Findlay Market. To be served by five modern streetcars, the line is scheduled to open in late 2013, and thereafter be extended to the other areas, including Uptown, near the University of Cincinnati.

Tucson (Streetcar Circulator)

Construction is in progress on the 6.3-km (3.9-mi) Sun Link streetcar circulator connecting downtown with the University of Arizona main campus and University Medical Center. Seven vehicles have been ordered from United Streetcar. A 2014 opening is anticipated.

Washington, D.C. (Streetcar Circulator)

A 2014 opening date now has been targeted for the H Street–Benning Road streetcar line. The Anacostia line is to follow later, after which several more streetcar corridors are under consideration.

Additional Streetcar Proposals

Though not yet advanced into final design or construction, several cities are pursuing plans to develop streetcar circulator lines or systems. These include Detroit (Woodward Avenue), Fort Lauderdale, Milwaukee, Kansas City, Northern Virginia, Oklahoma City, Providence, San Antonio, Santa Ana, and others.

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What Happens When a Transit System Does, or Does Not, Build Light Rail?

WHAT HAPPENS WHEN A TRANSIT SYSTEM DOES,
OR DOES NOT, BUILD LIGHT RAIL?

Streetcar Implementation Policy Analysis

A Survey and Observations of Streetcar Institutional Structures

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INTRODUCTION

In the last 20 years urban streetcar rail circulators have been developed across the United States to fulfill various roles in transportation and economic development. The streetcar projects can be divided into three categories:

1. Streetcar lines that have been resurrected or reconstituted in the few cities that never completely discontinued their streetcar services. These are typically implemented by the transit authority but may have involvement from the private–business, philanthropic, or municipal sectors with limited federal involvement.
2. Heritage streetcar projects—which include lines with restored old equipment, or replicas, or a combination of both—that operate in an urbanized area and perform a transportation function (streetcar museum rides that are solely intended to give the rider an impression of a streetcar ride and typically take the rider only back to their point of origin are intentionally excluded).
3. Modern streetcar projects that include equipment that is designed featuring the application of modern vehicles, typically styled after European counterparts, such as the the Portland, Oregon, modern streetcar application, which has been the impetus for many systems around the country.

One thing that has been common among all of these systems has been that the institutional structures used to fund, implement, and operate these streetcars have not been the typical structures that are used for FTA-type projects. Many institutions that are not typical decision makers for rail projects are included in a major way in these projects, acting as funders, decision makers, and federal (FTA) grant applicants. While the traditional model has been a transit authority acting as the primary grantee to the FTA and the implementation agency for rail transit projects, new streetcar projects have introduced many additional nontraditional parties who may have little to no experience in the implementation of rail transit projects. These include business improvement districts, municipal and local governments, nonprofit organizations, metropolitan planning organizations (MPOs), state departments of transportation (DOTs), and others.

As part of the current federal administration's new focus on streetcars as eligible uses of federal funds, FTA became a relatively new agency involved in the construction of streetcar projects. This has resulted in the application of the federal process for rail project development being applied to streetcar projects for the first time, at the same time that many new institutions are getting involved. The resulting issues that have been created by the experiences of these new organizations, which have partnered with local traditional FTA grantees at differing levels nationally, with the FTA processes have led to implementation issues. These issues are the result of what have been called traditional FTA "New Starts" project development processes being applied to smaller, less capital-intensive streetcar projects that feature project sponsors who oftentimes are not at all familiar or receptive to these processes.

Following discussions with the industry through the APTA Streetcar Subcommittee, the Community Streetcar Coalition, FTA, and many project sponsors it became clear that there was no clear model for implementation of a streetcar project. What was clear is that the institutional structures were all different but were common in that they are all nontraditional. Also, FTA faced some challenges in applying its standard project development process to streetcar projects, particularly with regard to how FTA holds grantees accountable for the liability ("federal interest") for a grant. All of these factors, when combined, have led the investigators to conclude that this was an area of research worth investigating.

The authors determined—in conjunction with the members of the APTA Streetcar Subcommittee, with collaboration from the Community Streetcar Coalition and FTA—that investigation was warranted and could inform future policy making. The best methodology was determined to be a survey of all of the streetcar projects across the United States that either are in planning, development, or implementation, or are currently in operation. This paper is intended to provide the status of the research to date as of the drafting of this paper, given that the research is ongoing and may lead to additional conclusions.

The methodology of the research is to conduct a national survey of all streetcar projects as per above and to summarize the results. From these results the investigators will draw observations and preliminary findings. Using the APTA Streetcar Subcommittee, the staff of the Community Streetcar Coalition, and the FTA, the investigators will publish observations and potential areas of policy development that may assist in the implementation of current and future streetcar projects. It is intended that this research will primarily focus on three areas: to act as an introduction or preamble to the efforts of the APTA Streetcar Subcommittee to develop a Guide to the Implementation of Modern Streetcar Vehicles, to assist APTA in engaging with all of the nontraditional institutions getting involved with rail transit (through its Urban Circulator program), and to assist FTA in engaging with nontraditional grantees and other institutional arrangements engaging in federally funded rail transit project development.

The authors developed a list of potential survey participants with the assistance of the Community Streetcar Coalition. Survey efforts have resulted in many respondents having returned their written surveys. The team has a more detailed follow-up phone questionnaire, which has also been implemented with many projects. This paper summarizes the responses to date, primarily through observations of trends with future publications and updates that will provide additional information and analysis as the survey is completed.

FUNDING

Streetcar project funding is different from more traditional transit projects for the feasibility–planning, capital development–construction, and operations elements. Federal funds come from a variety of different sources including the FTA Small Starts, FTA formula funds (section 5307), highway flex funding, Congestion Mitigation and Air Quality (CMAQ) Improvement Program, and particularly, the new major capital investment discretionary programs such as TIGER and Urban Circulator. While there are no formulaic programs for streetcar capital funding (yet) there are various entities exercising decision-making authority over programming and allocation of federal funding, including the U.S. Congress, the Office of the Secretary of Transportation, FTA, MPOs, state DOTs, and others. Local funding is programmed from many sources including local government general fund balances, transit authority funding sources, tax-increment financing, other private sources, and many others. A common theme is that streetcar capital programs involve a diversity of funding sources that are directly correlated to their complex governance structures and intergovernmental agreements. State and regional funding are included in a handful of projects but a key attribute of the streetcar movement is the use of highly local (municipal or improvement/tax district) funding matched with federal discretionary funding.

Table 1 summarizes the various streetcar funding survey responses.

DESIGN

Utilities are the single largest driver of design decisions. Utilities frequently play a role in determining trackway, overhead contact system (OCS) poles, and slab design, and can have significant impacts on the project schedule. In some instances, utility work is done long before the actual streetcar infrastructure is built or before a streetcar project even wins funding. Some cities with long-term plans to add streetcar service ensure utility upgrades or major street redesign can accommodate future streetcar infrastructure without being moved again. Generally a "zone of influence" is established for all corridors that could one day have streetcars. Utility conflicts are also influenced by the level of comfort the utility has with co-location of their facilities with operating streetcars. Stray current and steel plating over a concrete encasement are two examples of the type of issues that have to be determined on streetcar projects. Fiber optic cables and major underground electricity transmission lines are highly sensitive and must be protected during construction. Generally those systems planning extensions of existing systems (Tacoma, Portland, Seattle) had fewer issues with utility relocations impacting design, budget, scope, or schedule.

Utilizing an existing vehicle maintenance–storage facility is a major driver of design (Charlotte, Dallas, Tempe, Salt Lake). Some cities also face the challenge of building a new maintenance–storage facility, and it is necessary to select a route where a facility can be built. Finding underutilized or unused land can be a challenge in some urban areas. Some cities, such as Portland and Atlanta, have located their maintenance–storage facilities under highway bridges. Starting from scratch on a new facility can significantly increase the cost of building the system given the real estate required in the urban area. Some projects to date have discussed or temporarily shared existing transit agency maintenance facilities. Los Angeles is weighing the benefits of this approach against the additional deadhead costs and trackage versus constructing their own facility on their alignment. The Portland streetcar has evolved the capability of their

TABLE 1 Streetcar Project Funding Summary

City	Project Capital Cost ($M)	Project Utilizing Federal Dollars?	Other Funding?	Funding Swaps?
Arlington–Fairfax–Columbia Pike	255	30% Small Starts (*)	State (15%); City (55%)	No
Arlington–Alexandria–Route 1 Corridor Streetcar Conversion	na (planning)	Not right now		No
Atlanta, Ga.–BeltLine	1,500	Yes for AA	TIF	No
Austin, Tex.	550	50% New Starts (*)	In planning; 50% city	STP MM funds from TA to city
Boise, Idaho	na (AA by 2014)	Yes for AA	In planning	na
Charlotte, N.C.	37	70% UCG	City (30%)	No, barred from using TA's 1/2-cent sales revenues
Cincinnati, Ohio	110.41	35% TIGER3, UCG, CMAQ	City (65%)	No
Dallas (vintage–modern)	9.9	50% UCG	In planning	Regional toll revenues from MPO
Dallas–Oakcliff–Downtown	64.8	40% TIGER 1	State (25%); City (7%); BID (14%); TA all O&M	Regional toll revenues and TIF
Dayton, Ohio	(On hold)	Yes for planning	In planning	No
Ft. Lauderdale, Fla.	142	50% Small Starts	State (25%); City (7%); BID (14%); TA all O&M	Florida DOT State New Starts to MPO (SFRTA)
Los Angeles	125	40% Small Starts (*)	In planning; 10% City; 50% BID	O&M partially from TIF
Lowell, Mass.	4 (design)	60% NPS TRIP	TA (1%); MPO (3%)	TRIP monies from RTA to city government
Oklahoma City	120	5307 and TIGER 2 (only for AA and EA)	In planning	No
Pasadena	0.1 (feasibility study)	No	In planning	na
Portland	140	50% Small Starts	State (13.4%); City (22.8%); BID (10.5%)	No
Sacramento	1.3 (AA)	90% 5307	In planning	Toll credits for local match

continued on next page

TABLE 1 (*continued*) **Streetcar Project Funding Summary**

City	Project Capital Cost ($M)	Project Utilizing Federal Dollars?	Other Funding?	Funding Swaps?
Salt Lake City	38	70% T2	$5M from Cities (2x) / $1.5M TA	In exchange for both cities subsidizing O&M, UTA donated 3 Siemens S-70s
St. Paul	0.25 (feasibility study)	No	In planning	No
San Antonio	200	Only $0.9M for AA (5339)	In planning	No
Seattle–1st Hill	136	No	TA (100%)	City contributes to road betterments
Seattle–SLU	53	28%	Pvt (50%); state (10%); city (12%)	Metro operates, city subsidizes 25% of operations costs and all major maintenance–replacement costs
Tacoma	79.2	Not right now	TA (100%)	No
Tempe, Ariz.	134	68% T4/SS/ CMAQ	In planning; TA (32%)	No
Tucson, Ariz.	197	35% T1 and NS Exempt	City (11%); TA (38%); private (7%); MPO (9%)	Intra-agency project swap for MM bridge construction

NOTE: na = not applicable; not right now = possibly considering seeking funding in future; no = will not utilize federal dollars.

maintenance facility as they have grown their system and fleet, relying less on the Tri-Met heavy maintenance capabilities as they have evolved.

Buy America compliance is another major influence of vehicle, Traction Power Substation (TPSS), and rail–special work procurement options. Additionally the relatively small market for streetcar vendors has limited the ability of project sponsors to obtain components, such as girder rail, turnout hardware, and other components no longer manufactured in the United States as fabricators are not willing to invest in U.S. production for such a small market. Many cities buy their vehicles and other long lead time components as an option off another agencies' contract as opposed to procuring the vehicles or components themselves. This can allow for faster delivery, but makes customization more complicated and more expensive.

Buy America compliance also significantly influences where rail is purchased from and what type of rail is used. Girder rail and T-Rail are the most common types of rail used for streetcars, but the lack of a domestic supplier for girder rail has precluded federally funded projects from procuring girder rail, which has better performance in curves and does not require a poured flangeway since no domestic supplier exists. Most federally funded projects have had to adapt railroad T-rail to an embedded track design through the use of a poured flangeway and restraining rails in curves.

Vehicle door to platform mechanical bridgeplates and platform height and length are a significant design decisions. While bridgeplates make operations slower and more difficult because of the extra on-board equipment and deployment time, they allow the stops to be at curb level instead of raised. Raised platform stops allow for easier and faster ADA access, better delineation of the stop (which is especially important if a “fare paid zone” is used), and allow for the use of safer median style stops. On the other hand, raised platforms take up sidewalk space, require ADA-compliant ramps and more concrete, and can be aesthetically displeasing in certain neighborhoods. Raised stops also require that the vehicle and the stop meet minimum tolerances for the gap between the platform and the vehicle. Platform length is also a design consideration, as some systems are designed for future coupling of vehicles and some are not. The systems that are not designed this way could be precluded from a higher capacity operation if it was needed in the future or if the system is expanded.

Some survey respondents described how bridges play a significant role in the design of streetcar systems, especially when bridges are not owned by the project sponsors. If the streetcar has to pass under or over a bridge, great care must be taken in the design for OCS support and stray current protection. This involves an institutional relationship with the entity that owns the bridge. Charlotte; Washington, D.C. (Amtrak); Atlanta; Dallas; Oklahoma; and several other projects have had to work through this or are currently working through this.

Some systems are being built to use vintage vehicles as well as modern streetcar vehicles. Dallas is a notable example. Dallas’ Urban Circulator project will initially use vintage vehicles, which operate at a lower voltage than modern vehicles. Thus, Dallas had to work so that its modern vehicles from the TIGER project will have the capability to operate at a lower voltage on this part of the alignment. Dallas’ modern vehicles will also be equipped with batteries in order to span a viaduct bridge that will not have OCS wires. Some cities are designing their OCS to accommodate dual pole–pantograph capability to allow for the use of a vintage or heritage vehicle on the modern streetcar alignment in the future.

Since streetcar alignments tend to operate, at least partially, in urban neighborhoods, designing to accommodate special events is a major consideration for many projects. One of the largest events in the downtown Tucson area is the 4th Avenue Street Fair. The design includes turn-arounds, stop locations, and power distribution accommodations at each end of the Street Fair to allow for service to continue while the Street Fair was taking place. As observed in the survey results, preserving and improving cyclist safety is a major design consideration for a streetcar project. Unfortunately, there is no simple mitigation strategy to prevent bike tires from being caught in a streetcar track. Cycle tracks, contra-flow bike lanes, two-stage turning movements, bike–pedestrian-only traffic signal phases, signage, and a host of other mitigation strategies can be used, but funding to implement them is an issue. Surveys from cities that have built streetcars indicated that they have cyclists that are more accustomed to negotiating the perils of streetcar tracks. Many streetcar projects include cyclist safety features in their budgets or apply for other grants and funding sources to build bicycle infrastructure in conjunction with the streetcar project. Atlanta, for example, secured a $5.1-million MPO grant that will be used in part for improved bicycle facilities on the alignment.

FEDERAL TRANSIT ADMINISTRATION WORKING RELATIONSHIPS

General Observations on Federal Funding

Out of all of the streetcar projects that were surveyed, an overwhelming majority of them used federal monies to both plan and construct their projects. Out of all of the projects that have made it past feasibility studies, only Seattle's First Hill Streetcar has been able to completely forego seeking any federal funding to plan and implement the project. Four projects have used FTA planning grants, but have not as of yet received FTA monies toward construction. Projects lacking construction dollars are either too early in project development (e.g., currently completing Alternatives Analysis–San Antonio and Tacoma) or intend to be funded using other means (e.g., flexed highway funds or local sources). Feasibility studies are often done using entirely local funding sources, and there are examples of entirely locally funded planning efforts including Seattle's First Hill Streetcar, the Cincinnati Streetcar, and the Atlanta Streetcar.

Project Owner Status and Traditional FTA Grantee

Although regional arrangements can and do often vary, in general, traditional FTA grantees are the established operators of transit services that have qualified with the FTA and executed the FTA Master Agreement, including all required federal certifications and assurances, and are therefore eligible to receive and manage FTA grants. FTA, as a grant-making rather than regulatory agency, has established systems in place for the management of grantees and ensuring compliance. This structure provides for regular oversight, access to FTA electronic systems for reporting and grants management, drawdown of federal funds, and tracking of assets and operations of federally funded transit assets. These organizations include transit agencies, regional transit authorities, and others. MPOs are also typically grantees for the purposes of drawing FTA planning grants. An exception oftentimes occurs when a city or county government, usually through its department of transportation, runs a municipally owned transit system, as in the case of Charlotte, Los Angeles, and Tucson. In some instances a regional transit authority, such as Seattle's Sound Transit, or a transit agency, such as the Utah Transit Authority, may own the project. Streetcar project and infrastructure ownership tends to rest with city governments. Thus, the owner of the streetcar project is often not a traditional FTA grantee.

Grantee and Subrecipient Arrangements

In order for a streetcar project to receive federal funding it must execute a grant agreement between an FTA grantee and FTA. Traditional FTA grantees usually serve as the grantee for streetcar projects. This often means that the FTA grantee for the project is not the owner of the project, but rather a funding partner aside from the owner, such as an MPO or a regional transit authority. Streetcar projects tend to exhibit a nontraditional FTA arrangement because of the difficulty in becoming an FTA grantee. Oftentimes subrecipient relationships are established when there is a need for the grantee (e.g., not the owner or FTA-designated recipient) to maintain continuous communication with FTA. If there is a subrecipient for a streetcar project, that entity is usually in charge of operations for the project, as in Seattle's South Lake Union (the city is the owner and sought designated status, and King County Metro operates) and Tempe (the city is owner, and Valley Metro operates), or has been delegated a managing role for the project, as in the case of Portland's not-for-profit Portland Streetcar Inc. A major challenge for streetcar projects, given that they are oftentimes municipally owned, is how to transfer federal liability from the FTA grantee to the owner, including how to pass through FTA oversight from the grantee to the owner.

INTERGOVERNMENTAL–INTERLOCAL AGREEMENTS

General Observations on Intergovernmental Agreements

All projects that are currently operating have an Intergovernmental Agreement (IGA) in place that delineates each partner entity's formal roles and responsibilities, as well as the decision-making processes used for any issues or disputes that may arise. The majority of projects that are past the design phase have drafted IGAs for project funding, delivery, operations, and maintenance, but have not yet finalized the agreements. Many projects that are not through the design phase have not yet finalized their cooperative agreements, but have, nevertheless, begun to take the proper steps that will allow them to secure a consensus on project governance once the design has been finalized. The only streetcar project without an IGA was Charlotte and that is because the project is completely housed within one entity and relied only on internal and federal funding sources. The majority of respondents said that there were no major political impediments to securing their cooperative agreements. According to a few respondents, the only major issue that seems to delay the finalization of an IGA is the delegation of oversight authority for the streetcar project. Another observation is the separation of IGAs for construction from those that are used for operations once construction is complete.

Partnerships and Roles

IGAs typically include all funding partners for the streetcar project. Sometimes these agreements also include external entities that contribute oversight efforts, such as a state Department of Transportation (DOT) (Ft. Lauderdale) or a not-for-profit organization (Portland Streetcar, Inc.). Aside from Charlotte, city and county governments are rarely involved in the technical aspects of planning streetcar projects. Instead these entities serve more of an implementation-oriented role, often acting as the political champion and overall project manager. As most municipal governments do not have a strong background in rail operations, they tend to delegate all of the technical work and responsibilities to an entity that has a strong track record of delivering and operating rail transit. Thus, it is the transit agencies and regional transit authorities that often end up doing the bulk of the planning and design work. MPOs are usually charged with maintaining communication between all of the entities within the partnership and tend to serve an organizing-oriented role.

Observations on Governance Structures

Due to the fact that most of the projects surveyed were still in the early phases of project development, the majority of the projects did not have a finalized plan as to how the entities would cooperate together in order to implement and operate the streetcar project. In general, the projects that have been successful at signing IGAs for streetcar governance, such as Salt Lake

City, have provided each partner entity with equivalent decision-making power, while at the same time, specifically delineating the responsibilities of each entity to one another and the overall project.

For projects that use revenues from a tax increment financing (TIF) district, a not-for-profit project management board, such as Los Angeles or Portland Streetcar Inc., is often created in order to manage the TIF monies. TIF monies are most often used to subsidize operations and maintenance of the streetcar and have rarely been used for construction. In order to address the needs, desires, and concerns of the residents and adjacent property owners within the TIF area, the not-for-profit provides an extra space on its representative board to lobby for these stakeholders. Relatively few of the projects surveyed have a formal citizens' or community advisory committee to serve as liaison between the project staff and the public. For all of the projects that had a formal public representation entity, the survey respondents said that public comment significantly contributed to the creation of a better project than the initial concept.

COLLABORATIVE DECISION MAKING

Forms of Collaboration

For streetcar projects with IGAs in place for project funding, delivery, operations, and maintenance, collaboration is institutionalized by requiring that each partner entity assign a staff member(s) to attend project team meetings on a monthly and sometimes even a weekly basis. For projects without a finalized IGA for the post-design phases, collaborative decision making often takes a more informal form (e.g., impromptu, sporadic meetings) or simply does not occur at all.

Influence of Nonraditional Project Partners

According to a respondent, "The greatest challenge in multilateral relationships has been differing objectives, community cultures, and levels of enthusiasm by different interest groups." Aside from the entities who are signing members of the IGA, the other major class of entities that tends to be involved in decision making is large institutions, such as state universities (the University of Massachusetts at Lowell and the University of Arizona) and hospitals (Dallas and Charlotte), that serve as major employment centers. While they are often not directly represented on the governing board, these entities are essentially too big for the project team to neglect and are thus often consulted by the project leaders prior to major design decisions.

As streetcars are often championed because of their economic development benefits relative to other modes, the streetcar decision-making table can also include representatives from TIF districts and development companies. TIF areas (TADs) are often created for a streetcar project in order to subsidize the operations and maintenance costs of the new service. TIF monies are rarely used for construction. As a spokesperson for adjacent property owners and residents along the alignment, the TAD representative lobbies the other formal stakeholders to respond to the needs and desires of the community. In the cases of Los Angeles, Portland, and Seattle, the TAD representative can sometimes act as the project manager and directly control a significant source of the project's budget. One unique instance of collaborative decision making with a developer was Seattle's South Lake Union streetcar project. During the planning and design phase of the project, the City of Seattle worked closely with multiple developers who owned property along the streetcar's alignment to identify stop locations. As a result of this collaboration, the stop locations identified were then integrated into concurrent development projects and actually built by the developers!

Impacts of Collaborative Decision Making on the Efficiency of Project Implementation

Many respondents identified that there is a tension between delivering a project in a time-effective manner and creating a quality project that responds to a broad array of stakeholder needs and desires. Stated differently by a survey respondent, "Collaborative decision making has not always been efficient, but the process has resulted in a superior project." According to one respondent, "Having multiple [project] champions has been a benefit." According to another survey respondent, "Having multiple perspectives on the project has enhanced the efficiency and quality of the project because of the recognition that its objectives are not just transportation, but include economic development and land use components." In the case of Charlotte, the city government invited the private utilities to participate in the project early on and this "allowed the appropriate time to coordinate scope, schedules, and budgets."

Impacts of Collaborative Decision Making on the Quality of Project Implementation

Public involvement early on was cited by numerous respondents as a key to quality project implementation. By conducting public workshops and meetings, the project team can create a venue in which "the public takes ownership of the project and provides valuable input that can be integrated into the project." Furthermore, these meetings "can be used not only to understand public expectations, but to demonstrate to the public how its input has been incorporated into the project." According to one survey respondent, "While the collaborative approach takes additional time, the goal is to implement a project that is embraced by the local community."

Negative Impacts of a Collaborative Decision-Making Approach on Project Implementation

All respondents recognized that when you bring more parties to the table, it takes more time and effort to come to a consensus. One respondent noted that "collaboration was labor-intensive." Another respondent noted that "primary challenges have resulted from the numerous policy boards of our perspective agencies that force us to navigate an extremely aggressive schedule." For projects that involve a municipally-owned redevelopment area, throwing a private developer into the mix "adds a layer of complexity to this project."

TRANSIT COORDINATION

Fare Collection Technology

All projects surveyed intended for the streetcar service to accommodate the same fare collection technology and regional fare medium (if in place) that is used by the existing local or regional operators, or both. In the case of Arlington–Columbia Pike, the streetcar staff wanted to run the service using off-board fare collection. However, the D.C. area regional transit authority, WMATA, has not been quick to embrace off-board fare collection. Thus, Arlington County Transit has decided to use a multi-use fare payment system that accommodates off-board fare collection, but also allows for regional transit riders to make use of their regional SmarTrip fare card on board the vehicle.

Fare Policy

None of the survey respondents indicated that their streetcar projects would have a fare policy that strongly deviates from the existing fares and transfer arrangements of the other local operators. In the case of Portland, the streetcar project has gone out of its way to offer the Tri-Met fare, in addition to the streetcar fare, in order to allow for easy transfers with one fare payment method across multiple operators. In the case of Lowell, the Lowell National Historical Park has been operating a fare-free trolley that will be extended to the University of Massachusetts at Lowell campus. The university has been approached to offset the increase in operation and maintenance expenses resulting from the extension by contributing a portion of its student transportation fees to help subsidize the new operation, which will provide some overlap with its existing campus bus service.

Multimodal Service Integration and Reconfiguration

Many of the projects surveyed, such as Charlotte, Dallas, Portland, and Salt Lake City, were built to connect to existing light rail lines or, in the case of Atlanta, heavy rail service. Given that streetcars often serve high traffic areas where significant bus service already exists, many streetcar projects, such as Arlington, Austin, Lowell, Tempe, and Tucson, are planning to reconfigure their local bus networks in order to optimize multimodal travel and connectivity. In most of these cases, there is an assessment period during which bus service is unaffected and the streetcar is implemented. Once users have become oriented to the new service, performance across all modes is then analyzed and a decision as to how to modify which routes is then implemented.

In the cases of Tucson and Arlington's Columbia Pike, a great amount of effort was put forth to reach out to the local bicycling community. Staff from both projects met with local bike stakeholders and university students in order to investigate how to best plan for bicyclists and mitigate potential conflicts between bikers and streetcars. Arlington's Columbia Pike project plans to include Capitol Bikeshare facilities on adjacent streets in the near future. In general, other systems seem to lack this level of outreach and coordination with the cycling community. Solutions, if proposed at all, tend to involve routing cyclists onto other streets, providing safety signage, and adding contra-flow sharrows. Unfortunately, there frequently appears to be a disconnect between many project sponsors and understanding the needs and desires of the cyclist community.

Stop Locations

Surprisingly, only two streetcar projects specifically mentioned coordinating stop placement so that some stops have the ability to serve more than one mode. In the case of Portland, some of the streetcar platforms will be built so that stops can be shared between local bus and streetcar service. Charlotte is considering co-locating some of its streetcar stops with bus stops; however, this would require the complete alteration of the current bus stops (e.g., raising of platforms) in order to provide for level boarding on the streetcar.

ECONOMIC DEVELOPMENT

In addition to serving as transportation providers, streetcars are known for their ability to help attract economic development to locations along their routes. The fixed nature of a streetcar and the preference for rail over bus has a tendency to attract significant urban development. There are but a handful of projects that have quantified their economic development along their routes, but nearly all of them report that either developers are seeking their project out or they are seeking developers. Economic development quantification usually takes into account economic development within a half-mile of the alignment or simply two city blocks.

Portland is the most well-known example of this. According to the *Portland Streetcar Development Oriented Transit* (*1*) study, $3.5 billion in economic development had occurred within two blocks in 11 years after the initial identification of the streetcar alignment. While the official number is still being calculated, Portland has also seen significant economic development within its Loop project, which was slated to open on September 22, 2012. A recent report also indicates that over half of the 40 new apartment building permits that have been filed in Portland over the last year and a half have been designed without parking (*2*).

While Portland has done the most comprehensive tracking of economic development and also has the most streetcar-related economic development, other cities have also seen transit-oriented development springing up along their alignments. Charlotte's Elizabeth Avenue was put on a "road diet" to improve pedestrian facilities around Central Piedmont Community College. In conjunction with the Greenway project, the area has been significantly improved, and developers have taken interest. Elizabeth Avenue provides direct access from the central business district to Presbyterian Hospital and the college. The land use in between these two anchors is currently characterized by low-rise, low-density office and retail uses. In 2009 the City of Charlotte contributed $8.2 million for the reconstruction and reconfiguration of Elizabeth Avenue.

Atlanta has also seen significant development near its future Beltline project and small, but not insignificant, growth along its streetcar route (which is currently being designed and will go into construction later this year). Atlanta boasts approximately $1.5 billion in economic development within the Beltline's tax allocation district. To date this has been created by the adoption of a redevelopment plan inclusive of transit and implementation of parks, trails, and affordable housing components of the project. Transit implementation is approximately 2–5 years in the future, so the actual impact of building a streetcar in the Beltline corridor has not been quantified at this time. The Atlanta Streetcar project (largely a TIGER II project) has spurred small amounts of redevelopment in its immediate vicinity. The Edgewood Corridor is an up-and-coming neighborhood, and many storefronts have been revamped. The Atlanta Downtown Improvement District (one of the local funding partners) is actively pursuing revitalization along the alignment (*3*). This includes the identification of over 80 acres of land and buildings within two blocks of the alignment; collaborating to formalize incentives available to developers at these locations; and reaching out to the community in order to understand their plans and visions, as well as to identify perceived challenges and constraints.

In Cincinnati the Center City Development Corporation (3CDC) has a strong, nationally recognized record of attracting new infill and adaptive reuse development to the streetcar alignment in Downtown and the Over-the-Rhine neighborhoods on the streetcar alignment. While Tempe's Streetcar is still in an early stage of development, it is reasonable to expect significant development along this corridor. This is evident with the light rail starter line, as it is experiencing more than $7 billion in public and private investment within one half mile of the line. This increase in development activity is significant because it demonstrates the impacts that can occur with streetcar investment, even in a region that is just now making its first major investment in rail. The project cost $1.2 billion and opened in 2008. Los Angeles' Streetcar is at an even earlier stage, but Downtown Los Angeles's 2011 AECOM Economic Impact Study revealed that $125 million in streetcar investment would create an additive value of $1.1 billion in development above and beyond the normal growth rate over the next 25 years.

UTILITIES RELOCATION

Utility relocation is one of the biggest and most ambiguous challenges to a streetcar project. The inherent nature of streetcars makes preparing a city street for transit operations incredibly complex. Some cities have taken the initiative ahead of time to develop a "Rules of Practice" document before design and construction begin. This has created the ability to work with the utility companies so that the project is not delayed due to utility relocation. Other cities are not as fortunate. Cities that are building a starter line that require utilities to relocate at their own cost while on a tight construction schedule put themselves at great risk of schedule delay and cost overruns. Utility relocation is a critical path item the instant a project schedule is formalized. If a track slab cannot be poured or an OCS pole cannot be placed because a utility has not moved, it could be considered a delay to the project. At that point, the project sponsor(s) have to assign the delay and the associated costs to someone or absorb it themselves.

There are no known projects that have fully reimbursed the utilities for their cost to relocate and associated betterments, but some projects reimburse the utilities more than others. City projects generally provide the funding for the public utility relocation (water, sewer, stormwater) and require the private utilities to relocate at their own cost. Traditionally, transit agency projects must reimburse utilities that have to move as a result of the project. However, if a streetcar is a city project, the city has the authority to require utilities to move at their own cost. Thus, from a utilities relocation perspective, having a municipal government as the project lead can save money.

Generally, the older the infrastructure is and the more dysfunctional the streetscapes are, the more complicated and ambiguous the issue of utility relocation becomes. Projects that also include streetscape upgrades often have trouble discerning what constitutes a cost to the streetcar account and what counts as a cost to the street betterment account. Therefore, the designer and the project partners have to make a determination between what is streetcar related and what is simply a pedestrian–bike–traffic improvement, and this is often a contentious debate. A related issue is the gray area between what is considered strictly a utility relocation and what constitutes a utility infrastructure upgrade or betterment. Utility companies constantly have to upgrade and repair aging infrastructure. The project sponsors are generally not quick to assume it is only a utility relocation if they have to pay the costs. Likewise, a utility company is not quick to assume it is only a utility upgrade if they can get the project sponsor(s) to pay for it. It usually comes down to who is the owner of the project. If anyone other than the City, as the owner of the right of way and the franchisor, is the final owner of the asset, the utility companies are not liable to pay for the costs of utility relocation. FTA-funded projects must also follow FTA guidance, which precludes project expenditures on utility betterments.

Portland and Charlotte have developed a Rules of Practice document, and Austin has a similar standard in development. These documents were negotiated beforehand with the utility companies, so that when a project gets funded there are fewer concerns about where and how to relocate. The Rules of Practice is intended to be a guide for the utility companies to know what the sponsors' expectations are without spending valuable time negotiating. There is a significant correlation between a city's streetcar experience and utility companies' confidence in the project. Utility companies are not likely to move expeditiously if they are not comfortable with the project sponsor's design, especially if streetcars are new or being reintroduced. Cities that have built streetcars or light rail in city right-of-way have significantly better chances of getting utilities to move at a 10%, or in some cases a 5% design. Cities that have never built modern streetcars, or that are reintroducing them, tend to have more difficulty getting the utilities to move that early in the design process, and are more likely to see relocation progress at 30% design and beyond.

Utility relocation is also heavily influenced by the future operating arrangement of the streetcar. The ability of a utility company to access its facilities, along with the future operating and safety rules under which suspension or curtailment of streetcar operations will occur, influences the need for relocations.

OPERATIONS AND MAINTENANCE

The operations and maintenance of a streetcar system tend to be as complicated as their funding and governance structures. There is certainly no one-size-fits- all approach. There are four general approaches to operations and maintenance:

1. The existing transit agency operates the streetcar. In some cities this is very feasible. Charlotte has an existing talent pool of vintage trolley operators that used to drive the trolley when it was operating in conjunction with the light rail. Should Charlotte get more S-70s to use specifically on the new streetcar route, they already have operators and a training program for the Blue Line.
2. The existing transit agency contracts the operations and maintenance out to an operations and maintenance contractor. This is what Atlanta is considering but has yet to determine. Tempe's METRO currently contracts their maintenance and operations and intends to add streetcar operations to that contract.
3. The city–nontraditional partner contracts the operation and maintenance out to an operations and maintenance contractor. Washington, D.C., DOT is utilizing this method (*4*).
4. A third-party nonprofit organization operates and maintains the streetcar system. Portland Streetcar Inc. is the most notable example of this.

For projects with several partners, it is common for the project partners to develop a responsibility matrix, assign responsibility to each of the partners, and develop an IGA based on the ownership of responsibilities among the project partners. A relationship built on mutual trust and a common goal is an essential part of developing these IGAs. These responsibilities include policing and fare enforcement, stop cleaning and maintenance, state safety oversight, insurance and legal services, and more.

CONCLUSION

A key anecdotal observation of the survey results is that the development of streetcars has changed the rail project development process from what has been considered traditional to date. This is due to the fact that streetcars, as major capital investments, serve a relatively small area and are intended as much to promote economic development as they are intended for transportation. This means that a traditional transit agency would typically not fund a streetcar given the resources involved and the smaller constituencies served. This means that municipal governments, business associations, and other improvement districts and nonprofits are sponsoring and owning projects. The advent of federal funding becoming available for streetcars has brought transit agencies to the table to act as grantees and has created some very complex institutional arrangements for project delivery and system operations. As with many arrangements in the transit industry, there is no one size fits all, and streetcar projects vary considerably across the country.

Additionally the survey results demonstrate that streetcar projects tend to be funded through a larger number of sources (both capital and operations and maintenance) as a package and that the funding overwhelmingly comes from two distinct sources: federal discretionary and local. State and regional funding is included in a handful of projects, as is transit formula funding, but these sources are not typical and form a small percentage of the project budgets where they are applied.

The oversight, regulatory, and grant-making structures currently in place at the national level, primarily through FTA, are designed for a traditional grantee approach. This has caused issues with some projects adapting grant agreements to situations where the project sponsor and owner is not the grantee. The transfer of liability through the grantee to the owner and the transfer of oversight through the grantee from FTA to the owner is an issue with these arrangements, which is accomplished through IGAs at the local level rather than through federal contracts, which recognize only grantees.

The operations of streetcar projects have also presented some complicated arrangements. Many systems utilize, or plan to utilize, the local transit system for operations. This can be accomplished through either direct operation by transit system personnel (Portland, Seattle) or through a third-party contractor (Tampa) managed by the transit agency or local streetcar organization. Additionally the funding sources for the streetcar operations are also varied and are bundled into complex packages that are usually intentionally segregated from the existing transit system's revenues and expenses. Another challenge identified in survey responses is the integration of the streetcar into the existing regional transit system both in terms of system planning and fare media and policies. The level of integration varies considerably with Portland, Seattle, and Atlanta planning full integration and Washington, D.C., Memphis, and Cincinnati having some or no fare or service integration.

The objective of this research was to document the different institutional arrangements and factors for streetcar projects. It is clear that the complex arrangements being used for streetcar project development and operations lend themselves to policy refinement discussions at the national level and perhaps best practices further research and development. In survey responses issues such as FTA-grantee status, operating arrangements, governance structures, and collaboration in a multilateral decision-making process were all identified as both challenges and opportunities for projects. It is clear to the authors, following examination of the survey results, participating in interviews, discussing issues with peer projects and systems, that this an area of further examination in the streetcar policy area. The current situation oftentimes leads to overly complex institutional structures, which causes issues with decision making and varying levels of experience with transit project and service delivery. At the same time survey respondents also identified the need to preserve having all perspectives at the table to integrate the economic development aspects of the project with the transportation functionality, a complicated balance.

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WHAT HAPPENS WHEN A TRANSIT SYSTEM DOES,
OR DOES NOT, BUILD LIGHT RAIL?

Comparative Examination of New Start Light Rail Transit, Light Railway, and Bus Rapid Transit Services Opened from 2000

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Electric light rail transit (LRT) projects (both New Starts and the expansion of existing systems) have long been vulnerable to criticism of high investment cost, project capital budget overruns, and failure to achieve ridership targets. This criticism continues to prompt proposals for modal alternatives, such as non-electrified diesel-multiple-unit (DMU) light railways and particularly for bus rapid transit (BRT) projects, that are presented as supposedly less costly and more reliably implemented technologies that can achieve similar benefits.

In considering this issue, this study has attempted to examine the following specific questions with respect to such projects in U.S. cities:

- Can major differences in capital cost per mile (kilometer) be detected among LRT, DMU light railway, and BRT projects?
- Are there major differences in how closely the final capital costs match the projected and budgeted costs of such projects?
- Are there major differences in how well ridership goals are achieved?

Of course, there are other important aspects and benefits associated with major transit investments: land use and urban development impacts, environmental benefits, energy and greenhouse gas implications, and others. However, this study has endeavored to stay within a manageable scope and focus on more readily available indicators, in terms of both initial projections and actual performance data.

It was originally intended to include comparison of operating and maintenance (O&M) cost, particularly per passenger-mile, but such data are either not readily available or not currently available in a consistent, standardized form to facilitate reliable and fair comparisons, especially with regard to BRT operations, whose data are routinely blended in and reported with systemwide bus data. It is hoped that this problem will be overcome, and a reliable comparison based on these performance indicators can be presented in a future study. Nevertheless, with respect to each system where O&M expenses per passenger-mile (p-m) have been available in FTA's National Transit Database, for the most recently available year (2010), that data has been included to facilitate a general comparison among the transit modes operated by that agency.

To approach the three specific research questions, this analysis has examined selected recent LRT, light railway, and BRT projects serving extended line-haul corridors (as opposed to short circulator types of operation) with respect to performance data relating to the research questions. While short, purely circulator-type streetcar operations are excluded, some streetcar operations providing line-haul functionality are included (e.g., Memphis and Portland).

The study has focused particularly on "New Start" projects (totally new systems, or major extensions to existing new systems) that received New Start funding or oversight from FTA, although other projects have been examined in cases where data were readily accessible. Study results have been limited because of constraints on readily available data. Therefore, this study has had to exclude projects for which data were simply insufficient or not readily available .

Unfortunately, this has been a particular problem involving DMU light railways, of which currently only three have been installed in the United States. While certain data (generally in a standard reporting form) have been available for North County Transit District's Sprinter light railway linking Oceanside with Escondido, California, serious problems have been encountered with respect to cost and operating data for the DMU light railways of New Jersey Transit's (NJT's) RiverLine (Camden–Trenton) and Capital Metro's 32-mi MetroRail linking Austin, Texas, with the suburban town of Leander:

- NJT's RiverLine. Capital and operating costs have been somewhat obscured since this was a design-build-operate-maintain project, and also because O&M costs and other performance data are not separated from NJT's electric LRT operations.
- Austin's MetroRail. While the final capital cost of this locally funded project was roughly $120 million, neither this nor the originally estimated cost has yet been presented with sufficient clarity and reliability to facilitate comparison with other projects. With regard to O&M costs and passenger-mileage, data for the latest year available at the time of this study (2010) reflect only the partial first year of MetroRail's operation, with anomalous startup costs, and are therefore not suitable for comparison with other new projects. Furthermore, FTA considers MetroRail as "commuter rail," not a light railway.

"BRT" for this study refers to bus services operating on exclusive or reserved alignments with in-line stations (thus, excluding nominal "BRT" systems in mixed traffic such as many Los Angeles Metropolitan Transportation Authority (MTA) MetroRapid lines as well as simple point-to-point express bus operations). For each BRT project, only the segment in exclusive or reserved alignment (i.e., in "guideway" or paveway) is accepted as BRT for this study; segments in mixed traffic (i.e., when buses depart from operation in the guideway) are considered ordinary street bus operation and excluded from the BRT route length.

Projects studied include a selection of New Start rail and BRT projects opened since 2000. The analysis includes brief descriptions of these projects.

EVALUATION METHODOLOGY

Addressing the original three research questions, to compare projects, especially on the basis of mode, this analysis has examined the following performance indicators:

- Forecast capital cost versus actual final project cost (including evaluation of any anomalous or mitigating factors influencing disparities);
- Actual total cost per mile/kilometer or route; and
- Forecast ridership versus actual ridership (on the basis of targeted time frames).

However, any type of comparison of projects must deal with a number of challenges. For example, it's widely known that ridership and cost projections do not always match reality. Multiple reasons may account for this (e.g., economic factors driving up resource costs, changes in land use patterns, the expansion of competing highways, mitigations to address neighborhood concerns, etc.).

Comparing costs of different projects around the country can also be somewhat misleading. For example, projects tend to be located in metropolitan areas with widely different costs of living (e.g., Seattle versus Houston versus Hudson-Bergen), topography, density, and other characteristics. Such factors can drive substantial disparities in total costs, cost per unit of length, and even to what extent the final, actual investment cost compares with the original projected cost. For example, the St. Louis area's Metrolink St. Clair LRT extension is generally at-grade on a separate right of way; Seattle's Link LRT tunnels under Beacon Hill and runs on a long viaduct near the airport; and Boston's Silver Line Phase II project is constructed entirely in tunnel. Such differentials have presented a methodological challenge to this comparative study.

A further caveat is important with respect to over-emphasis on initial capital cost in assessing the effectiveness and value of these major transit projects. Such transit investments should be evaluated from the perspective of a long time horizon—even 10 to 11 years (the earliest projects evaluated in this study) may not be sufficient to fully analyze a project's effectiveness.

Comparing ridership among disparate projects also tends be quite difficult, since gross ridership differences among different systems (e.g., large cities versus smaller cities, very short lines versus longer regional routes) can be substantial and inappropriate for direct comparison.

What this study therefore has attempted to do is to make some comparison among systems in terms of how well each has achieved a preset ridership target. Given the complications of different time horizons and other factors, this, too, has not been easy.

In this context and facing these challenges, the study has developed the following evaluatory criteria and methodological approach for comparing these disparate projects.

- Final capital cost per mile. It's useful to compare generally similar types of projects on the basis of capital investment cost. However, for a more helpful comparison, projects have been categorized on the basis of type and magnitude of construction:
  - Minimal installation, applying to at-grade projects with negligible (less than 5 percent of route length) heavy civil works, such as grade separations, elevated, or subway alignments;
  - Substantial installation, applying to projects with 5 percent or more of route length involving heavy civil works as previously exemplified. This major is simply a per-mile (per-kilometer) cost figure for projects in both categories. For parity, and to make these costs more meaningful, they have been uniformly escalated to 2012 dollars.
- Final-to-projected capital cost ratio. This indicator is used to evaluate how well the final investment cost of each project adhered to the original cost estimate, with the aim of detecting any differences among these modal categories. In this measure, called a capital cost ratio (CCR) in this study, the final cost is divided by the last projected cost (adjusted, if necessary, for any known expansions of project scope), and rounded to two decimals; thus, 1 signifies the project was completed exactly within budget; < 1 indicates the project was completed under budget; > 1 indicates a budget overrun.

- Ridership Achievement Index (RAI). This measure has been developed in an effort to assess the degree with which disparate projects (with widely differing levels of investment, service, ridership, etc.) meet their original average daily (weekday) ridership targets, while also accounting for targets set for differing lengths of time. The study has used the latest available projection; for federally funded projects, this has typically meant a forecast included in the draft environmental impact study, final environmental impact study (FEIS), or full funding grant agreement (FFGA). This study has addressed the problem of differing ridership volumes, time horizons, and more by focusing on the rate of ridership growth, beginning with the first full calendar year after opening, comparing this with the rate needed to achieve the initial target, expressed as a ratio of actual rate to target rate (RAI), rounded to one decimal. Thus, if the rate of growth is exactly the same as what's needed to achieve the target ridership, the RAI is 1; if it exceeds the target rate, it's > 1; and if it's less than what's needed, it's < 1.

Two previous FTA-sponsored comprehensive assessments of major projects have been of substantial value to this study, in providing both data and methodological models: Predicted and Actual Impacts of New Starts Projects—Capital Cost, Operating Cost, and Ridership Data (*1*) and The Predicted and Actual Impacts of New Starts Projects—2007—Capital Cost and Ridership (*2*).

The results of this study, project by project, are summarized below.

ELECTRIC LRT PROJECTS

Denver—Southwest LRT Line (2000)

- Opened: July 2000, Regional Transit District (RTD).
- Length–installation: 8.7 mi (14.0 km), substantial.
- Capital cost: Projected $176.9 million, actual $177.7 million, CCR 1.00 (*1*, *2*).
- Unit cost (2012): $30.9 million/mi ($19.1 million/km).
- Ridership: Projected 22,000 (2015, FEIS), actual 19,083 (2002), RAI 6.5 (*1–4*).
- O&M unit cost (2010): NA for project. Systemwide LRT $0.51/passenger-mile (p-m), bus $0.73/p-m (*5*).

Portland—Portland Streetcar (2001)

- Opened: July 2001, Portland Streetcar, Inc.
- Length/installation: 2.4 mi (3.9 km), minimal.
- Capital cost: Projected $42.0 million, adjusted to $48.8 million, actual $56.9 million, CCR 1.20 (*6–8*).
- Unit cost (2012): $34.6 million/mi ($21.5 million/km).
- Ridership: Projected 4,200 (2006), actual 4,820 (2003), RAI 2.9 (*6–8*).
- O&M unit cost (2010): NA for project.

Portland—MAX Red Line Airport Extension (2001)

- Opened: Late 2001, Tri-Met.
- Length–installation: 5.5 mi (8.9 km), substantial.
- Capital cost: Projected $125 million, actual $125 million, CCR 1.00 (*9*).
- Unit cost (2012): $33.2 million/mi ($20.6 million/km).
- Ridership: Projected 2,300 (2002), actual 2,800 (2002), RAI 1.2 (*9*).
- O&M unit cost (2010): NA for project. Systemwide LRT $0.51/p-m, bus $1.03/p-m (*5*).

St. Louis—Metrolink St. Clair Extension (2001)

- Opened: May 2001, Metro Transit (Metro).
- Length–installation: 17.4 mi (28.1 km), eight stations, substantial.
- Capital cost: Projected (adjusted) $322.2 million, actual $339.2 million, CCR 1.05 (*1*, *2*, *10*, *11*).
- Unit cost (2012): $28.5 million/mi ($17.6 million/km).
- Ridership: Projected 20,274 (2010, FEIS), actual 15,976 (2002), RAI 7.1 (*1*, *2*, *10*, *11*)
- O&M unit cost (2010): NA for project. Systemwide LRT $0.39/p-m, bus $1.12/p-m (*5*).

Dallas—Red Line extension, Park Lane to Plano (2002)

- Opened: December 2002, Dallas Area Rapid Transit.
- Length–installation: 12.5 mi (20.2 km), nine stations, substantial.
- Capital cost: Projected $517.3 million (FFGA), actual $437.3 million, CCR 0.84 (*1*, *2*, *12*).
- Unit cost (2012): $49.3 million/mi ($30.6 million/km).
- Ridership: Projected 17,000 (2020, FEIS), actual 13,581 (2007), RAI 2.9 (*1*, *2*, *12*).
- O&M unit cost (2010): NA for project. Systemwide LRT $0.89/p-m, bus $1.50/p-m (*5*).

Sacramento—South LRT Line (2003)

- Opened: September 2003, Regional Transit.
- Length–installation: 6.3 mi (10.2 km), 7 stations, minimal (*1*, *2*, *13*).
- Capital cost: Projected $219.7 million (FFGA), actual $218.6 million, CCR 0.99 (*1*, *2*, *13*).
- Unit cost (2012): $47.4 million/mi ($29.3 million/km).
- Ridership: Projected 12,550 (2015, FEIS), actual 8,734 (2007), RAI 2.1 (*1*, *2*, *13*).
- O&M unit cost (2010): NA for project. Systemwide LRT $0.58/p-m, bus $1.22/p-m (*5*).

Los Angeles—Gold Line to Pasadena (2003)

- Opened: July 2003, MTA.
- Length–installation: 13.7 mi (22.1 km), substantial.
- Capital cost: Projected $854.0 million, actual $725.5 million, CCR 0.85 (*14*–*16*).
- Unit cost (2012): $72.2 million/mi ($44.7 million/km).
- Ridership: Projected 68,000 (2015), actual 23,068 (2009), RAI 0.7 (*15*, *16*).
- O&M unit cost (2010): NA for project. Systemwide LRT $0.50/p-m, bus $0.64/p-m (*5*).

Houston—MetroRail (2004)

- Opened: January 2004, Houston Metro (Metro).
- Length–installation: 7.5 mi (12 km), minimal.
- Capital cost: Projected $300.0 million, actual $324.0 million, CCR 1.08 (*17*, *18*).
- Unit cost (2012): $56.9 million/mi ($35.3 million/km).
- Ridership: Projected 40,000 (2020, Metro), actual 37,400 (2012), RAI 1.9 (*1*, *2*).
- O&M unit cost (2010): LRT $0.61, bus $0.72 (*5*).

Memphis—Madison Avenue–Medical Center Streetcar Extension (2004)

- Opened: March 2004, Memphis Area Transportation Authority.
- Length–installation: 2.0 mi (3.2 km), minimal.
- Capital cost: Projected $73.3 (FFGA, adjusted), actual $58.1 million, CCR 0.79 (*1*, *2*).
- Unit cost (2012): $38.2 million/mi ($23.7 million/km).
- Ridership: Projected 4,200 (2020, FEIS), actual 720 (2007), RAI 0.9 (*1*, *2*).
- O&M unit cost (2010): NA for project. Systemwide LRT (STC) $4.51/p-m, bus $0.78/p-m (*5*).

Portland—MAX Yellow Line (2004)

- Opened: May 2004, Tri-Met
- Length–installation: 5.8 mi (9.4 km), 10 stations, substantial.
- Capital cost: Projected $321.5 (FFGA adjusted), actual $323.6, CCR 1.01 (*1*, *2*).
- Unit cost (2012): $73.5 million/mi ($45.6 million/km).
- Ridership: 18,860 (2020, FEIS), 12,785 (2007), RAI 3.6 (*1*, *2*).
- O&M unit cost (2010): NA for project. See systemwide data under Red Line Airport Extension details.

Minneapolis—Hiawatha LRT (2004)

- Opened: December 2004, Metro Transit.
- Length–installation: 11.6 mi (18.7 km), 17 stations, substantial.
- Capital cost: Projected $708.4 (FFGA adjusted), actual $696.7, CCR 0.96 (*1*, *2*).
- Unit cost (2012): $79.1 million/mi ($49.0 million/km).
- Ridership: Projected 24,800 (2020, FEIS revised), actual 27,871 (2007), RAI 6.0 (*1*, *2*).
- O&M unit cost (2010): LRT $0.47/p-m, bus $0.80/p-m (*5*).

San Diego—Mission Valley East Extension (2005)

- Opened: July 2005, Metropolitan Transit System.
- Length–installation: 5.9 mi (9.5 km), four stations, substantial.
- Capital cost: Projected $426.6 (FFGA adjusted), actual $506.2, CCR 1.19 (*1*, *2*).
- Unit cost (2012): $109.2 million/mi ($67.7 million/km).
- Ridership: Projected 10,795 (2015, FEIS), actual 7,572 (2007), RAI 3.5 (*1*, *2*).

- O&M unit cost (2010): NA for project. Systemwide LRT $0.33/p-m, bus $0.76/p-m (*5*).

Hudson-Bergen County, New Jersey—Hudson-Bergen Light Rail Transit (2000–2006)

- Opened: April 2000 through February 2006 (*1*, *2*).
- Length–installation: 15.4 mi (24.8 km), substantial.
- Capital cost: Projected $1,842.0 million (FFGA), actual $1,756.2, CCR of 0.95 (*1*, *2*).
- Unit cost (2012): $140.2 million/mi ($86.9 million/km).
- Ridership: Projected 68,160 (2010, FEIS), actual 38,190 (2008), RAI 0.40 (*1*, *2*).
- O&M unit cost (2010): NA for project.

Denver—Southeast LRT Line (2006)

- Opened: November 2006.
- Length–installation: 19.1 mi (30.8 km), 13 stations, substantial.
- Capital cost: Projected $867.8 million (FFGA adjusted), actual $850.8 million, CCR 0.98 (*1*, *2*).
- Unit cost (2012): $54.8 million/mi ($33.9 million/km).
- Ridership: Projected at 38,100 (2020, FEIS), actual 2012 totaled 26,192 (2007) RAI 9.6 (*1*, *2*).
- O&M cost (2010): NA for project. See systemwide data under Southwest Line details.

Charlotte—Lynx Green Line (2007)

- Opened: November 2007, Charlotte Area Transit System (CATS).
- Length–installation: 9.6 mi (15.5 km), substantial.
- Capital cost: Projected $426.85 million (FFGA), actual $426.85 million, CCR 1.00 (*19*).
- Unit cost (2012): $52.8 million/mi ($32.7 million/km) (*10*).
- Ridership: Projected 17,650 (2025, CATS), actual 15,000 (2012), RAI 3.1 (*1*, *2*).
- O&M cost (2010): LRT $0.94/p-m, bus $0.76/p-m (*5*).

Phoenix—Metro (2008)

- Opened: December 2008, Valley Metro.
- Length–installation: 19.6 mi (31.6 km), 27 stations, minimal (*20*).
- Capital cost: Projected $1,412.1 (FFGA), actual $1,400.0, CCR 0.99 (*20*, *21*).
- Unit cost (2012): $82.0 million/mi ($50.8 million/km).
- Ridership: Projected 49,900 (2020, FEIS), actual 44,000 (2012), RAI 2.6 (*10*, *21*, *22*).
- O&M unit cost (2010): LRT $0.38/p-m, bus $0.90/p-m (*5*).

Seattle—Link LRT South Segment (2009)

- Opened: July 2009, Sound Transit.
- Length–installation: 15.6 mi (25.2 km), substantial.
- Capital cost: Projected $2.49 billion, (FFGA), actual $2.57 billion, CCR 1.03 (*23*, *24*).

- Unit cost (2012): $182.6 million/mi ($113.2 million/km).
- Ridership: Projected 42,500 (2020, FEIS), actual 26,200 (2012) RAI 2.3 (*10*, *23*, *24*).
- O&M unit cost (2010): LRT $0.79/p-m, bus $0.92/p-m (*5*).

Portland, Oregon—MAX Green Line to Clackamas (2009)

- Opened: September 2009, Tri-Met.
- Length–installation: New LRT 8.3 mi (13.8 km), total 15.0 mi (24.2 km), substantial.
- Capital cost: Projected $557.4 million, actual $575.7 million, CCR 1.03 (*25*).
- Unit cost (2012): $76.9 million/mi ($47.7 million/km).
- Ridership: Projected 46,500 (2025, Tri-Met), actual 24,300 (2012), RAI 2.8 (*25*, *26*).
- O&M unit cost (2010): NA for project. See systemwide data under Red Line Airport Extension details.

Los Angeles—Gold Line East (2009)

- Opened: November 2009, Los Angeles County MTA.
- Length–installation: 5.9 mi (9.5 km), substantial.
- Capital cost: Projected $898.81 million (FFGA), actual $898.8 million, CCR 1.00 (*27*, *28*).
- Unit cost (2012): $168.9 million/mi ($104.7 million/km).
- Ridership: Projected 15,000 (2020), actual 13,900 (2012), RAI 3.4 (*29*).
- O&M unit cost (2010): NA for project. See systemwide data under Gold Line to Pasadena details.

Norfolk—The Tide (2011)

- Opened: August 2011, Hampton Roads Transit (HRT).
- Length–installation: 7.4 mi (11.9 km), substantial.
- Capital cost: Projected $198.5 million, actual $318.5 million, CCR 1.60 (*26, 30*).
- Unit cost (2012): $44.5 million/mi ($27.6 million/km).
- Ridership: Projected 10,500 (2020, HRT), actual 4,000, RAI 3.4 (*10, 30*).
- O&M unit cost (2010): NA for project.

FUEL-POWERED LIGHT RAILWAY PROJECT

Oceanside–Escondido, California—Sprinter (2008)

- Opened: March 2008, North County Transit District (*31*).
- Length–installation: 22.0 mi (35.5 km), 15 stations, substantial (*31*).
- Capital cost: Projected $351.5 million (FFGA), actual $484.2 million, CCR 1.38 (*26, 31*).
- Unit cost (2012): $25.2 million/mi ($15.6 million/km).
- Ridership: Projected 15,100 (2015), actual 7,200 (2012), RAI 0.8 (*10*).
- O&M unit cost (2010): Light railway $0.69/p-m, bus $1.08/p-m (*5*).

BRT PROJECTS

Pittsburgh—West Busway (2000)

- Opened: September 2000.
- Length–installation: 5.6 mi (9.0 km), substantial.
- Capital cost: Projected $326.8 million (FFGA), actual $419.2 million, CCR 1.28 (*33*).
- Unit cost (2012): $113.1 million/mi ($70.1 million/km).
- Ridership: Projected 23,369 (2005, FEIS), actual 9,000 (2002), RAI 1.0 (*32–34*).
- O&M unit cost (2010): NA for project.

Boston—Silver Line Phase II/Piers Transitway/Waterfront Tunnel (2003)

- Opened: December 2004
- Length–installation: 1.0 mi (1.6 km), three stations, substantial (*1*, *2*).
- Capital cost: Projected $457.4 (FFGA adj.), actual $600.2, CCR 1.31 (*1*, *2*).
- Unit cost (2012): $790.3 million/mi ($490.0 million/km).
- Ridership: Projected 24,300 (2010, FEIS), actual 12,500 (2007), RAI 1.0 (*1*, *2*).
- O&M unit cost (2010): NA for project. Systemwide Trolleybus $2.55/p-m, bus $1.23/p-m (*5*).

Los Angeles—Orange Line Busway (2005)

- Opened: Late 2005.
- Length/installation: 14.0 mi (22.5 km), minimal.
- Capital cost: Projected $300.5 million, actual $324.0 million, CCR 1.08 (*35*, *36*).
- Unit cost (2012): $29.4/mi ($18.2 million/km).
- Ridership: Projected 18,700 (2020, FEIS), actual 24,779 (2012), RAI 2.8 (*15*, *35*, *36*).
- O&M unit cost (2010): NA for project.

Eugene, Oregon—Emerald Express (2007)

- Opened: January 2007.
- Length–installation: BRT 2.5 mi (4.0 km) out of total route of 3.9 mi (6.3 km), minimal (*37–39*).
- Capital cost: Projected $13.0 million, actual $24.6 million, CCR 1.89 (*37–39*).
- Unit cost (2012): $11.7 million/mi ($7.2 million/km).
- Ridership: Projected (NA), actual 9,600 (2012), CCR (NA) (*37–39*).
- O&M unit cost (2010): NA for project.

Cleveland—HealthLine–Euclid Avenue (2008)

- Opened: October 2008.
- Length–installation: BRT 4.4 mi (7.1 km) out of total route of 6.7 mi (10.8 km), minimal (*40–43*).

- Capital cost: Projected \$168.4 million (FTA New Starts, 2005), actual \$197.2 million, CCR 1.17 (*40–43*).
- Unit cost (2012): \$51.4 million/mi (\$31.9 million/km).
- Ridership: Projected 39,000 (2025, FTA New Starts), actual 15,000 (2012), RAI 1.6 (*40–43*).
- O&M unit cost (2010): NA for project.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study suggest that the capital costs of LRT, BRT, and light railway projects may fall generally within similar ranges—especially in terms of cost per mile or kilometer—although some deployments of BRT seem to be closer to streetcar investment than full LRT. All of these modes seem capable of attracting passengers and producing significant increases in ridership; however, the rail modes seem to offer more documented evidence of generating sizable numbers of riders and fulfilling projected ridership targets.

With regard to the specific questions examined in this study: Can major differences in capital cost per mile (cost per kilometer) be detected among LRT, DMU light railway, and BRT projects?

Yes. Average costs per mile for substantial installation projects:

- LRT—\$79.8 million/mi and
- BRT—\$451.7 million/mi.

These results suggest that BRT projects do not have any particular advantage when very heavy installation (tunnels, elevated structure, etc.) is involved. Also, the single DMU light railway compares favorably at \$25.2 million/mi.

Average costs per mile for minimal installation projects:

- LRT—\$51.8 million/mi and
- BRT—\$30.8 million/mi.

BRT does appear to have some advantage in this category.

Are there major differences in how closely the final capital costs match the projected and budgeted costs of such projects?

Yes. Average CCR shows:

- LRT—1.02 and
- BRT—1.35.

With a CCR of 1.38, the single DMU light railway project did not rate well in this comparison. Are there major differences in how well ridership goals are achieved?

Yes. The RAI shows:

- LRT—3.3 and
- BRT—1.6.

Apparently, these LRT projects, on average, seemed to meet their ridership targets much better than the BRT projects. The single DMU light railway project, with an index of 0.8, did not compare well.

It's important to note that simply comparing gross capital cost and ridership is insufficient in a fully effective comparative evaluation of any project. One needs to account for the different economic lives of systems and rolling stock (railcars typically have longer lives than buses), consider both O&M cost and total *annualized* capital cost, and develop effectiveness indexes based on cost per passenger-mile. And of course, there are many other considerations, including overall public attractiveness of the mode, influence of transit-oriented development, etc.

Evaluation of the effectiveness of New Start LRT, light railway, and BRT projects in reaching intended goals has been especially difficult because of the absence of a consistent, standardized data reporting system. In addition, some projects neither clearly set or state critical goals (such as ridership targets), nor report such key data elements even after the project is operational.

These problems seem to be particularly true of many of these types of projects:

- BRT projects. Ridership targets (if there are any) are rarely publicly revealed, and both ridership and O&M costs are typically blended with systemwide bus data (despite efforts in some cases to portray BRT as something other than a bus mode).
- Streetcar projects. Ridership targets often seem to be obscured or even ignored, as the stimulation of economic development is prioritized in justifying these projects. Yet they're fundamentally mobility projects, and it would seem that ridership, at least to some extent, should be factored into their justification and evaluation.

A further problem lies with extensions to existing LRT systems. Key evaluatory data on the individual projects (particularly ridership and O&M costs) are almost never disaggregated from systemwide LRT data.

Based on the efforts in this study, the following recommendations are suggested as strategies for improving the evaluation and comparison of New Start projects (whether or not funded by the FTA's New Starts program) undertaken by public transit agencies within the industry:

- Agencies need to use consistent, standard evaluatory data criteria to enable a common set of measures of effectiveness. These criteria would assist in identifying the useful elements associated with the project, both targeted and experienced after project implementation. Examples of performance measures might include ridership; passenger-mileage; O&M cost, gross, and per passenger-mile; and total cost, both annualized capital and O&M, gross, and per passenger-mile.
- Critical evaluatory data, such as previously described, should be made readily accessible for public scrutiny.
- All projects (LRT, BRT, streetcar, light railway) should establish ridership targets and report their success in meeting those targets for an extended period after the project is completed.

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Eastside Extension Light Rail Transit
Mobility, Connectivity, and Integrated Project Design in Los Angeles

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The Los Angeles Metro Gold Line Eastside Extension (MGLEE) provides an example of a successful light rail transit (LRT) investment. The project has garnered local and national attention for successful completion on time and on budget. The six-mile extension has improved mobility and accessibility for a largely transit-dependent, predominantly Latino population. The project, originally conceived as part of a proposed heavy rail subway extension, now connects riders east of downtown Los Angeles to the rest of the region via LRT. Development of the project involved long-term and ongoing involvement from the area stakeholders and residents, through a review advisory committee, which helped shape the design and local integration of MGLEE. Today the project provides both at-grade and underground service and includes two underground LRT stations. In particular, underground stations have served to enhance public space. Mariachi Plaza station exemplifies integrated project design, weaving transit service into the existing landscape of the community. The plaza provides space for musicians, outdoor concerts, farmers' markets, and other cultural festivals. New investments in bike lanes, enhanced sidewalks, and streetscape design have also improved accessibility. MGLEE offers a unique example of a light rail project that has improved mobility within the context of a diverse urban community and involved local residents in the process.

INTRODUCTION

The introduction of light rail infrastructure in major metropolitan areas is a complex and multidisciplinary process. It typically involves various stages and iterations of planning and design before reaching construction. Much of the existing research on infrastructure projects has focused on the analysis of planning, designing, and measuring outcomes, such as ridership and cost-effectiveness. This area of research provides valuable contributions to analyzing the technical planning process and evaluating outcome measures. In addition, there exists alternate bodies of research interested in the role of actors and the decision-making process associated with large-scale infrastructure and mega-projects (*1*, *2*). It is here that the authors hope to situate the contributions of this paper by exploring the role of public participation in the planning and design of a major light rail transit (LRT) infrastructure project in Los Angeles. In doing so, the authors present preliminary research investigating the Metro Gold Line Eastside Extension (MGLEE).

Like many other light rail investments in urbanized metropolitan areas, MGLEE experienced challenges associated with integrating transit infrastructure within the existing urban fabric of a city. For the purposes of this paper, the development of MGLEE is analyzed as a process of introducing light rail into existing neighborhoods and communities, particularly within an area of high transit usage and a predominately Latino population. Understanding the complexities associated with the project, the county metropolitan transit agency responsible for the project undertook a more involved approach to public participation. At the heart of the participation process was the review advisory committee (RAC). This paper presents an initial investigation of RAC in relation to Los Angeles County Metropolitan Transportation Authority (Metro) and its role in the development of MGLEE. Furthermore, the paper examines the integration of light rail projects within existing neighborhoods, as a focus for a discussion at the 12th National TRB Light Rail Conference.

In doing so, the paper provides background on the study area, a brief overview of transit planning in Los Angeles County, discussion of the development of MGLEE from heavy rail subway to light rail technology, integration of light rail within existing neighborhoods, and future plans for expansion. The paper presents preliminary findings and discusses future areas of research as part of a larger program focused on the investigation of light rail projects in minority communities within the United States. Initial findings are intended to share tools on the development of public participation programs and highlight unique challenges associated with the development of complex transit projects in sensitive communities.

OVERVIEW OF STUDY AREA

Metro provides transportation planning, funding, construction, and operations for transportation services and infrastructure across Los Angeles County. Los Angeles County is home to almost 10 million people. Large in population and size, (4,000 mi^2) the urban form is characterized by a number of high-density areas mostly concentrated in and around downtown, disbursed job centers, and sprawling suburbs.[1]

MGLEE is situated at the eastern edge of the City of Los Angeles' central business district (CBD), an area near the heart of downtown Los Angeles where the urban scale and concentration of residents counters the sprawling nature of the county as a whole. MGLEE is situated within the Eastside Transit Corridor, the project area studied as part of Metro's transportation planning process.

Los Angeles County

Los Angeles is often recognized for its high level of traffic congestion, a result of mid-20th century federal transportation and housing policies, which encouraged the creation of highways and bedroom communities. Congestion issues are so prevalent that the Texas Transportation Institute has ranked Los Angeles number one nationally in annual travel delay consecutively since 1982 (Figure 1).[2]

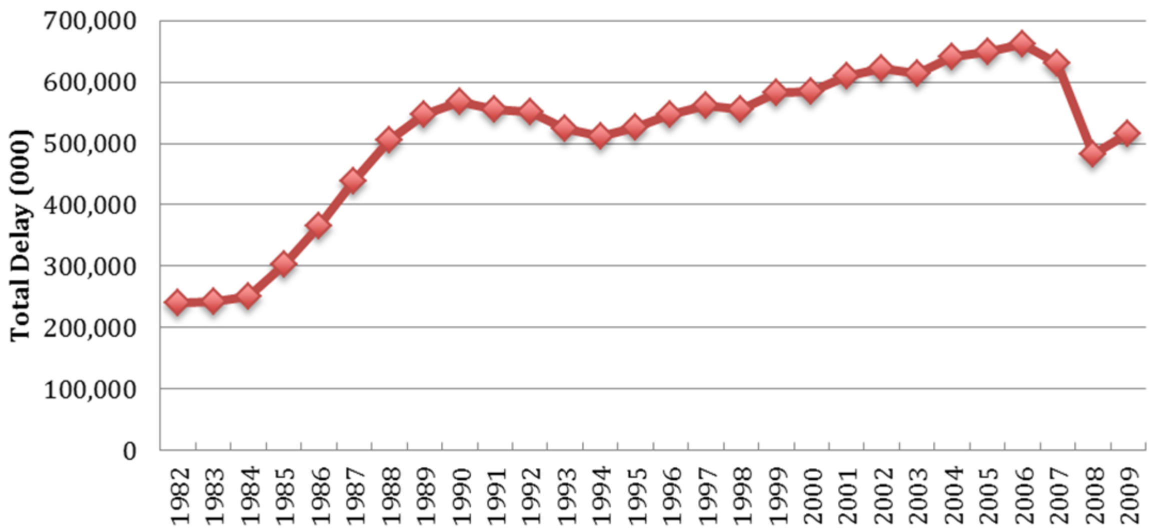

FIGURE 1 Los Angeles Metro area annual hours of delay (*3*). (Note: Los Angeles Metro includes Los Angeles, Long Beach, and Santa Ana.)

The 1980s marked an important turning point in Los Angeles's transportation history. The Southern California Rapid Transit District (SCRTD), the agency that preceded Metro, was charged with improving the bus systems and designing and building a transit system for Los Angeles County, a program, which would result in the overhaul of the bus network and the creation of modern urban rail.[3] The Los Angeles renaissance in public transportation built on the area's early 20th-century history of inter-urban rail and streetcars. In many cases, Metro purchased, abandoned, and underutilized railroad right-of-ways for the backbone of the bus and rail network. Construction initiated on heavy rail subway and light rail project in the late 1980s.

The 1990s represented a continuation of this momentum. The decade kicked off with the opening of SCRTD's first rail project in 1990, the Blue Line Light Rail, followed quickly in 1993 by the first segment of the Metro Red Line subway.[4] That same year, California legislation mandated the creation of Metro, merging the Los Angeles County Transportation Commission and SCRTD to oversee multimodal transportation solutions for the county.

Throughout much of the 1980s travel delay continued to increase in Los Angeles at a significant rate, transportation planners looked to transit to alleviate traffic congestion and provide mobility alternatives.

During the 1990s Metro focused its efforts on construction of the Metro Red Line and Purple Line subways. Political pressure began to mount given the rise in cost and increased delay in implementing the subway. During this time, leaders at Metro began to look for other cost effective solutions to expand the transit network, including LRT and bus rapid transit. Today, Los Angeles provides over 80 mi of urban transit, characterized by heavy rail, light rail, and bus rapid transit (Figure 2).

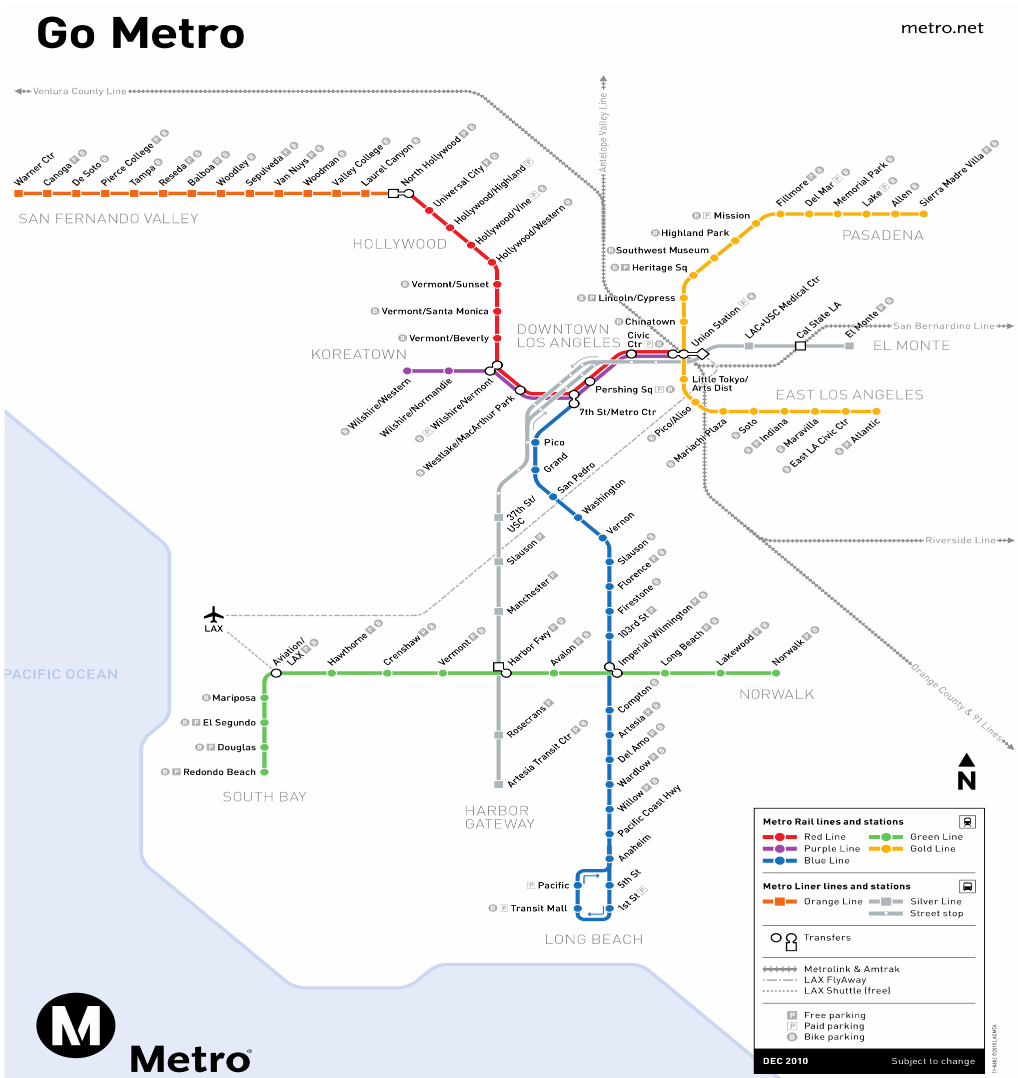

FIGURE 2 Los Angeles Metro urban transit network. (Source: Downloaded by author, December 2011. Available online at www.metro.net.)

Eastside Transit Corridor Area

Metro investment in the Eastside began with early studies initiated in the late 1980s, documenting demographics and transit needs for residents east of downtown Los Angeles. The Eastside study area originally incorporated areas including Boyle Heights; East Los Angeles; portions of cities including Montebello, Pico Rivera, Monterey Park, Downey, Santa Fe Springs, and Whittier; as well as unincorporated areas of Los Angeles County.

Many of these areas were early streetcar suburbs. During the late 19th to mid-20th century, the Eastside included areas served by early cable car and electrified streetcar service (Figure 3).

Current estimates for the area suggest that the population for this area is approximately 720,850 residents, about 7% of the total population of Los Angeles County.[5] Earlier estimates suggest that by 1994 the study area population had reached approximately 500,000.

FIGURE 3 Early streetcar service in Boyle Heights. (Source: Los Angeles Transit Lines Yellow Car streetcar at Ditman Avenue, Boyle Heights, Los Angeles. December 1957. Dorothy Peyton Gray Transportation Library and Archive at the Los Angeles County Metropolitan Transportation Authority. http://lacmtalibrary.tumblr.com/ post/14343826757/los-angeles-transit-lines-yellow-car-streetcar-at.)

Projections anticipated a 25.3% growth in population, reaching approximately 620,000 by 2020 (*4*).[6] Current numbers supersede these early estimates, highlighting the rapid pace of growth experienced within the study area.

The population of the Eastside is predominately Latino, with low- to middle-income households. Portions of the area rely heavily on transit usage. Early studies estimated the areas with the highest transit use were those immediately east of downtown including the communities of Little Tokyo–Art District, Boyle Heights, and East Los Angeles. Furthermore, a 2000 study conducted by Metro found that 19% of workers in the area used the bus system for their commute, indicating higher rates within the study area in comparison to Los Angeles County residents as a whole (6.8%). The area also experienced higher rates of carpooling and walking, compared to county averages. Additionally, many households within the study area lacked access to a vehicle (25%), rates higher than those experienced by residents in the City of Los Angeles (15%) (*4*).

PLANNING FOR TRANSIT INVESTMENTS

Modern rail transit service for the Eastside was originally conceived as a subway extension project. During the late 1980s and 1990s, Los Angeles saw renewed investment in urban transit, particularly rapid bus and rail. Los Angeles's first subway project, the Metro Red Line, was conceived as a heavy rail network intended to connect the city's polycentric geography. The project was to link the downtown CBD to key subcenters to the north, west, and east. The project was ultimately divided into segments, some of which were constructed in phases, and other sections, which were never built.

Red Line Subway, Major Investment Studies

Plans called for the Red Line subway project to connect the downtown CBD to North Hollywood (to the north), Wilshire (west), Mid-City (southwest), and the Eastside (east of downtown). The first phase of the project provided heavy rail subway through the CBD, along two routes, the Red Line to North Hollywood and the Purple Line to Wilshire–Western. Plans for subsequent phases (2 and 3) would connect existing rail in the CBD to the Mid-City and Eastside areas.

Planning studies for rail transit service to the Eastside initiated in the late 1980s. The project was originally conceived as a 3.7-mi extension of the Metro Red Line subway system providing heavy rail service and four additional underground stations, Little Tokyo Station, 1st–Boyle Station, Cesar Chavez–Soto Station, and 1st–Lorena Station, at a total cost of more than $1 billion. The planned Eastside underground subway extension successfully achieved environmental clearance and received a full funding grant agreement (FFGA) for approximately $500,000. Despite strong community support for the project and achieving significant planning milestones, the project was met with challenges.

During the mid-1990s, further advancement of the Eastside underground subway extension was halted. It was a period in which many of the other transit projects in Los Angeles County experienced rising construction costs and increased public scrutiny. Political pressure began to mount given the rise in cost and increased delay in implementing the subway. Despite a contract award, property acquisitions, and initiation of some minor construction activities, Metro halted construction and began planning studies to re-evaluate the range of alternatives. Soon thereafter a legislative mandate banning the use of sales taxes for projects with subway tunneling was approved by Los Angeles County voters. As a result, Metro's plans for an underground subway extension were never realized (*5*). To address mounting community pressure, Metro was able to negotiate with FTA to reserve the allocated FFGA funding for a future fixed-guideway transit project on the Eastside. The revised project would be identified as part of a re-evaluation study.

Metro recognized that community involvement would need to be a centerpiece of plans to re-envision transit to the Eastside as part of the re-evaluation study. To maintain support for the project, Metro directed continued involvement from the RAC. The RAC was originally established in 1995, as part of the outreach strategy for the heavy rail subway extension. It included established bylaws, held monthly meetings, and provided a cohesive process for Metro to make presentations to the communities within the corridor and allow people to be able to provide input.[7]

In 1999 at the end of the re-evaluation study, Metro initiated a major investments study (MIS) to complete alternatives analysis for the project. The plan includes analysis of heavy rail, bus, and light rail fixed-guideway options. By 2000 Metro had initiated the draft environmental clearance studies. The project, however, was modified from a heavy rail subway extension to an at-grade light rail extension of the Metro Gold Line to Pasadena, which was already under construction at the time. Given the political climate, lack of funding, and legislative ban, heavy rail subway was no longer considered a feasible option. Light rail technology was ultimately selected as the preferred alternative for the Eastside.

Studies suggested that the LRT option would provide improved transit reliability and service to an area of Los Angeles where buses were heavily utilized and lacked additional capacity to serve riders. By building light rail, the Eastside project would connect riders to the Metro Gold Line to Pasadena (to the north) via Union Station, and allow for transfers to the Red Line subway (for travel to downtown and further west) (*4*).

The light rail project, eventually renamed MGLEE, would provide 6 mi of light rail transit, operating primarily at-grade with approximately two miles of tunnel and eight new stations (including stations at three of the four original station locations). Cost estimates for MGLEE were less than the estimates for the original project, but provided a service that was twice as long and with twice as many stations.

In 2001 the final environmental impact statement–environmental impact review was approved. In 2004 Metro executed a contract award and a new FFGA. Still Metro encountered challenges during the pre-construction phase of the project. Six months prior to the award of the contract, all bids received were over the cost estimate produced. Metro pursued modifications to elements discussed with the community related to urban design, maintenance and operations, as well as construction techniques to help contractors reduce costs. Weekly meetings were conducted with the RAC members, who in turn discussed the current status of the project with community members along the alignment. Understanding the limited budget and the potential for failing to bring a transit project to the Eastside for a second time, RAC worked with community members to identify areas in urban design that could be prioritized. Metro identified elements of materials, changes in maintenance yard sites, and modification of construction techniques that allowed the selected contractor to come within budget. As a result, modifications were made to the design and maintenance approach consistent with community presentations. This resulted in the ability of Metro and the contractor to move forward.

Construction of MGLEE

Metro continued to involve community members and RAC to address concerns throughout the construction process. Upon contract award, both Metro and the contractor encouraged continued involvement from RAC, valuing their contributions in the process, a scenario not typical of major construction projects. The contractor's project manager attended RAC meetings and worked with RAC on finalizing station designs, allowing members to view concepts and materials prior to finalization. The contractor's project manager also worked with Metro and RAC to review construction techniques that would further reduce impacts but move the project forward more quickly. This included strategies such as closing streets on weekends to allow for decking installation at stations using cut and cover construction rather than the longer, extended construction activity of maintaining some traffic at all times. This reduced the schedule for one of the most disruptive activities of construction by almost 3 months. Enhanced participation of RAC proved to be a unique arrangement for Metro, but one that continues up until today, approximately 3 years after the MGLEE operation was initiated.

The project also included partnerships with other agencies and municipalities including Caltrans, for the realignment of a portion of the SR-101 freeway and the construction of the LRT bridge; Los Angeles Unified School District, for the reconfiguration of a small high school and construction of a new high school, both adjacent to the alignment; and the City of Los Angeles, for the widening of the 1st Street Bridge. These partnerships are normally very difficult to maintain successfully. RAC became instrumental in providing support to Metro and the contractor when negotiating with the cities or other agencies about design and construction activities. RAC provided the voice of the community and local decision making about the direction on design issues throughout the construction process. RAC members met on a monthly basis and worked closely with elected officials, Metro staff, and the contractor to guide the implementation of the project.

Finally in 2009, 5 years after breaking ground, MGLEE was completed (see alignment in Figure 4). The project was recognized locally for its completion within budget ($898 million), on schedule, and with a superior safety record.[8]

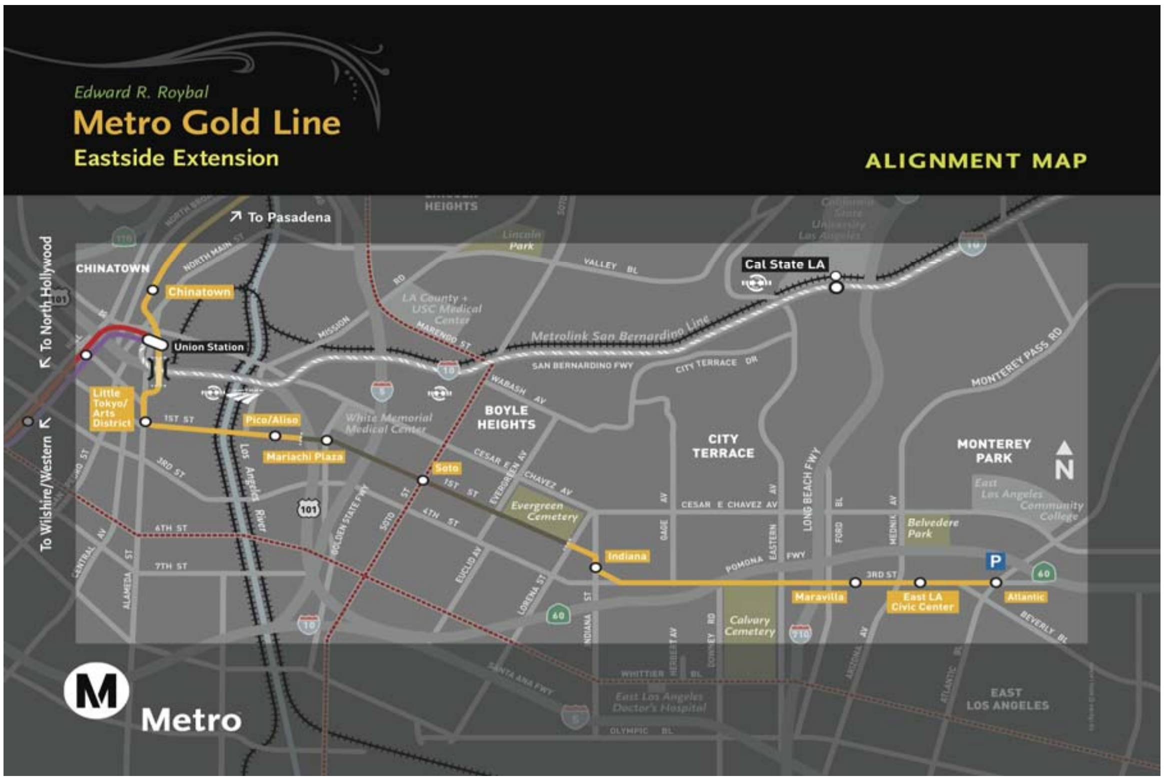

FIGURE 4 MGLEE alignment map. (Source: Downloaded by author, December 2011. Available online at www.metro.net.) (Note: MGLEE extends from the terminus of the Pasadena Gold Line at Union Station and heads south over the 101 freeway to the Little Tokyo–Arts District Station at 1st and Alameda Streets. The alignment continues heading east on 1st Street, on the historic 1st Street Bridge, and over the Los Angeles river to a second station, the Pico–Aliso Station. The alignment then heads underground and enters its first underground station, the Mariachi Plaza Station at 1st and Boyle Avenue. The alignment continues underground to a station at 1st and Soto Streets and finally rises to the surface at 1st and Lorena Streets and continues heading south on Indiana Street to an at-grade station. At 3rd Street, the alignment heads east again with three at-grade stations at Ford Street, Eastern Avenue, and Pomona Boulevard.

Within Los Angeles County, this proved to be an improved record for an agency that had faced cost overruns and public scrutiny decades before on other transit projects. Furthermore, despite the challenges faced by the Eastside project—a transition to an alternative transit technology, a period of mandated bans on tunneling, and high construction estimates—the final project was completed with strong support and continued involvement from RAC. The process demonstrates the benefits of a strong commitment to building local partnerships and maintaining meaningful community participation and representation throughout this process.

A November 2009 Metro press release describes to local tenor of the re-introduction of transit rail service on the Eastside (*6*):

> For the first time in nearly half a century—since the last trolley ran down 1st Street—rail will again carry passengers from downtown L.A. to East Los Angeles.
>
> —Los Angeles Mayor Antonio Villaraigosa

Metro went on to approve Spanish translation of a 6-mi portion of the Gold Line that extends from Boyle Heights, a first for the agency, referring to MGLEE as *La Linea de Oro.*

In 2009 the project initiated street running and underground operations. The project, which has been in operations for 3 years, meets anticipated ridership levels well ahead of projections and maintains one of the best safety records for street running light rail in Los Angeles. Recent ridership estimates provided by Metro, indicate that by fiscal year 2012, the project had already reached 80% of the projected 2020 ridership levels (Figure 5).

Despite a great safety record, Metro continues to strive for improved safety measures. Although street running rail is typically controlled by normal traffic signals and posted speeds, Metro is pursuing additional safety measures at select locations, where deemed feasible. As part of this process, RAC provided input on safety and development around stations and the establishment of pedestrian linkages.

MGLEE Station Areas

The unique characteristics of MGLEE are summarized in a recent study conducted by Metro in which users were recruited and surveyed at station stops. In line with early study findings, MGLEE study area respondents were reportedly

- More ethnically diverse: over 80% were of Hispanic origin (many of which are predominately Spanish speaking);
- Include low- to moderate-income households: roughly 50% of respondents at seven stations reported annual incomes of $14,999, with the exception of Little Tokyo, where 50% of respondents reported making $34,999 a year or less; and
- Maintain low levels of vehicle ownership, approximately 20% to 40% of respondents at stations reported zero car households.

A few key demographic indicators for respondents along MGLEE stations are provided in Figures 6 through 8. Cumulative information for stations along the entire Metro Gold Line alignment (Pasadena to East Los Angeles) is provided for comparative purposes.

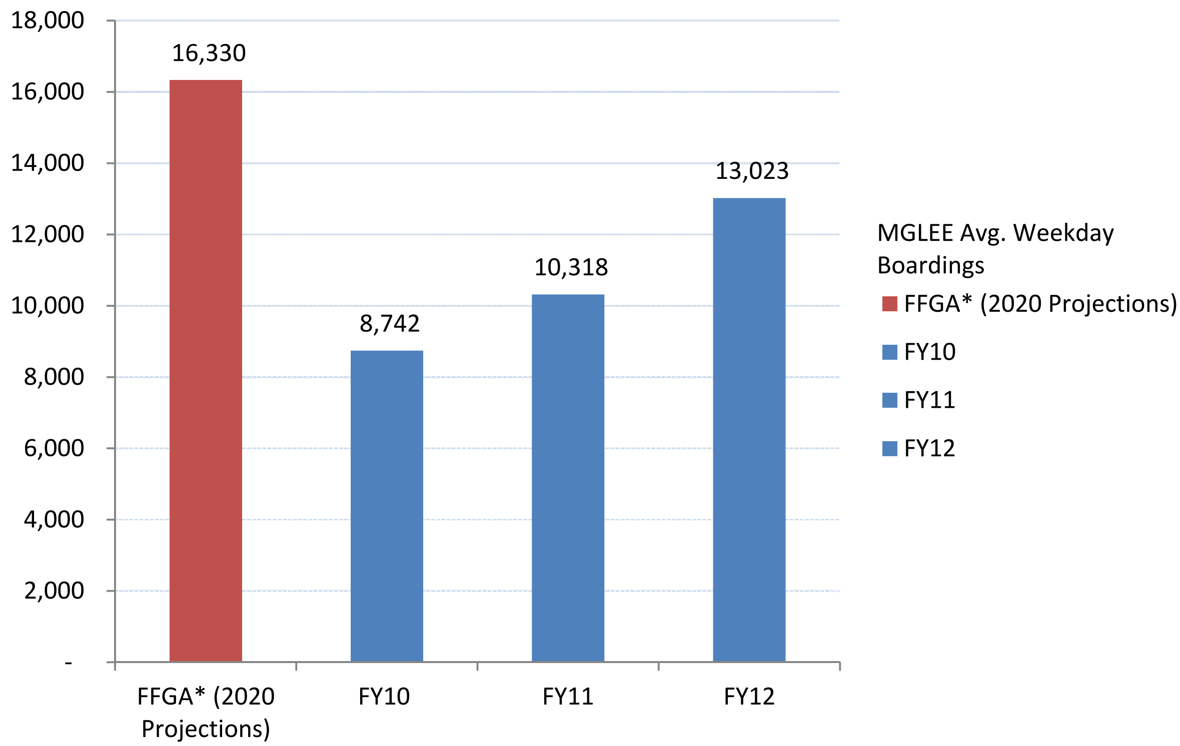

FIGURE 5 MGLEE fiscal year ridership estimates and Horizon Year 2020 projections. (Source: Data provided by Metro, 2011 Origin and Destination Survey. Information presented by authors. *FFGA prepared in 2003 for Horizon Year 2020 Projections.)

LIGHT RAIL LINKAGES

Station Design and Neighborhood Integration

In contrast to Metro's other LRT projects, the planning and design of stations along MGLEE has sought to draw on the local layout, character, and rich cultural history of the Boyle Heights and East Los Angeles neighborhoods. In contrast to standardized station features and canopies, observed on other stations along the Metro system, MGLEE provides alignment and station options scalable to the surrounding environment. The Eastside Extension provides a mix of underground stations with street level plazas and at-grade stations in strategic locations for bus transfers within proximity to neighborhood retail, housing, and recreational and civic uses. Throughout the planning, design, and construction phases of MGLEE, Metro has worked with RAC to provide feedback and input on keys decisions, including station design elements and selection of station artist and artwork.

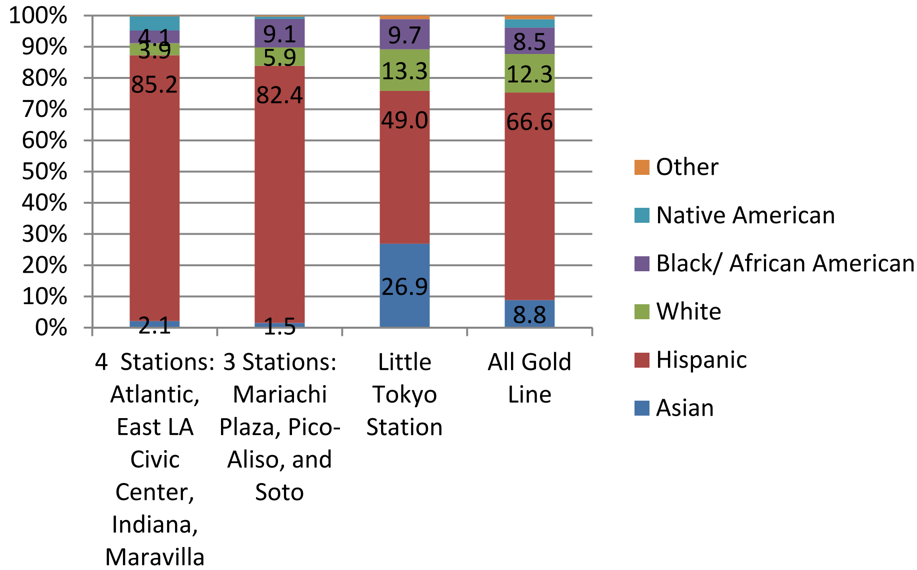

FIGURE 6 MGLEE station survey demographics: ethnicity. [Source: Data provided by Metro, 2011 Origin and Destination Survey. Select data provided for all eight stations along MGLEE, broken down by neighborhood: Little Tokyo (1), Boyle Heights (3), and East Los Angeles (4). A summary of information for the entire Metro Gold Line alignment (Pasadena to East Los Angeles) is presented for comparative purposes. Information presented by authors.]

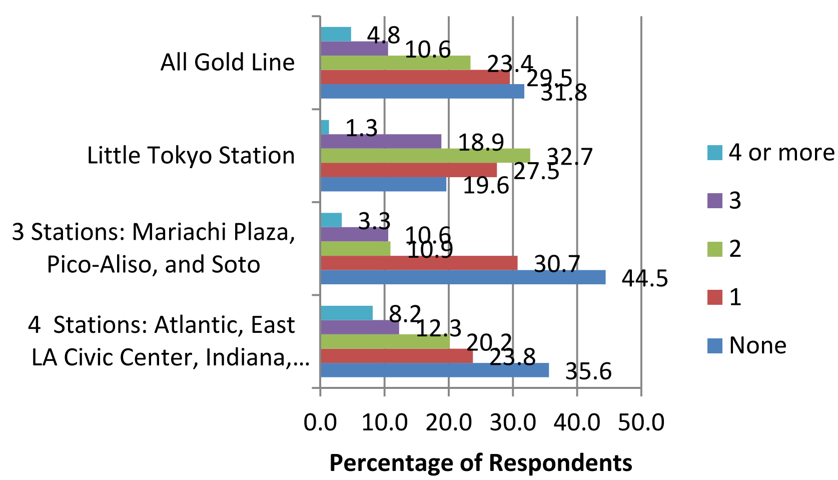

FIGURE 7 MGLEE station survey demographics: vehicle ownership. [Source: Data provided by Metro, 2011 Origin and Destination Survey. Select data provided for all eight stations along MGLEE, broken down by neighborhood: Little Tokyo (1), Boyle Heights (3), and East Los Angeles (4). A summary of information for the entire Metro Gold Line alignment (Pasadena to East Los Angeles) is presented for comparative purposes. Information presented by authors.]

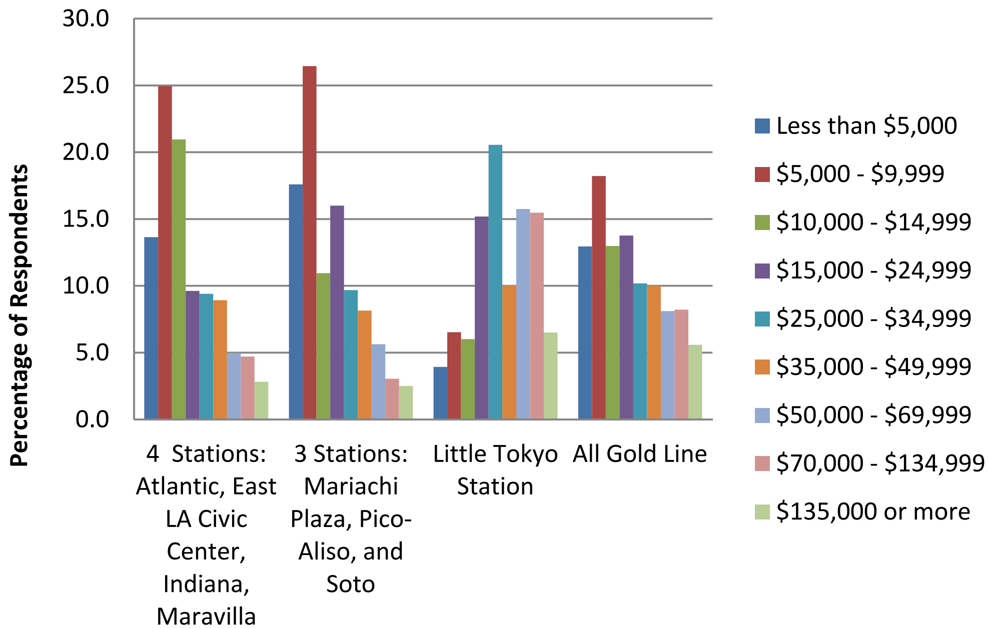

FIGURE 8 MGLEE station survey demographics: annual household income. [Source: Data provided by Metro, 2011 Origin and Destination Survey. Select data provided for all eight stations along MGLEE, broken down by neighborhood: Little Tokyo (1), Boyle Heights (3), and East Los Angeles (4). A summary of information for the entire Metro Gold Line alignment (Pasadena to East Los Angeles) is presented for comparative purposes. Information presented by authors.]

An early study commissioned by Metro as part of the original Red Line heavy rail subway project documented the cultural needs and input from the community (*7*). The document provided guidance to planners, architects, artists, and participants of RAC for early planning. It also provided a framework for what would eventually be constructed, stating:

> The Cultural Needs Assessment highlights the rich and diverse history of East Los Angeles. Since its beginnings, East Los Angeles has been the gateway and first home for many people. As the planning process for the East Side Extension evolved, it was clear that community cultural and art components had to play a key role in the architectural and urban design elements of the project. The station (portal and plaza included) to fully succeed had to be designed with the clear understanding that it will be a community landmark. As such its role is diverse. It is a place to arrive and depart from the community, it needs to be welcoming, interesting and safe. It is a place that invites the riders to visit and discover the community.

Unique aspects of the MGLEE project include the 1.8 mi of underground LRT tunnel and two underground stations. Community members and businesses in the Boyle Heights neighborhood were adamantly opposed to at-grade fixed-guideway investments in the narrow streets within Boyle Heights (*4*). In response to this, the original concepts evaluated as part of Red Line subway extension to the Eastside included underground alignment and stations. Local elected officials, including County Supervisor Gloria Molina, alongside community advocates, worked with Metro to ensure that this issue was addressed in the design of the revised light rail project (*4*).

Two underground LRT stations, Mariachi Plaza and Soto Street, provide plaza-level public space that seeks to integrate with the local streetscape, bus transit stops, and community uses. At-grade stations along the remainder of the route offer street level access to platform canopies and architectural features designed by local artists. While there are admirers of the design, location, and functionality of the MGLEE stations, challenges and critiques persist.

Metro and the City of Los Angeles continue to work with local nonprofit and for-profit developers on adjacent parcels to support economic development opportunities. The Little Tokyo–Arts District, Boyle Heights, and East Los Angeles neighborhoods have a rich cultural history and local advocacy network. Some community representatives continue to be involved through the RAC process, while others have partnered with local nonprofits on specific neighborhood priorities.

Still, what is observed at key stations is an attempt to integrate the existing urban fabric with the uses and interests of the local area. One example of this is observed in and around the Mariachi Plaza station. Mariachi Plaza is a unique example of how LRT design and implementation can work to integrate with the local fabric of the built environment, as well as build upon the social–cultural activities and rich local histories of the community.[9] The area had a well-established local Mariachi network, where enterpenarial musicians and public space were well integrated. Sensitive to this, Metro worked with the local community to integrate these elements into the design of the Mariachi Plaza station (Figure 9). Unique to this stop are a Gazebo, donated from a partnerhsip with the City of Guadalajara, Mexico; a bandstand area for performances; and artwork representing cultural iconography associated with mariachi culture. The area provides ample public space for patrons and local users. And while areas for improvement still exist, such as the need for additional tree canopy and shade, the plaza continues to be a place for communitiy activities and gatherings.

Community Development Around Stations

Mariachi Plaza is recognized for both its cultural destination as a meeting place and business site for mariachi bands in East Los Angeles County. The area is also well known for its historical elements, which seek to preserve and celebrate the contributions of Mexican–Americans in the Los Angeles area. Metro has worked with city offices, nonprofit partners, and community organizations to foster and expand local events held on site at Mariachi Plaza (Figure 10).

The station site is now home to the weekly Boyle Heights farmers' market, which started in 2010, and the annual Mariachi Festival, now in its 21st year. Other events, such as the International Farmers Market and annual Los Angeles Taco Fest (sponsored by Jovenes Inc.), continue to offer programs and festivities throughout the year (*8*).

Transit Supportive Land Use

Metro's roles in developing around stations are two-fold. First, Metro encourages local cities and the county to implement land-use supportive policies, especially around transit stations. Metro as an agency does not have any land-use control except as it pertains to property obtained and operated by Metro for the development and operation of its transit system. For MGLEE, the property required for construction of the project was under Metro control. However, beyond these selected sites, city or county agencies are responsible for implementing transit-oriented development near stations.

FIGURE 9 Photos of Mariachi Plaza.
(Source: Photos provided by Monica Villalobos, 2011.)

FIGURE 10 Community festivals at Mariachi Plaza Station. (Sources: Community festivals and activities sponsored by Los Angeles Council Member Jose Huizar, CD 14. http://cd14.lacity.org and other agencies. Information found online at http://www.mariachifestival.info/Home_Page.html and www.latacofestival.com.)

As highlighted in Metro's pursuit of an FFGA for the project, both the county and the city had specific supportive transportation and land-use policies. This policy primarily relies on the development market for initiation of projects. Metro also maintains a policy for joint development around stations. Metro's policy is proactive in that it first develops a vision of each site with the community. For MGLEE, RAC provided the guidance for the establishment of joint development guidelines. Metro then releases a request for proposals for relevant development projects. Metro completed this and selected developers just before the economic downturn. These developments were a mix of mid-sized residential and commercial developments around MGLEE.

Two high-density developments have occurred near the Mariachi and the Pomona Stations (on properties not owned by Metro). These developments are primarily housing and include a mix of affordable and market-rate units. However, for the Mariachi Station, the developer, a nonprofit housing corporation, was able to capitalize on mitigations resulting from the property acquired as part of the original project planned for the area. This mitigation is targeted at assisting in the replenishment of the affordable housing, accommodating what Metro acquired during the development of the original project. As part of the mitigation effort, seed money was provided, in grant form, to assist developers in including affordable housing as part of their pro forma. The 1889 Boyle Hotel project, directly across from Mariachi Plaza station, developed by the East Los Angeles Community Corporation, is part of ongoing efforts to provide affordable housing to local residents.[11] The Boyle Hotel is a historic cultural landmark site, currently under construction and scheduled to open in 2012. The $24.6-million renovation will offer affordable housing and cultural space for the local residents and Mariachi musicians (*8*).

Still, challenges exist related to development around stations. There is a demand for affordable housing in the project area and a lack of available funding. The study area includes a mix of low-income and moderate-income households, many of them renters. As mentioned previously, and in a recent survey of MGLEE stations, over 50% of respondents at seven of the eight stations reported annual household incomes of $14,999 or less.[12] This has been further aggravated by larger mark shifts following the start of the recession, which has presented challenges for many in the development community.

FUTURE EXPANSION

After about 10 years of little development in new urban rail projects, due to the halting of projects in the mid-late 1990s, Los Angeles is now undergoing a tremendous amount of transit growth. In 2008 two-thirds of Los Angeles County voters approved a local sales tax initiative, Measure R, to address congestion and provide viable transit alternatives raising between $30 to $40 billion for rail and other transportation projects over 30 years. The mayor and local elected officials are lobbying for financial assistance to accelerate the expansion of urban transit and provide transportation improvements. Measure R includes additional projects geared toward improving mobility in the Eastside Corridor, including the Metro Eastside Access Study and the Metro Eastside Phase 2 project. Both projects present opportunities for further investigation. A short description of each project follows.

Measure R

In November 2008 Los Angeles County voters approved the passage of Measure R, a ½-cent sales tax to fund transportation improvement projects. Measure R identifies priority transit and highway projects throughout the county. Los Angeles Mayor Antonio Villaraigosa has continued to lobby Congress on the additional federal funding and loans to help accelerate the development of 30 projects in 10 years as part of the America Fast Forward program (*9*). The goal is to identify federal loans to advance project delivery for Measure R projects.

In July of this year portions of the America Fast Forward program were signed into legislation expanding financing through the Transportation Infrastructure Finance and Innovation Act (TIFIA), as part of the 2-year federal transportation spending bill. These signs point to the ongoing interest and investment in expanding transit in Los Angeles County.

Furthermore, based on recent approval from the Metro Board, under a new proposal, Measure J, Los Angeles voters will have the option on the November 2012 ballot to extend the current sunset of Measure R from 2039 to 2069 (*10*). With this extension, Metro will also be able to borrow from future revenues in order to, again, complete and operate 12 specific transit project within 10 years instead of 30 years.

Eastside Access Study

As part of the package of Measure R projects, $12 million was allocated to improvements along the MGLEE corridor. The goal of this project is to provide further linkages and infrastructure improvements to neighborhoods surrounding stations. The Eastside Access study, which began in 2010, is designed to identify short-term improvements to address the streetscape, safety, and nonmotorized mobility enhancements. The project is currently underway and continues to involve local members through the formation of a community advisory council. This presents an area for further research on the integration of light rail and additional community linkages associated with transit projects in existing neighborhoods.

Eastside Phase 2 Project

Metro is currently conducting planning studies for extending the Metro Gold Line further east. The Alternatives Analysis was completed in 2009 and environmental clearance is underway. This project is funded by Measure R, which provides funding for construction in 2027. However, with efforts such as America Fast Forward and a more recent proposal to extend the life of Measure R, if approved by voters, the Eastside Phase 2 project could be expedited and be in operation within 10 years. When originally conceived, this project was to operate like the current Metro Gold Line, however with the implementation of the approved Measure R project, the Regional Connector, the operations of the Eastside Phase 2 project would connect riders from Santa Monica through downtown and on to the Eastside. Currently, two LRT alternatives are being evaluated in the environmental document.

SUMMARY

This paper presents preliminary research on the planning, design, and implementation of MGLEE. Specifically, the paper discusses the role of participation in decision making through the establishment and involvement of RAC and presents evidence on the integration of light rail projects in existing neighborhoods. While it is widely recognized that planning and implementation strategies for light rail projects differ across agency and geographies, as does outreach and public involvement, this paper presents lessons learned, useful to other planners and policy makers. As research suggests, the role of decision making in infrastructure planning is perhaps one that is understudied and under-examined. MGLEE provides insights into one local transit agency's approach to addressing local partnerships in a minority-rich area for what may be considered a complicated and yet successful light rail project. It provides insights into the role that advisory committees can play in the implementation of transit projects and discusses the role that stations and design play in linking infrastructure to existing sociocultural neighborhood dynamics. This paper documents an initial examination of the MGLEE case, and as such, presents preliminary findings as part of a larger research program. Future research on the topic will focus on primary data collection from actors, including planners, policy makers, and residents, and additional systems analysis. Nonetheless, the paper presents timely preliminary research useful for planners and policy makers working on light rail projects in diverse urban areas.

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10. Metro Officials Endorse Measure to Extend Half-Cent Sales Tax. *Los Angeles Times*, June 28, 2012. Available at http://latimesblogs.latimes.com/lanow/2012/06/metro-officials-endorse-measure-to-extend-half-cent-sales-tax.html.

NOTES

1. Demographic information for Los Angeles 2008 provided by the U.S. Census Bureau. Available at http://quickfacts.census.gov/qfd/states/06/06037.html.

2. Congestion Data for Los Angeles are provided by the Texas Transportation Institute and based on data published in the 2010 Urban Mobility Report. Data tables are available at http://mobility.tamu.edu/ums/congestion_data/west_map.stm.
3. Los Angeles transit history is available on Metro's website at http://www.metro.net/about/library/about/home/los-angeles-transit-history/.
4. Metro transit timeline is available online at http://www.metro.net/around/maps/blooming-map/.
5. Population estimates based on 2000 U.S. Census Data and SCAG Projections. Data was gathered and assembled by AECOM, 2011.
6. Population estimates based on data from SCAG, 1998 RTP, and the Los Angeles County Metropolitan Transportation Authority, 1998. Data are available in the Eastside Transit Corridor Study, Re-Evaluation/Major Investment Study (MIS) Draft Report, February 24, 2000.
7. RAC was established in 1995 with an organizational structure that includes 25 active appointed members representing various interests including resident tenants, resident property owners, businesses, community-based organizations, religious institutions, and educational institutions. More information on the structure and activities of RAC can be found at http://beta.metro.net/projects/eastside/goldline_rac/.
8. $898 million is the year-of-expenditure budget indicated in the MGLEE FFGA.
9. Sites such as www.mariachiplazalosangeles.com demonstrate information on the area's rich cultural and architectural history.
10. Jovenes, Inc., is an organization that works to provide opportunities to youth to become active members in the Boyle Heights–East Los Angeles neighborhood. They offer programs and fundraisers including the annual Los Angeles Taco Fest. Information is available at http://www.jovenesinc.org/la-taco-festival.
11. Information on the East Los Angeles Community Corporation found at http://www.elacc.org/index.html.
12. This includes respondents surveyed near Mariachi Plaza, Pico–Aliso, Soto, Atlantic, East Los Angeles Civic Center, Indiana, and Maravilla stations, where 50% reported incomes of $14,999 or less. Half of patrons surveyed at the Little Tokyo station reported incomes of $34,999 or less. Data was provided by Metro, 2011 Origin and Destination Survey.

Proof-of-Payment Fare Collection
A North American Perspective

Off-Board Fare Payment Using Proof-of-Payment Verification

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YUNG KOPROWSKI
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Completed in 2011, *TCRP Synthesis 96: Off-Board Fare Payment Using Proof-of-Payment Verification*, reported on a comprehensive state-of-the practice study of all North American transit operators using proof-of-payment (POP) verification. The subject of off-board fare payment and POP verification typically leads to inquiries related to fare evasion. However, the subject is significantly more complex than evasion rates. It involves related subjects such as inspection rates, enforcement techniques, duties of fare inspection personnel, adjudication processes, and the sort of penalties involved for evasion. Plus, there is a need for acquiring capital equipment, mainly ticket vending machines and, perhaps, handheld verification devices if the operator uses smart cards as part of its fare media. Since the late 1970s POP verification has become the standard fare collection technique employed by all modern light rail transit systems in North America. Further, POP has been extended to other transit modes: regular bus, bus rapid transit, heavy rail transit, modern streetcars, and commuter rail services. There are currently 30 North American transit operators relying on off-board fare payment using POP verification. TCRP Synthesis 96 provided a summary of the state-of-practice among the POP operators, a summary of common practices as observed from the case study POP operators, and recommendations for additional research. In addition, TCRP Synthesis 96 can be of practical use for those operators considering POP fare collection for a new transit service, especially a medium-capacity service with multi-door boarding, and can be a resource for existing POP operators.

INTRODUCTION

Completed in 2011, *TCRP Synthesis 96: Off-Board Fare Payment Using Proof-of-Payment Verification* (*1*), reported on a comprehensive state-of-the practice study of all North American transit operators using proof-of-payment (POP) verification. Included in the study were a literature review, an extensive survey of the transit operators, and detailed case studies of seven of the operators.

The subject of off-board fare payment and POP verification typically leads to inquiries related to fare evasion. However, the subject is significantly more complex than evasion rates. It involves related subjects such as inspection rates, enforcement techniques, duties of fare inspection personnel, adjudication processes, and the sort of penalties involved for evasion. Plus, there is a need for acquiring capital equipment, mainly ticket vending machines (TVMs) and, perhaps, handheld verification devices if the operator uses smart cards as part of its fare media.

Typically, the majority of POP operations require a transit customer to purchase fare media off-board the transit vehicle. For instance, purchase could be at a TVM on a station platform, or via the Internet, or at a retail outlet. With a valid ticket or pass in hand, the customer is permitted to board the transit vehicle through any door. The individual does not have to show the POP to the driver, and there are no conductors on board.

As a result, enforcement of fare payment through inspection is a necessary and complementary function of POP in order to ensure fare compliance. The enforcement relies on fare enforcement and inspection personnel, who randomly query riders to show POP. Passengers unable to do so may be issued citations imposing a fine as a deterrent to fare evasion.

The initial application of POP fare collection in North America was with the SeaBus ferry services in Vancouver and then was extended to light rail transit (LRT) services in the late 1970s in Calgary, Edmonton, and San Diego. Over the ensuing 30-plus years POP fare collection has essentially become the standard way for subsequently developed LRT lines in North America. Coinciding with this increase in the number of operators have been many changes in how POP fare collection has been carried out. Further, present applications of POP are used on other transit modes: regular bus, bus rapid transit (BRT), heavy rail transit, modern streetcars, and commuter rail services.

LITERATURE SEARCH

The literature search was based upon five themes: experiences with implementation, BRT applications, measuring evasion, managing for POP, and facing media attention.

With regard to implementation, the 2002 document *TCRP Report 80: A Toolkit for Self-Service, Barrier-Free Fare Collection* (*2*) remains a valuable resource for any transit operator using POP fare collection, and especially for any operator considering its use. Although the data in the report are generally dated, most of the guidelines in the toolkit remain practical. Enforcement practices are an essential part of the POP fare collection function and, as such, must address the role of discretion in issuing citations for fare evasion. The regular presence of uniformed officers on transit vehicles is likely to be seen by riders as the best way to provide them with a safe feeling while riding.

On the matter of BRT, POP fare collection has been found to have application especially when ridership numbers are high enough. Whether it will prove to be cost-effective will largely depend upon the loading volumes at the BRT stops and stations and the need for boarding at the rear doors to assure a relatively high bus operating speed.

The management of the fare inspection function and the control of fare evasion will significantly benefit from collection of sufficient fare-evasion data to permit disaggregate analysis (e.g., by time of day, day of week, and location).

A wealth of material is available from transit operators who use POP fare collection, for example, policies and ordinances, performance reports, standard operating procedures, manuals, audits, and special reports. These materials are generally available to other operators and provide a source of research not often available in the public forum. As a product of this study a reference and resource base has been established within the TRB Committee on Light Rail Transit (standing committee AP075). The majority of resources collected as part of the study have been transferred to the committee and are available on the committee's website at http://research.lctr.org/trblrt/.

Fare evasion and fare abuses make for popular headlines in the local news media. It is important for POP operators to be proactive and have a program and strategy for dealing with the media on fare abuse issues. Such a strategy can include preparation of a regular management report that presents the facts and trends related to fare evasion and a summary of enforcement efforts being undertaken. A scan of a random list of headlines provides a sampling of the media interest in issues related to POP fare collection:

- RTA Board Approves $50 Fine for Juveniles Who Ride Without Paying (Cleveland);
- Fare Cheats Costs City Millions (Edmonton);
- Zero-Tolerance Fare Inspection Begins Monday on Metro Light Rail (Phoenix);
- Investigation: RTD Letting Many Riders Travel for Free (Denver);
- Fare Evasion Crackdown Won't Solve All of TTC's Problems (Toronto);
- Muni Employee Punched While Writing Fare Evasion Citation (San Francisco); and
- It's Like Christmas in June for Some Calgary C-Train Riders (Calgary).

SURVEY OF POP OPERATORS

As part of this study an online survey was prepared and distributed to 33 transit operators in North America; all 33 properties responded to the questionnaire and are listed in Table 1.

Of these operators, 30 (90.9%) employed POP fare collection for one or more of their services. Further, 29 of the 30 were either not considering any changes to POP use or were in the process of implementing POP on more services. Of the three operators not using POP, two were considering using POP for future services.

When POP fare collection was initiated in the late 1970s and early 1980s in North America, its application was largely limited to LRT operations. In this study's survey the range of transit modes using POP was found to be diverse: LRT, BRT, heavy rail transit, commuter rail, bus (non-BRT), passenger ferry, and streetcars. The survey found that the 30 properties, in aggregate, operate 91 routes that use POP fare collection. Table 1 also shows the number of routes in each region on which POP is applied (except for the non-BRT bus routes).

The survey explored operator practices in a variety of functional areas associated with POP fare collection including organizational aspects, fare evasion and inspection rates, adjudication, penalties for nonpayment, types of fare media used, TVM functions, and operator acceptance of POP. Key findings are summarized in the following paragraphs.

Organizational and Personnel Aspects of the Fare Inspection Function

It was found that 60% of POP fare enforcement personnel are directly employed by the transit agency and 58% have police powers.

Monitoring and Inspecting for Fare Payment

Almost all operators, 96.5%, allow warnings to be issued by inspectors when warranted, and the average number of citations issued was 3.5 more than the number of warnings. It was found that 39% of the operators issue more warnings than citations. The majority of agencies indicated that they were satisfied with the accuracy of their measured fare evasion rate—86.2% were either satisfied or better.

TABLE 1 Summary of Transit Operators Participating in the Study

		Principal Transit Modes Operated						
Region	Operator	Bus (non-BRT)	BRT	LRT	MS/VT	HRT	CR	Ferry
Baltimore, Maryland	Maryland Mass Transit Administration	●		2		●	●	
Buffalo, New York	Niagara Frontier Transportation Authority	●		1				
Calgary, Alberta	Calgary Transit	●	●	3				
Charlotte, North Carolina	Charlotte Area Transit System	●		1				
Cleveland, Ohio	Greater Cleveland Regional Transit Authority	●	1			1		
Dallas, Texas	Dallas Area Rapid Transit	●		3			1	
Denver Colorado	Regional Transit District	#		7				
Edmonton, Alberta	Edmonton Transit System	●	●	1				
Eugene, Oregon	Lane Transit District	●	1					
Everett, Washington	Community Transit	●	1					
Honolulu, Hawaii	Honolulu DTS Rapid Transit Division	●						
Houston, Texas	Metropolitan Transit Authority of Harris County	●	●	1				
Las Vegas, Nevada	Regional Transit Commission of Southern Nevada	#	2					
Los Angeles, California	Los Angeles County Metropolitan Transportation Authority	●	1	3		2		
Memphis, Tennessee	Memphis Area Transit Authority	●			●			
Minneapolis-St. Paul, Minnesota	Metro Transit	●		1			1	
Newark, New Jersey	NJ Transit	●		3			●	
New York City, New York	MTA New York City Transit	●	2			●	●	
Oceanside, California	North San Diego County Transit District	●		1			1	
Ottawa, Ontario	Ottawa Regional Transit Commission	●	7	1				
Phoenix, Arizona	METRO Light Rail			1				
Pittsburgh, Pennsylvania	Port Authority of Allegheny County	●		●				
Portland, Oregon	Tri-County Metropolitan District of Oregon	#		4			1	
Sacramento, California	Sacramento Regional Transit District	●		2				
Salt Lake City, Utah	Utah Transit Authority	●	1	3			1	
San Diego, California	San Diego Metropolitan Transit System	●	●	3				
San Francisco, California	San Francisco Municipal Transportation Agency	#		6	1			
San Jose, California	Santa Clara Valley Transportation Authority	●		3				
Seattle, Washington	Sound Transit	●		1			2	
St. Louis, Missouri	Bi-State Development Agency	●		2				
Toronto, Ontario	Toronto Transit Commission	●		●	1	●		
Vancouver, BC	TransLink/SkyTrain	#		3			1	1
York, Ontario	York Region Transit/Viva	●	5					

NOTE:
BRT = bus rapid transit; LRT = light rail transit; MS = modern streetcar; VT = vintage trolley; HRT = heavy rail transit; CR = commuter rail.
● = indicates a transit service mode operated by this operator, but POP is not employed.
1 = indicates a service that uses POP fare collection and the number of POP routes.
■ = indicates a service that uses POP fare collection and is one of the seven case studies.
= indicates fare–ticket inspectors are deployed on buses in combination with onboard fare collection.

Measuring Performance

A majority (62.1%) of operators do not set fare evasion goals, and even more (72.4%), do not set inspection goals. The predominant action taken by operators to curb fare evasion spikes are special "sweep" tactics where 100% of the riders are inspected during a specific time and at a specific location. As depicted in Figure 1, across all modes the range of fare evasion rates observed was from 0.1% to 9%, with an average of 2.7% and a median at 2.2%. Figure 2 shows inspection rates that ranged from 0.4% to 30%, with the average at 11.3% and the median at

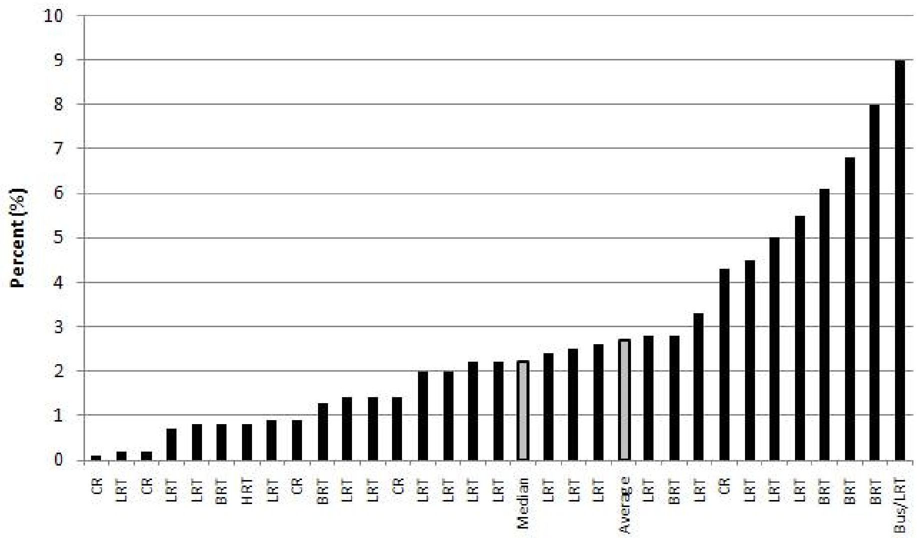

FIGURE 1 Survey of evasion rates.

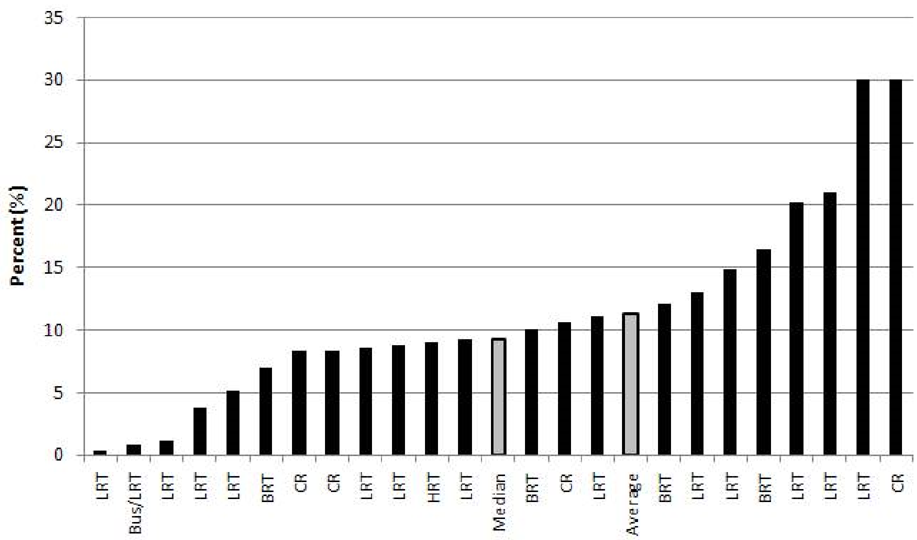

FIGURE 2 Survey of inspection rates.

9.2%. Substantial fluctuations in the fare evasion rates were observed when viewed over a 12- to 14-month period; data from five operators found that in one case the highest monthly rate was five times the lowest rate.

Legal Aspects and Adjudication

The fine for a first fare evasion offense averaged $121 and for repeat offenses the maximum averaged $314. For repeat offenders there are also nonfinancial penalties; the three main ones are the offense escalates to a misdemeanor, a summons is issued to appear in court, or the individual is excluded from using the system for a period of time. For most operators (58.6%) the first fare evasion offense is treated as a civil penalty as opposed to a criminal penalty.

POP Fare Collection Operations

To facilitate enforcement of fare payment the station platform areas are designated to be "paid zones" by 70% of the operators. Examples of the different sign treatments are shown in Figure 3.

Fare Media and Fare Purchase Options

All the operators accept single-ride tickets on their POP services; less used but prominent were monthly passes (89.7%) and day passes (82.8%). Transfers for free or for a charge were issued by 86.2% of the operators.

TVMs

Almost all of the operators' TVMs issue single-ride tickets (96.6%), and the majority issue day passes (69%) and monthly passes (55.2%) as well.

Smart Cards and Stored-Value Cards

Smart cards are used by 13 of the 30 operators in either contactless (11 operators) or magnetic stripe (two) versions. Of those with smart cards, 10 operators have cards that are reloadable (i.e., can be reloaded with additional value). For smart card fare payment verification purposes, 11 operators rely upon handheld mobile devices.

Transit Industry Pulse Regarding POP Fare Collection

A small majority of operators, 56.3%, expressed being moderately or very satisfied with the cost-effectiveness of their POP fare collection operation.

FIGURE 3 Examples of sign messages informing patrons of paid zones.

COMMON PRACTICES AMONG SEVEN CASE STUDY OPERATORS

In order to examine current practices of North American transit operators with regard to off-board POP fare collection in more detail seven transit operators were selected:

- Niagara Frontier Transportation Authority (NFTA), Buffalo, New York;
- Dallas Area Rapid Transit (DART), Dallas, Texas;
- Los Angeles County Metropolitan Transportation Authority (MTA), Los Angeles, California;
- Metro Transit Minneapolis–St. Paul, Minnesota;
- New York City Transit (NYCT), New York City, New York;
- Valley Metro Rail, Inc. (Phoenix Metro), Phoenix, Arizona; and
- San Francisco Municipal Transportation Agency (SFMTA), San Francisco, California.

These operators were selected to represent a cross-section of regions having a diverse range of conditions with POP fare collection experiences to include bus and rail modes, differing geographical areas of North America, and a range in the age of the systems.

Evasion and Inspection Aspects

Base ridership, evasion, and enforcement facts related to the seven case study operators are compared in Table 2. As discussed in this chapter the operators represent a diverse set of operating conditions and a variety of modes. Six of the seven agencies operate an LRT mode, two have BRT modes, and two have commuter rail operations. In one case, for Phoenix, its

TABLE 2 Case Study Operator Fare Evasion and Inspection Statistics

Operator	Modes	Annual Ridership (1,000s)	Annual Citations + Warnings	Fare Evasion Rate: Goal	Fare Evasion Rate: Actual	Number of Inspectors (FTEs)	Inspection Rate: Goal	Inspection Rate: Actual
Niagara Frontier Transportation Authority (Buffalo)	LRT	6,216	4,526	2%	<2.0%	5	None	8.6%
Dallas Area Rapid Transit	LRT	17,799	36,106	3.75%	2.6%	48	None	n/a
	CR	2,469			4.3%			
Los Angeles County Metropolitan Transportation Authority	BRT	7,043	84,700	2-5%	0.8%	300	10%	16.4%
	LRT	46,650			0.8%			20.2%
	HRT	47,900			0.8%			9.0%
Metro Transit (Minneapolis-St. Paul)	LRT	10,322	4,907	5%	0.7%	18	10%	8.8%
	CR	710			0.1%		25%	30.0%
MTA New York City Transit	BRT	21,200	12,037	No worse than before implementation (13%)	6.1%	42	None	7.0%
METRO Light Rail (Phoenix)	LRT	12,600	3,779	None	4-6%	17	20%	12.4%
San Francisco Municipal Transportation Agency	Bus	167,333	57,000	None	9.0%	42	None	0.8%
	LRT	42,447						
	Streetcar	7,002						

agency essentially has sole operating responsibility over one LRT route. The others have multiple services and multiple modes. For three of the entities (Buffalo, New York City, and Phoenix) POP is applied on only a small part of the overall regional system.

Five of the operators have fare evasion goals and, except for the Dallas TRE commuter rail, the fare evasion rates experienced are within the goal. NYCT's goal, at least initially, is to achieve fare evasion rates below what it had incurred prior to implementation of BRT, Select Bus Service.

Three of the agencies set inspection goals for their services: two were set at 10% (LA Metro and Minneapolis–St. Paul Metro Transit LRT), one at 20% (Phoenix METRO), and one at 25% (Minneapolis–St. Paul Metro Transit Northstar commuter rail).

In comparison to the overall evasion and inspection statistics displayed in Figures 1 and 2, the case study operators generally were found to have the following:

- A modestly higher inspection rate, on average 12.4% compared to 11.3% and
- An average fare evasion rate in the same general range, 2.2% compared to 2.7% overall.

Enforcement and Adjudication Aspects

As shown in Table 3, four of the seven case study operators administer their own court, and one operator (Los Angeles Metro) will have their own transit court by 2012.

While there are some unique differences as to how the adjudication process works among the seven operators there are numerous consistencies:

- All of the operators employ forces specifically designated for fare enforcement. However, each force has different titled positions for what amounts to be similar functions, mainly focused on fare enforcement.
- Fare enforcement personnel with six of seven of the operators do not possess police powers.
- The first fare evasion offense is treated as civil or administrative matter. In four of the cases the offense becomes a misdemeanor or criminal offense under differing situations, for example, based on whether the initial fines were paid, or how fast they were paid, or how many times fare evaders received citations.

One of the inconsistencies was related to the penalty schedule. The fine for the first evasion offense ranges from $50 for Buffalo to $190 for Metro Transit. The maximum amount has an even larger range: $75 to $1,000.

The detailed review of the POP experiences of the seven case study operators found common experiences and practices:

- Using a customer-oriented enforcement to fare payment rather than a traditional policing approach. Phoenix METRO reported that its fare enforcement training stresses the three Es: Engage, Educate, and Enforce. For NYCT the philosophy is to "skillfully educate the public on proper fare payment" and "get the passengers into the habit of paying their fare." San Francisco Muni characterizes its approach as a soft approach to fare compliance, assisting people to pay by escorting them to TVMs without issuing citations.

TABLE 3 Case Study Operators: Summary of Enforcement and Adjudication Aspects

Operator	Adjudication Forum	Fine Amounts for Evasion, 1st Offense/Max	Is Fare Evasion Offense Civil or Criminal?	% of Fine Revenue Retained by Operator	Department/ Entity Responsble for Fare Enforcement	Fare Enforcement Personnel: Position Title	Fare Enforcement Personnel: Police Powers?
Niagara Frontier Transportation Authority (Buffalo)	Niagara Transit Adjudication Bureau	$50/$280; escalates dependent upon how soon paid	Civil; Criminal after two or more unpaid citations	100%	NFTA Rail Operations and Transit Police	Metro Fare Inspectors	No
Dallas Area Rapid Transit	DART	$75/$500	Civil if paid within 30 days; Class C misemeanor after 30 days with a court procedure	100% if paid administratively within initial 30 days; otherwise, $5 received per citation	DART Police Department	Fare Enforcement Officers	No
Los Angeles County Metropolitan Transportation Authority	LA Metro Transit Court*	Fine schedule not approved yet*	Civil if paid within initial 45 days; after 45 days,	0%*	Los Angeles County Sheriff Transit Services	Sheriff's Deputies	Yes
						Sheriff's Security Assistants	No
Metro Transit (Minneapolis-St. Paul)	County Court	$190/$1,000	Civil if paid; if defaults then becomes misdemeanor; two or more offenses are misdemeanor	0%	Metro Transit Police Department	Metro Transit Patrol Officers	Yes
MTA New York City Transit	MTA/NYCT Transit Adjudication Bureau	$100/$100	Civil	100%	NYCT Department of Security	Special Inspectors	No
METRO Light Rail (Phoenix)	Municipal/County Courts	$50/$500	Civil	0%	METRO Department of Safety and Security	City of Phoenix Police Assistants	No
						Transit Enforcement Aides (private)	No
San Francisco Municipal Transportation Agency	SFMTA Customer Service Center	$75/$75	Civil	100% if paid administratively through the Service Center	SFMTA Security and Enforcement Department	Transit Fare Inspectors	No

*The Transit Court is expected to be operational by end of 2011

- Implementing an agency-administered adjudication process. Buffalo NFTA, Dallas DART, NYCT, and San Francisco MTA retain the adjudication process in-house. Los Angeles Metro is in the process of going that route by the end of 2011. In a Board report LA Metro notes that having a Transit Court "benefits its customers by providing a more direct, simpler method for resolving citations issued for transit related violations … and by reducing the number of cases that are currently required to be adjudicated in the Superior Courts."
- Instituting an administrative process for payment of the fare evasion penalty. Consistent with an in-house adjudication process the same operators offer an administrative process for payment of the fare evasion penalty. A good example is DART: its process permits a person to pay a $75 administrative fee within 30 days and avoid a criminal court proceeding. DART makes payment very convenient, too. The individual can pay in person at DART offices, by mail, or by using the DART store (DARTstore.org).
- Creating a focused fare inspection team with nonsworn officers. Six of the seven case study operators use personnel for fare inspection that do not possess police powers: Buffalo Metro fare inspectors, DART fare enforcement officers, Los Angeles Sheriff's security

assistants, NYCT Eagle Team special inspectors, Phoenix police assistants and private security, and SFMTA–Muni transit fare inspectors. The two primary advantages of this approach are labor cost savings and a force dedicated to one primary purpose: fare enforcement. In each case, the inspectors are uniformed but not armed. For incidents that require police support the inspectors have radio contact with either transit police or municipal police.

- Adding smart cards to the menu of fare media available for fare payment. LA Metro, Minneapolis–St. Paul Metro, Phoenix METRO (Figure 4), and SFMTA have smart cards as part of their fare payment mix, and DART is in the process of adding them. Smart cards are a popular medium for fare payment but add complications to the POP fare collection process. The primary issue for POP is related to there being nothing printed on the card to allow for visual inspection of POP. While NYCT's is not a smart card, they handled this issue by requiring its MetroCard users to access special TVMs, insert their cards, and acquire printed receipts. Most operators provide their inspectors with handheld verification devices. Smart cards have provided a new fare evasion offense whereby a patron with a card with value on it does not "tap in" to the system in order to pay a fare (i.e., and have it deducted). Knowingly or not, without "tapping" the person has avoided payment of a fare.
- Employing POP fare collection on BRT services. LA Metro's Orange Line and the two NYCT Select Bus Service routes (Figure 5) have shown that POP can beneficially work for BRT—just like it does for LRT. The daily ridership on the Orange Line is about 24,000, and the NYCT routes both exceed 30,000. Use of the rear doors for passenger boarding is necessary in order to minimize station dwell times for those services and provide a high operating speed. However, for BRT services where station loading volumes may not be sufficient to warrant use of the rear doors in boarding it may not prove to be cost-effective to use POP.
- Using independent management audits as an aid in reviewing an agency's POP experience. As part of the study, audits for two case study operators, Minneapolis–St. Paul Metro Transit (*3*, *4*) and San Francisco MTA (*5*) were reviewed. Another study, performed for LA Metro in 2007 (*6*) but not called an audit, had similar objectives as an audit might have had and provided a useful review of fare evasion on Metro's high-capacity routes. However, to be useful the audit needs to provide practical and constructive assistance and not be used for purposes of trying to search for problems.

FIGURE 4 METRO public information message reminding riders to tap their passes.

FIGURE 5 NYCT Eagle Team fare inspectors boarding NYCT's select bus service.

- Expanding the provision of public information via the Internet and YouTube. All of the operators provided some information on their websites regarding how to pay fares and the POP process. Several sites were fairly minimal. On the positive side, Minneapolis–St. Paul Metro Transit went a step further and had a series of short—roughly 2 min in length—YouTube videos on a range of subjects related to using the system including fare payment.
- Deploying a show of force on a new service using POP fare collection. As demonstrated in Los Angeles and in New York City, heavy use of inspection enforcement as a show of force can be a valuable part of educating users exposed to POP fare collection for the first time. However, the show of force is not be limited to enforcement activities. In its case study NYTC provided an example of a customer focus on its two new BRT routes where it placed "customer ambassadors" at BRT stops along the routes for first 2 to 3 weeks of service.
- Using sweeps (also referred to as blitzes, surges, enhanced fare enforcement) to demonstrate uniformed presence on the system in serious way. Stories are told about passengers applauding fare inspectors when they are on a sweep. Fare paying passengers want to see inspectors. These sweeps, randomly deployed, also send a message to evaders, keeping them guessing as to where and when a sweep may be called.
- Using temporary barriers and turnstiles for crowd control at special events. Minneapolis–St. Paul Metro Transit, Phoenix METRO (Figure 6), and SFMTA serve major sporting venues and rely on special techniques for managing crowds, especially post-game. Use of temporary barriers and turnstiles also help with POP fare inspection, which can be done off-board rather than on crowded trains.

FIGURE 6 METRO light rail special event fare inspection using temporary queuing barriers.

CONCLUSIONS

Based upon the literature review, surveys, and case study interviews there were found to be various gaps in data, and questions that could not be answered within the scope of this study. These gaps and questions led to areas identified for further research:

- The range of loading volumes that would result in POP fare collection being a cost-effective alternative. At what range of loading volumes at stations and stops is all-door boarding necessary in order to attain a high operating speed? The evaluation of the cost-effectiveness of alternative fare collection strategies and whether to implement off-board fare payment and use POP fare collection depends on whether all-door boarding is necessary.
- The relationship among the evasion rate, rates of inspection, and penalty amounts. The relationship among these three factors is unclear. How high does a financial penalty have to be set in order to significantly influence the evasion rate? Which is more important to curbing fare evasion, higher penalties or higher rates of inspection? What is the best balance between financial penalties and inspection rates? How much discretion is tolerable when it comes to issuing warnings and what influence, if any, does the rate of issuing warnings have on evasion?
- A manual or guidelines for statistical analysis of fare evasion. Would there be industry benefit to have a technical manual that would provide elements of a sampling method for measuring fare evasion, and a common definition? Such a manual would help practitioners—most of whom are not schooled in statistics—with statistical analysis to ensure a reasonable level of accuracy, for example, number of samples to obtain, inspection techniques, sampling approaches to assure representativeness, levels of disaggregation, and frequency.
- A transit smart card forum for POP operators. How does the industry keep up with the rapidly changing technological aspects of smart cards? How effective are the handheld verification devices and in what ways can they be used to be increasingly cost-effective?

Development of a forum that would facilitate on-going communication and transfer of experiences among POP users is a gap that exists today.

- The cost-effectiveness of alternative adjudication processes. Are the local agency processes more cost-effective than the court-oriented approaches? An evaluation of alternative adjudication processes now in operation would confirm advantages and disadvantages, as well as costs and benefits. Such an evaluation would include reviewing the details of the administrative processes, the associated costs and revenue return to the operator, and the effectiveness in discouraging repeat fare evasion offenses.
- The costs—capital, operating, and maintenance—of alternative off-board POP fare collection and enforcement approaches. One of the primary data gaps uncovered in TCRP Synthesis 96 relates to costs, for example, capital, operating and maintenance costs associated with TVMs, verification devices, and inspection forces. In addition, some transit properties are implementing fencing and gating to assist in fare enforcement, what are the added costs—as well as any cost savings—associated with these measures?

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Tackling Fare Evasion on Calgary Transit's CTrain System

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Calgary Transit is a medium-sized integrated transit system with a staff of over 2,800 providing bus, community shuttle, and light rail transit (LRT) service. In 1981 Calgary Transit became one of the first transit agencies in North America to operate an LRT system; it was called CTrain. Today CTrain is considered to be one of the most successful LRT start-up operations based on ridership. CTrain carries over 275,000 riders on an average weekday. Since its inception CTrain has grown from a single line to three lines comprised of 37 stations and platforms and 48 km (30 mi) of dual track with a fourth line tentatively scheduled to open in December 2012. CTrain operates on the surface and is characterized as an open system, in which there are no turnstiles or barriers controlling access. Consequently, Calgary Transit relies on voluntary compliance and proof of payment from customers for fare payment. Calgary Transit peace officers, hired in 1981, conduct regular fare-checking activities to ensure compliance. Since 1993 Calgary Transit has conducted annual fare evasion studies to estimate current fare evasion levels to monitor the effectiveness of fare checking and enforcement efforts. This paper describes the fare evasion study methodology employed by Calgary Transit and historical fare evasion study results, and details the findings of the 2011 study. In addition, the paper outlines Calgary Transit's efforts to increase compliance through public awareness activities and describes the findings from a survey of over 1,400 fare evaders conducted as part of the 2011 fare evasion study. The paper concludes with a discussion of the role of fare enforcement as a means of controlling crime and disorder on transit systems. The authors contend that during the day the primary role of proof of payment checks is to serve the revenue and business interests of transit agencies while during the evening the primary focus is on passenger behavior, which has a secondary impact on reducing fare evasion.

INTRODUCTION

Over the past decade many North American public transit systems have experienced increasing ridership. Rising oil prices, growing concerns over the environment, and people's desire for a less stressful means of commuting have all contributed to greater use of public transit. Transit riders pay a portion of the cost of providing service in the form of a fare payment. Increasing ridership results in additional revenues which, in turn, helps transit agencies to expand their service. On the other hand, fare evasion, riders who ride transit services but who do not pay a fare, remains a concern for transit agencies, especially for those agencies such as Calgary Transit who operate proof-of-payment systems. Fare evasion not only results in lost revenue to transit agencies, it makes the riding experience less enjoyable for fare paying customers and reduces public and political confidence in the service.

This paper provides an overview of Calgary Transit's light rail transit (LRT) system known as CTrain and describes the approach to dealing with fare evasion. Considered one of the most successful light rail systems in North America based on ridership, CTrain operates at surface level with open access to stations and platforms. Riders are required to produce proof of payment on request when in fare restricted areas and when travelling on CTrain. Since 1993 Calgary Transit has conducted annual surveys to determine fare evasion rates on the system and to address ways to reduce this evasion. The 2011 survey resulted in a fare evasion rate of 4.5% on the CTrain system. The paper concludes with a discussion of alternative methods to foster fare compliance among riders and the ancillary benefits of controlling crime and disorder through fare checks.

OVERVIEW

Calgary is Canada's fourth largest city with a population almost 1.1 million people situated in the foothills of the Canadian Rocky Mountains. The foundation of Calgary's economy is agriculture, energy, and tourism. Today, Calgary is home to the second highest concentration of corporate head offices in Canada representing the energy, finance, transportation, and manufacturing industries.

Over the past decade (2001–2011) Calgary's population increased by 24.5%, with most of this growth occurring between 2005 and 2009. During the same period, ridership on Calgary Transit increased by 28.4% to over 96 million rides in 2011. It is projected that Calgary's population will grow to 1.25 million over the next 10 years because of its economic potential, geographic position, and desirability as a place to live.

Calgary Transit is a medium-sized transit agency, operating an integrated transit network consisting of light rail, regular bus, and community shuttle service. The existing CTrain service includes over 48 km (30 mi) of dual track, 37 stations (27 suburban and 10 downtown), 11,000 park-and-ride stalls, and 192 light rail vehicles. By 2014 the system will have grown to include nine additional stations and 13 km (8 mi) of additional track.

CTrain is primarily a surface-level open system with no turnstiles or barriers controlling access. Customers can pre-purchase tickets or passes from a variety of vendors throughout Calgary. In addition, customers can pay cash at ticket vending machines located at all CTrain stations and platforms and receive a receipt confirming proof of payment. Calgary Transit is in the process of implementing an electronic fare payment system, which will be operational in 2013, providing additional payment options for customers.

Within the downtown, CTrain operates along the 7th Avenue transit corridor that is shared with buses and emergency vehicles. The 10 downtown stations are side-loading platforms located next to the sidewalk in the curb lane with LRT tracks located in the center lanes. Twenty-seven of the system's 37 stations are located in suburban areas and are spaced every 1.6 km (1 mi) (Figure 1). The design and scale of suburban stations varies depending on their immediate environment and passenger volumes. Stations range from simple in-community platforms with at-grade pedestrian access to large enclosed steel-and-glass structures with elevators and escalators. Most suburban stations have bus terminals and park-and-ride lots.

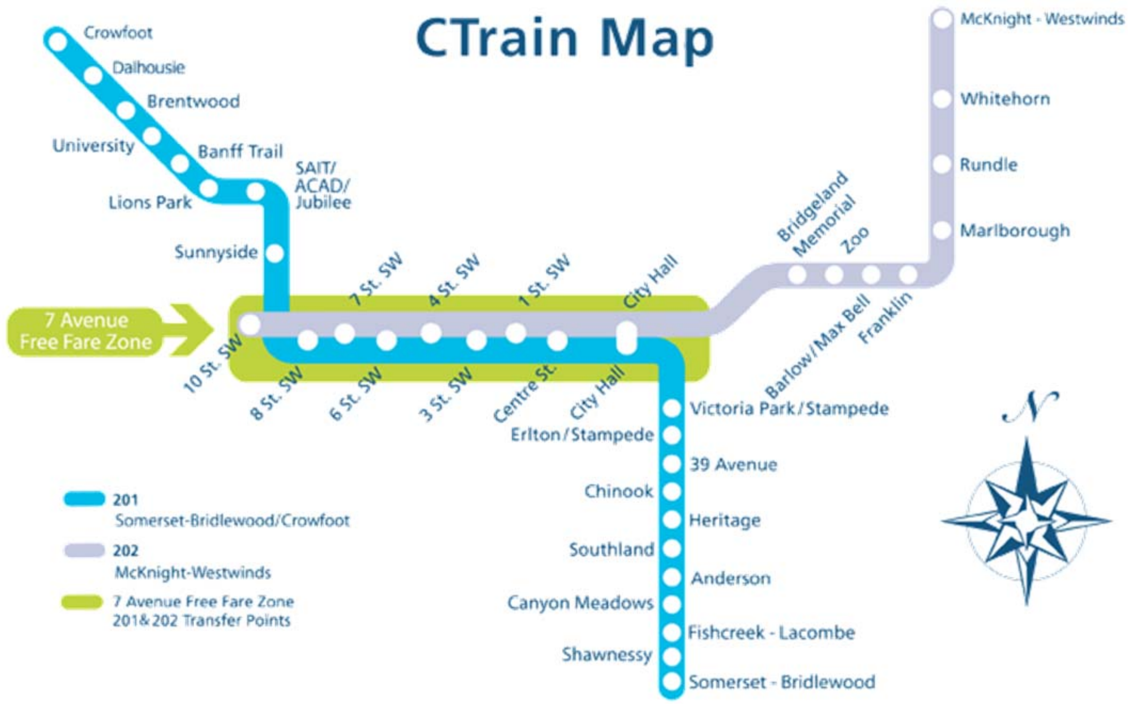

FIGURE 1 Calgary Transit CTrain map.

In September 2012 the CTrain system expanded by another two stations and 2.9 km (1.8 mi) of track on the northeast leg. A new leg of the CTrain system serving the west side of Calgary is tentatively scheduled to open in December 2012, adding another six stations and eight km (5 mi) of track.

Bus service consists of a network of radial routes serving the downtown, feeder routes and cross-town bus routes. The bus system encompasses over 170 routes covering approximately 4,500 route kilometers. The bus fleet is comprised of 980 buses, which includes 863 regular 40-ft and articulated buses and 117 community shuttle vehicles.

In the past 10 years, strong population and job increases in Calgary have resulted in significant growth in Calgary Transit ridership and demand for increased service. During this period, annual transit ridership increased by 28% from 74.9 to 96.2 million revenue trips. Ridership growth on the CTrain system has increased at an even faster rate, reaching approximately 275,000 weekday boardings—an increase of over 50%. Over half of the trips entering Calgary's downtown core are made using transit.

OVERVIEW OF CALGARY TRANSIT PUBLIC SAFETY AND ENFORCEMENT SECTION

The provision and delivery of security is authorized and organized through Calgary Transit's Safety and Security Division, Public Safety and Enforcement Section. Calgary Transit employs peace officers to provide for customer safety and security and the enforcement of fare payments. Peace officers are aligned and fully integrated with Calgary Transit's day-to-day operations. There are 77 peace officers who respond to all incidents such as medical emergencies, passenger harassment, acts of vandalism, or any other situations generating feelings of insecurity. The 2012 annual budget for the 77 peace officer (wages and benefits) is $8.13 million.

Uniformed peace officers patrol the CTrain system 24 h a day. Peace officers are authorized by the Alberta solicitor general to enforce municipal and provincial laws, including the Transit Bylaw, Gaming and Liquor Act, and on-view criminal (federal) offenses. Given the law enforcement role of peace officers, Calgary Transit, and the Calgary Police Service have entered into a memorandum of understanding to ensure roles are understood by each party and to ensure a cooperative relationship whereby customer service has the diffused benefit of overall improved community safety.

Peace officers are deployed throughout the CTrain system based on both geographic and call demand factors. The goal is to ensure peace officers are nearby based on predicted call volumes. In the free-fare zone, high-visibility patrol is the primary strategy for maintaining order, and patrol modes include foot and mountain bike patrol.

A key aspect of the duties performed by the peace officers is checking for proof of payment. Recently, Calgary Transit established a “high enforcement team” of six peace officers whose primary focus is to target fare evasion during peak periods (e.g., a.m. and p.m. rush hours) on CTrain. The deployment of the High Enforcement Team is based, in part, on the results of the 2011 fare evasion survey described below.

FARE EVASION PENALTIES

In July 2012 fines were raised to a minimum of $250, including fare evasion. In addition, if a person is convicted twice for the same offence in a 12-month period, the fine will double. Similarly, a third conviction for the same offence in a 12-month period will result in a tripling of the penalty. For example, a person convicted twice for fare evasion would receive a summons for $750.00 in the event they were caught for a third time in a 12-month period.

An increase in the penalty for fare evasion was last considered by Calgary City Council in 2006. At that time the price of an adult monthly pass was $70.00, and the penalty for fare evasion was $150.00. Since 2006 the price of an adult monthly pass has increased to $94.00 while the penalty for fare evasion remained the same. In seeking an increase in the fare evasion fine, Calgary Transit contended that customers were engaging in a cost–benefit analysis—weighing the cost of purchasing a fare against the chance of getting caught and having to pay the $150.00 penalty. Therefore, Calgary Transit sought an increase in the specified penalty for fare evasion to $250.00 to address the increase in transit fares since 2006 and to encourage customer compliance in the purchase of fares.

Fine revenue in relation to the municipal transit bylaw is deposited in the Calgary Transit general revenue fund and is used to offset expenditures related to the provision of service. Failure to pay a fine typically results in a warrant for the arrest of an individual. The discretionary enforcement practices of peace officers ensures that marginalized and vulnerable riders do not fall into a perpetual negative ticketing cycle in which they receive a ticket, which goes to an arrest warrant and then subsequent future arrest. Fine revenue in 2012 is estimated to be $1.5 million. The fine revenue includes tickets written for fare evasion as well as for other bylaw offenses. While the goal is to strive for high rates of compliance, fine-based revenue does offset financial losses due to fare evasion.

FARE EVASION SURVEY METHODOLOGY

Since 1993 Calgary Transit has conducted annual surveys to determine fare evasion rates, assess the effectiveness of fare enforcement activities, and areas to target future deployment and enforcement activities. The 2011 fare evasion study was conducted between May 25 and June 25. Two teams of eight plainclothes Calgary Transit staff boarded CTrains at various stations throughout the city at different times of the day. Customers were asked to show proof of payment after they boarded the train at a station and when the CTrain left the downtown free fare zone. Customers who did not possess valid fares, transfers, or passes were recorded as fare evaders and asked to exit the train at the next station. The study focused on individuals who did not have valid fares. The study did not take into consideration other forms of fare evasion such as the improper use of a fare product (e.g., adults using a concession fare for seniors or youth).

At the station, customers who were identified as fare evaders were offered two choices:

1. Purchase a fare and continue on their journey, or
2. Participate in a 10-question survey.

If customers chose to participate in the survey, they were issued a 90-min transfer to continue their trip on Calgary Transit. Summonses were not issued as part of the fare evasion study. The intent of the survey was to better understand fare evaders with a goal of designing strategies to mitigate fare evasion on the CTrain system.

Sampling protocols from previous studies were used to develop the fare evasion sample plan for 2011. To allow for multiyear comparison of fare evasion rates during specific times of the day, the sampling time periods that were used in previous fare survey studies were repeated in this fare survey. Weekday time periods were broken down into the following segments: 0630 to 0900, 0901 to 1500, 1501 to 1600, and after 1800. Weekend survey time periods were between 1030 to 1630 on Saturday and Sunday. No attempt was made to weight the survey samples to reflect actual ridership patterns.

As it is impossible from a practical perspective to survey the entire CTrain system in one time period, the different legs of the CTrain system were surveyed on different days. As in previous studies, minimum sample sizes were set at 25 passenger checks per station both inbound and outbound from a CTrain station during a specified time period.

The sample size for the 2011 fare evasion study exceeded previous studies. Typical statistical parameters used are precision and level of confidence. Precision refers to the amount of potential variation in the data, in this case, the number of customers identified as fare evaders in the study. The level of confidence refers to the frequency with which the findings or survey results are within that range. In other words, if the same fare study was repeated would the results fall into a similar range.

A total of 33,499 customers were checked during the 2011 May–June study, with 1,496 being identified as fare evaders. This yields a fare evasion rate of 4.5% systemwide. Using Calgary Transit's station ridership 15-min interval population survey to define the population, this study provides a statistically reliable figure with a confidence level of 99% with a margin of error no more than ± 0.7%.

2011 FARE EVASION STUDY RESULTS

The following is a summary of the systemwide and line-by-line fare evasion rates for 2011 May–June with a comparison to previous studies. Figure 2 shows the historical CTrain system fare evasion rates from 1993 to 2011. The lowest evasion rate of 1.1% was recorded in April 1995 and March 1999. In 2009 the fare evasion rate was 4.5%, which represented an increase of 2.6% from the 2008 study. Similarly, in 2011 the systemwide fare evasion rate was 4.5%, up slightly from 4.2% the previous year. The increase in the fare evasion rate over the last three calendar years can be attributed to changes in sampling methodology and remedying potential sampling errors from previous years (pre-2009) as well as to increases in the overall sample size. The increased sample size in 2011 served to validate findings from 2009 and 2010 in which smaller sample sizes were used.

It is difficult to determine the lost revenue attributable to fare evasion. The estimated annual revenue loss associated with the fare evasion rate of 4.5% is $4.75 million based on (68.5 million trips on the CTrain system) and the average fare of $1.54 per trip. This represents 3.3% of Calgary Transit's 2011 fare revenues of $142.4 million.

For the purposes of analyzing the fare evasion results, the CTrain system is divided into four lines: 7th Avenue corridor, 201 Northwest line, 201 South line, and 202 Northeast line. The 7th Avenue corridor is called the "free fare zone" because fare payment is not required when riding the CTrain between 10 street station in the west and City Hall station in the east. Payment is required when a customer leaves the downtown free fare zone. Table 1 depicts the fare evasion rate by CTrain line from 2009 to 2011. The Northwest line has the highest overall fare evasion rate of 6.3% to 1.8% higher than the overall 2011 system rate. The northeast and south lines are considerably lower at 3.6% and 3.8%, respectively. Over the past 3 years the fare evasion rate on the Northwest line has increased, while the Northeast and South lines have declined.

Table 2 illustrates that fare evasion rates vary by time of day and CTrain line. Generally speaking, fare evasion rates are higher during the morning (0600 to 0900) and afternoon (1501 to 1800) rush hours and lower during off-peak hours. This suggests that customers may be taking advantage of the fact that it is more difficult for peace officers to conduct fare checks during peak periods because the light rail vehicles tend to be full. The Northwest line experiences the highest fare evasion rate during the morning rush hour (8.4%) followed by the afternoon

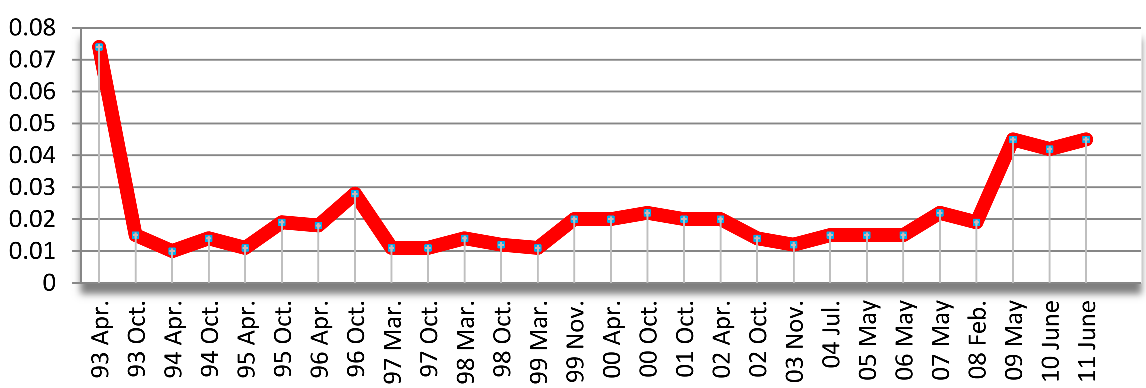

FIGURE 2 CTrain system fare evasion rates 1993–2011.

TABLE 1 Fare Evasion Rate by CTrain Line, 2009–2011

LRT Line	2011	2010	2009
Northwest	6.3%	5.2%	4.4%
Northeast	3.6%	3.4% 4.2%	
South	3.8%	3.9%	4.7%

TABLE 2 Fare Evasion Checks by CTrain Line and Time-of-Day Summary

	Weekdays		Weekend		Total	
Time Period	**0630–0900**	**0901–1500**	**1501–1800**	**1800+**	**1030–1630**	**All Days**
Northeast						
Total checked	3,098	2,656	2,076	1,813	768	10,411
Evaders	88	86	88	70	40	372
Evasion rate	2.8%	3.2%	4.2%	3.9%	5.2%	3.6%
South						
Total checked	3,973	3,775	3,321	1,633	1,210	13,912
Evaders	166	110	146	75	45	542
Evasion rate	4.2%	2.9%	4.4%	4.6%	3.7%	3.9%
Northwest						
Total checked	3,309	2,424	1,598	842	1,003	9,176
Evaders	278	150	95	34	25	582
Evasion rate	8.4%	6.2%	5.9%	4.0%	2.5%	6.3%
Total checked	10,380	8,855	6,995	4,288	2,981	33,499
Total evaders	532	346	329	179	110	1,496
System rate	5.1%	3.9%	4.7%	4.2%	3.7%	4.5%

rush hour (5.9%). The lowest fare evasion rate on the Northeast line occurs during the morning rush hour (2.8%) followed by during the midday off peak (3.2%).

Fare evasion rates vary by station. It should be noted, however, that given the study sampling methodology, evasion rates by station do not necessarily reflect the actual evasion rate at that particular station. Rather the data represent how many fare evaders were on a CTrain at that point in the system. In part, one would expect that customers would be more likely to not purchase a fare depending on the number of stations they were travelling to or their proximity to the free fare zone of 7th Avenue. For example, one would expect to see higher fare evasion rates at the stations immediately adjacent to the 7th Avenue free fare zone (e.g., Sunnyside, Bridgeland, and Victoria Park–Stampede stations). Table 3 shows the top 10 stations with the highest evasion rates for 2009–2011. The data support this hypothesis, with Sunnyside, Bridgeland, and Victoria Park–Stampede stations appearing in the top 10 over the previous 3-year period.

SURVEY OF FARE EVADERS

As part of the 2011 fare evasion study Calgary Transit sought to gather information about fare evaders, their demographic characteristics, and reasons for not purchasing a fare that day. To this end, customers identified as fare evaders were offered the opportunity to participate in a brief survey. Of the 1,496 identified fare evaders, 1,399 chose to complete a survey. The survey was administered verbally by Calgary Transit staff.

Demographic Characteristics

Of the fare evaders 54% were male and 46% were female. The majority of fare evaders (45%) were in their 20s, followed by those 19 years of age and under (20%), and those in their 30s (19%). Respondents were asked about their annual household income before taxes. Almost one-third of respondents (28%) reported an annual household income of less than $15,000, 35% between $35,000 and $65,000, while the remainder of respondents who replied to this question (26%) had income exceeding $65,000 annually.

Reasons for Using Calgary Transit

Approximately 43% of the fare evaders were on their way to work, 23% were on their way home, and 13% were on their way to school. Interestingly, more than three-quarters of fare evaders (77%) indicated that Calgary Transit was their main form of transportation.

Type of Fare Usually Used and Reasons for Not Having a Valid Fare

Just over half (55%) of the people surveyed said that they use single-fare payments (e.g., cash payment or ticket) when riding Calgary Transit. The second most common type of fare payment was a monthly pass used by almost one-third (31%) of fare evaders. When asked about why they did not have a valid fare, 17% indicated they forgot their bus pass, 13% indicated that they didn't think they would get caught, and 11% stated that the train came and they didn't have time to purchase a ticket.

TABLE 3 Top 10 Stations with the Highest Evasion Rates, 2011–2009

June 2011		June 2010		May 2009	
Banff Trail	8.0%	Sunnyside	8.2%	Sunnyside	7.5%
Downtown NW	7.5%	Bridgeland	8.0%	Stampede VP	7.0%
SAIT–JUB–ACA	7.1%	Banff Trail	6.7%	Downtown S	6.0%
Lions Park	6.4%	University	6.3%	Banff Trail	5.6%
Sunnyside	6.3%	Franklin	6.1%	Heritage	5.5%
Stampede VP	6.0%	SAIT–JUB–ACA	6.1%	Shawnessy	5.5%
University	6.0%	Stampede VP	5.9%	39 Avenue	5.4%
Crowfoot	5.4%	Downtown NW	5.3%	Marlborough	5.3%
Dalhousie	5.0%	39th Avenue	5.1%	Somerset	5.2%
Brentwood	4.9%	Somerset	5.1%	Zoo	5.1%
System rate	4.5%	System rate	4.2%	System rate	4.5%

Distance Traveled

Using departure and destination information, researchers were able to determine the number of stops travelled by fare evaders. Most fare evaders (73%) were planning to travel six or more stations. The results indicate that a small percentage of respondents (3%) were only planning to travel one station before disembarking. These results dispel the notion that customers take the chance of not paying when only riding CTrain for one station.

Frequency of Fare Evasion Checks

Survey participants were asked how many times they were checked for a fare in the last year. The majority (38%) indicated they had never been checked, 17% indicated they had been checked five or more times, followed by 14% who reported being checked twice and 13% who reported being checked once. Over half of those surveyed (58%) had received a ticket for not paying a fare in the past 5 years. A further 16% said they had received at least two tickets, while 26% said they had received three or more tickets.

Incentives to Purchasing Fares

Customers were questioned if they saw more peace officers on the CTrain system whether they would be more likely to pay a fare. Overwhelmingly (91%) of those surveyed indicated they would be more likely to pay a fare if they saw more peace officers.

Finally, fare evaders were asked to estimate the percentage of people who do not pay a fare. Interestingly, almost one-quarter of those identified as fare evaders declined to provide an estimate. Of those who did respond, 14% estimated the fare evasion rate to be 0% to 9%, 26% estimated it to be 10% to 19%, and 19% estimated it to be 20% to 29%. The remaining 40% of respondents estimated the fare evasion rates to exceed 30% of passengers.

OTHER STRATEGIES TO ADDRESS FARE EVASION

Calgary Transit has experimented with a variety of other methods to encourage fare compliance. In part, this stemmed from a peace officer initiative in 2009 called Operation Fare Warning. One of the more interesting approaches used in this operation involved CTrain operators giving a two-station advance notice of peace officer fare checks via on board announcements. Once the announcement was made, nearly 70 riders exited the train, purchased fares, and then continued their trip where they were stopped two stations further down the line. Somewhat surprisingly, an additional 29 riders made no attempt to pay and were ticketed in accordance with the CTrain operator's announcement.

Another method involves peace officers parking emergency vehicles in highly visible locations to ensure customers know that peace officers are out on the system. This performs both a reassurance role and serves to gain compliance among riders who conduct a risk–reward analysis in terms of their decision to pay.

Recently, electronic announcements have been used to alert customers that peace officers are conducting proof-of-payment checks. Figure 3 illustrates a picture of the announcement on Calgary Transit's Automated Passenger Information System (APIS).

FIGURE 3 APIS announcement (2012).

ANCILIARY BENEFITS OF FARE CHECKING

Providing for customer safety and security is a primary function of Calgary Transit peace officers. There is an important connection between fare enforcement and security. Conducting fare checks is an important component of protecting a transit system's revenue base. The presence of peace officers provides a reassurance function for customers, provides for an orderly environment, and discourages social disorder. A key aspect of what makes customers feel uncomfortable when using transit service is not necessarily crime but social disorder (e.g., the presence of apparently homeless individuals, riders using profanity, open consumption of alcohol, large groups of young people, and individuals loitering).

The best method for establishing and maintaining order on Calgary Transit's CTrain system stems from peace officers' authority to approach anyone found on the CTrain system to request proof of payment. From a social control perspective this is tantamount to throwing a safety net over the entire system. The primary benefit is to deter noncompliance, which serves as an important affirmation role among paying customers. However, an equally important role, based on the "broken windows" thesis is that there is a clear connection between regular proof of payment checking and the reduction of anti-social behavior on the transit system.

The broken windows thesis is a metaphor for a neighbourhood that tolerates visible signs of decay such as abandoned and dilapidated houses. Failure to make necessary repairs results in growing physical disorder, which leads to social disorder and subsequently increasing crime. On a transit system, tolerance of antisocial behaviours and noncompliance with municipal bylaws will eventually breed crime and disorder. Fare evasion checking represents organizational due diligence to control crime and disorder from taking root.

A recent study examining the certainty of punishment on Zurich's suburban transit system (*1*), found that efforts to reduce fear of crime in the evenings had the collateral benefit of reducing fare evasion during daytime hours. The study examined the impact of placing attendants on all trains after 9:00 p.m. Attendants were responsible for dealing with disorder and also checking the tickets of all passengers. The researchers found a dramatic reduction in fare evasion during the evening hours, and unexpectedly during daytime hours as well. The researchers concluded that certainty of punishment works as a deterrent and that the benefits from increased certainty can be maximized if checks are concentrated on critical hours and areas.

In May 2012 Calgary Transit's High Enforcement Team of peace officers wrote nearly 1,000 tickets for fare evasion during peak hours. After 1 month of operation a number of benefits and potential positive outcomes have begun to emerge:

1. Overall system disorder appears to have reduced, particularly in the evening hours;
2. Fine revenue rates of recovery are higher than overall recovery rates; and
3. A reduction by 2% of the cumulative north–west line evasion rate from 6.1% to 4.1%.

If the impact of Calgary Transit's High Enforcement Team is correct, then conducting proof-of-payment checks serves dual business objectives for Calgary Transit. First, customers who perceive a higher likelihood of being asked for proof of payment will be more motivated to purchase a fare (thereby increasing transit system revenues). Second, regular fare checks may decrease the visible signs of disorder. Finally, improved perceptions of safety may result in increased ridership, particularly during evening hours. Experience suggests that increased passenger density serves as a natural deterrent to crime and disorder, which ultimately lowers security costs.

CONCLUSION

This paper provides an overview of Calgary Transit's approach to addressing fare evasion on its CTrain system. The CTrain system consists of three lines with 37 stations and platforms, using almost 200 light rail vehicles to carry over 275,000 riders on an average weekday. The CTrain operates on the surface and is characterized as an open system in which there are no turnstiles or barriers controlling access. Consequently, Calgary Transit relies on voluntary compliance and proof of payment from customers for fare payment. Calgary Transit peace officers conduct regular fare checks to ensure customer compliance.

Calgary Transit has conducted annual surveys since 1993 to determine the extent of fare evasion and to deploy peace officer resources to encourage compliance. The fare evasion rate has ranged from a high of over 7% when the survey first began to a low of just over 1%. The 2011 rate was 4.5% based on a check of some 33,499 customers.

The 2011 fare evasion study included a unique component in the form of a survey administered to individuals identified as fare evaders. The survey provides valuable insight into the characteristics of fare evaders (equally divided between males and females; younger, in their 20s; with annual household incomes of over $35,000). The primary reasons for not having a valid fare included having forgotten their bus pass, thinking that they would not get caught without a fare, and not having sufficient time to purchase a fare because their train had arrived. Not surprisingly, the overwhelming majority of fare evaders surveyed indicated that they would be more likely to purchase a fare if they saw more peace officers.

Fare checks are an important component of protecting a transit agency's revenue base particularly for those systems operating on a proof-of-payment basis. Regular fare checks by peace officers fulfill a guardianship function providing for an orderly environment, which in turn discourages crime and social disorder. Fare checks enable Calgary Transit peace officers to approach individuals on the system to establish their legitimacy to be there. Moreover, perceptions of safety and security play an important role in attracting additional riders to a transit system particularly during evening hours. A greater number of riders acts as a natural deterrent to crime and disorder ideally attracting additional ridership.

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Seattle Sound Transit's Experiences with Proof-of-Payment Fare Collection

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This paper examines the development of the fare enforcement system used by the Central Puget Sound Regional Transit Authority (Sound Transit). The paper briefly discusses the legal authority and the board of directors' decision enabling Sound Transit to enforce fares. The paper then examines Sound Transit's fare enforcement officer selection and training program from initial development through today, showing how the program has matured based on changing conditions and lessons learned. The selection and training of fare enforcement officers is a critical factor in the success or failure of a fare enforcement program. The paper also looks at the methodology behind the standard operating procedures that were developed to maintain a random inspection pattern while severely reducing the appearance and opportunity for biased inspection or profiling. Sound Transit's rationale for warnings, citations, and theft of services is outlined in the paper, as are the processes used to sort out an evader's information. Performance measurements are also identified and discussed. At Sound Transit, the most common fare inspection and fare evasion rates are used to trend agency performance over time. Less common performance measurements, including individual officer daily contact performance and evader demographic information, along with conformance to the standard operating procedures, are also used to monitor the health of the program. Finally, the paper looks into the value of the fare enforcement officer; their role in providing for a safe, secure, and comfortable environment; and how they are the face of the agency.

INTRODUCTION

The Central Puget Sound Regional Transit Authority's (Sound Transit's) fare enforcement program began in August 2009, shortly after revenue service for the Central Link Light Rail began. Before 2009 Sound Transit conducted fare inspections, with no enforcement component, on a quarterly ad hoc basis to determine the level of evasion. The decision to operate a barrier-free system and the anticipated increase in ridership caused the need to develop a fare inspection and enforcement program.

Sound Transit's fare enforcement program establishes several goals. The crux is to verify that passengers have a valid fare. Fare enforcement officers (FEOs) also ensure that passengers are using the system for the purpose of transportation. Special emphasis is placed on the FEOs to provide information and assistance to all passengers.

The fare enforcement program has developed since inception to meet these goals. The first section provides the background to include the legal and board authority to conduct fare enforcement activities. The second section describes the FEO from selection, training, and deployment. The third section presents the methodology developed to help ensure a fair and equitable fare enforcement system and discusses the process for documenting fare evaders. The fourth section outlines the performance metrics that provide the data needed to measure the effectiveness of the fare enforcement program along with compliance to the standard operating procedures. The final section discusses the value of the FEO to the traveling public and the agency beyond the inspection of fares.

BACKGROUND

Before the opening of Sound Transit's Link light rail system in 2009, fare enforcement was not cost effective. The agency's Regional Express Bus program contracted the operations and maintenance to three local bus agencies. This contract included the enforcement of fares according to each individual agency's policies. The Sounder Commuter rail system demonstrated a low evasion rate of 1% or less during quarterly fare inspections conducted by staff volunteers. The cost associated with the establishment of fare enforcement program just for Sounder Commuter rail outweighed the benefit considering the low evasion rate. A cost benefit could not be realized unless Sounder could be included as part of a fare enforcement program that encompasses other modes of service.

The 2009 opening of the initial segment of the Central Link light rail brought a shift in the fare enforcement paradigm. The light rail would replace many of the local bus routes that provided service along the alignment's route. Ridership assumptions of a 40% increase over the first four years, coupled with an assumed evasion rate of 5% to 7% pushed fare enforcement to the forefront of the overall security plan. The fare enforcement plan called for inspection of 10% of the ridership per day with a goal to keep fare evasion at 3% or less. Inspection alone would not deter the evader. Sound Transit determined that the fare enforcement program would use the legal authority granted by state law to assess a penalty stiff enough to modify the behavior the chronic fare evader.

Legal Authority

The Revised Code of Washington (RCW) 81.112 and 7.80 allows Sound Transit to designate persons to monitor and enforce the agency's fare policy. The State of Washington recognizes these persons as enforcement officers. Enforcement officers have the limited authority to issue civil infractions under the agency's fare policy. These laws also state that a person receiving a civil infraction must produce reasonable identification. Persons who are unable or unwilling to identify themselves may be detained for a period no longer than is reasonably necessary to identify the person for purposes of issuing a civil infraction. The law also provides that the infraction-issuing agency shall adopt rules on identification and detention of persons committing civil infractions.

Board Motion

Resolutions R99-2-2 and R2009-01 establish Sound Transit's policy regarding fare payments for Sounder Commuter rail and Link light rail. Resolution R2009-02 establishes the fare enforcement policy, adopted by the Sound Transit board of directors, and sets forth the required guidance and procedures as required by state law. R2009-02 also directs the chief executive officer to establish, monitor, and keep current a program as may be necessary to implement the fare policy and fare enforcement policy. Establishing guidelines for designation of fare enforcement officers, a standardized civil infraction form, and a schedule of fines and penalties without being too prescriptive, along with the "keep current" phrase of the resolution, has allowed the program to adapt rapidly with lessons learned and to issues raised by the district courts.

Regardless of the legal authority, the success or failure of any enforcement program hinges on the people selected to carry out routine daily tasks and interact with the public. The backbone of the fare enforcement program is the selection and training of the FEO.

FARE ENFORCEMENT OFFICER

RCW 81.112.210 states that Sound Transit "may designate persons to monitor fare payment…is authorized to employ personnel to either monitor fare payment, or to contract for such services, or both." Sound Transit considered options to use law enforcement officers, employ in-house fare enforcement staff, or to contract for fare enforcement. Analysis determined that expanding the contract with the current private security provider, Securitas Security USA (Securitas), would be the most cost-effective option. Specific selection and training criteria were developed in order to provide a consistent level of qualification throughout the unit as time progresses and turnover occurs.

Selection

Securitas provides the applicants for Sound Transit's FEOs. Consideration for a position as an FEO requires an applicant must not have any prior criminal convictions and have a clean driving record. Applicants must have prior law enforcement or military experience or responsible experience in the security field. If the applicant meets the minimum qualifications, a board interview consisting of the fare enforcement manger and members of the fare enforcement team determines if an applicant has the desired traits and qualifications. Every FEO must maintain a core value of integrity; FEOs are subpoenaed to court to testify in judicial proceedings because of citations issued or theft cases they have filed.

Customer service skills and the ability to work well in a team atmosphere as well as independently are also vital in this position since FEOs interact with the public and are the face of Sound Transit to many of our customers. A willingness to learn and the ability to accept constructive criticism are also desired traits sought in applicants.

After the board interview is complete, an eligibility list for future open positions is posted based on interview ranking. Should the applicant be given a conditional offer of employment a background investigation is conducted. Once the applicant passes the background investigation, he or she begins the training program.

Training

Original Training Program

The first iteration of the fare enforcement training program was an inital 80 hours and 10 hours of annual refresher training; both relied heavily on classroom training. The initial training modeled the training programs from San Francisco Muni, Denver RTD, Charlotte CATS, and Phoenix Metro.

This training program presented several challenges. Pieced together from the programs of other agencies throughout the nation, some information did not translate to Sound Transit due to regional and systemic differences among all the agencies. Training relied heavily on classroom instruction and provided relatively little practical experience before certification. The short period of practical training proved to be inadequate from a trainee evaluation standpoint. The minimal amount of contact with the public did not allow the trainee to evaluate if fare enforcement was good fit for them. The resulting turnover was higher than anticipated and became a burden from a training perspective. A large percentage of the training relied on external sources, relying on these sources was logistically challenging creating inconsistencies and lack of uniformity in the training program.

The most challenging aspect of the training program's format was the development of the standard operating procedures (SOPs). Initially, the SOPs developed as part of the training manual were based off the material provided by other agencies. As the Sound Transit fare enforcement program grew, it was evident that the SOPs needed to expand and modify; it was soon clear that the training was not growing in a contemporaneous manner with the SOPs. The inconsistencies in the training and in the real-world application of the fare enforcement procedures made fair and consistent enforcement unnecessarily complicated for both the FEOs and the traveling public.

Sound Transit made the decision to overhaul the training program. The SOPs and training became stand-alone documents, making updates and revisions controllable. Dedicating full-time trainers and resources within the fare enforcement unit, moving from a classroom-based program to a mentor-based program, and expanding the initial and continuous training hours effectively lowered turnover and improved the ability to provide fair and consistent enforcement.

Current Training Program

New trainees for fare enforcement spend the first 40 hours in Securitas security officer pre-assignment training. This training expanded to 80 hours in response to an incident that occurred to a partner agency in the Downtown Seattle Transit Tunnel. In addition to the mandatory administrative training, each trainee completes certification in Management of Aggressive Behavior (MOAB), Practical and Tactical Handcuffing (PATH), Defensive Baton, and CPR–AED–Standard First Aid.

On completion of the pre-assignment training, the trainee will report to Sound Transit for the next phase of training. The first 40 h cover railroad safety, emergency response to rail incidents, and the FEMA NIMS 700 course. The trainee learns about security threats to transit vehicles and stations in the National Transit Institute (NTI) training videos as well as Department of Homeland Security (DHS) Frontline Responders Training Course—Terrorism Awareness:

Protecting the U.S. Public Transportation System. The trainees are oriented with various stations and specific security concerns.

The next 40 h is dedicated to learning about the fare enforcement program with the fare enforcement training supervisor. The trainee is educated in the mission of Sound Transit and the mission of fare enforcement in conducting fare inspections, providing customer service, and providing security for the system. They must learn all policies, rules, and regulations relating to fare enforcement as well as procedures on performing fare inspections in the field. These procedures include the types of fare media, contacting fare evaders, educating the public on using the ticket vending machines (TVMs), handling diverse populations, and working with surrounding police agencies. The trainee receives instruction in the use of the fare enforcement equipment, such as the radio and handheld One Regional Card for All (ORCA) readers and station equipment, including ORCA tap stands, TVMs, and emergency phones. The trainee is required to read the *Fare Enforcement Standard Operating Procedure Manual* and *Sound Transit Security Handbook*. The training supervisor ensures that the trainee observes and learns key information from each and knows where to find policy information. In addition, the trainee is required to read the informational section of Sound Transit's *Transit Guide* and several pamphlets including the *ORCA Tips and Tricks* and the *Bike Riders Guide*. The training supervisor ensures that the trainee learns key information from these guides to act as ambassadors to customers and to understand the information available to the public. A tourist map is also used to familiarize the trainee with the downtown Seattle area.

Over the next 120 hours, the trainee works with three different field training officers (FTOs) working three different rotations (morning, afternoon, and night). Each FTO mentors a trainee for four shifts during their rotation. In the field the trainee implements the knowledge gained during the previous weeks of training. The trainee will spend the first two shifts in an observational role, watching the FTO performing fare inspections. Shifts three and four include the application of skills by performing fare inspections under the guidance of the FTO. Each FTO provides daily documentation tracking the progress of the trainee.

During the last 24 h of the training program, the trainee spends 16 h with the Sounder squad observing fare inspections on the Sounder Commuter Rail. The fare enforcement training supervisor spends the final eight hours with the trainee reviewing the information and discussing the field training evaluations. The trainee then takes the final written exam and field evaluation. If the trainee passes all of the training and evaluations, Sound Transit certifies him or her pursuant to RCW 81.112.210 as a Sound Transit FEO and assigns the newly appointed FEO to his or her squad and team.

Continued Training

Sound Transit initially assumed that 10 h of continued education would be sufficient to keep the FEO's skill set current. The reality is that an FEO needs between 4 and 10 h a month to maintain proficiency. The current work schedule provides one day a week in which the schedules of both fare enforcement squads overlap. Squads take advantage of the overlap to take turns conducting training as needed.

All officers receive continuous refresher and recertification training on all use of force, safety, and policy material. FEOs are given SOP quizzes on a monthly basis to ensure they have retained and comprehended the information within the *Fare Enforcement Standard Operating Procedure Manual*. In addition, each FEO receives a field evaluation every 12 months by the

Sound Transit trainer to ensure FEOs are competent and proficient regarding all aspects of officer safety, customer service, situational awareness, as well as Securitas and Sound Transit policy and procedure.

Squads, Teams, and Schedules

The fare enforcement division operates with three squads: two squads assigned to the Link Light Rail and the third assigned to the Sounder commuter rail. The two Link squads consist of six FEOs, operating in three teams of two officers, and one supervisor. These squads operate from the hours of 0600 to 0100 h (18 h) each day. Each Link squad consists of three teams of two, scheduled to work staggered shifts throughout the day. The first team works 0600 to 1600 h. The second team works 1300 to 2300 h, and the last team works 1400 to 0001 h. Link FEOs work four 10-h shifts in a week. One Link squad works Sunday through Wednesday, and the other Link squad works Wednesday through Saturday. Wednesday is an overlap day when both squads are available. This day is for conducting any division meetings and training that may be needed.

The fare enforcement unit divides the Link light rail alignment into three fare enforcement zones in order to manage individual team activities. During the times when more than one team is working, each team will work in one of the three zones to increase visibility and ensure they are not checking the same commuters. Staggering the shifts within the squads and working in zones, the unit increases visibility and enforcement during the afternoon commute since a majority of activity occurs during these hours.

The Sounder squad consists of three FEOs and one supervisor. The Sounder squad operates Monday through Friday, from 0500 to 1900, in 8-h shifts during the commuter hours in the morning from 0500 to 0900 h (4 h) and then during the afternoon commutes from 1500 to 1900 h (4 h). The Sounder squads FEOs typically work as individuals when they work on the Sounder. They need the flexibility and availability to adjust inspection patterns to ensure every scheduled Sounder is inspected a minimum of once per week and that inspection patterns remain random. Sounder FEOs augment the Link squads during the midday period of time when Sounder commuter rail is not operating. Sounder FEOs form a two-person team to provide an additional team on Link or fill in any gaps in Link fare enforcement teams that may exist due to vacations, sick leave, or vacancies. This allows Sound Transit to maximize the amount of coverage available with the limited resources available.

FARE ENFORCEMENT METHODOLOGY

Fairness and impartiality are the key tenants in Sound Transit's fare enforcement methodology. SOPs govern the inspection process, processing of evaders, documentation, and special circumstances. Supervision ensures daily adherence to the SOPs through direct inspections of their teams, review of randomly selected video from the light rail vehicle and station CCTV systems, and verification of the validity of documentation and the data contained within. In addition to performing spot checks of enforcement processes, management monitors collected data on a weekly and monthly basis. Trending performance over time allows management to address any potential anomalies or problems on a proactive basis.

Singling out an individual or group for selected enforcement is against Sound Transit's values and policies. Perceived discrimination detracts from customers' transit experience and negatively influences public support for the fare enforcement program. Actual discrimination can expose Sound Transit to litigation and would have lasting repercussion on the agency's reputation. The inspection and enforcement processes adopted by Sound Transit and outlined below enable FEOs to accomplish their mission with a consistency shared from team to team and squad to squad. This consistency provides a common picture to the traveling public on how fare enforcement looks in Seattle, thereby minimizing the appearance of discrimination and aiding in the identification of instances when procedures were not followed.

Inspection Process

Light Rail

Onboard For the light rail system, the current operations use train consists that are generally always two light rail cars coupled with no internal pathway between each car. The light rail consist has eight doors per side, four doors per car. Station configurations only allow one side of the light rail consist to be accessed at that station. In this configuration, FEOs will wait at a platform and randomly board trains in their assigned zone. Once a train is selected at random for inspection the officers notate in their officer's notebook the time, station boarded, direction of travel, consist, and car numbers.

When the train comes to a complete stop, the FEO team selects one of the two cars and enters the same car from the opposite end once the deboarding passengers receive the opportunity to exit unobstructed. The FEOs enter the car and announce to the passengers that they will be inspecting tickets and passes. The officers then turn to their left or right and work in a clockwise or counterclockwise (depending on which door they entered) path through the car,. The officer immediately inspects the fare of the first customer in that path and continues to inspect every customer in order until that officer contacts a fare evader. Inspection interruptions occur only when an officer contacts an evader or addresses a security issue; otherwise, the officer continues until that officer meets up with his or her partner, theoretically in the middle, and all passengers are inspected.

Once inspection of that car is complete, the officers record the number of all passengers contacted and any information regarding evaders. At the next station, the fare enforcement team moves from that car to the next car of that consist. Due to dwell time constraints, the FEOs exit the first car at the door closest to the second car and then enter as a team to the door of the second car closest to the first car inspected. One FEO walks inside the entire length of the car to the opposite end while the second FEO waits at the door just entered. Once the walking FEO reaches the starting point, both FEOs begin inspections at the same time in the same manner as the first car.

Platform The Revised Code of Washington (RCW) 81.112.220 provides for Sound Transit to inspect and enforce fares within designated areas of the stations and station platforms. Sound Transit has clearly marked portions of Link light rail platforms as "Proof of Payment Required" zones. In addition to signage, no fare media vending or verifying equipment is located within the zone. That equipment has been installed prominently before the entrance to these zones. A customer would have to pass both signage and fare vending equipment with no alternate path, bypassing both in order for an area to receive designation as a Proof of Payment Required zone.

Fare inspection and enforcement share a similar process as the onboard process. Officers start at one end of the platform's Proof of Payment Required zone and announce to passengers that they will be inspecting tickets or passes and will inspect the very first passenger the officer approaches as they move toward the opposite end of the proof-of-payment zone. Every passenger is inspected in order until a fare evader is identified or the entire zone has been inspected. For larger platforms with larger zones, it is acceptable for the team to split up and inspect fares from the opposite sides of the zone and meet in the middle. Sound Transit has made a policy decision to inspect only those passengers on the platforms that are waiting to board the light rail and not those passengers exiting the light rail on completion of their trip. The exception to this decision is the inspection of "hoppers."

Hoppers Hopper is the term given to those passengers that exit the light rail after the reasonable opportunity to exit the light rail vehicle with the majority of the exiting customers and on observing the fare enforcement team enter. It has been Sound Transit's experience this behavior is indicative of persons attempting to evade fare. Under this circumstance, the fare enforcement team will deboard and contact that individual immediately on the platform for the inspection of that individual's fare. To maintain consistency, FEOs contact all hoppers unless deboarding the consist will cause a safety issue or operational delay.

Sounder

Sounder Commuter Rail is comprised of two routes. The first route runs from Tacoma to Seattle during the morning commute and reverse during the evening commute. The second route runs from Everett to Seattle in the morning and reverse in the evening. The Tacoma–Seattle commutes consist of seven trips to Seattle with two reverse commute trips to Tacoma during the morning. The evening commute is the opposite, with seven trips to Tacoma and two reverse commutes to Seattle. For every Tacoma–Seattle trip, the Sounder consists are comprised of one locomotive and seven Bombardier Bi-Level VI coaches. The Everett–Seattle commutes consist of four trips from Everett to Seattle in the morning, with no reverse commute and four trips from Seattle to Everett in the evening, once again with no reverse commute. Each of the Everett–Seattle consists are comprised of one locomotive and three coaches. Both the Tacoma and Everett consists are coupled in a manner that allows for free movement from one coach to the next while the train is in transit.

Sounder fare inspection is conducted on-board only; Sounder platforms are not proof-of-payment zones. It is typical for one officer to work during the morning commute and two officers during the evening, though the flexibility of the Sounder squad allows individual officers to adjust their schedules to meet the weekly work plan. Sound Transit requires that each commute trip is inspected at least once a week. Since the Sounder has a limited of number of total trips in a day, it is important that all trains see an FEO on a regular but random basis. Each officer submits a work plan to the Sounder Squad supervisor, who ensures that the FEO is not forming a pattern with their inspection routines and the work plan satisfies the overall inspection requirements. Once approved the FEO works the plan as detailed and reports any deviations to the supervisor.

During the inspection, the officer boards the train and locates the conductor to inform the conductor that fare enforcement activities are going to take place on that trip. Once the conductor is notified, the FEO will board on the either of the extreme ends of the consist. Inspection takes place in a linear manner moving from one end to the other. The officer immediately inspects the fare of the first customer in that path and will continue to inspect every customer in order until that officer contacts a fare evader. Interruption of inspection occurs only when an officer contacts an evader or addresses a security issue; otherwise, the officer will continue through both levels until that entire coach has been inspected. This process is repeated on all coaches.

Processing Evaders

Sound Transit defines evaders as any passenger who does not have proper fare. The goal of the fare enforcement program is to elicit compliance with the fare structure and Sound Transit rules. From the standpoint of fare box recovery, it is in Sound Transit's best interest to modify the behavior of fare evaders to purchase fares more so than writing citations. When fares are purchased, Sound Transit receives those funds. When issuing citations 100% of the fines collected stay with the county court system.

Standardization of processing fare evaders maintains consistency in the fare enforcement process, meeting goals of operational need as well as educating and modifying behavior of evaders contacted. With the exception of obviously fraudulent fare, all evaders receive a warning on their first encounter, a citation with the second and third encounters. On the fourth encounter without fare, the evader may be processed for theft of service. Every passenger contacted that involves a fare violation results in a warning, a citation, or a theft of service charge.

Warnings

It is necessary to differentiate between fare evaders and passengers that may not be intentionally evading fare. There are many reasonable explanations as to why a passenger may not have valid fare or is unable to provide proof of payment (as a rule, passengers are assumed to be unintentionally evading fare until the facts of the situation establish otherwise):

- TVMs or ORCA readers may be malfunctioning at the time the passenger boarded.
- Passengers may not understand the barrier-free system.
- A passenger may be visiting from out of town.
- A passenger may have been given inaccurate information about how to ride.
- A passenger does not understand how the ORCA tap-on–tap-off procedures work.

If a passenger has a legitimate and verifiable reason for not having fare it will be an educational encounter. If a passenger does not have a valid excuse for not possessing proper fare (e.g., did not know how to purchase) a first warning violation will occur.

An FEO identifies the passenger by asking for a state-issued driver's license or identification card. The identification card is photographed via digital camera to verify identification, date of birth, and current address; this step also gives the FEO a picture of the subject if needed. The passengers are advised that they will be entered into the Sound Transit warning log for a period of 12 months and that any future violations will result in the issuance of a citation.

Fare evaders who have received a previous warning will deboard at the next stop with the FEO. The FEO will educate the passenger on how to correctly use the system and give the passenger the opportunity to purchase fare to continue their journey and collect the required information for the issuance of a citation. Due to the low number of trips and the longer headways, Sounder passengers do not deboard but are educated to the system while in transit.

At the end of the shift, the FEO makes the proper annotations in the warning log, the notes are verified by the supervisor, and then the digital image of the identification is deleted. The warning log resides on a secure Share Point site that allows all FEOs, supervisors, and dispatchers to view the same and most current information.

Citations

On the second or third violation, the interaction between the FEO and the evader is similar to the warning procedure. If the evader does not have a legitimate reason for not having valid fare and if a records check with the Security Operation Center (Dispatch) reveals that the individual has been contacted for evasion in the previous 12 months, the FEO informs the evader that he or she will be receiving a citation in the mail. The FEO then documents the identification via digital camera and the circumstances around the evasion in a notebook. The evader is then asked to exit the train at the next stop and either purchase fare or leave the property.

At the end of the shift, the FEO makes the proper annotations in the citation log, writes the citation, and fills out the affidavit that will accompany the citation to the district court in the county the violation occurred. The supervisor ensures that all the documentation is complete and accurate and that all documents are signed and dated. The supervisor then has all the citations for the day delivered to the respective courthouses within 48 h.

Once the court receives the citations the cases become a court matter. The court reviews the citations and mails infractions to the evaders with instructions on how to pay the fine or contest the citation. Evaders who choose to contest will receive a court date and be given an opportunity to present their defense to a judge. This process allows due process for evaders by using the court to decide if the infractions are valid. This system enables an opportunity for Sound Transit to educate the public, and by arrangement, 100% of the monetary fees and fines collected by the district court are kept by the court, thus dispelling any notion that fare enforcement is a revenue-generating program for Sound Transit.

Theft of Services

Theft of services is classified as theft in the third degree under RCW 9A.56.050, which is a gross misdemeanor, punishable by up to 90 days in jail or a fine not to exceed $1,000, or both. When an FEO contacts a passenger with three or more previous contacts for fare evasion within a one-year period, the officer will request assistance from the Sound Transit Police. The responding police officer will determine whether to arrest the subject for theft in the third degree or release the subject and have him or her charged by investigation.

Should the police officer arrest the subject, the FEO composes a theft statement detailing the subject’s fare violation history and the events of the contact. Once approved by a supervisor the report will be forwarded to the arresting officer. The police officer remains responsible for the remainder of the investigation.

If police response is unavailable or the police officer requests the case to be filed through investigation, the FEO will process the investigation. The FEO will compose a theft statement detailing the subject’s fare violation history and the events of the contact, and forward the statement to the fare enforcement unit’s designated filing officer for review. The filing officer determines if the theft case meets the required elements of a theft, meets the county prosecutor's filing requirements, and determines whether to file the case through Sound Transit police. The filing officer composes the theft of services complaint. The complaint details the elements of each previous fare violation and outlines the evader's actions as intent to commit theft. The filing officer forwards two copies of the theft of services complaint form with all supporting documents to the Sound Transit Police Department for review and submittal to the prosecutor.

In 2011 the Sound Transit Fare Enforcement Unit submitted 159 theft of service cases to the Sound Transit Police for filing.

PERFORMANCE METRICS

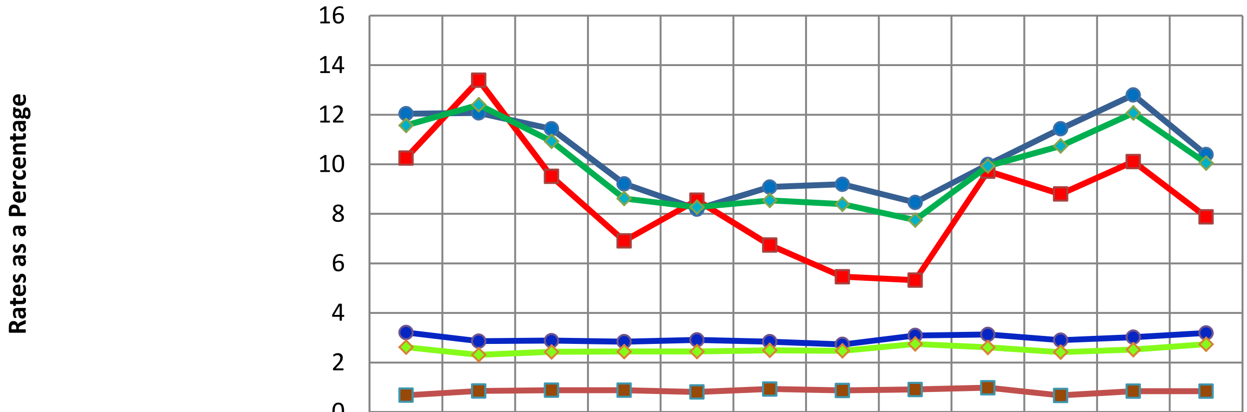
Metrics are invaluable to the fare enforcement program. Without measurements, effective management cannot occur. Sound Transit uses a variety of metrics, the chief ones are inspection and evasion rates, annual loss expectancy, the court system's citation performance, and demographics of the evader.

Inspection Performance and Fare Evasion Rates

Inspection performance and fare evasion rates provide a measurement on how successful fare enforcement efforts have been. The fare evasion rate, measured as a percentage of passengers without fare (warnings, citations, theft of service) compared to number of passengers inspected, predicts the overall evasion rate when the inspection sample is at least 10% of the total ridership. The inspection rate measured as a percent of all passengers inspected compared to the published ridership numbers indicates success in obtaining the set 10% ridership inspected goal as well as providing a baseline into required staffing needs. Figure 1 shows the 2011 inspection rates (inspections to total ridership) and evasion rates (passengers without fare to inspections conducted). The data shows that the evasion rate remains consistent even with the fluctuations in inspection rates. The evasion rates only began to rise (August and September) after a sustained period of low inspections (June and July).

Additionally the fare evasion rate can be used to express some manner of fare box recovery performance. Using an annual loss expectancy formula where the expected loss per transaction (ELPT) equals the likelihood (L) multiplied by the severity (S), and inserting the fare evasion rate as the likelihood and the average fare price as the severity, the expected loss per transaction provides a cost per fare lost to evasion. For example, using the 2011 Link fare evasion rate of 2.97% as L and $2.75 as S, then the ELPT would be $0.08 per fare lost to evasion. Multiplying the ELPT by the number of transaction per year results in a close approximation of the annual loss due to fare evasion, a direct impact on fare box recovery. Continuing with 2011 Link data, multiplying the ELPT of $0.08 with the annual ridership of 7.8 million riders (rounded), the annual loss due to fare evasion on Link for 2011 is approximately $624,000.

Comparing the nearly 3% evasion rate to the five and the 7% estimated evasion rate that may result without a proactive fare enforcement program, the ELPT (rounded) becomes $0.14 and $0.19, respectively. This would result in an annual loss expectancy due evasion of $1.09 million for a 5% evasion rate and $1.48 million for 7% using 7.8 million riders as the annual transactions. Fare enforcement efforts contributed an estimated $466,000 to $856,000 in fare box recovery.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Link Inspection Rate	12.04	12.07	11.43	9.21	8.19	9.08	9.19	8.46	9.99	11.43	12.8	10.39
Sounder Inspection Rate	10.25	13.39	9.51	6.91	8.55	6.74	5.46	5.32	9.72	8.8	10.11	7.88
Combined Inspection Rate	11.57	12.4	10.93	8.62	8.27	8.54	8.39	7.75	9.93	10.74	12.07	10.05
Link Evasion Rate	3.21	2.86	2.88	2.84	2.91	2.84	2.73	3.09	3.13	2.9	3.02	3.19
Sounder Evasion Rate	0.68	0.85	0.88	0.88	0.81	0.93	0.87	0.91	0.98	0.67	0.84	0.84
Combined Evasion Rate	2.62	2.31	2.43	2.44	2.44	2.49	2.47	2.75	2.61	2.42	2.52	2.74

FIGURE 1 2011 Sound Transit inspection and evasion rates.

Citation Performance

The performance of the citation in the court system is another metric that provides insight into how training, supervision, and procedures are working. In 2011 the Fare Enforcement Unit submitted 3,251 citations to the courts for adjudication. Of those 3,251citations, the courts issued 3,203 of them to the offenders. The courts did not issue 48 of the citations most often when the administrative 48-h deadline expired prior to submission.

The 2011 final disposition of the citations broke down to 2117 (66%) citations being committed (upheld), 127 (4%) dismissed, 17 (>1%) not committed, 411 (13%) paid; and 531 (17%) no response. The "No Response" disposition occurs when the courts issue a citation to a valid address of an evader and the evader chooses not to respond in any manner. Since the infraction is civil and not criminal, the citation is sent by the courts to a collection agency for recovery versus the issuance of a warrant or other criminal penalties. The data is interesting in that 70% of the evaders chose to contest the citations. Removing the citations where the evader just paid the fine or did not respond; 2,261 evaders chose to contest. In 2,261 contests the citation was upheld 2,117 times, giving the citations a 93.6% success rate in front of a judge. This success rate is directly attributed to the FEOs' training, the standardized procedures, and of the documentation accompanying the citation to the court. This metric provides an indication for the health of the training, procedures, and documentation, but also gauges the communication with the courts and how the public views of the citations may shift over time.

Evader Demographics

Typical of most types of enforcement, the primary complaint against fare enforcement are complaints of bias enforcement. The demographics data kept on all persons not having fare, both warnings and citations, ensure that FEOs treat all passengers fairly and equitably. Tracking the data for each officer allows comparison to the other officers and the Fare Enforcement Unit as a whole. Trending data for anomalies identifies potential concerns for addressing before complaints of discrimination or profiling. Figure 2 displays the 2011 evader demographics report for the entire fare enforcement unit.

FARE ENFORCEMENT'S ROLE IN PROVIDING A SAFE, SECURE, AND COMFORTABLE ENVIRONMENT

Sound Transit security's mission statement is to provide a safe, secure, and comfortable environment. The Fare Enforcement Unit has a key role in accomplishing that mission. Even though the unit is the dedicated resource to the inspection and enforcement of fares, fare enforcement is third on a list of three priorities. The primary priority is customer service. FEOs contacted over 1 million passengers in 2011. A fare evasion rate of nearly 3% means that 97%

2011 YTD Monthly Totals for Warnings/Citations by Age, Race, Gender

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL	%
WARNINGS / CITATIONS														
Warnings Issued	2,006	1,640	1,813	1,404	1,587	1,743	1,664	1,881	2,070	2,108	2,405	2,087	22,408	
Citations Issued	305	266	256	237	275	261	319	278	293	278	273	210	3,251	
TOTAL	2,311	1,906	2,069	1,641	1,862	2,004	1,983	2,159	2,363	2,386	2,678	2,297	25,659	
BY AGE														
Juvenille	165	133	156	146	304	141	160	166	150	150	131	95	1,897	7.40%
Adult	2,146	1,774	1,913	1,495	1,558	1,863	1,810	1,993	2,213	2,236	2,547	2,202	23,750	92.60%
TOTAL	2,311	1,907	2,069	1,641	1,862	2,004	1,970	2,159	2,363	2,386	2,678	2,297	25,647	100.00%
BY GENDER														
Male	1,453	1,173	1,265	997	1,054	1,128	1,140	1,269	1,216	1,392	1,607	1,378	15,072	58.77%
Female	858	734	804	644	808	876	830	890	1,147	994	1,071	919	10,575	41.23%
TOTAL	2,311	1,907	2,069	1,641	1,862	2,004	1,970	2,159	2,363	2,386	2,678	2,297	25,647	100.00%
BY RACE														
Asian	267	230	243	187	219	226	249	241	289	312	286	428	3,177	12.39%
Black	641	556	580	488	520	544	590	620	630	663	646	536	7,014	27.35%
Hispanic	126	97	116	95	112	97	103	118	120	142	151	99	1,376	5.37%
Indian	2	3	3	6	2	5	5	0	2	1	3	3	35	0.14%
Other	207	160	143	135	177	181	179	188	219	204	234	185	2,212	8.62%
White	1,068	861	984	730	832	951	844	992	1,103	1,064	1,358	1,046	11,833	46.14%
TOTAL	2,311	1,907	2,069	1,641	1,862	2,004	1,970	2,159	2,363	2,386	2,678	2,297	25,647	100.00%

FIGURE 2 2011 Sound Transit evader demographics.

of the contacts are with individuals using the system as intended. Therefore, using the FEOs as ambassadors to assist that 97% serves Sound Transit's interests more so than strict enforcement. The second priority is security of the passengers, revenue vehicles, and platforms. A security issue, observed or reported, suspends fare enforcement activity until those issues are fully resolved. The consistent uniformed presence and the random train inspections coupled with the close connection to the Sound Transit Police and Sound Transit's other transit security personnel provide a cost-effective security mechanism. Fare enforcement activities resulted in 190 arrests in 2011 and the removal of five illegal firearms. Those arrests, primarily warrant and drug offenses, address a small element that detract from the comfort of the majority of the traveling public.

CONCLUSION

Fare enforcement is a unique among all systems. Even in a barrier-free, proof-of-payment system; the effectiveness of FEOs may vary from region to region. The success depends largely on the legal authority, executive support, and the cultural environment of that system's local area. In the case of Sound Transit, success comes from the lessons learned in four key areas. Training that is based solely on a classroom environment and built of the programs of other agencies is a good place to start, but has a short shelf life. Having a formal and structured on-the-job training program developed from the agency's own experience in fare enforcement reduces both turnover and complaints. Using a standard methodology for conducting inspections presents a consistent picture of enforcement to the public. Consistent enforcement eliminates both the ability and perception of officers profiling. Metrics provide invaluable data to both executive management and the public on the health and value of fare enforcement. Finally, placing a higher priority on customer service is more valuable to the 97% of customers with fare versus focusing strictly on the enforcement of the 3% of customers without fare.

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Smart Cards and Proof-of-Payment
A Marriage of Necessity

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Proof-of-payment (POP) fare collection uses random inspection of fare media and fines for nonpayment to provide an economic incentive for transit riders to pay the proper fare. At any time during a trip, an individual rider may be asked to show a fare inspector a ticket or pass as proof that the fare has been paid. A quick visual check of the printed information on the ticket or pass was usually sufficient for the fare inspector to verify its validity. Today's new fare systems are using new and emerging electronic payment technologies to expand the means available for riders to pay their fares, without cash, while reducing the cost of collecting and processing the revenue. However, is POP becoming outmoded with the shift from paper to electronic media? The new payment media, smart cards, have no printed information for quick visual confirmation by inspectors; it is all encoded and electronically stored. The latest systems are neither encoding nor printing the information needed for inspectors to confirm valid payment; that information is being processed and stored at the central computer system. This paper explores the means by which POP has evolved to adapt to the new electronic environment. POP continues to be a viable and practical method of enforcing the payment of fares. There have been challenges: the need for handheld card readers to visually display encoded fare data, the inspection of fares on a vehicle when the fare is distance-based and is not determined until the destination. However, there are also benefits: more accurate tracking and reporting on inspection and evasion rates, less likelihood of evading payment by altering the fare media.

INTRODUCTION

This paper explores the means by which proof-of-payment (POP) fare collection has adapted to the environment of electronic payment technology. Application of emerging technology to transit fare collection has provided more convenient and efficient methods for transit riders to pay their fares. The technology has brought both challenges and opportunities to POP fare collection systems, which continue to be a viable and practical method of enforcing payment of fares.

PROOF OF PAYMENT: WHAT IT IS AND WHY WE NEED IT

POP fare collection is an intrinsic part of modern light rail transit (LRT) systems in the United States. The POP concept relies on the cooperation of the vast majority of riders to pay the proper fare prior to a trip and to have a valid ticket or pass in hand as POP of the proper fare. Fare inspectors routinely circulate throughout the transit system inspecting the proof of payment of passengers on a certain percentage of trains each day. Individuals found to be riding without having paid the correct fare can be cited for nonpayment and face having to pay a stiff fine as a penalty. When properly implemented, the likelihood of inspection, the amount of the fine, and the certainty of enforcement provides a financial disincentive against evading payment of the fare.

By design, POP fare collection requires no barriers—no staffed fare booths, no automatic faregates—that collect the fare as a condition for system access. Nor are riders required to board through the front door of a vehicle, where the vehicle operator checks pre-paid fare media and monitors cash payments into the farebox. Riders are free to board and alight through any door on the vehicle. Thus, POP is often referred to as barrier-free.

POP has contributed to the success of modern light rail systems in this country. It has permitted station design to be simple and affordable, without barriers and access controls. It has also enabled trains to make better time, allowing riders to board through all doors of a train when the alternative would have been filing passengers past the operator. Faster times have made the service more competitive with automobile travel. POP is an efficient method of ensuring payment of fares. A small force of personnel inspect the fare media of a small percentage of riders as a way to encourage everyone to pay the proper fare. Properly implemented, potential loss of revenue to fare evasion is more than offset by the lower cost of collecting the fares using station barrier systems.

POP was conceived in a time of printed fare media. It works on visual inspection of the fare media. With details of the fare printed on the ticket or pass, inspections are quick. Fare inspectors—working either individually or as part of a team—work to complete inspection of a bus or rail vehicle before reaching the next station.

ELECTRONIC FARE COLLECTION: NEW AND EMERGING SMART CARD APPLICATIONS

An increasing number of transit agencies are implementing contactless smart card technology for collecting fares. The smart card contains an embedded integrated circuit, or chip, onto which data can be electronically stored (and in some cases processed). Contactless smart cards communicate via radio frequency (RF) waves with reading devices in close proximity.

The contactless smart card fare payment system relies on electronically-encoded information to track an individual's trip and determine the appropriate fare. A transit rider with a smart card begins a trip by touching (tapping or tagging) the card to a field device (most commonly referred to as a smart card reader or validator). The system either verifies that the rider's pre-paid fare product (e.g., monthly pass) is valid for the trip or deducts the appropriate dollar value of the fare from the rider's e-purse; the e-purse holds the electronic equivalent of cash (i.e., in dollars and cents rather than as a monthly pass or single-ride ticket) much the same way that a bank account holds your money.

Whereas printed paper fare media is discarded once the validity has expired, contactless smart cards, typically plastic and credit-card sized, can be re-encoded (reloaded) with new fare products as the older ones expire or are depleted. These cards are intended to be used over a period of several years (typically 3 to 5 years). Less expensive paper-based contactless smart cards are also available for limited applications and are typically intended to be discarded after the encoded value is exhausted.

The design of most systems now in operation in the United States is referred to as card-based and closed loop. The term card-based refers to the fact that pertinent trip, fare, and eligibility data are encoded on the card. The cards are programmed specifically for use on the transit system and are typically issued or distributed by the transit agency; thus, the term closed-loop. Systems starting to come online in the United States are departing from the card-based approach and adopting an account-based platform. In this case, the card simply identifies an associated account holding a pre-paid fare product (e.g., monthly pass) valid for the trip or an e-purse with cash value from which to pay the fare. The account information is stored in a central database.

With a card-based system, the fare transaction is processed locally by the field device (most commonly referred to as a smart card reader or validator) and completed via communication between reader and card. Data are read from and encoded back to the card by the reader.

With an account-based system, each fare transaction is processed at the central system in the agency back office. The reader authenticates the card, transmits the card identification (ID) to the central system along with other pertinent information regarding card reader location, service line, and time and day for determining the fare to be charged. The reader then receives verification from the central system that the card is valid and the associated account has the necessary fare product or necessary funds for payment.

Interest in moving to an account-based design rather than card-based is the opportunity to expand from a closed-loop platform to an open payments one. Whereas the closed-loop system only processes cards that are specifically programmed for the system, an open payments system can accept machine-readable cards that are issued both by the agency and by third parties, including bank cards, government and corporate employee IDs, and student IDs. In an open payments system, the card reader looks for information that corresponds to a list of serial numbers that are accepted for riding on the system and then sends the ID information to the central system for processing of the transaction.

TRANSIT SYSTEMS WITH PROOF OF PAYMENT AND SMART CARDS

Public transit agencies in North America have been implementing smart card fare payment systems for the past 10 years. Virtually all of those agencies using POP have retained this approach, adapting it to work with the new electronic fare media. Agencies that have introduced smart card fare media to a POP environment are identified in Table 1. Those services with both POP and smart cards are predominantly light rail, but also include commuter rail and bus rapid transit lines as well as one local bus system (San Francisco).

To date, two transit agencies have opted to convert from POP to barrier fare collection. Metro in Los Angeles and Translink in Vancouver, British Columbia, have concluded that fare gates are a more cost-effective means of collecting fares on their rail systems. The agencies have also identified rider security as a reason for gating the stations. The fare gates are expected to allow access only to paying transit riders. LA Metro has installed fare gates at all heavy rail Red Line stations and a number of light rail stations. POP fare inspections will continue along those portions of the light rail system where station design could not accommodate fare gates. Translink is currently installing fare gates at all Skytrain stations.

TABLE 1 North American Transit Systems Where POP and Smart Cards Coexist

Agency	City	Modes w/POP	Smart Card Brand	Smart Card Start Date	Smart Card System Description	Smart Card System Characteristics
Metro Transit	Minneapolis–St. Paul	LRT, CRT	GoTo	2007	Multiagency regional system	Closed loop, card based
San Francisco Metropolitan Transportation Agency	San Francisco	LRT, bus	Clipper	2007	Eight-agency regional system (formerly Translink)	Closed loop, card based
Santa Clara Valley Transportation Authority	San Jose	LRT	Clipper	2007	Eight-agency regional system (formerly Translink)	Closed loop, card based
Caltrain	San Francisco–San Jose	CRT	Clipper	2007	Eight-agency regional system (formerly Translink)	Closed loop, card based
Los Angeles Metro	Los Angeles	LRT, BRT	TAP	2007	Seven-agency regional system	Closed loop, card based; introduced hybrid TAP–debit card
Utah Transit Authority	Salt Lake City	LRT, CRT	No brand	2007	Annual passes, contactless credit cards, and ski resort passes	Account-based, open payments; credit cards billed per ride
Houston Metro	Houston	LRT	Q Card	2008	Fare policy is stored-value only	Closed loop, card based
GO Transit	Toronto	CRT	PRESTO	2008	Multiagency regional system	Closed loop, card based; open payments planned
Sound Transit	Seattle	LRT, CRT	ORCA	2009	Seven-agency regional system	Closed loop, card based

continued on next page

TABLE 1 (*continued*) North American Transit Systems Where Proof of Payment and Smart Cards Coexist

Agency	City	Modes w/POP	Smart Card Brand	Smart Card Start Date	Smart Card System Description	Smart Card System Characteristics
King County Metro	Seattle	BRT	ORCA	2009	Seven-agency regional system	Closed loop, card based
Metropolitan Transit System	San Diego	LRT	Compass	2009	Two-agency regional system	Closed loop, card based
North County Transit District	San Diego	CRT	Compass	2009	Two-agency regional system	Closed loop, card based
Valley Metro	Phoenix	LRT	Platinum, UPass	2009	Currently, employer (Platinum) and university (UPass) only	Account-based; employer, university billed per ride
South Florida Regional Transportation Authority	Miami, Ft. Lauderdale	CRT	Easy	2009	Two-agency regional system	Closed loop, card based
Maryland Transit Administration	Baltimore	LRT	CharmCard	2010	Accepted by MTA and systems accepting SmarTrip	Closed loop, card based

NOTE: LRT = light rail transit; CRT = commuter rail transit; BRT = bus rapid transit.

ELECTRONIC FARE COLLECTION: FARE POLICY FLEXIBILITY

Systems relying exclusively on printed paper fare media have favored selling fare products with known value prior to trip start. The customer pays the full amount of the fare at the start of the trip and must be prepared to show proof of payment that is valid for the duration of the trip. In addition to the single-ride fare, this process favors the use of passes of various durations: day, weekly, and monthly passes. Electronic fare collection provides new approaches to paying a fare, made possible by sophisticated fare system processing power and data storage. These features can be customer-friendly in their ease-of-use and arguably improve fare equity among demographic groups of varying income levels. Implementing these new processes also creates a number of the challenges to POP fare-collection system.

Stored Value on E-Purse

Providing an e-purse for carrying stored value (electronic cash) on the smart card is a marketable convenience to the transit customer. In addition to being able to purchase in advance a particular fare product—day pass, monthly pass, single ride, etc.—the customer has the option of paying the fare with the electronic equivalent of cash stored in an e-purse of the smart card. The e-purse helps an agency achieve an important objective: reducing the costly collection and handling of cash. The customer benefits as well. Paying the proper fare is less of a concern with an e-purse than carrying exact change in your pocket or purse.

Stored value itself is not new. It has been the basis for paying fares on the gated systems at BART and WMATA since those rail systems began service. The smart card takes greater advantage of stored value. It provides options. The customer can load one or more pre-paid fare products on the card or carry only stored value in the e-purse. The customer can find it advantageous to carry both a pre-paid product and stored value. Carrying both enables the system to deduct from the e-purse any fare not covered by the loaded pass (e.g., an express fare upgrade for a local pass). Many transit agencies also permit a cardholder to ride when the stored value in the e-purse is lower than the fare that is due. Policies vary among agencies; however, Sound Transit permits a registered ORCA to "go negative" (i.e., carry a negative e-purse balance) if that card has been registered by the cardholder and set for automatic reload ("autoload") via credit card.

Tap-On–Tap-Off for Zone or Distance-Based Fares

Another new payment feature is applied to zone or distance-based fares. With a fare system relying on paper-based fare media, the patron determines and pays the entire fare in advance. The ticket or pass must cover the length of the trip. Fare inspectors checking fare media will see a fare valid for the entire trip.

The electronic system can emulate the paper-based process, with payment paid and checked in advance. In this case, the rider paying the fare using the e-purse presses a button on the card reader signifying the intended destination. The reader deducts the entire fare in advance and records the transaction accordingly for possible fare inspection.

Alternatively, the system can be configured to process e-purse fares when the rider is exiting the system. In these cases, the rider taps the card to the reader at the start of the journey and again at the end. This process is often referred to as tap-on–tap-off, because the riders tap the card to the reader when getting on the bus and again when getting off the vehicle. This is similar to the approach in place at barrier systems such as BART or WMATA; the difference is that there are no fare gates or other barriers to control a rider's exit until the correct fare has been paid.

The advantage of the tap-on–tap-off approach compared to tap-on only is that the former involves pressing no buttons to select the destination. Instead the customer simply taps the card at both entry and exit. Whereas the rider is responsible for selecting the correct fare with tap-on only, the electronic system does all the thinking with tap-on–tap-off. Of interest, remembering to tap-off at the end of the trip is a greater challenge than one might expect.

Caltrain originally planned to implement the Translink–Clipper card using the tap-on approach, with a series of keys for the rider to select destination. It subsequently opened the system with the tap-on–tap-off method, disabling and covering the destination keys.

Loyalty Discounts for the Frequent Rider

Electronic fare collection provides broader opportunities for offering loyalty discounts to frequent transit users. Traditionally with paper-based fare media, discounts are provided for the bulk purchase of transit, such as the annual, monthly, weekly, or daily pass. The pass might be discounted on a per-trip basis compared to the single-ride fare, based on an assumed travel frequency. The entire fare is paid in advance for these products, which then permit unlimited travel for the duration of the validity period.

One consequence of paying the entire fare in advance of travel is that any reward for frequent travel (e.g., discount for the frequent traveler) is also determined in advance of travel. Thus, the monthly pass is often discounted from the full per-trip fare based on a projected frequency of travel. For example, in Seattle a commuter riding Sound Transit to and from work each weekday would pay $105 in cash fare (21 days with a $2.50 single-ride fare), but only $90 with a monthly pass.

Electronic fare collection enables the agency to set fare caps for daily, weekly, and monthly travel. Thus, the rider pays full fare for each boarding but rides for free once the fare cap for that period has been reached. This system of frequent rider rewards is more equitable to the low-income transit-dependent rider, who rides very frequently but cannot afford the price of a monthly pass in a lump sum. Santa Clara Valley Transportation Authority in San Jose may soon implement a daily fare cap for riders using a Clipper card e-purse, in place of the existing day pass.

MOBILE FARE PAYMENT: THE GROWTH MARKET

Another form of electronic fare payment that is emerging is the mobile phone. Double-density barcodes displayed on the screens of mobile phones are gaining in popularity for a number of uses: entry to venues of special events, and boarding passes for flights giving access through airport security and at the boarding gate. Approximately half of all mobile phones are smart phones, functioning as microcomputers with web connectivity and downloaded commercially available software applications.

Mobile e-commerce is growing rapidly. The mobile phone is readily available (it is already in your pocket or purse), the customized applications are designed for ease-of-use in the mobile environment, and the customer can complete the purchase wherever there is cell phone, and in most cases WiFi, connectivity.

Because mobile e-commerce is growing so quickly in popularity, a growing number of transit agencies are introducing mobile ticketing applications. The customer selects from among a number of fare products displayed on the mobile phone screen, pays by credit card, and receives a barcode as a machine-readable proof of payment along with a customer-readable receipt in text. The e-commerce site may be linked to the transit agency website or work from a customized application that is downloaded from an online app store.

Mobile ticketing is in place on the Hampton Roads Transit light rail line (called The Tide) and on San Diego's Coaster commuter rail service, both of which utilize POP fare collection. Other agencies that are planning to introduce a mobile ticketing option in a POP environment include Dallas Area Rapid Transit, Virginia Railway Express, and Portland's TriMet, all of which use POP on their rail services.

AS IN MARRIAGE: SOME CHALLENGES

The new age of electronic fare media has brought a number of challenges for continued use of POP. It has also created opportunities to address some perceived weaknesses of POP. First, let's discuss the challenges.

Visual Inspection to Verify Fare Validity

The first obvious issue with POP is its reliance on visual inspection when there is nothing visual to inspect. Smart cards and other integrated circuit form factors typically show no visual information regarding the purchased fare or its period of validity. It is either electronically encoded into the memory of the card's circuitry or is stored in the central database. Fare inspectors must carry handheld card readers that can read and interpret the data on the card and then display it on the handheld device's screen for visual verification of validity.

A number of disadvantages have been associated with the handheld reader:

1. The device is something new to procure. It represents a new line item in the agency budget. Electronic payment media require the handheld device for fare inspection; paper tickets and passes do not. Each fare inspector needs to carry one when on duty. And even the ruggedized models may be lost or damaged during a relatively short life, requiring replacement.
2. The device must be carried by the inspectors. Typically, personnel assigned to fare inspection duties, particularly peace officers, are already carrying a number of items on their utility belt. These personnel are reluctant to carry another bulky item, particularly one that serves one function.
3. The device must be rugged and their power must last through a work shift. The battery charge on these devices varies among models and features. Built-in printers in particular can be a drain on the battery. Changeable batteries can mitigate the issue; however, this means that the extra battery must either be carried or stored in a readily-accessible location.
4. Using the handheld device to read and display encoded data typically requires more time than a quick visual inspection of printed information. An inspector can verify the printed information on several paper tickets and passes standing in a single location. The inspector with

a handheld reader must hold it to the presented card until the reader verifies validity via either audio tone or visual display.

An exception to this penalty in inspection speed appears to be in those cases where the smart card replaces the notorious eight- and 10-ride paper ticket. The multiride paper ticket must be inserted into a validator, which prints date, time, and location. In many cases, the printing by the validator is of poor quality, requiring careful examination by a fare inspector. GO Transit in Toronto reports inspection of the PRESTO smart card with the handheld reader is faster than visual inspection of the multiride tickets they replaced.

Material Record of Transaction

A patron riding on a service utilizing POP risks a heavy fine if he or she cannot show proof that the fare was paid for the trip. With the paper system, the rider can see that the fare is valid from the printed information. Electronic systems rely on tonal and visual indicators on the validator that the transaction has been completed. The patron receives no readable receipt of the transaction. There is only an electronic record of the transaction either on the card or back on the central system. The risk exists that a patron will misinterpret indicators on the platform device and will board the train thinking the card is encoded with valid POP when in fact it is not.

Immediate Verification of Payment in an Account-Based System

With an account-based smart card system, wireless connectivity between field devices and the central system is critical. A wireless handheld device that is not communicating with the central system in an account-based system cannot immediately verify that the cardholder has paid the fare. A cardholder's claim that the fare has been paid cannot be verified. A dead zone in wireless coverage, whether in a tunnel or the canyons of downtown high-rises, risks becoming a free-fare zone.

Tap-On by Pass Holders

One of the selling points of implementing a POP fare collection system on a rail line has been that those customers with a pre-paid pass would be able to board a train directly without stopping first at a ticket vending machine, validator, fare gate, or station booth. That can change with a smart card system where other objectives take priority. One of the selling points of implementing smart card technology has been that the agency gets much improved data of the travel habits of its riders. However, in order to get a complete picture of travel patterns, each rider needs to tap a smart card to record the trip and in the very least the point of origin. This requires a change in habit of many of its regular riders.

Most agencies encourage riders with smart card passes to tap their cards, but will not cite those who do not. It is difficult (some would argue unenforceable) to fine an individual who has deprived the agency not of revenue but of data. As TCRP Synthesis of Transit Practice 96 reports, Metro Transit in Minneapolis–St. Paul encourages all riders to tap their Go To cards before boarding a light rail train. Riders failing to tap their valid Go To Card pass may be escorted from the train to a validator to tap their card.

Some agencies rely on pass holders to tap their smart cards in order to receive fare revenue. Valley Metro invoices employers based on actual trips taken on each employee's

Platinum pass. Rather than citing Platinum pass holders for failing to tap, the agency has increased its public communications and marketing efforts to encourage all riders to tap their cards.

Sound Transit relies on all of its riders to tap their ORCA cards, including those loaded with a monthly pass. Because the regional Puget Passes are accepted by five agencies in the ORCA program, Sound Transit receives its share of both ORCA pass and stored value revenue based on recorded travel. Riders with a valid pass on an ORCA card will be cited and risk the same fine as a nonpaying rider if the ORCA card was not tapped prior to boarding the train. Fare inspectors will issue a warning to first offenders.

Tap-On–Tap-Off on Systems with Zone or Distance-Based Fares

Fare gates on barrier systems, such as those at BART and WMATA stations, ensure that each fare transaction is processed both on entry and exit. The exit fare gate prevents a rider from leaving the system until the correct fare is paid. The barrier-free system has no means of physically enforcing the tap-off. Financial incentives are used instead: when paying for travel using stored-value from an e-purse, transit systems have established a business rule deducting an amount equal to the highest fare on the system when tapping-on and then reconciling the correct fare for the trip when tapping-off, essentially restoring some of the deducted amount to the card or account. The challenge with tap-on–tap-off on a barrier-free POP system occurs when riders inadvertently forget to tap-off. These riders may end up paying a higher fare than necessary because the end-of-trip reconciliation has not occurred. Strictly enforcing this approach may also require riders to carry an e-purse balance that exceeds the fare of a planned trip.

Tap-on–tap-off has little effect on the inspection process. With either the paper-based or smart card-based fare system, the fare inspector is interested in confirming that the fare paid is valid for the trip at the specific time and location of inspection.

Tap-On–Tap-Off with a Short Round-Trip

This is one of the minor quirks that can be experienced with an electronic fare system utilizing tap-on–tap-off for calculating distance-based fares in a barrier-free system. The scenario goes like this: a courier is given a package to deliver to a customer downtown. It is a short trip by light rail. The courier uses a smart card e-purse to pay the fare for the trip. The courier taps-on before boarding the train to ride downtown. For whatever reason, forgetting or not tapping correctly, the courier does not tap-off at her destination. After delivering the package to the customer, the courier returns to the rail station and taps the card to the reader to begin the return trip to the home office. On the return trip, a fare inspector cites the courier for failing to tap-on before boarding. What the courier thought was a tap-on was processed by the system as a tap-off at the end of the initial ride.

A number of riders and fare inspectors have experienced this scenario on the Sound Transit Link light rail line in Seattle. The agency has identified and is implementing a series of measures to mitigate the negative impacts, recognizing that the risk of this occurrence cannot be eliminated. The measures include modifying the audio tones and visual indicators produced by the platform reader to clearly distinguish between tap-on and tap-off transactions. Fare inspectors have also been given discretion to accept this explanation from a rider when records of recent tap activity supports the claim. Sacramento Regional Transit is planning similar measures for its rollout of the Connect Transit Card as it prepares to implement a distance-based fare structure.

Last-Minute Mobile Ticketing Purchases within Sight of a Fare Inspector

Mobile ticketing provides an alternative to queuing at a ticket vending machine to purchase a ticket prior to boarding. The customer can purchase a fare anywhere at any time before the trip, whether at home the night before or immediately before boarding the train. However, can the mobile ticketing app be too convenient and quick? Conceivably, a rider might have the ticketing app set to complete the purchase the moment a fare inspector is spotted boarding the car. Timing then is everything; a delay built into the transaction process can reduce the likelihood that an individual can apply this trick successfully. On the other hand, slowing the transaction process may lessen its marketability as a convenience to the customer.

Multiple Boardings Using Mobile Ticketing

Mobile ticketing is a logical application of mobile e-commerce for travel on public transit. There are, however, notable differences between applying the concept to transit and applying it to special events or air travel. For a special event, a unique barcode is issued for each purchase. Once that barcode is read and authenticated by a reader, the transaction is recorded and the barcode can no longer be used for access. The reader is tied to a central database that is updated in real time to block use of the barcode for a fraudulent second entry.

What is unique about the transit application is that the barcode may be legitimately scanned a number of times for boarding several vehicles during a period of fare validity. Any period pass, whether a daily, weekly, or monthly pass, will involve boarding several vehicles and validating the displayed barcode each time. A single trip may also involve transferring to a second or third vehicle requiring multiple validations.

Under these circumstances, steps must be taken to distinguish between the legitimate authentic barcode and a possible clone. With insufficient built-in security, cloning a barcode on a mobile phone display can be as simple as forwarding the e-mail or text message containing the barcode or photographing the barcode using the camera of another mobile phone. Dynamic security features in the application software can foil most cloning. However, as with printed fare media, transit agencies are often in a footrace to stay ahead of counterfeiters and hackers who routinely look to defeat the latest security.

BENEFITS OF MARRIAGE

Hand-in-hand with the challenges are material benefits which are arguably improve the POP process.

Handheld Reader Benefits

While needing to equip each fare inspector with a handheld reader may be costly, the advantages can outweigh the disadvantages. Benefits include the following:

1. Inspections can be more reliable using a reader. Electronic verification is superior to visual verification for authentication of documents. Fare information printed on a paper document can be forged or altered much more easily than an electronic record digitally-encrypted onto an embedded microchip. Whereas the visual inspection can be completed more quickly, the downside is that fraudulent media is more likely undiscovered during a hasty check.
2. The reader can be programmed to store a record of each inspection transaction. Other inspection details such as the time–date–location of the inspection, plus manually entered data such as inspector ID, train and car boarded, and a tally of visually inspected paper fare media can also be captured by the device for subsequent upload to the central system. These data can be analyzed to provide statistics on the number of riders inspected, the types of fares and fare media inspected, and the numbers of violations recorded and citations (and warnings) issued. These data and resulting statistics can be far more dependable than those based on visual estimates recorded by the fare inspectors themselves. Inspection activity can be tracked; inspector productivity can be monitored, and realistic and justifiable fare evasion statistics can be publicized. As TCRP Synthesis 96 reports, prior to issuing handheld readers to its fare inspectors, Valley Metro reported a light rail fare evasion rate of 1.0%. With the handheld readers in use, reported fare evasion has subsequently been revised upward to 5.0%. Management believes that more noncompliant rides are now being identified. It is possible that both noncompliant riders and total inspections are being more accurately reported.
3. The handheld reader can function as a mobile reference tablet. The unit can be programmed to store downloaded tables of valuable records, including those of repeat offenders, outstanding warrants, and hotlisted fare cards. The device can also store reference material such as text of the code or ordinance cited for fare violations and the operating procedures to follow.

The device provides an electronic record of each violation. Handwritten entries are replaced by electronic records, generated in the field, which need not be copied and recopied. This approach provides the electronic record an increasing number of courts are requesting of traffic and parking enforcement. Police departments are interested in a number of electronic features, including electronic signature, automatic record population via driver license bar code, and photograph of violator (to match up in case of false ID). Including a printer either within or connected to the handheld reader enables the fare inspector to issue the violator a printed copy of the notice of violation, in place of the handwritten citation notice on the multipart form. The Sacramento Police Department and Sacramento Regional Transit have requested these features for the handheld readers supplied for the Connect Transit Card system.

Agencies purchasing handheld devices will find that a variety of suitable products are commercially available. The products vary in size, functionality, durability, and price. Many agencies select multifunctional mobile devices that can actually replace a number of articles that must be carried by fare inspectors (and more appropriately, peace officers assigned to inspection duties).

Countering the Perception That Large Numbers of Riders Are Not Paying Their Fares

Under the proper circumstances, the electronic fare system can actually help to counter one of the most negative perceptions about POP: the perception that everybody cheats. The perception is often worse than actual experience. For a fare system in which tickets and passes are printed on paper, riders with validated passes typically board a train directly with no action required on the platform. Under these conditions, the rider with a valid pass appears no different than a nonpaying rider. The perception is at its worst on transit systems with very infrequent inspections; inspections are the one opportunity for riders to show everyone else on the train that they are in fact law-abiding, fare-paying customers.

Establishing an operating environment in which all riders are required to tap their fare media prior to boarding can help dispel the myth that everyone cheats. Observing other riders either tapping at the platform reader or purchasing a fare at the ticket vending machine or add-value machine can reassure the patron that the other riders are good, honest citizens.

At the same time, creating the conditions which compel all riders to tap their fare media can be a challenge. Certainly, riders need to tap their cards if tapping is required to calculate the fare to deduct from the fare card, or to determine how far a rider can travel from the trip origin. Some agencies have enforced tapping of passes with the argument that it is required to ensure that the agency receives its appropriate share of revenue from the multiagency revenue pool. Agencies having a flat fare and not sharing pooled revenue may have a more difficult time creating a culture of tapping. Can a fare inspector cite a rider for a violation if the rider has failed to tap, but had previously loaded onto the card a valid monthly pass? Legally there may be no basis; simply wanting the data would not stand in court.

CONCLUSIONS

It can be argued that electronic fare-collection systems function better as a barrier system than as barrier-free. The barriers can prevent rider error. They also provide physical counter measures to potential fare evasion. However, POP fare collection is here to stay, as it must in order to keep present and future light rail systems affordable to build, efficient to operate, and attractive service to riders. POP was conceived in an era of printed fare media and has had to adapt to remain practical and even viable in the evolving environment of electronic media. It has adapted. With experience, agencies will find ways to adapt POP policies and procedures to further address the challenges and take greater advantage of the technology. The marriage of necessity may become a match made in heaven.

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Light Rail and Streetcars in Urban and University Centers

Development of Sacramento's Streetcar System Plan Using Transportation, Land Use, and Economic Development Performance Measures

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On the 25th anniversary of the introduction of modern light rail transit (LRT) service, the City of Sacramento completed a Streetcar System Plan that identifies a network of streetcar lines that will serve the Central City and adjoining neighborhoods. The plan was shaped by a quantitative evaluation of land use and economic metrics, in addition to traditional transportation data. Streetcars were a primary form of transportation in Sacramento for more than 75 years. The first streetcar line began service in 1870, two years after completion of the transcontinental railroad. As the city's population grew, streetcar lines were extended from Sacramento's rail depot to serve the "streetcar suburbs" that ringed the Central City. The modern streetcar lines planned for Sacramento will complement the region's LRT system. The streetcar network is designed to connect employees, nearby residents, and tourists with major activity centers including transportation hubs, commercial districts, entertainment and cultural venues, recreation areas, shops, and restaurants. The development of a streetcar network that meets the City of Sacramento's transportation and economic development goals was accomplished by assessing quantitative metrics for more than a dozen candidate lines. Quantitative data that was generated included property value and retail sales tax data for the economic development evaluation; population and employment data for the land use evaluation; and ridership and cost data for the transportation evaluation. The economic development, land use, and transportation data was evaluated to identify the best performing routes that should be included in the streetcar network. The data was also used to determine the top-ranked line, which is identified as the starter line. The plan also provides a forecast of economic benefits, in the form of increased property values and sales tax revenues that would occur with implementation of the starter line. The project can help inform future transit planning efforts by illustrating how a broad range of livability performance measures can be applied. The transportation assessment included a comparison of forecasts from three different types of models (trip-based, activity-based, and a direct ridership model). The evaluation process and results could also be used to help inform the future development of warrants, or quick response criteria, for streetcar lines. New urban streetcar lines are being planned in more than 30 communities throughout the United States. Many of those cities are pursuing streetcars as an economic development tool that generates benefits based on their function as a local circulator to commercial districts, major activity centers, and adjacent neighborhoods. The Sacramento Streetcar System Plan was prepared by the City of Sacramento to identify a streetcar network for the Central City area and other key destinations. The plan was jointly developed by the City of Sacramento's Department of Transportation and Economic Development Department. The purpose of the plan was to provide more attractive travel choices, enhance transit and

pedestrian accessibility, support economic revitalization, and connect activity centers. The planning approach used to evaluate alternative routes or route segments, which was based on performance metrics derived from the transportation and economic development goals described above, is presented. The metrics were combined and equally weighted to identify the most productive route options as well as a preferred starter line. The following key performance metrics were evaluated: (*a*) Existing Population + Employment per track mile (in ¼-mile catchment area); (*b*) 2035 Population + Employment per track mile (in ¼-mile catchment area); (*c*) Existing Annual Retail Sales per track mile (within 1 block); and (*d*) Daily Ridership.

BACKGROUND

Five years after the Sacramento Area Council of Governments (SACOG) adopted a landmark Blueprint Vision (2004) for the region—which promotes compact, mixed-use development and more transit choices as an alternative to low-density development—the City of Sacramento and Sacramento Regional Transit District (RT) adopted long-range plans that support implementation of the Blueprint and laid the groundwork for the Sacramento Streetcar System Plan.

The City of Sacramento's General Plan Mobility Element, adopted in 2009, contains policies for a well-connected transportation network that offers attractive choices among modes and supports increased densities and a mix of uses in multimodal districts. The general plan also explicitly supports the development of streetcar lines in the Central City and other multimodal districts. The Transit Action Plan, adopted by the Sacramento RT the same year, calls for implementation of a system of streetcar lines throughout the region. The Transit Action Plan calls for these new streetcar lines to be integrated with existing intercity rail and light rail transit (LRT) lines that serve the region.

The City of Sacramento initiated preparation of the Sacramento Streetcar System Plan in 2011, with an overarching goal of developing a network of streetcar routes to serve the Central City and other key surrounding destinations. The streetcar network and starter line recommendations were established by undertaking an alternatives analysis using performance metrics that reflected the city's broad transportation, economic development, and land use goals.

The project can help inform future transit planning efforts by illustrating how a broad range of livability performance measures can be applied to develop transit plans, showing the value of using models or other forecasting tools that include greater sensitivity to the demographics and service characteristics that drive streetcar ridership, and informing the future development of warrants, or quick response criteria, for streetcar lines.

STREETCAR PLANNING PROCESS

The planning process employed to identify a streetcar network plan for the City of Sacramento is consistent with the requirements of a formal alternatives analysis as defined by FTA. This approach was employed to set the stage to pursue federal funding for one or more of the streetcar lines.

A purpose-and-need statement was developed early in the process to guide the screening and evaluation of streetcar routes. The purpose-and-need statement was born from the logical pairing of community goals with identified transportation deficiencies.

Three sequential planning stages, as shown in Figure 1, were undertaken to develop the streetcar network:

- Stage 1: route screening,
- Stage 2: route evaluation, and
- Stage 3: streetcar network development.

Stage 1. Route Screening

The purpose of the Stage 1 route screening was to select the most promising streetcar routes for the more detailed Stage 2 evaluation. The first step in this stage was the identification of key activity centers that should be served by streetcar lines as well as candidate streets that would both be ideal for streetcar lines and connect the activity centers. The key activity centers and streetcar-friendly corridors were identified through a series of brainstorming sessions with the Citizen's Advisory Committee, Business Advisory Committee, and Technical Advisory Committee, which were formed specifically for this project.

The initial screening process then filtered out routes that were cost-prohibitive due to physical barriers, lacked adequate connections to activity centers, were duplicative of existing transit service, or were forecasted to have low ridership potential based on existing and planned development. A total of 12 streetcar routes and route segments were identified for the Stage 2 evaluation.

Stage 2. Route Evaluation

The purpose of the Stage 2 evaluation was to identify the top-performing routes based on a more detailed quantitative analysis of a series of transportation, land use, and economic development performance measures. The evaluation criteria developed for this stage were borne largely out of an effort to assign value to the elements of the purpose-and-need statement.

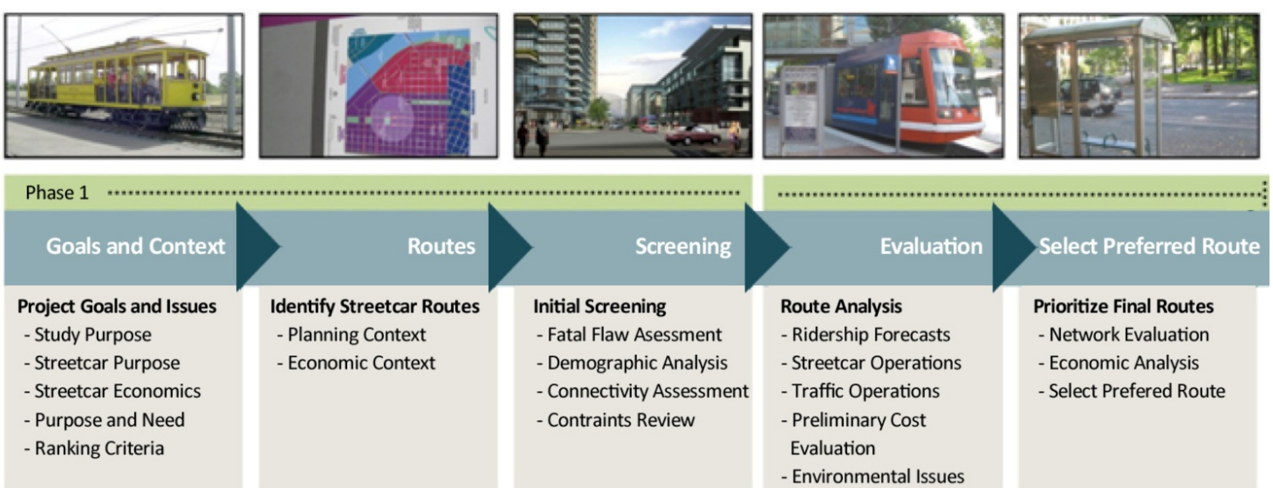

FIGURE 1 Planning process for Sacramento Streetcar System Plan.

Stage 3. Network Development

The purpose of the Stage 3 evaluation was to refine and optimize the top performing routes to establish an optimal streetcar network based on system factors such as ridership, efficiency, and other external positive impacts (e.g., enhanced economic growth, land use, air quality, and more).

PURPOSE OF STREETCAR SYSTEM

The multiple objectives of the Sacramento Streetcar System were established based on input from elected officials, agency staff, and representatives of a broad range of community organizations including business and neighborhood interests. They are based on a combination of policy goals, community values, needs, and transportation deficiencies.

- Create a network of streetcar routes that complements existing rail and bus service in the Central City, giving people more attractive travel choices.
- Help people get around the Central City area quickly and comfortably without their automobiles, extending the range they could walk in a given time period.
- Support the revitalization of neighborhoods and business districts in the Central City.
- Bring people to and from the intermodal transportation facility (i.e., downtown rail depot) where Capital Corridor, Amtrak, and future high-speed trains will connect Sacramento to other cities.
- Connect employment centers, commercial corridors, transit supportive residential neighborhoods, future development areas, visitor destinations, and other major activity centers.
- Enhance the identity of Sacramento's unique districts and neighborhoods.
- Support the city's green initiative by reducing the growth in energy use and air pollution and greenhouse gas emissions caused by transportation.

PERFORMANCE MEASURES

The following performance measures, which were derived largely from the streetcar purpose described above, were used to assess the 12 candidate route segments identified for more detailed evaluation in Stage 1 of the planning process:

- Transportation:
  - Projected ridership;
- Land use:
  - Population and employment per track mile:
    - Existing,
    - 2035, and
    - Growth, from existing to 2035; and
- Economic development:
  - Current retail sales data per track mile, and
  - Current property tax data per track mile:

- Taxable acres with no improvement value (vacant land) and
- Taxable acres with improvement to land value ratios less than 1.0 (underutilized land)

The identification of performance measures also took into account the Livability Principles established by the U.S. Department of Housing and Urban Development (HUD)–Environmental Protection Agency (EPA)–Department of Transportation (DOT) Partnership for Sustainable Communities and recent indications by FTA as to how those principles might be incorporated in new rules and guidance for the New Starts–Small Starts programs.

The following is a summary of the U.S. HUD–EPA–DOT Livability Principles:

- Provide more transportation choices;
- Promote equitable, affordable housing;
- Enhance economic competitiveness;
- Support existing communities;
- Value communities and neighborhoods; and
- Coordinate and leverage federal policies and investment.

FTA has taken a number of steps to update the rules and guidance for the New Starts–Small Starts programs, which provide federal funds for major transit projects, since the last U.S. transportation reauthorization legislation [Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)] was signed into law in 2005. This includes the 2007 Updated Interim Guidance on Small Starts, which provided the first guidance on the Small Starts program created under SAFETEA-LU, as well as the 2009 guidance that included new weighting values for project justification criteria for the New Starts and Small Starts programs. In January 2012 FTA released a series of proposed comprehensive changes to New Starts–Small Starts policies and procedures in a Notice of Proposed Rulemaking (NPRM) and Policy Guidance. The 2012 NPRM identifies the following three proposed evaluation criteria for the Small Starts program, the program where most local agencies will likely pursue federal funds for streetcar projects:

- Cost-effectiveness (based on cost per trip of the project);
- Economic development effects; and
- Existing land use, transit supportive land use policies, and future patterns.

TRANSPORTATION METRIC

The transportation metric for the Streetcar System Plan was the number of streetcar trips generated for each candidate route segment for the 2035 horizon year. While this type of ridership metric is common in transit studies, this study took a unique forecasting approach that relied on three different models as described below:

- **Trip-based model**. Initial ridership forecasts were prepared using the SACMET four-step travel demand model developed originally by SACOG for use in preparing regular updates to the metropolitan transportation plan (MTP) and other regional planning efforts. The horizon year, land use forecasts, and future transportation network in the MTP version of the regional travel model were used as a baseline for the Streetcar System Plan evaluation.

- **Activity-based model**. Once the initial forecasts were developed using SACOG's four-step travel demand model, supplemental forecasts were prepared for the highest performing route using SACOG's SACSIM activity-based model, which includes enhancements to transit forecasting by directly including the influence of population demographics.
- **Direct ridership model (DRM)**. As a final forecasting check, a DRM was developed and applied based on a regression formula estimated from ridership, demographic, network, and service characteristic data from the three modern streetcar lines (Portland, Seattle South Lake Union, and Tacoma) in the western United States. The forecasts developed using the DRM were for an opening day scenario. Key variables included urban density (a measure of retail intensity and residential density of the station area), special event center size, number of feeder trains (a measure of the magnitude of regional transit connections), start of line stop (accounting for larger catchment area), distance to nearest stop, stops to end of line (a measure of the how many potential destinations are accessible by stations on the remainder of the line from the boarding station), and fare level.

The SACSIM and DRM models projected substantially higher ridership for the highest performing streetcar route than the four-step travel model. Possible explanations for the difference included the greater sensitivity of the SACSIM model to demographics and the DRM containing variables that have a demonstrated relationship to streetcar ridership.

For planning purposes, the ridership forecasts for the 12 candidate route segments were separated into one of three ranges:

- Less than 1,000 daily riders,
- 1,000 to 3,000 daily riders, and
- More than 3,000 daily riders.

LAND USE METRICS

The land use metric for the Streetcar System Plan was the total population and employment in a catchment area a distance of ¼ mi from each candidate route. Land use data was generated for existing, 2035 conditions, and the increment of growth between existing and 2035 conditions. The data was derived from parcel level information developed by SACOG for their regional travel models. The data was imported into a geographic information system, which was used as the tool to calculate catchment area totals for each route option. All population and employment values were normalized on a per track mile basis.

Figure 2 shows how the population and employment data were shown visually, in a 3D format, to supplement the route-level numerical results show how the densities (i.e., on a population and employment per square mile basis) varied along the route. Figure 2 shows year 2035 data for the recommended starter line.

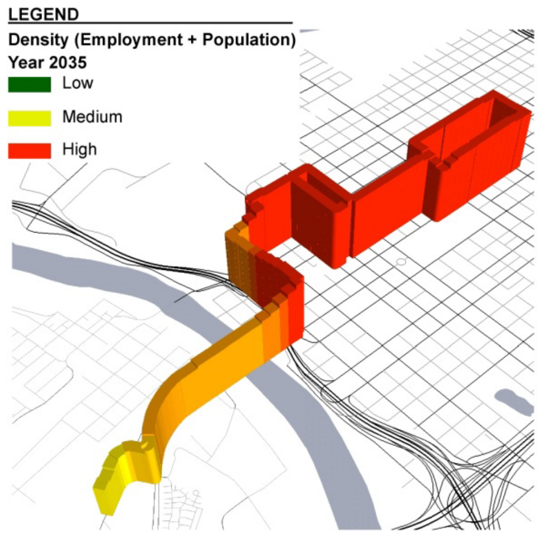

FIGURE 2 Population and employment for recommended starter line.

ECONOMIC DEVELOPMENT METRICS

Three different economic development metrics were used for the Streetcar System Plan including existing retail sales, the number of acres of existing vacant land, and the number of acres of existing underutilized land. The existing retail sales were viewed as an indication of the retail stimulus potential that any candidate route segment might have for existing businesses. The number of acres of existing or underutilized land was viewed as an indication of the development or redevelopment potential of a given route. The economic development data were generated for a one-block and three-block (i.e., approximately ¼-mi distance) catchment area for each route. All economic development values were normalized on a per track mile basis.

The retail sales tax data was generated by City of Sacramento staff for the 2010 calendar year. Sales tax data could not be provided for individual properties, due to state privacy laws. As such, city staff provided data on total retail sales for each catchment area.

The property value data was publicly available information provided by the Sacramento County Assessor's Office at the individual parcel level. The data that was evaluated includes taxable property only and does not include property owned by government agencies such as the State of California or City of Sacramento. The properties identified as underutilized included all parcels where the ratio of improvements (i.e., structures) to land value was less than one.

EVALUATION RESULTS

The location of the 12 candidate route segments that were evaluated are shown in Figure 3. Table 1 shows six of the performance metrics developed for the route segment alternatives including daily ridership, population and employment data, existing retail sales data, and existing vacant property.

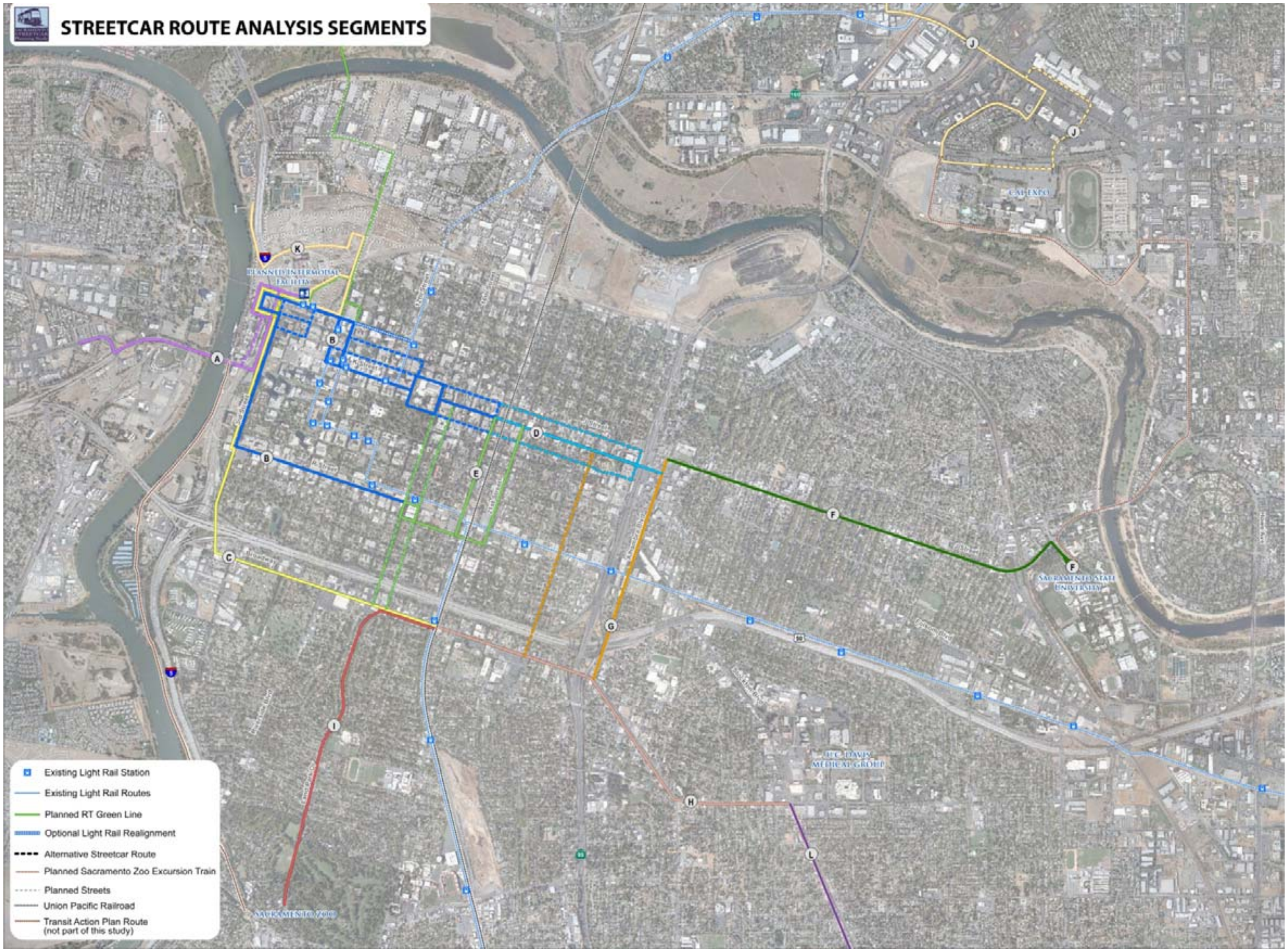

FIGURE 3 Streetcar route analysis segments.

TABLE 1 Performance Metrics for Sacramento Streetcar System Plan Study Alternatives

	Travel Metric		Land Use Metric (data per track mile, in ¼-mi catchment area)		Economic Development Metric (data per track mile, within 1 block)	
Alternative	**Daily Ridership**	**Existing Population + Employment**	**2035 Population + Employment**	**Growth in Population + Employment**	**Existing Retail Sales ($millions)**	**Existing Vacant Property (acres)**
A	1,000–3,000	5,600	12,200	6,600	$15.1	2.2
B-1	<1,000	10,900	16,000	5,100	$6.9	4.7
B-2	>3,000	20,500	24,400	3,900	$54.8	7.4
C	1,000–3,000	5,200	8,200	3,000	$15.8	9.6
D	1,000–3,000	14,600	15,400	800	$61.5	3.3
E	1,000–3,000	13,800	15,900	2,100	$60.2	10.3
F	1,000–3,000	4,000	7,000	3,000	$11.8	5.8
G	<1,000	6,900	7,700	800	$23.1	8.2
H	1,000–3,000	3,900	4.300	400	$7.1	5.7
I	1,000–3,000	2,400	2,600	200	$8.3	1.5
J	1,000–3,000	3,100	3,500	400	$121	4.2
K	1,000–3,000	5,300	15,000	9,700	$0	21.2
L	1,000–3,000	2,300	2,700	400	$14.3	10.3

Alternatives A and B-2, highlighted in green in Table 1, were combined to form a 3.3-mi-long recommended starter line based on a strong overall performance in all three performance areas. This route will serve a catchment area with the highest current population and employment density, as well as the two largest redevelopment projects, in the study area.

Three of the alternatives (G, I, and L), highlighted in yellow, were not included in the system plan because of their low performance levels. Alternative B-1 was included in the plan, despite a relatively low projected ridership, after modifying its planned route alignment to avoid duplication of service area with an existing light rail line.

The metrics were combined and equally weighted to identify the most productive route options as well as a preferred starter line. The best performing routes or route segments share the following characteristics.

- Existing population + employment per track mile (in ¼-mile catchment area) > 10,000.

- 2035 population + employment per track mile (in ¼-mile catchment area) > 15,000.
- Existing annual retail sales per track mile (within one block) > $15 million.
- Daily ridership > 1,500.

STREETCAR SYSTEM PLAN

Figure 4 shows the recommended streetcar network identified in the Sacramento Streetcar System Plan. The streetcars proposed for Sacramento would operate in mixed-flow traffic along with cars without any physical lane separation. The planned streetcar vehicles are modern, electric, and low-floor eliminating the need for steps on the streetcars or elevated platforms at the stops. This is consistent with the region's plans to convert the LRT fleet to low-floor vehicles over the next decade.

Four primary streetcar routes or route segments, located within the core of the Central City, comprise the heart of the Sacramento Streetcar Network. These four routes, labeled A–D in Figure 3, represent the highest performing lines. They are located in the area bounded by the Sacramento River on the west, H Street on the north, Broadway on the south, and the Union Pacific Railroad tracks (between 19th and 20th Streets) on the east. These routes can be operated independently, as phases, or part of a loop configuration once all the lines are constructed.

Two streetcar routes, labeled E and F in Figure 3, are recommended in areas planned for major development or redevelopment. This includes the Railyards and River District areas (Route E) and the Arden Fair Mall–Cal Expo areas (Route F). These routes all feature connections to one or more LRT stations.

Three route extensions, labeled G–I on Figure 3, would serve areas east of the central business district including the Midtown district, the California State University at Sacramento Campus, and the University of California, Davis Medical Center. The Union Pacific Railroad presents a significant constraint for extensions of the streetcar network east of 19th Street. Union Pacific (UP) must consent to new crossings of their freight rail lines. In the planning process for this streetcar network, the implementation of new bridges or tunnels across the UP rail line to support these future streetcar extensions, was assessed and deemed infeasible due to the impact on access to adjacent residential and commercial buildings. Despite the challenges associated with obtaining approval for an at-grade crossing of the UP freight line, it was the consensus of City of Sacramento and Regional Transit staff that potential extensions along the L Street–J Street corridor (to the Midtown district, East Sacramento neighborhood, and the California State University at Sacramento campus) and along the Broadway corridor (to the Oak Park neighborhood and the University of California, Davis Medical Center) be included in the streetcar network.

Route A, the recommended 3.3-mile starter line that spans two cities and two counties and crosses the Sacramento River, will serve the following major activity centers or destinations in the study area:

- City of West Sacramento Civic Center and Transit Center;
- Raley Field (AAA Major League Baseball park for Oakland A's, with year-round activity);
- Sacramento River;
- Old Sacramento Historic District (along Sacramento River);

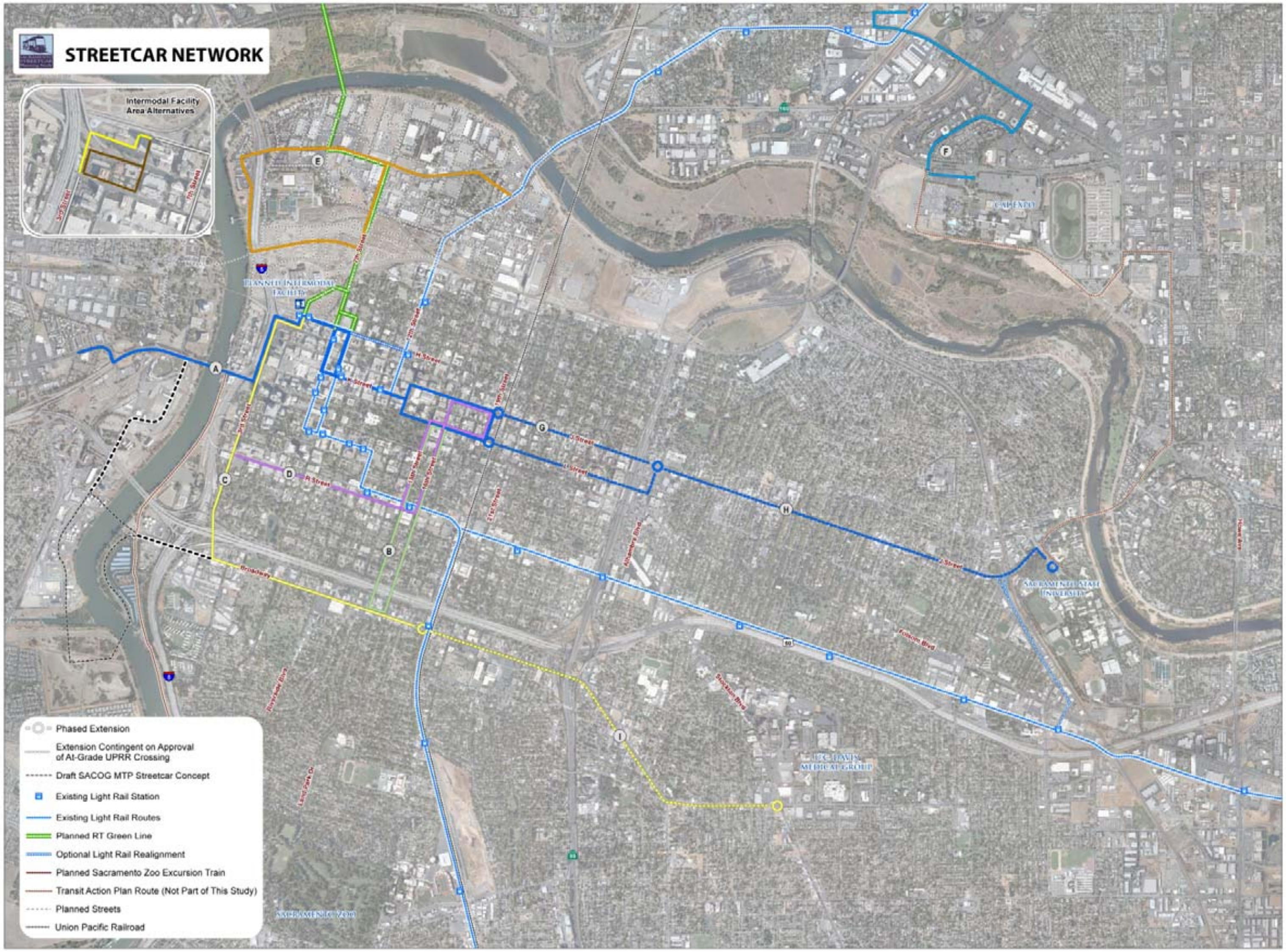

FIGURE 4 Recommended streetcar network.

- Sacramento Intermodal Terminal (i.e., Rail Depot);
- Two major redevelopment areas, the Railyards District and Bridge District;
- Sacramento's central business district;
- Westfield Downtown Plaza Mall (shopping center);
- California State Capitol Building;
- Sacramento Convention Center and all major downtown Sacramento hotels; and
- Multiple entertainment venues (Crest Theater, Community Center Theater, Memorial Auditorium, Music Circus).

Figure 5 shows the projected ridership for the starter line, along with the key activity centers at each of the stop locations, for opening day conditions.

CONCLUSION

The application of a broad range of livability performance measures, for those agencies that share similar policy priorities, can lead to the development of transit plans and the selection of individual transit projects that meet multiple community objectives and thereby justify the investment of federal and local funds. The data needed to gauge the land use and economic development performance measures for this project were readily available from the regional and local planning agencies.

Ridership forecasts were developed to inform the strategic planning process using three different models (trip-based, activity-based, and a direct ridership model). The trip-based model predicted a level of ridership that was much lower than the activity-based and direct ridership models which predicted similar ridership levels. Possible explanations include a greater sensitivity of the activity-based model to demographics and the nature of streetcar trips (i.e., large share of off-peak, nonhome–based trips) and the focused streetcar variables included in the direct ridership model that were derived from modern streetcar lines in Portland, Seattle, and Tacoma.

The evaluation process, performance measures, and results could be used to help inform the future development of warrants, or quick response criteria, for streetcar lines. Candidate streetcar lines that were eliminated from future consideration did not meet one or more of the following goals or thresholds:

- Avoid duplicating service provided by existing fixed guideway transit line,
- Existing population and employment density per track mile (for ¼ mi catchment area) of 2,500 or more, and
- Existing annual retail sales per track mile (for ¼-mi catchment area) of $10 million or more.

The best performing routes or route segments share the following characteristics:

- Existing population + employment per track mile (in ¼-mi catchment area) > 10,000,
- 2035 population + employment per track mile (in ¼-mi catchment area) > 15,000, and
- Existing annual retail sales per track mile (within one block) > $15 million, and
- Daily ridership > 1,500.

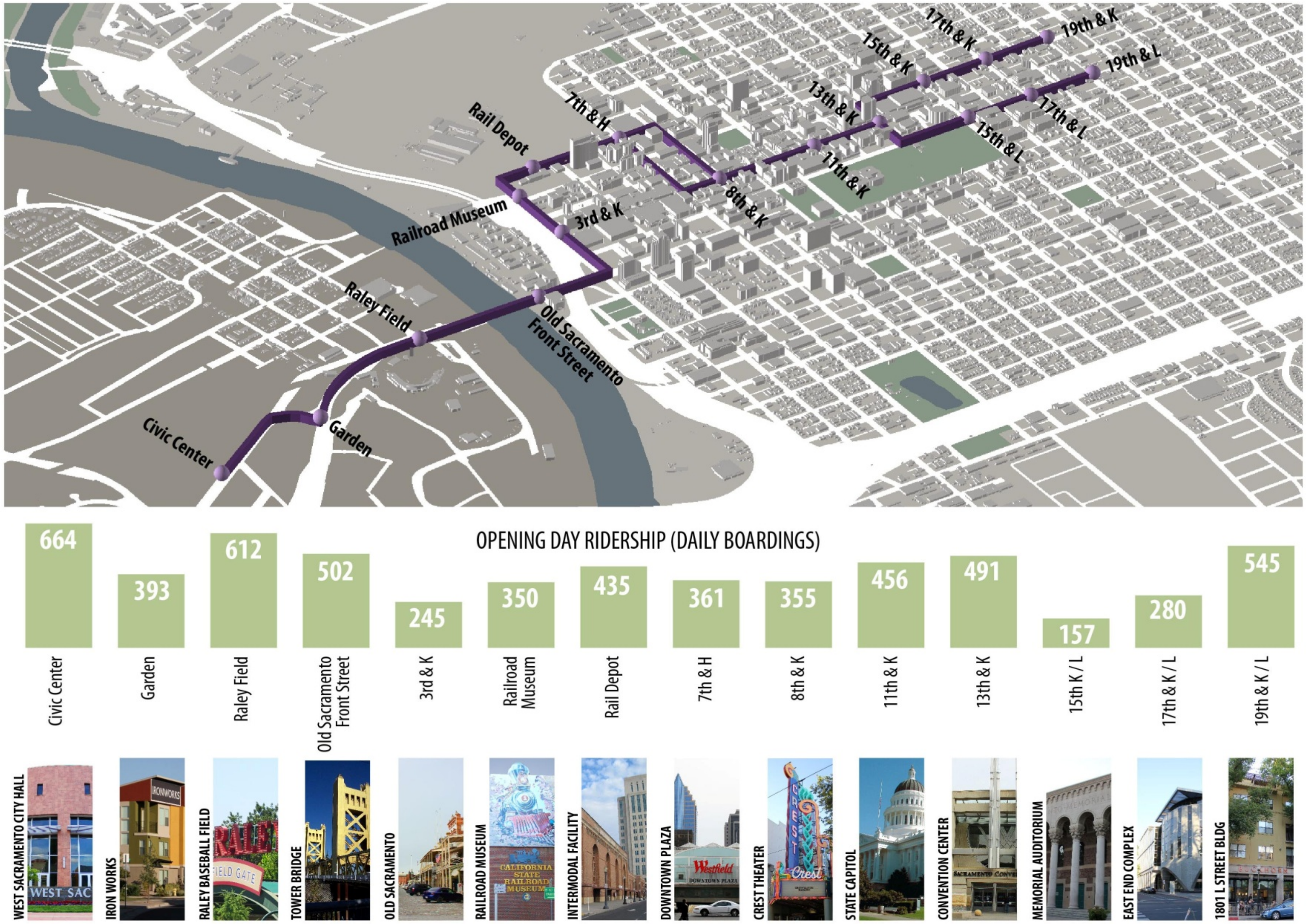

FIGURE 5 Projected ridership for recommended starter line.

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Light Rail Through a University Campus
The Purple Line and the University of Maryland

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The Purple Line is a proposed 16-mi light rail line in the Washington, D.C., suburbs that will pass through the heart of the University of Maryland at College Park, the flagship campus of the Maryland state school system. The university has long supported the Purple Line, but as the Maryland Transit Administration (MTA) worked to developed conceptual plans to build the Purple Line through the campus, a number of concerns were raised by the university. Concerns included pedestrian safety, electromagnetic interference, traffic, vibration, visual impacts, and noise. Most of these concerns are typical of concerns raised by communities faced with the introduction of a new transportation mode. The question is "What is different about a university?" Most important is the fact that the university is a single entity that has sole responsibility for everything that occurs on campus. In most locations the agency planning a transit system must deal with a wide range of stakeholders, the university on the other hand is one institution, speaking with one voice. At one point it appeared that the MTA and the university would not be able to reconcile the needs of the project with the concerns of the university, but now the project is moving swiftly forward. So how has the MTA worked through the issues with the university?

PROJECT OVERVIEW

The Purple Line is a proposed 16-mi light rail line in the Washington, D.C., suburbs, currently being planned and designed by the Maryland Transit Administration (MTA). It is located in Maryland just outside the District of Columbia boundary in older, established, inner-ring suburbs. The Purple Line is a circumferential route linking four branches of the radial Washington Metrorail system. The corridor is built out and contains a mixture of residential communities, retail and entertainment destinations, and institutions and major employment centers. The Purple Line will pass through the heart of the University of Maryland at College Park (UMCP). This is the flagship campus of the Maryland state school system; it is also the location of University of Maryland University College (UMUC), a comprehensive virtual university aimed at the adult student. The Purple Line will be valuable to the university, and likewise the university will be valuable to the Purple Line.

The university generates three distinct sources of student and visitor trip markets:

1. UMCP students, staff, and visitors. With more than 37,000 students and 13,000 employees, the university is the county's largest employer, making the university an important travel market for the Purple Line. There is no on-campus housing for graduate students, and

some years as many as 1,500 undergraduate students do not have on-campus housing, resulting in a large population of commuting students.

2. UMCP special events. The university campus is the site of many major sport and cultural events, including basketball, football, and numerous other sports events and tournaments, as well as concerts and similar cultural activities that bring several hundred thousand visitors to the campus throughout the year.
3. UMUC events and students. UMUC is primarily a distance-learning campus, but it does have on-site teaching facilities and activities, as well as a hotel and conference center at its campus immediately west of the main UMCP campus. There is a commuter student population that would be directly served by the Purple Line's West Campus Station.

Despite its size and proximity to Washington, D.C., the university campus is not directly served by the regional Metrorail system. When the Metrorail Green Line was being developed, political and community controversy shifted the line and station away from the University of Maryland campus to a location about 1 mi from the eastern edge of campus. The university provides a shuttle service between campus and the Metro station 22 h a day, with 6-min headways during peak periods. The university operates an extensive bus shuttle system connecting the university to the surrounding neighborhoods, and two other local providers, WMATA Metrobus and Prince George's County TheBus, serve campus, providing connections to the local region and other transit services.

The university has long supported the Purple Line, understanding the benefit of having quality transit service to campus and connections to the larger region, and supporting reduced reliance on automobiles and a reduced demand for parking on campus. However, once the MTA began developing conceptual plans for the Purple Line through the campus, the university began to consider the changes that would have to occur, and a wide range of concerns were raised by the university. Most of these concerns were typical of concerns raised by communities faced with the introduction of a new transportation mode. Fears about pedestrian safety, impacts to traffic operations, noise, vibration, and crime were raised. An additional concern was raised: the potential adverse impacts of electromagnetic interference (EMI) on university research activities. All of these concerns had been raised elsewhere in the corridor, although EMI only rarely, and then generally in reference to concerns about whether there were safety issues or emissions from the overhead wire system. What was different was that all these concerns were raised by one entity, and that entity was a major stakeholder with substantial influence.

WHAT IS DIFFERENT ABOUT A UNIVERSITY?

The question is what is different about a university? A university is far more than simply a place of employment or activity. Universities are almost a little world separate from the "real world." The word intramural (meaning inside the walls) reflects the fact that originally universities were walled. The campus as a place has a special value to students, faculty, and alumni. Change is not to be taken lightly.

The university administration is a single entity that has sole responsibility for everything that occurs on campus. In most locations the agency planning a transit system must deal with a wide range of stakeholders: the department of public works for roadways and traffic, local utility companies, the local planning authority, residents, local businesses and institutions, and elected officials. Each one of these stakeholders may have very different concerns and even among themselves may not have a monolithic position. There will be relationships between these stakeholders, but as planners and engineers, we will most likely deal with them individually.

The university on the other hand is one institution, speaking with one voice. This is not to say there is not a diversity of opinions on campus, but the official voice is one. The university is responsible for the campus and the people on campus (students, faculty, and staff). It is responsible for the roads and how they operate, the buildings, the utilities, the transportation system, and the image of campus: its aesthetics, architecture and landscape, and its legacy. The university's responsibility for the physical plant and its operation and future growth puts the university in a role not dissimilar to a commercial developer with concerns about use, value, and function.

The university has to protect the students physically; pedestrian safety and crime are concerns on all university campuses. The university also has to keep the students happy; the students are their customers. While the university will make the decision it thinks is right, even in the face of student opposition, no administration wants student opposition. However, the student population is transient, generally only at the institution for 4 years.

Faculty and researchers are long-term constituents. The university has to protect the researchers by ensuring that they have the environment and facilities they need to conduct their research. The competition for research grants and funding is fierce, and the success (or not) in attracting the top researchers affects the prestige, and by extension the enrollment, of a school.

A university has sole responsibility for this broad range of topics and it is habituated to making decisions independently. These large institutions are not typically used to working cooperatively with outside entities. They prepare master plans and make decisions based on their own needs and vision, generally consulting or coordinating with a limited number of stakeholders.

Another group the university takes into account is the alumni. Alumni are often resistant to physical changes to the campus that would make things different from when they were students. A new or enhanced building, whether a classroom, laboratory, or stadium is clearly recognized as an asset, but the addition of light rail may not seem like an asset to the alumni who may not understand the need and the potential benefits. As noted above, the university will make the decision it feels is best in the long term for the school, but alumni opposition may be more problematic than student opposition.

Pedestrian safety is a particularly sensitive topic because university campuses have very high levels of pedestrian activity. Given the levels of pedestrian activity, the fact that campuses generally have less vehicular traffic than off campus may not be apparent. The interaction between small numbers of cars and very large numbers of students will create the impression of a major congestion problem. Because of the numbers of pedestrians, even where the campus is not actually car-free, pedestrians (and students in particular) may have the expectation that they are walking in a car-free area. Pedestrians are less likely to watch carefully for vehicles in this type of environment. Introducing a new transportation mode requires cognizance of the character and environment in which it will operate; this is particularly true of light rail transit (LRT) because it operates so quietly.

The relationship between the university and the students is a special one. Undergraduate students are living away from home for the first time. They are developing skills and independence; but they are not yet adults and the university plays a parental role, part of which is providing a safe environment. Light rail is uniquely suitable for areas of heavy pedestrian activity, but universities are right to be cautious where safety is concerned, and light rail planners and engineers should respect this in their coordination with a university.

The University of Maryland, as a public institution, must also answer to an appointed Board of Regents, and ultimately the governor and other elected officials. This means that state-level policy positions may affect the university's stance, but it also means the university can be subject to political pressure, often behind the scenes.

THE UNIVERSITY'S CONCERNS

Situated just outside Washington, D.C., the university does not have direct rapid transit access to downtown Washington or the larger region. Like most universities today the demand for parking on campus has been steadily increasing, and the university is now beginning to replace the many large surface parking lots with structured parking, an expensive proposition. The University of Maryland understood the potential value of the light rail to the campus, but the devil is indeed in the details. Exactly what and where the Purple Line would be was far more challenging than expressing general support.

The MTA developed various conceptual plans and presented them in community meetings, as was being done throughout the project corridor.

The proposed alignment is 1.25 mi and crosses the center of the campus from east to west (Figure 1). For less than ½ mi the alignment would be on Campus Drive, the main transportation artery through campus. Campus Drive passes through the geographic and activity center of campus, passing by the Student Union; the Student Activities Building (formerly Cole Field House); classroom buildings; and near both McKeldin and Hornbake Libraries and Byrd stadium, the football and lacrosse stadium.

To support decision making about the alignment through campus the MTA conducted extensive traffic studies on campus collecting data at 27 intersections, collecting crash data, developing traffic simulation models, projecting future traffic levels and conducting origin–destination surveys (Figure 2). The average daily traffic on this segment of the two-lane road is approximately 7,000 vehicles, of which 750 are buses. The MTA conducted 3,500 driver interviews, incidentally learning that 17% of the traffic is cut-through traffic. Seven-thousand vehicles is not a high level of traffic, but there are about 25,000 pedestrian crossings daily,

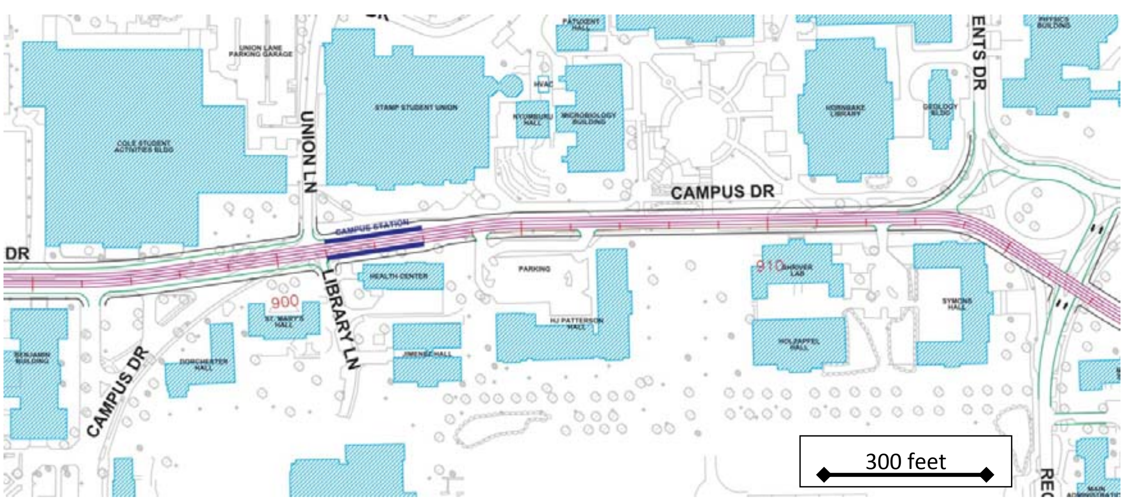

FIGURE 1 Alignment on Campus Drive.

FIGURE 2 Traffic survey on Campus Drive.

making travel on this road very slow during the peak periods. On campus the peak periods are the 10 min at the top of the hour when classes change, and the peak of the peaks is lunch time. The concerns about the safety of the thousands of pedestrians crossing throughout the day was exacerbated by the fact that Campus Drive is at a 6% to 7% grade, and university officials were concerned that light rail vehicles would not be able to stop quickly enough in emergency situations.

The MTA's initial proposed alignment through campus was to close Campus Drive to all traffic except transit vehicles and university service vehicles. This was consistent with the future vision described in the University's Facilities Master Plan. Campus Drive is the most direct and most heavily used east–west roadway on campus and therefore, if the MTA's proposal were implemented, the university was concerned about the impacts of all the diverted traffic on the other campus roads, and the steady stream of students crossing the road. The MTA developed plans and visualizations to demonstrate the proposed concepts. These initially included measures to address the high number of pedestrians crossing Campus Drive, and the fact that many of these crossings were not being made at formal crosswalks. The MTA showed landscaping and fencing features to channelize the crossings to the desired locations (Figure 3). The university expressed concern that the light rail and the associated landscaping would create a barrier in the center of campus, restricting movement.

As part of its analysis and in response to university requests the MTA evaluated many other alignments through campus, both at and below grade (Figures 4 and 5). However, the other alignments generally and simply shifted the impacts to another area of campus, and often created new or greater impacts, while serving the campus less well. Many of the other alignments were on smaller roads with curves and grades that could not accommodate the light rail.

The alternatives analysis (AA) and draft environmental impact statement (DEIS) included a 3,400-ft tunnel under Campus Drive, but this alternative was not selected because of the high

FIGURE 3 Campus Drive with landscaping and fences.

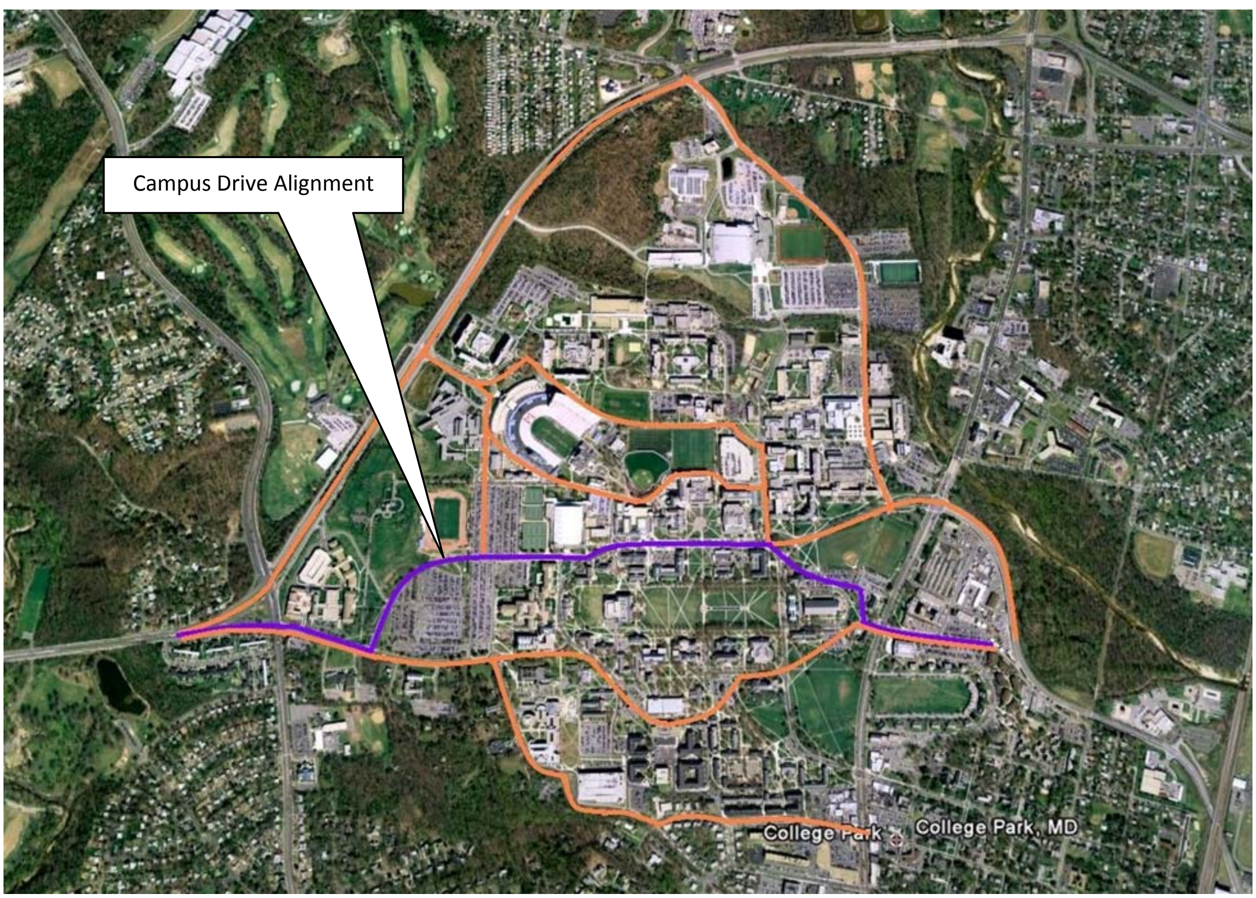

FIGURE 4 Surface alignments evaluated by the MTA.

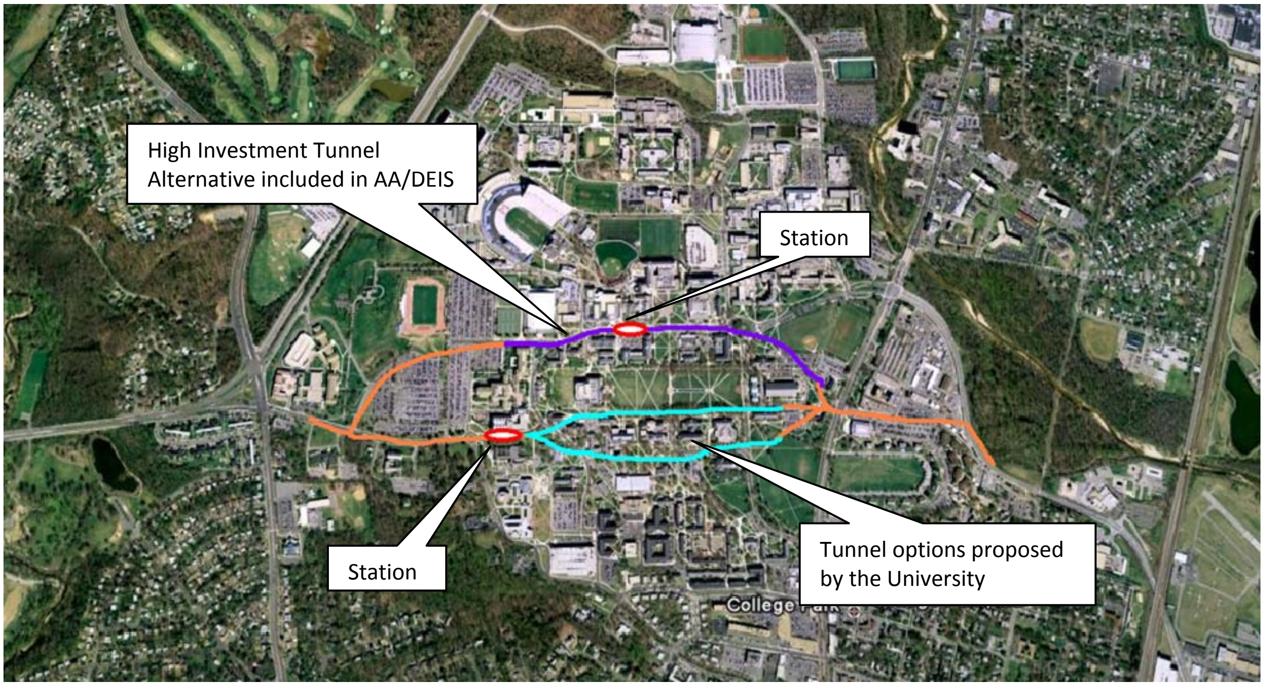

FIGURE 5 Tunnel alignment segments evaluated by the MTA.

cost of the tunnel and the associated underground station. The university proposed several other tunnel alignments, all slightly shorter, south of Campus Drive. The MTA assessed these alignments but found they were not feasible due to high costs and unacceptable impacts, particularly at the portals. Because they were less centrally located they did not serve the campus as well.

On the north side of Campus Drive are many of the university's science labs and research facilities. EMI is a common problem that occurs when the performance of a device is disturbed or interrupted by electromagnetic emissions. Familiar sources of EMI are cell phone towers and power lines, but we are surrounded by many smaller sources such as elevators, air conditioners, cell phones, and electric motors. EMI does not pose a health risk, but it can interfere with some delicate research equipment such as electron microscopes. EMI can cause blurred images from the research equipment.

LRT systems generate electromagnetic emissions from two sources: the electric power system and geomagnetic perturbation.

- The electric power system. Light rail vehicles use electricity to move and operate. The power comes from an overhead wire that runs about 19 ft above the rails. The electric current in the wire and return rail generates a magnetic field.
- Geomagnetic perturbation. Light rail vehicles are made of ferrous metals. The movement of large ferrous metal objects such as trains can cause distortions, or perturbations, in the earth's naturally-occurring magnetic field. When the light rail trains pass by there is a temporary surge in the EMI levels.

Whatever the source, EMI has the potential to affect some of the research equipment at the university.

These concerns resulted in pressure from the university to move the alignment off Campus Drive, away from the heart of campus. The high level of pedestrian crossings of Campus Drive, the proximity of the scientific research facilities, and the impacts to vehicular traffic, were all seen as reasons that the alignment of the Purple Line should be shifted. A second suggestion was to put the Purple Line in a tunnel through campus. As noted above, the MTA had evaluated a tunnel option under Campus Drive in the AA–DEIS, but while this would have avoided the pedestrians and not impacted traffic, it would not have mitigated the potential research impacts from EMI.

HOW THE MTA HAS WORKED THROUGH THESE ISSUES WITH THE UNIVERSITY OF MARYLAND

First and most important is to acknowledge the university's right to be cautious given its responsibilities. If the university agrees to something it later regrets, such as a particular alignment configuration or operating environment, it may be too late to effect a change. The impacts of decisions on capital investments in a transportation system may not be felt immediately, but in the long term. Given a university's ability to act almost unilaterally and independently it is important that the very real benefits to the university be clearly communicated and demonstrated.

In order to work through the university's concerns, the MTA and the University of Maryland created working groups that meet regularly to address each topic in turn. Once agreement on technical issues was achieved, the university's Facilities Master Planning committee worked as a partner with the MTA on the design of the Purple Line through campus. One factor that supported this collaborative effort was the concern of the university leadership under the new president, Dr. Wallace Loh, about the lack of access to the larger D.C. region. This issue resonated with various groups on campus such as the undergraduate and graduate student governments and the faculty senate. These groups reiterated the need for the Purple Line.

Many of the university's concerns were based on a lack of experience with this particular mode of transit. Modern light rail does not currently exist in the Washington, D.C., metropolitan area, and most people in the region tend to think of Metrorail when they hear about the Purple Line or the words "light rail." The MTA's first step was to educate the university about light rail and how it is uniquely appropriate for pedestrian environments and how it can be carefully designed to fit in with a campus environment. But beyond that it was still necessary to appreciate and address each of the university's concerns individually.

The first topics were related to the general issue of station location. The university was advocating an alignment near the edge of campus. Two of the major reasons for this were concerns about safety given the high levels of pedestrian activity along the MTA's preferred alignment on Campus Drive, and potential EMI to the research facilities in the center of campus.

The initial presentations to the university were educational. The principles of transit planning, particularly station locations, are not always obvious to those outside the profession:

- Transit stations should be centrally located.
- They should be where the people are.
- However, locating a station immediately outside the entrance to a 60,000-seat stadium is not ideal, as there will be issues related to crowding before, and particularly after, stadium events.

- In areas of high pedestrian activity, sightlines are important for safe light rail operations.
- Stations should be in well lit, open areas for safety.

The MTA compared the distances and walk times from the major origins and destinations on campus to the two different central station locations proposed by the MTA and the university.

The unique characteristics of light rail as a mode were explained. The MTA showed many examples of light rail in existing areas with high volumes of pedestrian activity, both in the United States and in Europe, with particular emphasis on university campuses. Particularly effective was a video of the Portland Max light rail passing through crowds of people at the Saturday Market, showing people standing and walking very comfortably near the light rail vehicles. It was explained that the light rail would observe all prevailing traffic control measures. There would be site-appropriate control devices at each interface with other movements that could include signing, markings, light rail vehicle-actuated warning devices, and speed restrictions. Light rail vehicles have a human operator who can exercise judgment and take action with respect to

- The need to operate below the speed limit as a precaution.
- The perception of pedestrian behavior that could be risky.
- The activation of warning devices (bell or horn).
- The ability to effect an immediate stop when necessary.

Because a portion of the alignment is on a slight grade the university was concerned about the braking ability of the light rail vehicles, particularly under adverse weather conditions or with wet leaves on the rails. The MTA provided detailed data on the stopping distances and times, demonstrating that a light rail vehicle could stop faster than a bus.

The topic of EMI was a more unusual issue and required a technical working group with appropriate expertise from the university and the MTA. The university's concerns were about interference with delicate research equipment. The MTA conducted a detailed analysis of the issue, the physical (geographic) extent of the potential interference, and the potential intensity. The university included several professors in the sciences in the review of the MTA's analyses. The experiences of other institutions (academic and medical research) were investigated. Electromagnetic emissions are generated by any rail system, and most advanced research facilities must deal with EMI, particularly those in denser urban areas or near rail lines. The University of Washington in Seattle, the University of Minnesota, and Washington University in St. Louis are just a few of the institutions that have dealt with this issue as new light rail systems have been built.

The university identified a level of electromagnetic emissions that it considered acceptable. Because the level of EMI decreases with distance from the source, the MTA developed plans showing the extent of the interference overlaid on a plan of the campus. Research facilities more than 1,100 ft from the tracks would not be affected at all. The location of sensitive receptors (research equipment) could be identified in relation to the zone of interference. Based on this information, the MTA proposed a solution using a combination of automatic controls limiting the speed and acceleration rate of the light rail vehicles as they pass through the campus to reduce energy levels in the overhead catenary system, and a double feeder power supply system at the train source. With a double feeder power supply, the overhead wire is augmented with a feeder wire. The feeder wire is buried underground and connected to the overhead wire at predetermined intervals. This reduces the interference level by splitting the current demand between the contact wire and a feeder conductor. Slower speeds also reduce EMI so MTA has agreed to limit the light rail speed through campus to no more than 15 mph. The proposed double feeder power supply and the reduced speed of the vehicle diminished the size of the zone to 450 ft from the light rail.

The MTA also researched the techniques that could be used to mitigate the EMI at the receptor. Based on the experiences and lessons learned from other institutions the MTA proposed to provide active cancellation or passive shielding at equipment still effected. Active cancellation systems are widely used to address EMI at other universities, including Harvard and Columbia, and the University of Maryland already uses these systems for some of its equipment. These systems are very reliable and are not excessively expensive, generally costing about $25,000 per instrument. The MTA agreed to provide all the active cancellation systems required now, and in the future. The MTA and the university will select a time frame for the provision of this equipment. The university reviewed the MTA's analysis and signed a term sheet consenting to a future memorandum of agreement on the proposed minimization and mitigation. The acceptance of the MTA's analysis and proposed mitigation by the university's scientists was key to the agreement by the university administration.

Figure 6 shows two sets of contour lines centered on the proposed light rail alignment. The green lines indicate where the EMI level would be 0.1 mG, without any mitigation. The two red lines show the 0.1 mG limits with the source mitigation. Only sensitive research equipment between the two red lines would need to use active cancellation systems to protect research.

MTA's reports documenting these analyses are available on the Purple Line project website: http://www.purplelinemd.com/en/studies-a-reports/additional-studies.

Once the EMI minimization and mitigation analysis were accepted the university and the MTA signed a term sheet outlining the scope, schedule, and terms for the planning, design,

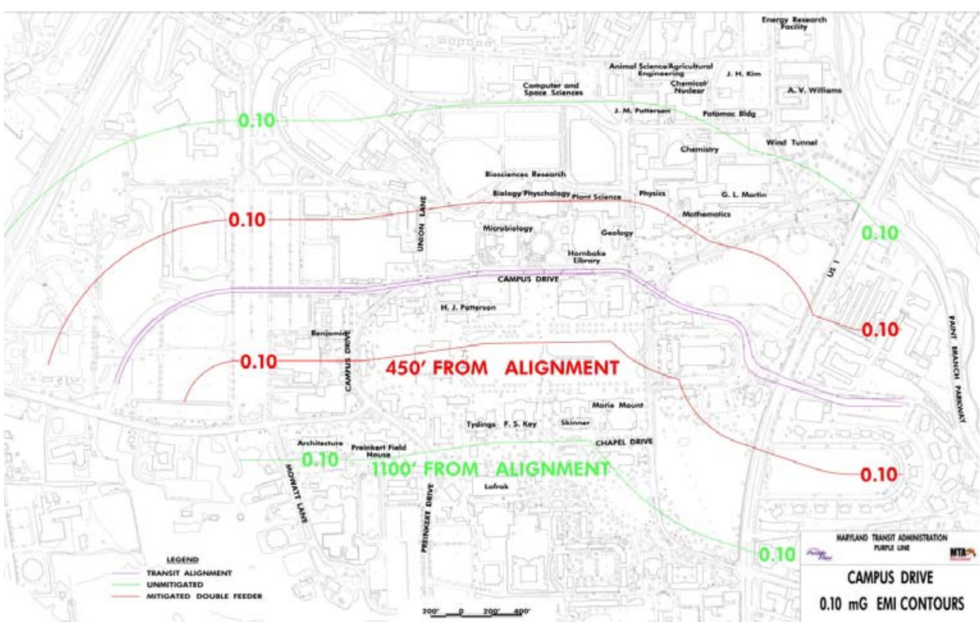

FIGURE 6 EMI contours with and without source mitigation.

construction, and operation and maintenance of the project through campus. The term sheet defined a partnership approach to the future deliberations. The term sheet stated that ultimately it would be superseded with a legally binding memorandum of understanding–memorandum of agreement.

The university was also concerned about vibration impacts to sensitive equipment. The MTA took measurements of the ambient conditions, both outside and inside buildings at the research equipment. This has provided a baseline for conditions under which the university is able to conduct research. These results can now be used for subsequent phases of the Purple Line Project such as vibration criteria selection, predictive modeling, impact determination, and mitigation, if needed.

Once the university accepted that the central Campus Drive alignment was safe and could be implemented without harm to the research, the remaining decisions have been about the specific station location, the roadway configuration and the resulting traffic options and implications, landscaping, and pedestrian accommodations. The MTA is working with the university's Facilities Master Planning Committee on these issues. The MTA has listened carefully to the university's concerns and desires, and has developed and evaluated a number of variations and options. The pros and cons of the options are fully explored. This process continues today, but enormous progress has been made, and the group is now considering landscaping plans.

Campus Drive today is a two-lane road used by general traffic and buses. As mentioned earlier, it has only about 7,000 vehicles per day, but the number of pedestrian crossings is about 25,000 and these crossing are concentrated in the 10 min at the top of the hour when classes change.

While the university's master plans have long stated a goal of creating "a more pedestrian-friendly central campus and significantly reducing the number of automobiles" and allowing "only restricted automobile access to internal streets with high pedestrian volumes," the university had not determined how and when to make such a dramatic change to the heart of campus and to how the campus streets are used. The university expressed particular concern about traffic on campus during special events, including graduation, sports, and arts performances. If the Purple Line were to operate on Campus Drive there were three basic roadway configurations possible. Most of the roadway is currently two lanes wide, with some bus pullouts, but there is physically enough room to construct a four-lane roadway, with two lanes for regular vehicular traffic and two for transit. While this option would fit physically, it would have constrained the width of the pedestrian walkways and sidewalks, and left little room for landscaping. A second option was to keep the two-lane roadway. This could be restricted to transit or university vehicles only, or it could operate as it does today with a mix of transit and regular traffic. A third option was to build a three-lane roadway, with two transit lanes and a one-way traffic lane. The university commonly manages traffic on campus during special events, changing traffic patterns and restricting uses. This lane could be used in one direction under normal conditions, but reversed during special events if desired.

The MTA has developed analyses showing that a two-lane option where the Purple Line would share lanes with regular traffic would have serious adverse impacts on Purple Line operations. But the MTA has continued to work with the university to explore various options. The MTA prepared additional traffic analysis, studying where traffic would divert to under different scenarios, considering travel times and impacts. When changes were proposed to the university's landscaping the MTA has prepared visualizations to support decision making.

CONCLUSION

As the MTA and university have worked together, a respectful trusting relationship has developed, supporting continued collaboration on the remaining issues. The term sheet has defined the framework for the ongoing negotiations. This document is available on the University Board of Regents' website (http://www.usmd.edu/regents/agendas/fb042511p.php). While the Purple Line project is still in the preliminary engineering phase, we are confident that the concerns will all be addressed, further analysis done where warranted, and solutions or education provided. The MTA has demonstrated that it appreciates the university's concerns and looks forward to continuing to work collaboratively to develop solutions that are acceptable to both parties. The university has recently taken the draft Facilities Master Plan, which includes the collaboratively developed plans for the Purple Line, out to its stakeholders in a series of presentations to the graduate and undergraduate student governments, the Faculty Senate, and the Board of Regents. The plans have been well received, and a continued team effort is anticipated as the project moves forward.

Applying a European Urban-Style Light Rail Transit Design Approach in North America

Recent Experience and Lessons Learned in Canada

ALAN JONES
Steer Davies Gleave North America

Over the last 5 years several cities in Canada have looked to European Light Rail Transit (LRT) design experience to address their need to develop integrated transit solutions, improve transit service and transportation choice, and support wider city shaping objectives. This paper examines studies undertaken in Vancouver (the UBC Line), Edmonton (West–Downtown Connector–Southeast Corridor), Calgary (North Central Corridor), Hamilton (B-Line, serving McMaster University), and Mississauga–Brampton (Hurontario-Main LRT). In each of these cities urban style LRT projects have been developed based on a European design approach. This approach advocates low floor, level boarding LRT, with segregated operation and priority at intersections. This maximizes the benefits of investment in LRT and also forms the basis for a wider "complete street" design approach, including a re-ordering of transportation hierarchies (more emphasis on pedestrians, cyclists, and transit users), a re-allocation of road space, a greater emphasis on comprehensive urban design, and an integrated planning approach that links LRT with complementary transportation demand management measures and transit-oriented land use policies. The paper highlights the methods and techniques that have been applied to develop the projects in each city, including the design process; development of complementary measures; focus on putting the passenger first; the discipline of the business case and multiple account evaluation; stakeholder engagement; and funding, procurement, and delivery strategies. The LRT in Dublin, Ireland, will also be used as an example to highlight the benefits of urban-style LRT, examining the benefits that have been realized since the project opened in 2004. The paper will conclude by setting out a practical checklist that can be applied to any city considering LRT as a means of upgrading its transit infrastructure and creating more sustainable lifestyles connecting residents to jobs, recreation, education, and other opportunities.

INTRODUCTION

During the late 1980s and 1990s many North American cities introduced light rail transit (LRT) systems, for example, in San Diego, San Jose, Sacramento, Denver, Salt Lake City, Portland, Edmonton, and Calgary (*1*). These systems link suburban areas and downtowns and were characteristically built to operate on former rail freight tracks to provide segregation, with street-running operation mixed with traffic in downtown areas (*1*, *2*). Typically, the light rail vehicles (LRVs) were high-floor, multiple vehicle trains, with internal steps for boarding and wheelchair access via ramps.

But since the early 1990s there have been a number of LRT system developments, the most significant of which has been the introduction of low-floor LRVs. Matched with low-floor LRT stops, these innovations allow easy level-boarding for all passengers, and result in less intrusive LRT stops that are easier to integrate into existing urban street spaces. Along with the development of standardized modular LRV designs, these improvements have resulted in many more cities introducing LRT, often as part of a wider transportation strategy, which in turn is linked to new city objectives, including economic regeneration, environmental improvements, and sustainability. With growing urban populations, increasing congestion, and higher gas prices many cities are now looking to urban style LRT to help redefine 21st-century cities, where wider transportation choice and less reliance on the auto are now key considerations.

Many North American cities are promoting a greater interest in higher density, mixed-use development and urban lifestyles. In response, a number of cities have introduced modern, urban streetcars in downtown areas, such as Seattle and Portland. Compared to the more extensive LRT projects listed, these streetcar systems are typically low budget and small in scope and tend to operate primarily in mixed traffic (*1*).

In a North American context both the older LRT systems and modern streetcars have been successful in providing a transportation alternative to auto use but fall short of wider 21st-century city planning objectives. More recent European examples show that urban style LRT has the potential to exert a greater impact on the city by creating integrated transit solutions and capturing the benefits of conventional LRT and modern streetcars in a single integrated design. This approach to LRT has a greater focus on serving local neighborhoods, while still linking suburban areas and downtowns, creating transportation choice, and supporting wider city-shaping objectives.

The European design approach has been used to develop urban style LRT projects in a number of Canadian cities over the last 5 years. This paper provides an overview of the urban style LRT, taking the Dublin Luas system as an example. Five studies within Canada are examined, with a summary of the methods and techniques that were applied to develop them, and lessons learned. These studies are the Vancouver UBC Line, Edmonton West–Downtown Connector–Southeast corridor, Calgary (North Central corridor), Hamilton B-Line, and Hurontario-Main LRT in the Greater Toronto Area (GTA).

WHAT IS URBAN-STYLE LRT?

Urban-style LRT is based on a wider planning approach that includes linkages with land use policy, and an understanding of how LRT fits within a wider transportation hierarchy. At a corridor level this manifests itself with urban style LRT that is part of a complete-street design: road space is re-allocated in favor of segregated LRT. Priority is provided at intersections, and there are improved connections with pedestrian and cycle facilities (the last mile). The urban realm is also a priority within the complete-street design approach. Autos are not excluded, but a wider corridor approach is adopted to redistribute traffic and relocate on-street parking. More frequent LRT stops directly serving key destinations and local neighborhoods result in easy and convenient door-to-door travel time that makes urban style LRT an attractive alternative to auto use for many trips.

Urban style LRT is designed to be the preferred transportation choice in order to maximize the benefits of the system. With a focus on putting the passenger first, key features include

- Complete-street designs, with LRT given priority over auto traffic;

- LRT designed to directly serve key destinations (jobs, education, health care, shopping, entertainment, etc.);
- Closer stop spacing to better serve communities and neighborhoods;
- Redesign of local transit services to complement the LRT alignment, and convenient transfer between LRT and regional rail services;
- Modern, low-floor, modular LRVs (Figure 1);
- Low-floor stops (Figure 2), integrated with surrounding development and encouraging transit-oriented development (TOD) (Figure 3); and
- Segregated LRT alignments, designed within the roadway and primarily at-grade (Figure 4).

Examples in many cities around the world demonstrate that urban-style LRT can help shape cities, neighborhoods, and communities. Integrating LRT into the urban realm through comprehensive complete-street designs can help to reorder transportation hierarchies and re-allocate road space to reflect local policy objectives. A key part of the planning process is the need to establish a clear hierarchy favoring pedestrians, cyclists, and transit users over the auto. When this approach is adopted, LRT stops become community and city focal points and hubs of

FIGURE 1 An example of a modern, low-floor LRV (Dublin, Ireland).

FIGURE 2 Step-free, level boarding: low-floor boarding allows step-free access for all, without the use of ramps or lifts (Lyon, France).

FIGURE 3 Typical LRT stop. Modern stops are integrated with their surroundings, creating a public realm that allows easy pedestrian accessibility and promotes TOD (Paris, France).

FIGURE 4 Segregated LRT operation. Segregated running maximizes the benefits of the LRT system through faster journey times and journey time reliability (Lyon, France).

activity, realizing wider city planning aims. Central to the complete streets approach is enabling LRT to become a focal point for new, higher density, mixed-use development. TOD is becoming a prerequisite to justify transit investment, allowing a higher proportion of the population to live within easy access of the LRT, with less reliance on autos.

With a greater focus on urban design, urban style LRT can help to transform a corridor, while facilitating transit, pedestrian, and cycling activity in the region. For this approach to succeed, a multimodal planning approach is required that embraces not only transit, but also complementary transportation demand management (TDM) and land use planning. TDM measures support LRT leading to increased ridership. Such measures include parking restrictions, local traffic management measures, road pricing, and Smart Choice programs designed to influence travel patterns.

DUBLIN LRT

Proposed in the early 1990s by the Dublin Transport Initiative, the Dublin LRT [branded Luas (Gaelic for "speed")] was opened in 2004 as one component of a wider transportation strategy (*3*). The initial LRT system comprised two separate lines (the Red Line to Tallaght to the west, and the Green Line to Sandyford) south of Dublin. The Red Line links suburban parts of Dublin with major hospitals, mainline railway stations, and the downtown core. The Green Line also serves suburban communities, linking them with central Dublin. The segregated alignment provides significant time savings over auto use for commuter trips. Since its opening the Luas system has been extended several times, with a branch to Saggart off the Red Line; an extension of the Green line to Brides Glen; and a link across central Dublin to connect to the Financial Services District, the DART Metro line, and the regenerated Dublin Docklands. With annual ridership of over 20 million passengers, the LRVs have also been extended to provide additional capacity. The system currently includes 54 stops and 38.2 km of track (Figure 5), with a further line planned to connect the Red and Green Lines in the downtown and continue on a new route to the northwest of the city.

Luas includes all the essential urban style LRT components: low-floor, level boarding operation (*4*), segregated running (*5*), and LRT priority at intersections (*6*) (Figure 6). In addition, the system provides an integrated system for passengers, through cross-mode ticketing, multilingual signage, an automatic fare collection and monitoring systems (*7*), and real-time information at stops. As a result, Luas had a 99% reliability performance in 2010 (*8*) and records high levels of customer satisfaction year on year.

As part of the integrated approach of the Dublin Transportation Initiative a range of TDM and infrastructure investment measures have been developed to complement Luas, including (*3*)

- Limiting city car parking spaces;
- Encouraging companies to introduce flexi-time for staff (to reduce peak travel);

FIGURE 5 The Luas LRT system in Dublin, Ireland, consists of two lines, both of which have undergone a number of expansions since the initial system opened in 2004. (Source: RPA.)

- Significantly expanding the bus network; and
- Expanding Luas.

This approach has resulted in high levels of ridership on Luas, with 2,800 to 3,700 passengers per direction per peak hour (*7*), and an average of 80,000 passengers per day (*9*). Further to this, the Luas system, in combination with the wider measures of the Dublin Transportation Initiative, has had a significant impact on city shaping in Dublin.

Land in close proximity to the LRT stops has become more valuable, which promotes higher densities and TOD. Between 2002 and 2004, homes close to both Luas lines saw an additional 15% price rise over and above the general increase in prices during the period (*10*). This impact on house prices goes beyond the effect of public transportation in general, as housing near the LRT stops commands a premium that is almost double than housing near (DART commuter) train stations (*11*). Localized opportunities to coordinate TOD through integrated planning and partnership are evident. The Luas stop at Dundrum is integrated with the country's largest retail development and has well-designed stop to shop linkages that provides full integration and benefits to passengers (*10*).

This major potential that LRT has to support urban regeneration and development has generated investment from the private sector to enable expansion of the original system. The city has used development levies raised from house builders to part fund the extensions of the Luas system, enabling some of the added real estate value to be reinvested back into infrastructure. This approach has led to extensions of the Red and Green Lines to provide access to new residential development. An integrated planning approach has also seen Luas extended into Dublin's former docklands, with new housing, a conference center, and a major event venue all

FIGURE 6 The Luas system is a European example of the urban-style LRT that is being designed in many cities in Canada, featuring level boarding, segregated running, and integration with TOD land uses.

being served by a new Luas extension, east from the Financial Services District. This extension and the associated land use was coordinated as a joint venture between the Dublin Docklands Development Corporation and the Rail Procurement Agency (the body responsible for Luas).

DEVELOPING THE PROJECTS

The approach adopted for the development of Dublin's LRT system is typical of the European approach to transit infrastructure planning, the key characteristics of which have been used to frame the development of a number of Canadian LRT projects over the last 5 years. A set of standard methods and techniques have been developed and applied to all the Canadian examples that follow. The key components are set out below.

- The need for a long-term integrated land use–transportation plan to set the context, vision, and objectives at a city region scale;
- Establish a transportation hierarchy that favours pedestrians, cyclists, and transit users.
- Plan direct LRT routes that serve existing (and new) neighbourhoods and key destinations, and set high design standards for LRT that maximize segregated operation and priority at junctions, in order to realize journey speed and reliability benefits;
- Adopt a "demand-led approach" when determining infrastructure and system requirements;
- Ensure that the detail of the LRT system—its route, stops, level of service (frequency and hours), and connections with other transit services—are all focussed on the passenger;
- Ensure stakeholders and the public are integral to the design process;
- Ensure that the resulting designs are affordable and that they deliver the appropriate project outcomes [using multiple account evaluation (MAE) techniques] to fulfill the project vision and objectives; and
- Use the MAE framework to inform decision making and provide a summary of the business case for the LRT project, a key requirement when seeking funding support

VANCOUVER—THE UNIVERSITY OF BRITISH COLUMBIA LINE

The Vancouver–University of British Columbia (UBC) Line is planned to serve the Broadway corridor linking the university campus to the west with the existing SkyTrain hub at Commercial–Broadway. The 13-km Broadway corridor (Figure 7) is currently served by buses with major passenger congestion and delay occurring as a result of the large volumes of students and staff traveling to and from the UBC campus. More than 100,000 daily bus trips are common during term times.

With employment expected to increase by 30% by 2041, buses on tight headways are unlikely to accommodate future demand (*12*). Rapid transit is proposed to address the specific transportation problems in the corridor, which are identified as

- Capacity and reliability: existing transit services do not provide sufficient capacity or suitably reliable services to the major destinations and economic hubs within the corridor;

FIGURE 7 The UBC Line would be the fourth line on Vancouver's Skytrain network, linking the university with the rest of the system and downtown.

- Transit trips and mode share: both directly and through the support of the Regional Growth Strategy and other regional objectives, in order to reduce vehicle kilometers traveled and associated air emissions; and
- Affordability: with limited regional funding for transit at present.

A number of mode alternatives were assessed using MAE to determine the option that best addresses the transportation problems on the Broadway corridor. These alternatives include bus rapid transit (BRT), both at-grade and grade-separated LRT, SkyTrain, and combination options. The study suggests that LRT with intersection priority would deliver sufficient capacity for future growth along the corridor, while achieving reliability benefits (*12*). The MAE indicated that LRT demonstrates value for money on the corridor and will have a significant impact on transit mode share. In comparison BRT did not have sufficient capacity to address the capacity problems in the UBC corridor, and SkyTrain, despite having capacity and journey speed advantages, was significantly more expensive, requiring a twin bore tunnel and costly (and less frequent) underground stations. Figure 8 shows an image of what segregated LRT might look like on the UBC corridor, highlighting the link with land use intensification opportunities.

In order to maximize the benefits of LRT, full system integration is required, with pedestrian and cycling crossings at all sections and the relocation of displaced on-street parking along the corridor. By improving the pedestrian scale of the street and providing opportunities along the full corridor, LRT can transform the Broadway corridor into a complete-street that has significant potential for TOD: 52 million ft^2 of built floor area has been identified surrounding the 14 proposed LRT stops that can be potentially developed by 2041 (*12*).

FIGURE 8 LRT envisaged on the UBC Line. Segregated LRT on the UBC corridor would create a mode of transportation attractive to the user, as well as create an urban realm that supports all modes.

EDMONTON—PLANNING THE WEST–DOWNTOWN CONNECTOR–SOUTHEAST CORRIDOR

Edmonton was the first North American city to build LRT in 1978 (*13*) and has since operated traditional style, high-floor LRVs on former rail rights-of-way. In 2005, the city initiated a series of long-term planning studies including The Way We Grow (land use) and The Way We Move (transportation). The outcome was a decision to re-think Edmonton's future urban form, "growing upwards, not outwards."

Responding to this policy shift and new vision for the city's future, a major review of Edmonton's LRT requirements took place. This resulted in urban-style LRT being adopted as city policy for future extensions of the LRT network. Studies to expand the transit provision using low-floor vehicles on new lines was spurred through a recognition of the need for alternatives that provide smaller scale, integrated LRT designs, with multimodal active transportation connections (*14*). This approach was linked to a set of TOD policy guidelines that aim to focus higher density, mixed use development around more closely spaced LRT stops. As a result Edmonton's 2009 LRT network plan consists of street-level LRT corridors that serve the downtown core, and provide pedestrian friendly facilities as well as a connection to the existing system at Churchill Square station. The system is designed to

- Build smaller scale stops that are spaced closer together;
- Provide better links to a greater number of destinations, with more direct transit, pedestrian, and cyclist connections;
- Maximize openness of space to create a safe environment;
- Reduce speeds in congested areas to support safe, pedestrian-oriented communities; and

- Invest in urban realm improvements, and architectural features to improve visual appeal (*15*).

The West–Downtown Connector–Southeast Corridor fits within the LRT network plan as the second priority line, following the expansion of the existing, traditional-style LRT to the north. The line will extend from Lewis Estates in the west, serving downtown Edmonton, before continuing southeast and terminating at Mill Woods town center (Figures 9 and 10). The line will predominantly at-grade, apart from some major highway crossings, total 27 km and include 26 stops.

The Downtown Connector forms a key component of the new line. The existing Edmonton LRT operates underground through the downtown connecting the South and Northeast lines. In contrast, the West to Southeast line will be linked by the Downtown Connector running on the surface with several downtown stops providing easy access to university and college campuses, shopping, office, leisure and civic facilities, and a transfer to the existing underground LRT at Churchill. The Downtown Connector will also feature road space re-allocated in favor of LRT, and urban realm improvements around LRT stops. This wider approach to planning the Connector included comprehensive stakeholder and public consultation to assist in the detailing of the LRT route and stop locations, including a stop integrated with new facilities for Grant McEwan College.

FIGURE 9 Edmonton West–Downtown Connector–Southeast Corridor. The Southeast to West line will connect neighborhoods from either side of the city to downtown Edmonton, providing access to a number of key destinations. Further urban-style LRT lines are proposed to the north of the city and downtown (circulator).

FIGURE 10 LRT envisaged on the Edmonton West–Downtown Connector–Southeast Corridor. The Edmonton West–Downtown Connector–Southeast will have modern, easily accessible stops, integrated into an urban realm that promotes TOD.

CALGARY–NORTH CENTRAL CORRIDOR

Similar to Edmonton's original LRT system, the Calgary LRT was implemented as a high-floor, traditional North American LRT in the early 1980s. The C-Train currently consists of two lines and 48.8 km of track serving the south, northeast, and northwest of the city, all operating through a surface-level Downtown Transit Mall.

Long-established plans from the 1970s had always envisaged a downtown tunnel to accommodate new LRT lines and additional train movements. Following completion of the West Line (currently under construction) a northern LRT route through Nose Creek was ear-marked, and this triggered for the need for the downtown tunnel.

Having reviewed its long-term growth plans, Calgary has since concluded that the Nose Creek corridor (currently undeveloped) does not serve enough urban communities, and a related study suggested that a North Central corridor will have more scope for the integration of LRT with TOD land uses (*16*). Initial studies have also examined a cross-downtown route linking to a proposed Southeast LRT corridor. Initial public engagement has shown support for the new urban style LRT planning approach and further studies are planned to develop the detail for the project.

HAMILTON B-LINE LRT

Hamilton, with a population of more than 500,000 is a former steel town that forms a part of the Greater Toronto and Hamilton Area (GTHA). The lower city (below the Niagara Escarpment) features a fine street grid and the city's downtown. Although underutilized, it has the potential for urban style LRT to act as a catalyst for urban regeneration.

The Hamilton B-Line is the first of the city's five proposed rapid transit lines known as the BLAST network (Figure 11), and a top 15 priority project for implementation within 25 years in the Regional Transportation Plan for the GTHA. The line is 14 km west to east, with 18 stops, from McMaster University through the downtown to Eastgate Square. The LRT will be two-way and almost entirely segregated, except at intersections where the LRT has priority over traffic and at a short section in the downtown where the LRT will operate mixed with traffic.

It is predicted that population and employment in Hamilton will grow by 30% and 43%, respectively, by 2031. During this period, transit demand is expected to increase by 63% as a result of growth, rising parking and motoring costs, and increasing congestion. LRT will support this demand as well as the wider objectives of the city.

The B-Line LRT study (*17*) forecasts that ridership on the line (currently the busiest transit corridor in the city) will double to approximately 20 million trips by 2031, with smart growth planning. Implementation of the LRT, with complementary policy that facilitates TOD and the city's intensification plans, will stimulate development along the corridor creating greater tax revenues and a reduction in costs associated with traffic congestion (e.g., journey

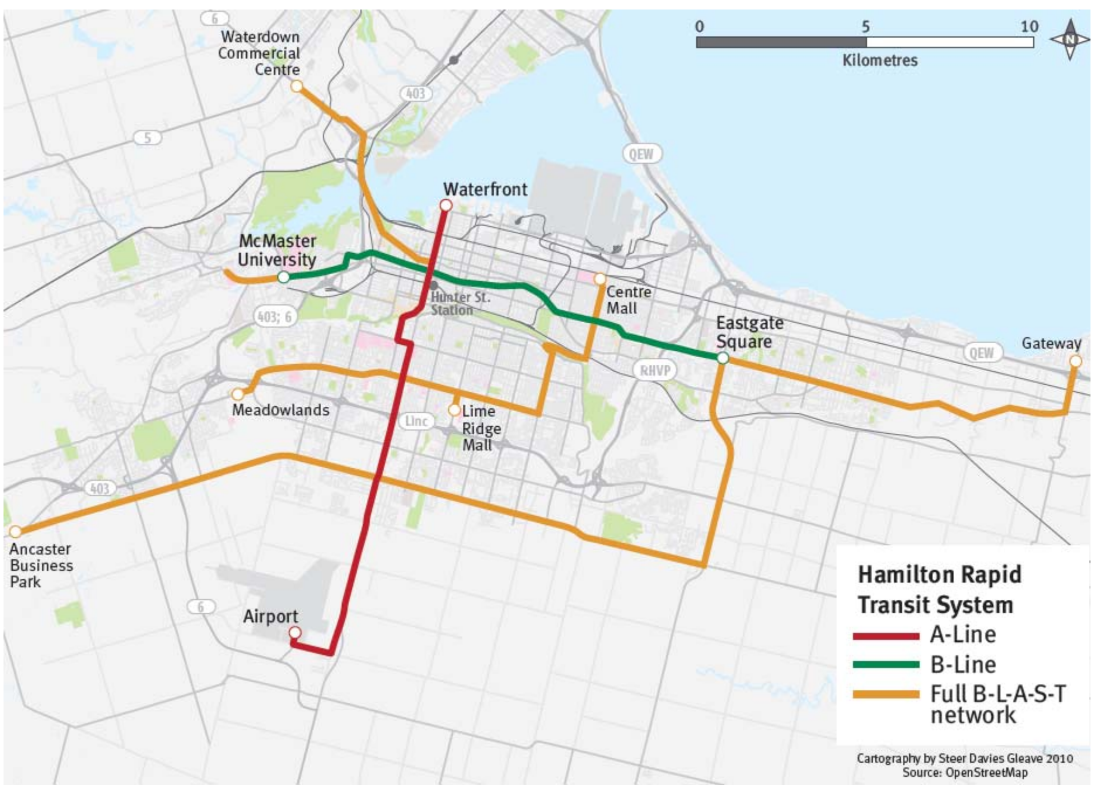

FIGURE 11 Hamilton BLAST Rapid Transit Network. The Hamilton B-Line is the first of five rapid transit lines proposed for the City of Hamilton.

time savings and accidents). In addition to stimulating development and supporting intensification, the LRT can also aid social regeneration and economic growth by improving access to jobs and opportunities in downtown Hamilton, which is currently the area of highest social need in the GTHA (Figure 12).

To respond to these challenges, the B-Line has been developed as an urban-style LRT, supported by complementary TOD policies. Existing buildings are being safeguarded for refurbishment, rather than demolition, and a wider transportation plan will re-route auto traffic, with LRT given priority. The local transit network has also been revised to complement the B-Line and form a wider integrated transit network, adding to passenger convenience.

MISSISSAUGA–BRAMPTON AND HURONTARIO–MAIN LRT

Hurontario-Main LRT connects two urban growth centres and five designated mobility hubs within the GTA. As with the Hamilton B-Line, it is one of the top 15 priority projects specified in the Regional Transportation Plan (The Big Move) to be taking forward within 25 years. The corridor links the Cities of Brampton and Mississauga, running from downtown Brampton, via downtown Mississauga, to Port Credit on Lake Ontario. The long-term vision for the project has been established in the Ontario Provincial Plan (Places to Grow), in which Brampton and Mississauga are designated urban growth centres, and in a corridor master plan that sets the long-term vision and objectives for the project (Figure 13).

FIGURE 12 LRT envisaged on the Hamilton B-Line. The Hamilton B-Line will include 18 low-floor, level boarding stops, providing access for all.

The corridor is expected to undergo significant growth in the next 20 years, with densities close to the LRT route increasing by 37% and 31% for residential and employment respectively (*18*). The corridor's vision is to change from an existing six-lane highway, dominated by auto traffic, to a 21st-Century Main Street, with the following objectives:

- Easy, reliable, frequent, comfortable, convenient, and integrated LRT service;
- A beautiful street that invites economic and social vibrancy; and
- TOD presence along the corridor that blends with surrounding neighborhoods.

LRT is seen as an enabler to achieving this vision while supporting high growth in the future. Highway lanes are to be re-allocated to urban style LRT and regular stops will link existing communities with new development areas and the current downtowns (in Brampton and Mississauga), and will provide opportunities for high quality "mobility hubs" to provide easy passenger transfers to the regional GO Rail network serving downtown Toronto and other parts of the GTHA.

FIGURE 13 Hurontario–Main LRT, GTA. The Hurontario–Main LRT (shown in yellow), will connect multiple mobility hubs and transit centers in the GTA.

The development of the project is based on an MAE, which assesses the project's transportation, economic, environmental, social, and urban development benefits. This wide-ranging assessment then forms the basis of formal environmental procedures and bids for project funding. Active stakeholder and public engagement lies at the core of the design process, aiding the development of a complete street outcome, in which urban-style LRT features alongside urban realm improvements and more space dedicated to pedestrians and cyclists.

LESSONS LEARNED

The application of the urban style LRT methods and techniques outlined in this paper has allowed a range of Canadian cities to re-think their requirements both for the future of their cities and how urban style LRT can play a part in shaping the way forward. The potential benefits are considerable, with the MAE approach highlighting that investing in transit should bring more than just conventional transportation benefits. Wider economic, environmental, social, and community benefits should also be realized.

But urban style LRT, embedding LRT investment within wider land use and transportation policies, requires a complex, multidisciplinary approach and strong political support. The experience in developing urban-style LRT proposals in recent years has highlighted a number of common issues that will need to be considered by other cities looking to introduce urban-style LRT:

- The vision and objectives for urban style LRT need to be established at a strategic policy level early in the process to set the context for more detailed corridor-level decisions. This requires strong political leadership to champion the benefits of the approach to LRT.
- The approach to urban-style LRT, linking the investment with the enhancement of neighborhoods, and complete-street designs, has been embraced by the public that see the wider benefits compared to engineering-led solutions.
- The public and stakeholders should be part of the urban style LRT design process. Again, champions are required to advocate for the urban style LRT approach.
- Promoting agencies must make sure all staff from many disciplines are engaged in the design process, and take ownership of the urban style LRT approach.
- Funding agencies should be identified and involved in urban style LRT early in the design process. The comprehensive approach will require local, regional, and national funding that goes beyond conventional sources. Funding for a comprehensive complete street design will require multiple funding sources.
- A wider corridor approach is required for high-quality segregated urban style LRT to succeed, with a new transportation hierarchy giving greater priority to pedestrians, cyclists, and transit users. Complementary TDM and TOD policies are also key components in the process.
- Decision makers have to be prepared to re-allocate road space for high-quality segregated LRT, with priority provided at intersections. This will realize journey speed and reliability benefits through the life of the project.
- Urban-style LRT design criteria need to be established early in the process to frame the design of the alignment, stops, intersections, pedestrian and cycle facilities, and transfer arrangements between LRT and other transit modes.

CONCLUSIONS

Examples from Europe have shown that urban-style LRT can deliver significant benefits to cities beyond traditional transit systems. The design philosophy for developing urban style LRT can translate and be applied in a Canadian context. Although many of the examples highlighted are at an advanced stage, none are yet constructed and operational so there is still much to be done; however, the examples presented in this paper highlight the benefits of an integrated approach to the development of urban style LRT. The focus on human-scale LRT, surface running and integrated into the urban fabric, presents a new opportunity for the evolution of the North American city in the 21st century.

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Light Rail Vehicles and Streetcars
The Evolution Continues

Development of Guidelines for Modern Streetcar Vehicles

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Since the implementation of the first U.S. modern streetcar system in 2001, there has been rapidly increasing demand throughout the country for more such systems. At the same time, agencies and suppliers have had limited familiarity with both the vehicles themselves and many of the basic technical and operating concepts associated with the streetcar mode. This has been especially true with many nontraditional organizations involved in delivering streetcar projects such as municipal governments, business improvement districts, nonprofits, and other organizations that may have limited familiarity with transit in general, and rail in particular. With no comprehensive source of modern streetcar recommended practice guidance available, the APTA Streetcar Subcommittee felt that a coordinated industry effort was needed to help the streetcar mode to reach its full potential. Beginning in 2010, the subcommittee undertook a project to create a guideline document to promote understanding of the core technical and operational issues relating to vehicle selection. From this understanding, agencies will be able to better navigate the process of specifying a vehicle and designing compatible infrastructure. Similarly, suppliers will be provided with a better understanding of the differences between North American and world operating and regulatory environments. It is estimated that North American agencies will spend over $2 billion dollars for the purchase of modern streetcar vehicles during this decade. If this industry segment can do an effective job of internal education and related standards work, vehicles and systems will better match, and cost savings will follow. It is hoped that the guideline project will help facilitate the adaptation of existing modern streetcar designs for the North American market and help make domestically produced vehicles a competitive, world-class product for all markets. This paper describes the process used to develop the *Modern Streetcar Vehicle Guideline* and provides an overview of its content. The guideline is scheduled for release through the APTA Standards Development Program in 2012–2013.

BACKGROUND

The APTA Streetcar Subcommittee was formed in 2000 with a mission to "promote the development of heritage trolley and modern streetcar lines in urban centers, to foster information exchange among those planning or operating such lines, and to encourage reasonable technical and safety standards".

In 2009 the subcommittee recognized that despite the growing number of projects in various stages of development, there was no comprehensive source for recommended practice guidance for modern streetcar systems or vehicles. Further complicating matters was the fact that many projects were being advanced not by transit agencies, but by other nontraditional project sponsors with varying levels of transit operating experience. Building on the successful experience of having produced an APTA standard for heritage trolley vehicle equipment in 2005 (Figure 1), the subcommittee embarked upon a project to create a comprehensive guideline document for modern streetcar vehicles.

FIGURE 1 Modern streetcar in Tacoma, Washington.

A working group was assembled from among the active ranks of the subcommittee, supplemented with several key agency personnel from U.S. and Canadian streetcar properties. At the group's initial meeting in January 2010, a set of project goals was agreed on along with a draft outline. A project website, www.modernstreetcar.org, was established shortly thereafter to facilitate information sharing and encourage interest in the project. The subcommittee also worked closely with APTA staff to determine where in the APTA Standards Development Program this effort would best fit, and where synergies might exist with other committees.

PART 1. INITIAL RESEARCH

Large Body of Global Knowledge

Work began with a thorough literature search. From the United States, several useful TCRP research projects were identified, including *TCRP Report 2*: *Applicability of Low-Floor Light Rail Vehicles in North America* (1995). Previous APTA standards and guidelines also provided ideas for how to approach the subject at hand. The search also looked to Europe, with emphasis on identifying standardization efforts in the tramway field, as well as any similar guideline efforts. The European literature search provided a significant reservoir of information, including the Light Rail Thematic Network (LibeRTiN) project, English language translations of the German BOStrab tramway standards, and the UK Office of Rail Regulation's *Guidance on Tramways* (2006) and *Tram Design and Construction Supporting Guidance* (2010) documents. The results of the literature search were published on the project website. The search for relevant documents and related standards work continues as an ongoing activity.

Carbuilder Survey

As a next step, a carbuilder survey was conducted. The fortunate timing of the biannual Innotrans trade fair in September 2010 allowed subcommittee representatives to meet with carbuilders to discuss the survey and its role in the guideline project. Each carbuilder was subsequently asked to provide answers to a technical questionnaire and to provide detailed information on the products they would offer in response to an inquiry from a U.S. purchaser. In addition to gathering together useful comparative data about the different streetcar vehicles being offered in the U.S. market, it also helped clarify what options carbuilders viewed as standard versus custom features. The process also served to engage carbuilders in the guideline effort. A total of seven carbuilders participated in the 2010 survey, and nine are participating in the 2012 update.

Recognizing that running gear represented an area where modern streetcar vehicles were particularly innovative, specific information was obtained for each vehicle and included in the survey. The running gear classification system in TCRP Report 2 was adopted, although it was quickly discovered that of the report's 18 running gear categories, only three were still in use for new vehicles being offered to the U.S. market. Six additional categories were created to classify the new running gear types. With continuing advances in traction motor technology, it was also noted that some of the new 100% low-floor designs now incorporated once-familiar running gear elements such as solid axles and rotating trucks. These seemingly fundamental concepts in running gear were actually not common in the first generation of 100% low-floor vehicle designs, where fixed trucks and independent wheels predominated.

Concurrent with the survey, an effort was made to better understand the global market for light rail and streetcar vehicles. Trade articles such as the annual updates on worldwide low-floor vehicle orders by Harry Hondius (published annually in *Metro Report International*) were consulted, along with numerous additional resources provided by subcommittee members.

It was found that of the more than 8,000 low-floor light rail and streetcar vehicles built or placed on order in the 25 years since the advent of modern low-floor technology, about half are 100% low-floor. In the United States as of July 2012, there were 1,040 partial low-floor vehicles in service or on order, and five 100% low-floor vehicles (altogether representing a modest 13% of world production of low-floor rail vehicles). In Canada, Toronto has a total of 386 100% low-floor vehicles on order to replace its existing streetcar fleet and equip its new light rail network. Recent western European orders suggest that the market trend is decidedly in favor of 100% low-floor vehicles for tramways and streetcars, with the 70% configuration still popular for light rail vehicles (LRVs), including the emerging tram–train application (Figure 2). It was further noted that the European approach seemed to put less emphasis on differentiating between what we in the United States call "streetcar" and "light rail," with the term "tramway" covering a broader range of applications.

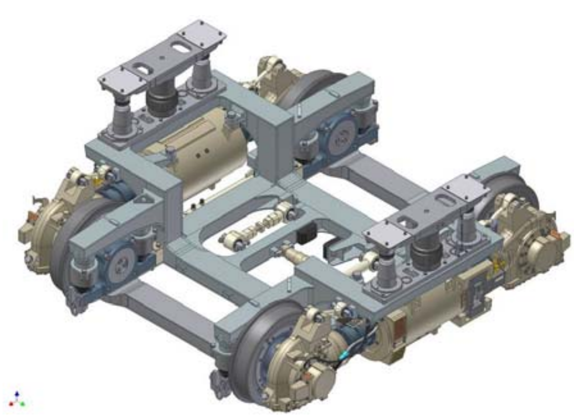

FIGURE 2 Example powered truck for 100% low-floor vehicle.

Operating Environments Compared

Another early step in the project was to compare European and North American streetcar operating environments to identify where differences might impact vehicle design or operation. A number of excellent resources were found to support this effort including *TRB Special Report 257: Making Transit Work: Insights from Western Europe, Canada, and the United States* (2001) and the *Light Rail Thematic Network* (LibeRTiN) topic reports. A peer reviewer from the United Kingdom also joined the working group at this time. The research was summed up in an *Operating Environment Research* working paper that contrasted U.S. and European practice in numerous key areas including duty cycle, passenger interface and expectations, street geometry, interaction with traffic, climatic conditions, fare collection methods, as well as several key standards related topics.

The primary conclusions were that U.S. operating environments alone were not different enough from those in Europe to require significant change in vehicle configurations. It was also noted that some European countries (for example France), had a parallel experience with the United States in having abandoned almost all of their first generation streetcar–tramway systems, followed in recent decades by a return of modern systems. As in the United States, Europe was noted to have a wide variety of street geometries, climatic conditions, and other physical conditions. Passenger expectations were thought to be somewhat different due to the differences in cultural acceptance of transit, but the impact of the automobile was still a strong factor in both the United States and Europe. As a general message from the European experience, streetcar–tramway lines were found to be most effective when implemented as part of a “transit first” approach to traffic management, which had the added benefit of creating more pedestrian-friendly streets.

From the vehicle perspective, the most influential differences were found to be in the area of standards. Separate standards development efforts in the United States and Europe have led to different standards covering the same topics. For example, differences in accessibility standards (tolerance of a slightly greater vertical step in Europe) impacted the overall approach to level boarding and the need for vehicle features such as load leveling and bridgeplates. Differences in crashworthiness and fire safety standards were also noted. This area was identified as needing additional research.

The Operating Environment Research document was updated numerous times through June 2011 and posted on the project website.

PART 2. GUIDELINE TOPICS

The process of developing the Operating Environment Research document distilled out five topic areas for inclusion in the guideline:

- Vehicle configuration,
- Vehicle–platform interface,
- Vehicle–track interface,
- Power supply, and
- Standards (now a separate project).

The top-level goal for the guideline is the following: To facilitate the successful introduction of modern streetcar vehicles into North American systems by promoting understanding of the core technical and operational issues. Recognizing that streetcar and light rail systems operate in more than 400 cities throughout the world, with considerable variation in form and function, the approach for each topic is to identify and explain the underlying principles and interdependencies, and to examine the pros and cons of the various different design approaches. Throughout the document, heavy emphasis is also placed on the need to treat vehicles, infrastructure, and operations as a system.

At the conclusion of each subtopic, concise guidance paragraphs summarize the topic and provide direction. The document also makes extensive use of graphics to help explain the subject matter (Figure 3 provides an example).

Guideline Introduction

In discussing the draft guideline with persons engaged in different phases of streetcar project development and design, it became clear that many decisions relating to the alignment (which, in turn, impact the vehicle) get made very early in the process, sometimes with only minimal consideration of vehicle and maintenance issues.

The introduction is aimed at project planners and others involved with the early phases of project development. It begins emphasizing the importance of a balanced approach to design (recognizing trade-offs and avoiding over use of design minimums and maximums) and starts the discussion about defining certain standard ranges of vehicle design characteristics, providing a means to identify areas where imposing requirements on the wayside infrastructure is preferable to modifying the vehicle, and vice versa.

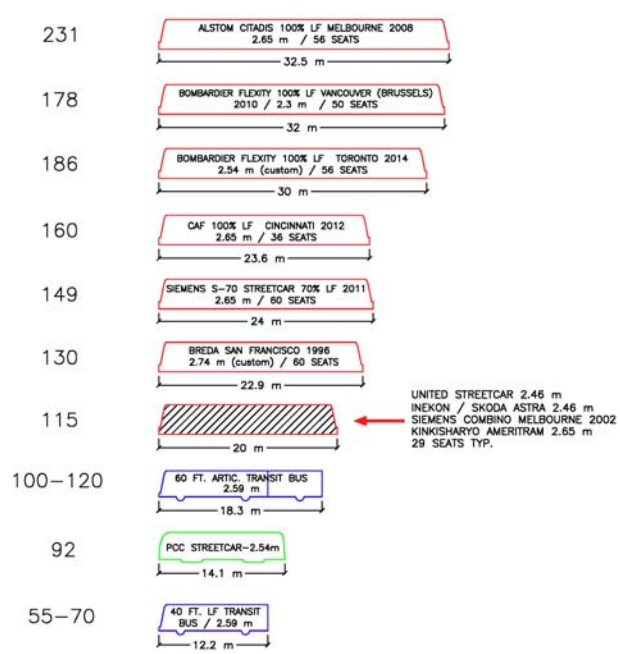

FIGURE 3 Example graphic from the document; comparison of vehicle lengths and capacities.

Topic 1. Vehicle Configuration

Key messages for this topic area include the following:

Modular Vehicle Designs

Carbuilders have developed modular product lines that permit multiple vehicle configurations and visual design elements based around standardized vehicle platforms. Within these modular product families, customers can select from a catalog of standard options to tailor the vehicles to their system. An example is vehicle width; there are three standard widths used by virtually all new tramway systems: 7 ft 6.5 in. (2.3 m), 7 ft 10.5 in. (2.4 m), and 8 ft 8 in. (2.65 m).

Understand and Communicate Duty Cycle

The adage "begin with the end in mind" applies. The first step in selecting a vehicle is to understand exactly how it will be used, and to be able to communicate that information as part of a vehicle procurement. The guideline provides users with a duty cycle checklist.

Optimize the Vehicle for the Streetcar Operating Environment

Modern light rail and streetcar vehicles are fundamentally very similar, the differences having largely to do with how they are applied. The primary difference between the two modes is the degree of integration into the urban environment and the scale of the associated infrastructure. This difference in application makes some common LRV design features unnecessary for streetcar application, but may also require the use of other features that may or may not be incorporated into a typical light rail vehicle. An explanation of key vehicle features is provided.

Consider Capacity

System planning should address the issue of how capacity will be expanded in the future to accommodate growth in demand. Although the first generation of U.S. modern streetcar vehicles were all 66 ft (20 m) in length, longer vehicles are also readily available. The 66-ft (20-m) length represents the short end of the global spectrum of modular vehicle lengths (and thus capacity), being only slightly longer than a typical articulated bus, with similar capacity. Streetcar vehicle lengths in the range of 98 ft (30 m) are more common in other parts of the world, reflecting their use as high-capacity transit.

Partial and 100% Low-Floor

More than 20 years after their debut in Europe, 100% low-floor vehicles are now appearing in North America. The 100% low-floor configuration offers further access improvements, but at the price of more complicated running gear due to limitations on space for conventional suspension and drive elements. Pros and cons of both configurations are examined.

Topic 2. Vehicle–Platform Interface

Key messages for this topic area include the following:

Americans with Disabilities Act Compliance

Both near-level and fully-level boarding have been used to achieve Americans with Disabilities Act compliance. The pros and cons of the two approaches are explored in depth, along with discussion of the many factors that influence this key decision.

Bridgeplates (If Used)

The numerous configuration and operating issues surrounding bridgeplates are explored in detail, and a recommendation made for further industry study.

Streetcar and Bus Sharing a Platform

The nature of the streetcar mode is such that streetcar and bus routes may overlap. This may present opportunities for different types of vehicles to share stops, improving passenger convenience and reducing costs by facilitating transfers and saving space in dense urban settings. Depending on the nature of the transit services using the stop, separate stopping places may also be desirable. Implementing shared stops involves a number of variables centering around the height of the platform. Generally, as streetcar platform heights increase above 8 in. (203 mm), additional design coordination is required to ensure compatibility with buses.

Topic 3. Vehicle–Track Interface

The essentials of this very complex topic are already well covered by other resources, such as TCRP Report 155 (2012), which is the revised version of *TCRP Report 57: Track Design Handbook for Light Rail.* This chapter of the guideline focuses on identifying areas where streetcar track and vehicle design are unique from light rail, centered largely around the sharper curvature typically needed to integrate into the urban environment. A top-level checklist is also included to provide a concise but more comprehensive overview of vehicle–track interface design considerations.

Recognizing that streetcars have changed significantly with the advent of low-floor vehicle technology, the draft guideline advises that "track design for new streetcar systems should be undertaken specifically with the use of low-floor vehicle technology in mind. Track designers should understand that modern streetcar vehicles are significantly different from earlier vehicles, having evolved into designs with smaller body sections and a greater number of articulations, and incorporating special running gear to accommodate the low-floor section(s) of the vehicle."

Other important subtopics include discussion of turning radius, gradients, and track twist–wheel unloading. The special running gear used in low-floor vehicle designs is also reviewed along with related wheel maintenance issues.

While it is acknowledged that the nature of a streetcar alignment is such that sharper curvature and steeper gradients than light rail may be necessary, emphasis is also placed on treating track, vehicle, and operations as a system. The draft document emphasizes that "because of the inherent flexibility of the light rail/streetcar mode, it is possible to operate over extremely demanding alignments in terms of curvature and gradient. However, minimizing the use of such extremes brings numerous benefits in terms of passenger comfort, higher operating speeds, lower operating costs, and the ability to purchase 'standard' vehicles from multiple suppliers."

Topic 4. Power Supply

This chapter provides an overview of basic traction electrification system concepts and their relation to new power supply technologies now being introduced for vehicle propulsion. More than any other section of the document, this topic is the most fluid in terms of the speed with which the technology is evolving. Consequently, the content merely reflects the current state of the industry, with the expectation that it may be distinctly different in the near future. A brief discussion of overhead contact system (OCS) aesthetics is also included, as it was felt that this topic is strongly connected to the subject of off-wire streetcar operation.

Key messages for this topic area include the following:

OCS Aesthetics Matter

Good OCS design practice recognizes the importance of context-sensitive aesthetics and treats in-street and other sensitive areas accordingly.

Energy Storage Has Multiple Roles

Some alternatives to using only OCS power distribution have now entered the marketplace. New types of ground-level power supply systems are now in limited use, and onboard energy storage capabilities are becoming increasingly common to reduce energy costs. Also, some vehicles can now be equipped with enough energy storage capacity to permit short range off-wire operation. Vehicles with longer off-wire range are also in development.

Examine Life-Cycle Cost When Comparing Technologies

When considering off-wire capable vehicles, recognize that while infrastructure may be made less costly to build and maintain, the opposite will happen to the vehicle; it will become more technically complex, and may also become heavier, more costly to purchase and maintain, and operationally less flexible. For these reasons, system size and future expansion impact the comparison of power supply options.

Operating scenarios for off-wire capable vehicles must also take charging time into account, and recognize that vehicles may need to operate in a reduced performance mode when "off wire" in order to reduce energy consumption and lengthen operational range. It is also important to make all technology comparisons on the basis of life-cycle cost, incorporating consideration of maintenance costs over the life of the system. This is especially important with consumable energy storage devices (e.g., batteries), which will have a finite number of operating cycles and a substantial replacement and disposal cost.

Apply New Technology in a Manner That Minimizes Impacts of Proprietary Designs

Because energy storage systems are still largely in a developmental stage, they can be expected to continue changing rapidly as the technology evolves. The ability to add energy storage equipment to the vehicle in a manner which minimizes the risks associated with the use of proprietary technology is therefore an important consideration.

Topic 5. Standards (Separate Project)

The research undertaken at the beginning of the guideline project provided these key observations relating to standards: that the United States comprises only a modest share of the global market for streetcar and light rail vehicles, and parallel but separate standards efforts have occurred in Europe and the United States for several key areas impacting vehicle design including accessibility, crashworthiness, and fire safety. It was further observed that a comprehensive European standard exists for braking rates (Figures 4 and 5) (covering all types of mass transit vehicles), but that no such national standard exists in the United States.

After preparing an initial draft of this chapter and circulating it for comment, it was decided that due to its complexity, this topic would need to be addressed in a separate work effort. Also, carbuilders are still examining the differences between the United States and European standards in order to understand where design changes may be necessary in order to comply with U.S. standards. Further research is required in order to fully understand the implications of the differences between these various standards.

FIGURE 4 Modern streetcar in Reims, France.

FIGURE 5 Off-wire operation in Nice, France.

APPENDICES: 2012 CARBUILDER SURVEY

The appendix will include an updated (2012) version of the carbuilder survey. Each carbuilder was again asked to provide detailed information on the products they would offer in response to an inquiry from a U.S. purchaser. Carbuilder response to the survey has once again been very strong, and a detailed compendium will result.

DOCUMENT COMPLETION

The subcommittee is currently circulating a draft of the complete document for industry comment. It will then go through the APTA balloting and approval process. Throughout the course of developing the guideline, it has facilitated industry dialogue on numerous streetcar-related topics. In some cases these discussions ended up being broader or more detailed than what was appropriate for the guideline, so a number of topics have now been identified for follow-up research and future work.

Practical Off-Wire Streetcar and Light Rail Vehicle Operation

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For more than 110 years, the use of overhead wires to power streetcars and light rail vehicles (LRV) has been considered unsightly and undesirable. Despite repeated attempts at inventing a wireless system, overhead trolley wire or catenary systems have been adopted as the only practical long-term solution. However, in recent years, new technological developments of a variety of alternative embedded switched contact continuous power transmission systems such as APS, Primove, and TramWave, as well periodic power transmission systems such as flywheels, batteries, supercapacitors, or hybrid combinations of these energy storage devices are at last offering a practical alternative to overhead systems. In this paper, the latest off-wire system developments are examined with particular attention to practical application to new streetcar or LRVs. From these comparisons, we can conclude that practical alternatives to overhead wires for light rail systems are rapidly becoming proven and commercially available.

THE STORY CONTINUES

This paper is the second in the series on this subject. For an overview of the various off-wire systems currently in operation or development, please consult "Practical Off-Wire Streetcar and Light Rail Vehicle Operation—1", which was presented at the APTA Rail Conference in Dallas earlier this year. Despite that paper's monitoring of developments over the last decade, this is an area that is in considerable flux, with new developments seemingly coming every week. This paper concentrates more on the specific characteristics of such system and is intended as a guideline regarding their potential application to revenue service vehicles.

These two papers have evolved over a period of many years, utilizing information provided by interviews and submittals by off-wire system vendors, site visits, press releases, and numerous published technical articles and papers on the subject. Particularly useful articles are to be found in European rail publications such as *Railway Gazette*, *International Railway Journal*, and *Tramways & Urban Transit.*

A LONG-SOUGHT DREAM

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 cities such New York City, Washington, D.C., London, Bordeaux, and Paris garnered enough political support to enact city ordinances prohibiting the erection of any type of overhead wires in specifically designated areas, which included streetcar operations.

Around the turn of the century, a flurry of wireless systems (now more commonly known as off-wire operation) were developed, the most successful being the conduit system, often as a replacement of earlier cable car systems. For most cities, however, financial and practical considerations usually ended up winning the argument and as a result, either overhead wires were erected or the system was abandoned. As a result, almost every streetcar and light rail system in operation or being planned today uses an overhead wire to supply power to the vehicles. But the dream lingers on.

NEW IDEAS IN GROUND-LEVEL POWER TRANSFER

Supercapacitors are best for energy savings and shorter off-wire distances. All of these systems place the power supply rails or coils at ground level directly between the running rails and pick up the power using special contact shoegear or pick-up coils located underneath the vehicle. All have a series of separate independent sections and provide a means by which each section can be switched on or off individually so that a particular power rail section is energized only when the vehicle is directly over it.

IMPROVED ONBOARD ENERGY STORAGE TECHNOLOGY

As an alternative to ground-level power transfer systems, onboard energy storage (OES) systems can store regenerative braking energy and supply power to move the vehicle when operation is off wire. The three basic OES devices in use today are

- Flywheels,
- Batteries, and
- Supercapacitors.

Some carbuilders are combining batteries with supercapacitors to give both fast and long term OES capabilities.

Hybrids are another approach to off-wire technology, by either dispensing with overhead wire entirely and operating completely off wire using an energy storage device (usually a battery) set supplemented by an onboard power generator set (diesel electric, microturbine, or fuel cell), or using a generator set to power the vehicle whenever operating off wire.

For additional information regarding the various off-wire systems currently in use worldwide please refer to part one of this paper presented at the APTA 2012 Rail Conference.

Advantages and Disadvantages

Ground-Level Power Transfer Systems

Continuous power transfer systems have the following advantages:

- No reduction in vehicle performance.
- Braking energy can be stored onboard the vehicle and released for acceleration of the vehicle, lowering overall vehicle installed power and saving energy.
- Pleasing, low-visual–impact installation.

There are, of course, some disadvantages:

- With the exception of the Alstom APS system, these systems are not proven in revenue service to any significant degree.
- Such systems are proprietary (i.e., sole source), potentially complicating current and future vehicle purchases. In the case of Alstom, the APS system is not available separately from the purchase of Citadis light rail vehicles (LRVS).
- No applications as yet in the United States. “Buy America” requirements could also be an issue.
- Installation has a significant civil–trackwork–systems impact.
- The systems are overall typically three to eight times as expensive as a traditional overhead catenary system (OCS) system, although recent studies by others have estimated these costs to be in the range of 1.5 to 2 times as expensive, not taking into account any additional civil work or utility relocation, etc.
- There is no reduction in the number of traction power substations required.
- Generally, regeneration back into the traction power system is not possible which can result in higher electricity costs than an OCS system, although for the APS and Primove system this is somewhat mitigated by the associated OES equipment.
- OES equipment is needed in addition to the basic power transfer equipment to reduce peak power requirements and propel the vehicle through any faulty or dead ground-level segments.
- Although hard data on maintenance costs are difficult to obtain or not yet known, for the APS and Primove system, given the large number of switching retractable undercar power collection equipment and other mechanical moving components involved, this cost will inevitably be higher than for normal OCS. The maintenance and replacement costs associated with the special flexible magnetic conducting power belt used in the TramWave system are also an unknown.
- The impact of extreme climactic conditions on such systems is unknown, particularly as regards snow, ice, dust, grit, and high temperatures.
- The systems also require significant vehicle-mounted equipment, which takes up additional space onboard the vehicle and must be mounted mostly on the roof of the vehicle, where space availability for additional equipment is usually low, especially on modern streetcars. Space for the power collection equipment mounted underneath the vehicle and integration with vehicle systems is also required.
- The weight and balance impact of the extra equipment on the vehicle is also a consideration.

Onboard Energy Storage Systems

Looking at the various types of OES systems available on an individual basis, vehicle-borne flywheel power has the following advantages:

- Braking energy can be stored in the flywheel and released for acceleration of the vehicle, lowering overall vehicle installed power and energy consumption.

- Flywheels can potentially serve as the complete vehicle propulsion system provided it can be periodically recharged at station stops or with an onboard auxiliary electrical power source.
- Multiple flywheels can provide a high level of redundancy on a multicar train level.
- Use of vehicle-borne flywheels reduces the voltage drop due to line losses and maximizes the regenerative power that can be stored.
- Flywheels allow very good acceleration rates and good braking rates.

Flywheels also come with the following disadvantages:

- Flywheel units are bulky and are usually designed for mounting on the roof, where space availability for additional equipment is usually low, especially with streetcar designs.
- Energy storage capacity is relatively low compared to other types of OES.
- Flywheels typically require 40 s to recharge, twice as long as a normal maximum station dwell time.
- Flywheel units are heavy, even the third generation 300-kW unit from CCM weighs over 1000 lbs (470 kg).
- Top speed using flywheel drive only is limited. Typically this tops out at about 25 mph (40 km/h).
- There is no fleet operating experience with any light rail or streetcar operator anywhere.
- Only one known non-U.S. supplier, potential Buy America issues.
- There appea.rs to be little current interest in further developing vehicle onboard flywheel technology
- Flywheels are generally mechanically complex, especially those with magnetic bearings and a vacuum pump system. Repair and maintenance skills required are new to LRV maintenance personnel.
- Although a 20-to-30-year service life is claimed, this is not yet proven. In any case this will mean the flywheel unit will need replacement at least once in the lifetime of the vehicle at a significant cost.
- Service life in extreme climactic conditions is unknown.

In recent years, OES systems have tended to use batteries or supercapacitors. For onboard vehicle applications, battery energy storage has the following advantages:

- No polluting emissions.
- No moving parts.
- Quiet operation.
- Ability to provide power for longer periods of time than other OES devices.
- Low periodic maintenance (sealed cells).
- Individual battery sets on each vehicle provide a high level of redundancy on a multicar train level.
- Use of vehicle-borne battery sets reduces the voltage drop due to line or third-rail losses and maximizes the regenerative power that can be stored.
- Already in use in revenue service.

The disadvantages of batteries as they currently exist are the following:

- Weight and physical size. Traditionally lead-acid and nickel-cadmium battery sets are very heavy, and great efforts have been made to reduce the size of a battery pack, mostly by reducing vehicle performance. Newer battery types such as Li-Ion and Ni-MH offer improved performance, but the overall weight and space required is still very significant. Although roof mounting is the ideal, the limited space available on the vehicle often requires batteries to be mounted underneath longitudinal seats.
- In addition to the battery set, a charge–discharge controller or a dc-to-dc inverter is also required to maintain system voltage levels.
- For off-wire operation, distances are typically limited to between 0.25 and 5.0 mi depending on the battery size, alignment gradients, and level of auxiliary load.
- Relatively short duty cycles (i.e., range with charge level above 80%) between charges.
- Long recharge times. For many battery types, overnight recharging is needed. However, the newer nickel-metal hydride batteries can recharge in 5 or 6 h, while lithium-ion batteries are able to recharge in as little as one minute (a 10-min recharge at turn-around points, supplemented by overnight recharging in the maintenance and storage facility is typically recommended). Charging rates are also dependent on the charge level of the battery when charging is started. They take up a lot of space and must be mounted either on the roof or under seats inside the vehicle, depending on the vehicle design, where space availability for additional equipment is usually low, particularly in streetcar designs.
- Additional safety considerations in the event of a collision need to be addressed.
- Battery life in extreme climactic conditions is unknown, particularly relating to sustained high temperatures.
- Typical maximum operating temperatures are around 104°F (40°C). Forced air cooling and active temperature management subsystems are required.
- With a typical battery life of 5 to 10 years, the battery set will need replacement at least twice in the lifetime of the vehicle. Replacement costs are currently between $150,000 and $250,000 depending on the size and type of battery set (although costs may reduce in future as more batteries are utilized for propulsion in the automotive sector).
- Many series electrical connections to achieve the necessary total voltage output. Failure of a single cell or connection could render the storage unit unserviceable. (Much work has gone into the design of such connections and the reliability of these is high.)
- Top speed using battery power only is limited. Typically this tops out at about 25 mph (40 km/h) or less, although this is usually due to keeping the practice of making the battery units as small as practicable rather than any inherent battery limitation.
- Long-term environmental considerations—costs, particularly recycling or disposal of large quantities of life-expired battery cells.
- There is generally no reduction in the overall number or size of traction power substations required except in exceptional circumstances.

Vehicle-borne supercapacitors have the following advantages:

- Braking energy can be stored in the supercapacitor and released for acceleration of the vehicle, lowering overall vehicle installed power and saving energy.

- Supercapacitors allow very good acceleration rates and good braking rates.
- No moving parts.
- No periodic maintenance.
- Very quickly recharged.
- As supercapacitors gradually age with use, they generally do not fail, but suffer a slight reduction in their overall capacity to store charge.
- Multiple supercapacitor units on each vehicle provide a high level of redundancy on a multicar train level.
- Use of vehicle-borne supercapacitor units reduces the voltage drop due to line and third-rail losses and maximizes the regenerative power that can be stored.

There are of course some disadvantages to using supercapacitors:

- They also take up a lot of space and must be mounted either on the roof or under the passenger seats inside vehicle, depending on the vehicle design, where space availability for additional equipment is usually low, notably on streetcar designs.
- In addition to the supercapacitor unit, a charge or discharge controller or a dc-to-dc inverter is also required to maintain system voltage levels.
- Weight is again a consideration.
- For off-wire operation, distances are typically limited to between 300 and 2,500 ft.
- There are numerous series and parallel electrical connections between the 2.7-volt cells, a potential reliability risk (typically over 1,700 connections). Failure of any of these connections or cells can seriously degrade the energy storage capacity. However, none have been reported to date.
- Supercapacitor life in extreme climactic conditions unknown, but predictable. Operation at temperatures up to 149°F (65°C) is possible, but life is known to be reduced when operating at higher temperatures.
- Forced-air cooling and active temperature management subsystems are usually required.
- Depending on the charge or discharge rate, life is expected to be between 23 and 30 years (after over 1 million cycles when their capacitance or ability to store charge has dropped 20% from the original design value). This means that the supercapacitor units may need replacement once in the life of the vehicle. Currently this cost is in the neighborhood of $275,000 per unit (although cost may reduce in future as supercapacitors are more widely utilized in automotive applications).

PRACTICAL APPLICATION OF OFF-WIRE TECHNOLOGY

Given the two methods of providing power to a vehicle without the use of overhead wires, the ground power transfer system would seem to offer the best technical solution due to its ability to provide continuous power to the vehicle with no reduction in vehicle performance, but the proprietary (sole source) nature, high installation and maintenance costs as well as lack of U.S. experience and equipment suppliers currently make it a nonstarter.

Currently in the United States, periodic power transmission and onboard energy storage systems are beginning to enter revenue service. Onboard battery systems would appear to be the best solution at this point in time, although use of supercapacitors is promising for very short distances off wire and may be combined with a battery system to give both energy savings and superior performance when operating off wire.

Designing a system for off-wire operation using periodic power transmission and energy storage devices is a complex task, which must dynamically balance the energy stored on the vehicle against the specific energy requirements of the areas to be operated without overhead catenary. In order to optimize the type and size of the vehicle OES devices to be used, an iterative approach is required to minimize the catenary and traction power substation installation within the limits of the energy storage devices that can be accommodated on the vehicle over the specified off-wire route profile and operational requirements.

The first step in this design process is to fully define the route where wireless operation is required or desired. However, in this case, specific operational performance limits for these areas are also applied, including speed limits, top operating speed, acceleration performance, station dwell times, number and location of station stops, number, type and location of traffic lights, gradient details, and any other alignment details that might affect vehicle operation in the area.

This information is used to perform fairly standard propulsion system simulations (usually undertaken by the propulsion system supplier) to calculate the vehicle's energy consumption over time (including regeneration) for propulsion when operating off wire. Such simulations are typical of propulsion performance calculations done on any new system as part of the normal design process.

Added to the propulsion power requirements are the vehicle auxiliary loads when operating off wire, including any acceptable reductions in auxiliary loads that would assist in reducing the overall power consumption. Typically this concentrates on heating, ventilation, and air conditioning system performance where low heating and cooling or ventilation only may be acceptable while operating in the off-wire areas.

The output of the propulsion energy calculations in conjunction with the off-wire auxiliary loads is then used as the input into an energy storage device or system operational simulator (usually provided by the energy storage device supplier), which allows the energy storage device capacity to be determined.

Following this first design iteration, the ability to accommodate the resulting size and type of energy storage devices on board the vehicle is investigated. Any energy storage system installed on a vehicle for the purposes of significant off-wire operation requires relatively large areas to physically accommodate all the equipment, as well the ability of the vehicle car shell in that area to structurally take the load while maintaining a reasonably balanced installation (i.e., not an excessive concentration of weight on one side of the vehicle or overloading trucks or articulation joints).

For simplicity, safety and accessibility for maintenance, as well as the dispersal of waste heat, the ideal first choice for locating additional energy storage equipment would be the roof area. However, for most North American light rail and streetcar vehicle designs, it is usually not possible to accommodate all the necessary equipment.

Therefore the only other practical solution to gain significantly more space is to locate the majority of the energy storage equipment inside the passenger compartments underneath longitudinal passenger seats. This has so far been the universal solution for the various modern streetcar designs having off-wire capability when using batteries.

To give an idea of what is involved, in a typical modern battery OES design, the battery sets weigh around 2,860 lb plus the roof mounted dc charge and discharge controller, which weighs another 1,764 lb, for a total additional weight of 4,624 lb. and requires the space under four groups of four longitudinal seats to accommodate.

Should the initial OES equipment prove physically impossible to accommodate, the off-wire area, vehicle propulsion, and auxiliary load requirements must then be revisited with a view towards reaching a reasonable level of operation while still accommodating the necessary OESequipment. This overall process may take several iterations before an optimal system design is achieved.

Once the OES equipment has been physically accommodated, the OES system must be integrated with many other vehicle subsystems including propulsion, auxiliary equipment (including load shedding), pantograph, operator controls, vehicle location system, data recorder, and the maintenance and diagnostic system.

In addition, the additional OES equipment will require changes in the operator's manual, the maintenance manuals, the illustrated parts list, personnel training, more special tools and equipment, and a larger stock of spare parts.

Last, but not least, are the substantial replacement and disposal costs for batteries and supercapacitors over the life of the vehicle.

CONCLUSION

For the first time in many decades, the dream of having quiet, nonpolluting, electric LRVs running without any overhead wires is becoming a practical reality. However, implementing off-wire capability remains, and probably always will be, an expensive and complex task not to be undertaken lightly. The key points include the following:

- Off-wire systems are available, but there are no common standards.
- There are two basic approaches—ground power transfer or OES.
- Ground power systems are proprietary, but provide continuous power.
- Ground power systems require additional wayside equipment located between the rails and are generally more expensive than OCS.
- Most OES systems use batteries or supercapacitors (or a combination thereof).
- OES systems have a finite energy storage capability and must be periodically recharged.
- For OES systems, batteries are best for longer distances off wire.
- Supercapacitors are best for energy savings and shorter distances off wire.
- The addition of OES equipment to a vehicle for off-wire operation is a complex undertaking and must be tailored to the specific system alignment and operational requirements.
- For longer distances off wire, battery OES equipment adds substantial weight to the vehicle and requires a considerable amount of room.
- Battery recharging time can have an impact on services schedules, turn-around times, etc.
- Except in rare cases, the provision of OES equipment for off-wire operation will not save on substation costs, although there will be some savings in catenary costs in the off-wire sections.

- There are substantial replacement and disposal costs for batteries and supercapacitors over the life of the vehicle.

The technology needed for off-wire operation of streetcars and LRVs is rapidly becoming available, proven, and practical. One thing is certain: public opinion is very supportive of wireless or off-wire systems for aesthetic reasons. As this technology becomes even more mature and available, widespread adoption is inevitable.

The New Seattle Streetcar with Onboard Energy Storage

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As part of the First Hill Streetcar (FHSC) Project, the Seattle Department of Transportation (DOT) began a procurement of six modern streetcars in early 2011. The FHSC alignment runs parallel with electric trolleybus (ETB) lines along part of its route, is crossed by several ETB lines, and is characterized by steep gradients. In order to avoid or mitigate interference with the existing ETB operations, Seattle DOT elected to pursue procurement of a modern streetcar capable of wireless operation along segments of the FHSC alignment through use of an onboard energy storage system (OESS) instead of conventional power pick-up via a pantograph from an overhead contact wire. This paper describes the development of the performance requirements for the OESS operation, the incorporation of these requirements into the overall technical specifications, and the procurement process that resulted in the award of the contract to the Inekon Group (IG), a firm based in the Czech Republic that has supplied streetcars recently to U.S. cities, including Seattle. Characteristics of the IG OESS streetcar are provided with a focus on those aspects that relate to wireless operation, along with a status of the design and the manufacturing plan.

INTRODUCTION

In 2007, the Seattle Department of Transportation (DOT) started revenue service on the South Lake Union Streetcar, the first modern streetcar line in the Seattle area since streetcars were phased out in the 1950s. Shortly thereafter, Sound Transit, the regional transit agency in the Seattle area, included approximately $133 million for a second streetcar line to replace a planned light rail subway stop in a Sound Transit referendum for rail transit improvements. As part of its streetcar network planning process, Seattle DOT worked with Sound Transit to define the line, and the two agencies eventually completed an interagency agreement to transfer funding and project development responsibilities to Seattle DOT. The First Hill Streetcar (FHSC) line was born. Conceptual engineering was started in 2009, followed by preliminary engineering in 2010 and final design in 2011. Construction is underway in mid-2012, with an opening planned for mid-2014.

This paper briefly outlines the FHSC project then focuses on the procurement of the streetcar vehicles. A study of wireless operation is summarized, resulting in a decision to proceed with procurement of streetcars with an onboard energy storage system. The procurement process is then delineated in detail, and a preliminary description of the selected vehicle is provided.

FIRST HILL STREETCAR PROJECT

The FHSC line is approximately 3.8 km (2.4 mi) in length (Figure 1) and will connect the diverse and vibrant neighborhoods and mixed-use neighborhoods, as well as serve employment centers, medical centers, institutions of higher learning (Seattle University and Seattle Central Community College), and major sporting event locations (Century Link and Safeco Fields). It will provide connections to two Sound Transit light rail stations, AMTRAK, the Sounder regional rail system, and numerous bus and electric trolley bus (ETB) lines. The line is entirely in city streets and is characterized by long stretches of moderate grades and short stretches of steep grades up to 9%. Overall the average grade is approximately 2.4% with the first 2.1 km at an average of 3.4%.

FIGURE 1 FHSC alignment.

WIRELESS STUDY

In early 2010 Seattle DOT asked LTK, its FHSC systems consultant, to conduct a study of the feasibility of building a portion of the FHSC alignment without an overhead wire system, thus requiring the new streetcars to be able to operate without an overhead power source. Seattle has an extensive ETB network, and wireless capability was of particular interest in Seattle as a means to reduce or mitigate potential conflicts between existing ETB overhead wires and new streetcar routes with traditional overhead wire systems. In April 2010 a report was produced that investigated the feasibility of wireless capability for the FHSC line and presented a preliminary assessment of streetcar–trolley bus integration along a representative alignment. In this context, wireless operation involved battery or capacitor drive across sections of streetcar alignment with no overhead wire but with the obvious requirement that the pantograph must be lowered before entering and raised after exiting the wireless section.

The purpose of the study was to answer the following questions:

- Where will streetcar–trolley bus integration be necessary along the representative alignment, and what are the most challenging locations?
- What is the state of the art in wireless technology?
- What onboard hardware is needed to permit streetcar operation across short sections of track without overhead wire?
- What are some of the factors that affect the sizing and capability of the hardware?
- For the FHSC Project, what locations or sections of track might benefit the most from these approaches?

Systems that use batteries or capacitors to store energy permit streetcars and light rail vehicles to operate for some distance without a physical connection to an overhead wire power source. Wireless operation is an emerging technology in the rail transit field, with approximately 5 years of development, although some bus applications have a somewhat longer history. Wireless operation is attractive in many locales for emergency recovery and for aesthetic reasons, in particularly sensitive or historic settings. Also, with today's interest in energy conservation, these systems are being developed to supplement, and not just intermittently replace, the normal traction power source by their ability to store regenerated energy.

The study provided a brief description of the existing Seattle streetcar, its current battery drive feature, and a brief survey of state-of-the-art battery drive approaches and other similar methods. It was learned that several major carbuilders have developed rail vehicles with a prototype version of an alternate power source, typically some improved battery system or a capacitor bank. At least two designs had entered revenue service, most notably the Alstom *Citadis* in Nice, France.

The existing Seattle streetcar fleet has a battery drive system for short emergency movements that operates at the normal battery level voltage of 24 Vdc. However, 24 Vdc is only a fraction of the typical 750-Vdc overhead contact system voltage, so current developed by the 24-Vdc battery would need to be many times the normal current levels to yield even remotely equivalent power, when compared to current levels supplied using an overhead wire. Unfortunately, low voltages and high currents would bring large electrical losses, large reduction in traction motor efficiency, and of course significant overheating problems. The traction equipment is generally not designed to accommodate, and cannot tolerate, such high current levels. The result is that vehicle operation with the 24-Vdc battery drive is limited to an emergency response mode, for example, moving the vehicle a very short distance at very low speeds to clear an accident, overhead wire, or pantograph problem. It was concluded that a 24-Vdc battery drive approach could not be used as a routine substitute power source in repetitive mainline operation.

Vehicles in service and under development by Alstom, Siemens, Bombardier, Tokyu, Kawasaki, Hitachi, and KinkiSharyo all utilize an enhanced battery or capacitor system, or both, at 400 Vdc or higher, thereby permitting more reasonable levels of wireless operation. Some have achieved an off-wire capability of over 1 km, and prototype test vehicles with very large, and heavy, battery systems have ranges exceeding 10 km. The study recommended that a battery drive system operate at a voltage approaching that of the overhead contact wire, for example, 600 Vdc, for realistic applications involving a few thousand feet of wireless operation, particularly when substantial grades or curves are involved.

An energy analysis was conducted, and the study offered the following conclusions:

- An energy profile was developed for a representative First Hill alignment from 2nd and Jackson to Broadway and Denny, a roundtrip distance of approximately 7.8 km. Depending on assumptions and contingencies, the total roundtrip energy requirement for the representative alignment was estimated to be in the range of 45 kWh to 70 kWh.
- Intersections with potential ETB and streetcar overhead-contact-system crossings were characterized and were an important consideration in analyzing and sizing wireless segments.
- Wireless segments were identified that appeared particularly promising in mitigating severe conflicts with ETB overhead wires yet not imposing excessive energy requirements.
- It should be possible for a new vehicle design to provide for wireless operation over the segments developed.
- Although charging capability was not studied in detail, a 600-Vdc lithium ion battery likely could be adequately charged at each end of the line in a reasonable timeframe.
- Alignment characteristics, vehicle performance characteristics, and operating scenarios all can significantly affect feasibility of wireless operation.

Responding to these conclusions, Seattle DOT decided in mid 2010 to proceed with its vehicle procurement based on a vehicle with an onboard energy storage system (OESS).

VEHICLE PROCUREMENT PROCESS

Chronology

In mid 2010, Seattle DOT started its procurement of streetcars with OESS capability by requesting letters of interest from carbuilders, followed in late 2010 by an industry review of preliminary technical specifications. In March 2011 Seattle DOT released its request for proposal (RFP) for the procurement of the streetcars and related materials and services. The chronology of the procurement is as follows:

- Industry review: late 2010;

- Request for proposals issued: March 2011;
- Proposals received: May 2011;
- Meetings with proposers: May 2011;
- Request for best and final offers (BAFOs) issued: August 2011;
- BAFOs received: September 2011;
- Selection of best-value proposer: October 2011; and
- Notice to proceed: March 2012.

The procurement was conducted in what has become a traditional two-step, best-value process.

In the first step, Seattle DOT evaluated proposals in accordance with its RFP requirements. This evaluation included first an assessment of basic responsiveness, then a quantitative evaluation of both technical proposals and price proposals, and finally a ranking of proposals and a determination of proposers within the competitive range. Seattle DOT then held discussions with proposers in the competitive range. While Seattle DOT reserved the right to award the contract to the highest-ranked proposer at the conclusion of the first step, Seattle DOT elected to proceed to the second step by preparing a request for best and final offer (RBAFO) based on the RFP and its discussions with proposers. In the second step, Seattle DOT issued the RBAFO only to those firms within the competitive range. Seattle DOT then evaluated the BAFOs in accordance with the RBAFO requirements and made a selection based on its RBAFO evaluation criteria.

Evaluation Process First Step

Seattle DOT appointed an evaluation committee to evaluate proposals and recommend whether to proceed to a second step. Technical proposals were opened first and reviewed for basic responsiveness and compliance with the RFP by the evaluation committee. Three proposals were received, and all were considered responsive. The evaluation committee reviewed each responsive proposal and established two intermediate scores, a technical score and a price score, which were then combined into the total score for each proposal. Seattle DOT established the following relative weights for the technical proposal and the price proposal:

- Technical proposal: 60% and
- Price proposal: 40%.

The evaluation committee employed the following main criteria and relative weights in evaluating technical proposals in the first (RFP) step:

- Proposed vehicle: 50%;
- Onboard energy storage system: 20%;
- Management approach and schedule: 10%;
- System support plan: 5%;
- Qualifications, experience, and references: 10%; and
- Ability to conform to Buy America: 5%.

While this procurement was not federally funded and therefore not subject to Buy America regulations, Seattle DOT considered Buy America conformance a desirable goal.

The sealed envelopes of the price proposals were opened by the evaluation committee after the technical evaluation had been completed. The price score was based on the basis for price proposal evaluation with the lowest proposed price assigned the maximum price score and all other price proposals were prorated accordingly. It is important to note that the basis for price proposal evaluation included the total base contract price (six streetcars, system support, spare parts, etc.), a defined number of option vehicles, plus a defined scope for option equipment and services.

All three proposers were considered to be within the competitive range at the end of the first step, and the evaluation committee recommended meetings with them and proceeding to the second step.

Evaluation Process Second Step

The evaluation process for the RBAFO step followed an almost identical approach as that of the first step with one twist. Seattle DOT considered the price proposals from the first step extremely high and infeasible from a budget perspective. Accordingly a decision was made to allow a conventional streetcar to be proposed in the BAFO as an alternate with identical requirements except for OESS and with the expectation that prices would fall within range of the budget. Thus a proposer (in the competitive range from the first step) could propose a conventional car or an OESS car or both. Technical score criteria were adjusted as follows:

		Conventional Car	**OESS Car**
A.	Proposed vehicle	70%	50%
B.	OESS	0%	20%
C.	Management approach and schedule	10%	10%
D.	System-support plan	5%	5%
E.	Qualifications, experience, and references	10%	10%
F.	Ability to conform to Buy America	5%	5%

Seattle DOT permitted the final determination of best value to be a qualitative assessment overlaid on top of the quantitative process.

SUMMARY OF RESULTS

Seattle DOT evaluated two BAFOs for a conventional car and three for an OESS car and determined the best-value conventional car and the best-value OESS car. Seattle DOT determined that the best-value OESS car was financially feasible and the best value overall and issued a notice of intent to award to the Inekon Group (IG) of the Czech Republic, the carbuilder of its successful SLU vehicles, in October 2011. Two unsuccessful protests and several months of contract negotiations followed. NTP was issued in March 2012 at a total base contract price (TBCP) of $26.7 million. The unit price of the IG OESS car was $3.155 million and systems support, spare parts, and more totaled almost $7.8 million. For the winning IG BAFO, there was an increase of only $90,000 in the unit price of the OESS car compared to that of the IG conventional car or an increase in TBCP of $900,000. The increases were considerably higher for the unsuccessful proposer. The TBCPs for the three OESS cars were within a range of 10%.

It should be noted that incorporation of wireless operation into the wayside design of the FHSC project was estimated to reduce overhead contact system costs by approximately $1 million or roughly equivalent to the OESS premium.

TECHNICAL REQUIREMENTS

From the beginning of the process, Seattle DOT intended to procure streetcars similar in size and type to its existing SLU cars: double-sided, double-ended, partial (or 100%) low-floor streetcars approximately 20 to 22 m in length and 2.46 m in width so as to offer basic compatibility between the SLU and FHSC lines.

The streetcars will operate singly as one-car trains, and, as has been described, a decision was made early on to incorporate an OESS to permit operation through wireless segments in Seattle DOT's FHSC alignment and potentially other alignments in Seattle. Seattle DOT recognized that OESS was an emerging technology with no proven examples of streetcars in revenue service in the United States as of 2011. Consequently, Seattle DOT identified minimum performance requirements of an OESS in the technical specifications and offered proposers the opportunity to propose equipment or techniques with the potential to exceed the minimum performance requirements with a concomitant consideration in evaluation of the technical proposals.

A summary of the OESS minimum requirements from the technical specifications is as follows:

- The vehicle shall be equipped with at least two OESSs, one per truck, with the combined capability of operating the vehicle over the required profiles.
- The energy storage device may be composed of capacitor or battery cells arranged to produce a high-voltage storage device.
- A control unit shall be provided to interface with the propulsion, auxiliary power system, and heating, ventiliation, and air conditioning (HVAC) system for the purpose of controlling energy storage device connections to those systems and monitoring the state of the energy storage device. This may be combined with the propulsion system logic.
- The system shall interface with other train and wayside systems, at specific locations along the right-of-way, which define the wireless segments, such that operation through the wireless segments can be accomplished without operator intervention. The system shall include automatic controls to drop and isolate the pantograph circuit from the car high-voltage bus before entering areas where wireless operation is required and to automatically raise the pantograph and reconnect it to the car high voltage bus when on-wire operation is to be restored.
- A wireless operation switch on the operator console shall permit manual control of wireless operation by the train operator, in the event that automatic operation malfunctions, or wireless operation is required at other locations. Wireless operation shall be interlocked with the pantograph such that wireless operation can only be activated or deactivated if the pantograph is down.
- Wireless operation mode shall be annunciated on the driver's console.

- A bidirectional converter (chopper) shall be provided to both charge the energy storage device and control energy storage power flow to the auxiliary power system and propulsion system.
- Components shall be provided to monitor and balance storage device cell voltages to prevent damage to cells due to too high or low charge in specific cells.
- A high-speed circuit breaker (HSCB) shall be installed in the high-voltage connection to the energy storage system, if independent of the propulsion system HSCB, as approved by Seattle DOT.
- Circuit protection and ground fault detection shall be provided.
- Temperature controls and forced ventilation equipment shall be provided to control the energy storage device cell temperature to keep the energy storage device cells at the optimum temperature for capacity and long life.
- If batteries are used, they shall be constructed using low-maintenance lithium ion type, service proven railway or transit quality battery cells. If capacitors are used they shall be constructed using high-current, high-capacity, service-proven railway or transit quality capacitors cells.
- The energy storage device shall be installed in a temperature-controlled ventilated enclosure outside the passenger compartment. Maintenance access shall be provided to service the devices.
- The OESS shall be capable of providing an acceleration rate of at least 1.0 m/s^2 and a top speed of 32 km/h with a fully loaded car (AW2).
- The vehicle shall be capable of providing normal service braking and emergency braking, spin–slide, mode change times, and more in OESS operation.

Key considerations with the wireless concept were the time or rate at which the vehicle would be discharging when operating wireless and the time or rate to recharge the OESS system. Lengthy charging times at the ends of the line could adversely affect operations and even require additional vehicles. Thus, a requirement was imposed that the OESS be charging whenever the pantograph was connected to the energized overhead wire or when the vehicle was in regenerative braking.

Examples of parameters offering proposers opportunity to propose enhanced performance, and potentially receive higher technical scores, included the following:

- Higher maximum acceleration rates and top speeds;
- Longer wireless segments; and
- Reduced charging time and increased performance capabilities at various charging conditions.

WIRELESS SEGMENT

Initial investigations during the wireless study discussed above recommended three wireless segments, two in the outbound (northbound) direction and one in the inbound (southbound) direction, for a total of about 1.5 km or 20% of the length of a roundtrip alignment. After review of initial proposals, it was decided that a longer wireless capability was practical and the RBAFO should include as a desired option a wireless segment running the entire length of the inbound line, approximately 3.8 km. The inbound direction is predominately downhill, thus reducing the energy demand on the OESS.

INEKON ONBOARD ENERGY STORAGE SYSTEM CAR

The IG OESS car fundamentally is based on Inekon's successful conventional streetcar in service in Portland, Seattle, and available for service in Washington, D.C. General arrangement, type, major dimensions, and several suppliers are the same. Figure 2 provides a general arrangement of the OESS car.

Suppliers of major systems are as follows:

- Propulsion (ABB),
- Network (ABB–Selectron),
- Friction brakes (Knorr),
- Doors (Bode),
- HVAC (Moran),
- OESS battery (SAFT),
- Carshell (IG),
- Truck assembly (Penn Machine), and
- Final assembly [Pacifica (Seattle)].

The basic manufacturing plan includes fabrication of car shells and assembly of the first car by IG at the DPO facility in Ostrava, Czech Republic, where the current SLU cars were built.

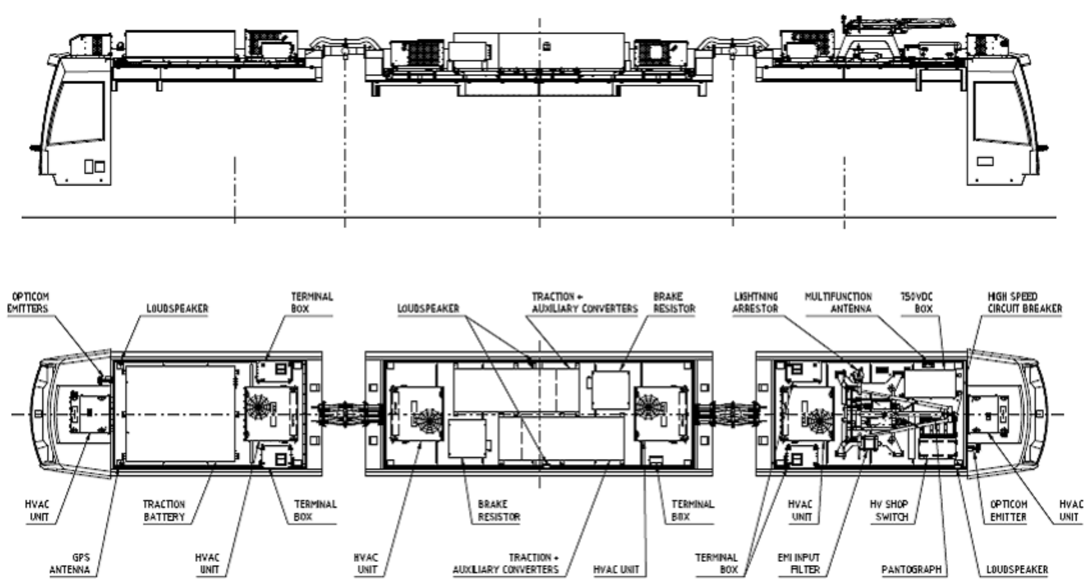

FIGURE 2 Roof general arrangement of Inekon OESS car.

The current plan is that the remaining five cars will be final assembled in the Seattle area by a Seattle company, Pacifica, under the auspices of IG.

As of the writing of this paper, the design review process is just beginning. Only a conceptual description of the two newest systems (compared to the existing SLU cars) can be provided at this time.

The propulsion system (less traction motors) will be supplied by ABB (Switzerland) and is based on their well-proven ABB BORDLINE CC400 series. There will be two propulsion packages, one for each truck, and each package will be an integrated unit and will contain the following:

- Two propulsion inverters to allow single-axle control;
- One auxiliary converter;
- One onboard battery charger;
- One control unit;
- Line contactors, fuses, input filters, and braking choppers;
- Two choppers with LC-filter for energy storage system;
- Braking resistors; and
- Liquid-cooled heat exchanger.

Figure 3 provides a view of the integrated CC400 unit chosen for this application. Space on the roof for a relatively small car such as this is at a premium and is further stressed by the need to accommodate the OESS batteries. The integration of the propulsion hardware into a single compact unit is fostered by the introduction of liquid cooling, thus permitting necessary roof space for the OESS batteries and related equipment.

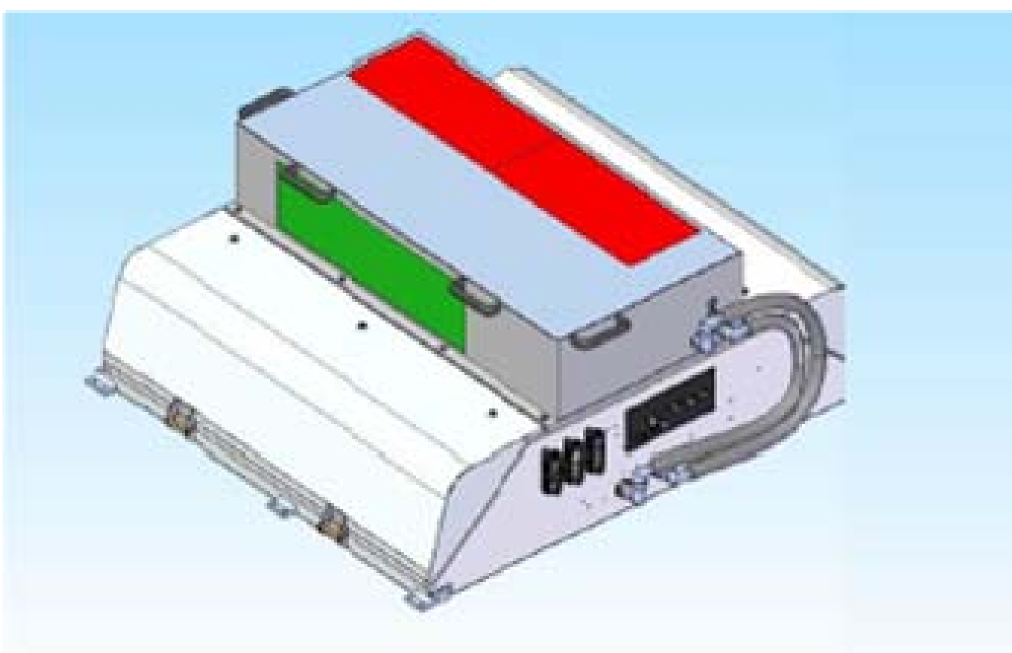

FIGURE 3 ABB integrated propulsion package.

IG has chosen a roof-mounted battery system as the primary component of its OESS concept with the following major characteristics:

- Lithium ion,
- Nominal voltage (515 V),
- Capacity (60 amp hour), and
- Weight (total) 1,300 kg plus 200 kg control equipment.

In addition to two battery packs (one per truck), the battery system will include hardware for safety and monitoring, battery management, and power measurement. In Seattle's environment, it appears that there may not be a need for routine cooling of the battery, but heating will be necessary. As the design progresses, these and various safety issues, and determination of appropriate standards are being explored.

NEXT STEPS

The schedule calls for fabrication to start in late 2012, a combined propulsion system or OESS-type test to be conducted in mid 2013, assembly and testing of the first car in the Czech Republic in late 2013, and delivery of the first car to Seattle in early 2014. Opening for revenue service is currently planned for mid 2014.

SUMMARY AND CONCLUSION

As part of the FHSC Project, Seattle DOT made the decision early on to pursue a procurement of a streetcar with an OESS primarily to reduce or eliminate conflicts between streetcar overhead wires and ETB overhead wires. Seattle DOT used a two step, best-value procurement process; however, defining basic OESS performance requirements was not as straightforward as in a procurement for conventional cars. Many new performance variables can come into play. Three solid proposals were received, and eventually Seattle DOT selected the Inekon Group from the Czech Republic, manufacturers of Seattle DOT's existing SLU streetcars. IG's new OESS cars will utilize a battery drive system operating at approximately 515 V. The battery system will be supplied by SAFT and the control by ABB. The cars are expected to be delivered and put into service in 2014.

Conclusions reached in this process are as follows:

- Battery or capacitor drive, or both, for rail vehicles is becoming a reality. There is sufficient interest in the industry to expect to see some future procurements requiring an alternate energy system.
- Operating voltage of a battery drive system must approach that of overhead wires in most applications in order to provide acceptable performance.
- Defining performance requirements for an OESS car requires the consideration of new and interrelated variables, such as charging time and operations.
- The cost premium for OESS was originally estimated to be in the range of $500,000 per car, but the Seattle results indicate it may not be as significant as originally assumed, with the bid results showing a range of $100,000 to $400,000 per car.

Tailoring Light Rail Operations to Fit the Modern Multimodal Metropolis

Light Rail to Airports
Lessons Learned, Key Issues, and Success Criteria

ANDREW SHARP
International Air Rail Organisation

This paper reviews worldwide experience of light rail transit connecting cities and airports, an area little discussed in the literature. It starts with a classification of the different types of rail service that have been developed to link cities and airports. It then considers a subset of these classifications: the solutions frequently described as light rail. This stretches from the conventional on-street multistop tram (as seen in cities like Bremen, Germany, and Phoenix, Arizona) to the RhônExpress, a high-speed tram between Lyon and St. Exupéry airport, and the Docklands Light Railway which serves London City Airport in the U.K. (which has the highest rail mode share of air passengers in the world at 51%). It discusses the factors around the airport interface and other effects which have been noted. The presentation then brings together a selection of the available statistics, and identifies some of the key issues. It then draws together some lessons learned. Finally, it reviews future research needs.

INTRODUCTION

This paper, while specifically covering light rail systems serving airports, raises issues which are common to many railways, with airport-related issues being the key focus.

It draws heavily on the resources of the International Air Rail Organisation (IARO) and, in particular, its extensive database of airport rail connections and its draft unpublished report, Light Rail to Airports.

CLASSIFICATION, TAXONOMY, AND DEFINITIONAL ISSUES

IARO normally identifies six types of passenger airport railway: light rail, metro, suburban or commuter, regional, high-speed network, and high-speed dedicated (the Airport Express).

Freight (in particular aviation fuel, building materials, and, to a lesser degree, air cargo) is also carried to and from airports by rail, but is much less significant.

Different people in different parts of the world have developed solutions to their local problem of airport access. Sometimes they have drawn on international experience, but even then they have adapted this to local needs, the local environment, and local regulatory requirements and standards.

Because of this, there are no clear boundaries between the different types.

The term light rail or light rail transit is widely used. It is defined by the APTA as follows:

> Light Rail is a mode of transit service (also called streetcar, tramway, or trolley) operating passenger rail cars singly (or in short, usually two-car or three-car, trains) on fixed rails in right-of-way that is often separated from other traffic for part or much of the way. Light rail vehicles are typically driven electrically with power being drawn from an overhead electric line via a trolley or a pantograph; driven by an operator on board the vehicle; and may have either high platform loading or low level boarding using steps. (*1*)

At the lower end of the spectrum, this paper excludes automatic people movers—short-distance shuttles within airports or between terminals and nearby car parks, consolidated car rental facilities, or transit stops. Examples of these can be found at many airports, for example, Newark Liberty International and New York's JFK, where they link the terminals, local transit stations, and parking lots.

This paper covers the streetcar or tram, which often run along trafficked streets. It includes the heavier systems (using partly or completely segregated infrastructure) like those in Vancouver and the Docklands area of London, especially those, like the Docklands system, that describe itself as light rail.

At the upper end of the spectrum, the heavier metro or subway is excluded. These are defined partly by size—longer and more substantial trains and wholly segregated routes. In German parlance, the tram (Strassenbahn) or light rail (U-Bahn or Untergrundtbahn) is included but the suburban railway (S-Bahn) is not.

LITERATURE SEARCH

Little has been published specifically on this subject. A search for "light rail + airport" brings up articles about specific systems, but no synthesis.

Three seminal TRB reports have been published on public transport to airports: *TCRP Report 62: Improving Public Transportation Access to Large Airports* (*2*); *TCRP Report 83: Strategies for Improving Public Transportation Access to Large Airports* (*3*); and *ACRP Report 4: Ground Access to Major Airports by Public Transportation* (*4*).

TCRP Report 62 was published in 2000 (*2*). It compared U.S. and non-U.S. experience of the use of public transport as an airport access mode. Pages 11 and 12 discuss definitions of public transport, but mainly in the context of road-based modes. Rail is treated as a single mode.

It was followed by TCRP Report 83 in 2002 (*3*). This gave practical information about planning and providing improved public transport, and in particular the issue of catchment areas.

A third report, ACRP Report 4 (*4*), gave advice on planning for public transport to airport planners.

HISTORY OF LIGHT RAIL TO AIRPORTS

It is not easy to ascertain the dates of the first light rail services to airports. Indeed, the railway may have ante-dated the airport, as streetcars served areas subsequently developed as airports.

Melbourne's Essendon is a classic example of an airport being developed on an existing tram line. Formerly, it was the main airport for the city; with the opening of Tullamarine airport it reverted to general aviation only. When the airport had commercial service, the tram route ran directly into the airport; now, it passes the gate (*5*).

In Hamburg the tram network served the airport until 1974, although it was more used by sightseers than by air passengers (*6*).

Chicago Midway Airport was also served by trams on Cicero Avenue (*7*).

NEXT GENERATION

What could be called the second generation of light rail to airports started to come into being in the decade starting with the mid- to late 1990s.

An excellent example of a modern tram to an airport can be seen in the north German city of Bremen, where Line 6 has connected city and airport since 1998. A prominent feature of this service is its excellent publicity. As passengers emerge from the airport terminal, they are greeted by the tram stop with big white-on-red signs publicizing the service to the city, the cost, frequency, and journey time.

The Nürnberg U-Bahn is interesting because the airport line is worked by a mix of staffed and unstaffed (driverless) trains. It opened in 1999. The line uses electronic obstacle detectors to ensure that the right-of-way in the station areas is clear, rather than the more common platform screen doors (*8*).

The light rail line to the international airport in Portland, Oregon, opened on September 10, 2001, hardly the most auspicious day. The Airport MAX (Red) line shows some impressive engineering evidence of the ability of light rail to fit into a constrained urban and suburban fabric. It was partly funded by the developer of an area of land near the airport, who saw that a railway would enhance its value by improving its accessibility (*9*). The Blue Line of city's light rail also serves the general aviation airport at Hillsboro.

Minneapolis–St. Paul shows an example of positive cooperation between airport authority and transit authority (*10*). The line goes under the runways (in a tunnel built by the airport authority) and is the connector between the two terminals. The line connects downtown Minneapolis with the airport and the Mall of the Americas. It opened fully at the end of 2004.

The saga of light rail to Los Angeles International Airport is uninspiring to a proponent of integrated air–rail transportation.

The east–west Green Line, opened in 1994 and running to the south of the city, approaches the airport at Aviation Boulevard where passengers can descend to street level for a bus shuttle to the terminals. Just beyond the station, there is a stub-end of route heading towards the airport, but the line turns south to Redondo Beach instead.

The Crenshaw Line of the Los Angeles Metro is in the planning stage. It will run north–south broadly along Crenshaw Boulevard to the west of the city. It will have a station slightly closer to the airport than that of the Green Line, but it is likely that a change of vehicle will still be needed (initially to a shuttle bus, but ultimately to some form of automatic people mover). The stub of the Green Line is likely to be extended to a wye (Delta) connection with the Crenshaw Line so that alternate Green Line trains can serve its airport station. It is unclear exactly how this will happen since the plans in the environmental impact study (EIS) show no sign of a turnback loop (*11*).

Passengers from the center of Los Angeles will still need to change line (between Blue and Green Lines at Imperial–Wilmington and between the Expo and Crenshaw lines at Expo–Crenshaw), so it will be an unattractive three-seat ride to the airport. It may be attractive to airport-based employees living locally, but it is unlikely to attract many air passengers.

This story is still running: more work is being done on the airport connection as part of the draft EIS–environmental impact report process (*12*).

Baltimore–Washington International Airport has had a light rail line to the downtown area since 1997. This runs direct from the international arrivals area and serves the Convention

Center and main hotels downtown. Formerly, it also served Penn Station in Baltimore, but that can now only be reached by a change of train.

LATEST GENERATION

A range of modern light rail systems has been built in the last decade and several serve airports. Those with particularly interesting features include the following:

- London City Airport, London's downtown airport in the Docklands redevelopment area and close to the city's financial district, has the highest rail mode share of any airport railway. Fifty-one percent of air passengers use the Docklands Light Railway to access the airport (*13*). The system has been progressively extended over the past 30 years, with the line to the airport opening in 2005 and being extended south of the Thames to Woolwich in January 2009. The airport station has two exits, one a short walk from the terminal, and the other serving the local residential neighborhood. A proposal to charge different fares for the two markets, for people using different exits, came to nothing.

  An interesting problem arose when the line opened. The airport is small and easy to use and prides itself on its lack of formality and queues. Before the line opened, passengers would arrive by car or cab in ones and twos, and by bus in tens. When the trains started, passengers arrived in groups of 50 to 100. This overloaded check-in and security until staffing and facilities could be enhanced to cope (*14*).
- Vancouver's Canada Line was created with the 2010 Winter Olympics in mind. Like the Docklands Light Railway, it is fully automated. A feature it shares with the Dubai Metro is common-use self-service check-in terminals at many stations. The airport authority invested C$300 million in the line, in particular, in the stations on Sea Island, on which the airport lies. This saved expenditure of C$450 million on car parks and a new bridge, neither of which had local support (*15*). It also resulted in a higher quality of station on Sea Island than on the rest of the system, including, in particular, escalators down as well as up. The airport authority is considering funding down escalators at selected downtown stations too because it deplores the fact that its passengers have to carry or bump their cases down fixed stairs.
- The Link Light Rail was completed to Seattle Tacoma International Airport in 2009. Because of funding constraints, it initially terminated at Tukwila with a bus shuttle to the airport, but the present terminus is at the airport. The line is to be extended further south to Tacoma, so the airport station is some distance from the terminal, a fact which has led to some criticism. A covered walkway connects the two; walking time is around 5 min. It is consistently signed in both directions, although it could be argued that Link Light Rail is not immediately comprehensible to inbound passengers as meaning the best way to downtown Seattle. The line has some dramatic engineering features, with much of the route at the airport end on elevated structures. A small section is on street (although segregated except at level crossings) with the remainder in tunnel.
- Phoenix's light rail system has had a shuttle bus connection from Washington Street into the airport since 2009. An automatic people mover is under construction to replace this (*16*).
- RhônExpress, which opened in 2010, is probably the most innovative light rail system serving an airport. It runs from the main downtown train station at Part Dieu east to Lyon–St. Exupéry Airport. For the first part of its route, it shares tracks with the city tram service (run by a

different operator). Between the terminus of the city tram at Meyzieu and the airport, it uses dedicated track. Unlike the city tram, it makes very few stops. There is only one (premium) fare to deter nonairport passengers. Many of the intermediate stations have passing loops, so that RhônExpress trams can overtake the city trams. It is a high-quality express link between city and airport, making imaginative use of existing infrastructure (*17*).

- Dubai's Red Line serves the city's international airport. It opened on September 9, 2009. It is a high-quality system with marble stations likened to the foyer of a five-star hotel. The car at the city end of each train is reserved: half for premium-fare (Gold Class) passengers and half for women and small children. There is excellent integration with the airport, using a dramatic two-level station.
- Zürich airport has recently (2008) acquired a tram connection to the city to serve places inconvenient to the nonstop heavy rail connection dating back to 1980, which has regional trains from many cities in the country. The tram also serves the airport's cargo area. A number of local hotels no longer operate shuttle buses; they urge customers to use the light rail line instead.

FUTURE PLANS

The following have been selected from a long list of future plans for light rail services to airports, usually because they have a particular point to illustrate.

- Salt Lake City's airport light rail is likely to be completed at the end of 2012, although the scheduled date was 2013 (*18*). Utah Transit Authority is one of the most innovative transit agencies in the United States; an example of this is the waiting area being built at the airport, which is being branded as the Welcome Center.

When the line was conceived, the operating agreement with the freight railroad which had rights over part of the route meant that light rail trains could not leave their depot until 6:00 a.m. in the morning. This would mean that the first train could not reach the airport before 7:00 a.m., making the service unusable for passengers with flights leaving before 8:00 a.m. It is understood that this is no longer a problem, with the economic downturn badly affecting the freight operator.

- Edinburgh's light rail system has a sad history. A bus rapid transit system was abandoned in favor of both heavy and light rail to the airport (*19*), but the heavy rail connection was canceled for cost reasons (*20*). Construction of the light rail line has been a long saga of delays, disputes, and cost overruns, with the prospect of the line ending short of the city center at one point. A major element of the problem seems to have been the requirement to move utilities away from the right-of-way in line with statutory requirements in the U.K. This led to a significant cost escalation and a major delay as contractor and operator argued about responsibilities for the cost overrun.
- A four-line tram network is being built in Shenyang (in the Liaoning Province of China), partly under the stimulus of the 12th National Games in 2013. One of the lines will serve the airport (*21*).
- The transport plan for Abu Dhabi (*22*) is amazing, with a network of light, regional, and long-distance rail services connecting all parts of the region at full fructification. The airport is to be served by trams, regional rail, and an airport express as well as a freight rail connection.

- Pisa, Italy, currently has an infrequent regional rail service between airport and city (and beyond). The line goes in a complete semicircle to get from the airport to the main station. The area partly enclosed by the railway is difficult to access, which has inhibited development and depressed its value. A new proposal by the Italian architect OneWorks is likely to change this (*23*). The ground-level heavy rail service will be replaced by a light rail line system on an elevated structure. It will have one intermediate stop (for a park-and-ride area, mainly for tourists). Because it will be elevated, it will give better access to the partially rail-locked site whose value will be released.
- There have been several plans for light rail connections to the new airport in Jebel Ali, connecting it to Dubai and to Dubai's existing international airport (*24*). The current proposal is for a new line, the 49-km Purple Line, linking the existing airport and the city with Al Maktoum Airport, paralleling the Red Line but further inland. Civil works for this started 2009.
- Following rejection of a heavy rail link in 2009, the idea of a tram–train has been put forward to serve Glasgow Airport (*25*). The heavy rail option would have meant moving the airport's fuel depot, clearly an expensive and disruptive operation. A tram capable of running on existing commuter rail infrastructure between Glasgow and Paisley on lighter infrastructure into the airport would obviate the need for this. The same concept has been proposed in the past for Leeds–Bradford Airport, where a conventional rail service would be difficult to provide because of local geography (*26*).

PLANNING ISSUES

As was pointed out in considering Portland and Glasgow, light rail, because of its lighter infrastructure and greater tolerance of curves and gradients, is easier to fit into the built environment and the urban and suburban landscape than heavier rail systems. It, therefore, may be the only form of high-capacity connection possible into some airports. It is usually cheaper, and because of its better acceleration and deceleration, it is easier to introduce stops where necessary (for example, at each terminal of a multiterminal airport).

Hence the Minneapolis–St. Paul situation, where the Hiawatha line, being rebranded as the Blue Line (*27*), serves both terminals and acts as the interterminal transfer system.

Los Angeles, however, is probably too much of a multiterminal airport to serve with light rail. It has nine terminals in a horseshoe formation. Consultation on the Crenshaw Line EIS led to an online discussion, locally in particular, of potential routes. It was clear that there was opposition to a diversion of the planned route into the airport because of the likely longer transit time for nonairport users (*28*).

Local opposition to serving an airport surfaces in a number of proposals for airport railways of all types. Reasons given for this include the observation that air passengers are affluent and therefore ought to use a cab; that air passengers have luggage for which urban transport is unsuited; and that they travel infrequently and (unlike local commuters) do not deserve high-quality trains. No doubt all have a degree of validity. What is clear is that local politicians are dependent on the votes of local people who, inevitably, have local interests. No one speaks locally for the international traveler.

Partly because of this, some light rail lines go close to, rather than into, airports. Los Angeles, Phoenix, and Minneapolis–St. Paul are examples where the line continues beyond the airport and a judgment has been made that it is better not to divert the line into the airport but instead to serve it by automated people mover or shuttle bus from a nearby station.

An interesting example of changing environments can be found at Dallas Love Field Airport. When an extension of the Dallas Area Rapid Transit (DART) light rail system was being studied in 2002, air traffic at Love Field was restricted because of local legislation, the Wright Amendment (*29*), protecting Dallas–Fort Worth International Airport (DFW). This meant relatively low traffic levels so the cost of the tunnel which would have been needed to reach Love Field would have brought the cost–benefit ratio below standards needed for federal funding (*30*). So the line serves the nearby Bachman Station, connected to Love Field by a shuttle bus. The legislation has now been repealed, so a direct service probably would have been justified after all.

Clearly, a system that runs on wholly segregated track is safer than one that shares infrastructure with road traffic. Level crossings are a major source of collisions and similar incidents. While it is likely that these are the fault of motorists rather than the light rail system, there is still a safety issue.

CONSTRUCTION ISSUES

As with any urban rail system, local issues arise during construction. If the line is in tunnel, considerations of noise, vibration, and subsidence have to be addressed. If it is elevated, there is likely to be ground-level disturbance while the structure is being built, and the loss of light and amenity can be a problem. If it makes use of disused railway right-of-way, current uses, official and unofficial, may be obstructive. If it is at ground level it can necessitate major construction work along urban and suburban streets. The latter, in particular, has been known to raise major problems when roads have been closed to traffic impacting on local businesses.

Vancouver's Canada Line was a classic example where the local press at one stage was full of complaints from residents and businesses in the Cambie Street area of the city (*31*).

Good practice in communications can be seen in Salt Lake City. Community involvement and communication about construction of its airport line is of a very high order. Utah Transit Authority issues regular e-mail construction updates, explaining what work is going on in the near future in each of five major work zones. If road traffic is disrupted, details of local diversions and temporary arrangements are given.

The main problem with the light rail system in Edinburgh was that, because of major delays caused by disagreements between management and the construction company, there have been long periods when work was completely halted. For obvious reasons, the construction is along major city shopping routes.

START-UP ISSUES

When launching any completely new product, two extreme options present themselves: a soft launch or a big bang.

A soft launch, with minimal publicity, allows a low profile to be adopted with less reputational risks from start-up problems. It does however give limited opportunities for publicity and high-profile ribbon cutting.

The complete opposite was adopted in Dubai, where the ruler announced that the Red Line (serving the airport) was to open on September 9, 2009 (09/09/09) and open then it did (*32*). The opening involved the majority, rather than all, of the system, with a section at the extreme end and some of the stations being opened in phases thereafter; but the big bang worked.

This approach does create focus and ensures that everyone involved works to a specific date.

A soft start issue is that of ridership. In the first few days, ridership tends to be abnormally high with significant numbers of sightseers, people just riding there and back to see what the new system looks like. This is sometimes encouraged, especially in North America, by giving free rides for the first few days. Acquiring a regular ridership, especially among air travelers and airport-based employees, can be more difficult. People have to be persuaded to change, to try something new. They need to be convinced that it will work for them and that it will perform reliably. This can be a challenge and needs imaginative and creative marketing.

OPERATIONS

Long hours of service are highly desirable in any service offering transit to airports. Even if there is a night curfew, the first flights out are likely to be around 6:00 a.m. Passengers will want to be there 1 to 2 h before this to check in and employees will need to be there an hour before that to check them in.

If employees cannot use the service to or from the airport for one of their shifts, they are unlikely to commit themselves to using it for those shifts when they can.

The reputation of an airport depends to a large degree on people who are not well paid: people who clean the toilets, serve the coffee, and load the bags. They need a reliable low-cost means of transportation.

It helps if the system is driverless, and several systems have the potential for this. The Docklands Light Railway in London (serving London City Airport) and the Canada Line in Vancouver were designed for this from the start.

TRAINS, STATIONS, AND THE AIRPORT INTERFACE

The airport interface can be a key to the success of an intermodal system. Is it convenient and easy to use or not?

There is an obvious relationship between rolling stock design and infrastructure.

Historically, many light rail systems were built with high-floor vehicles, with the floors above the bogies (trucks) and traction equipment. This meant either high platforms or internal steps up into the vehicles. The former can be seen at Seattle in the northwest of the United States and at London City and Newcastle airports in the United Kingdom. The latter can be seen at Baltimore–Washington International Airport and on older trains in Portland (Oregon).

Disability legislation discourages steps, so newer systems tend to use low-floor vehicles. This easier for those with disabilities and for air passengers and air crew with luggage. A very small gap between train and platform, a floor on level with the platform, is a boon to those with wheeled cases, golf carts, and buggies.

It also reduces the potential for injury from the slip, trip, and fall kind of accident.

Air passengers in particular also dislike interchange, partly because of the sheer hassle, and partly because each sector of the journey adds to potential unreliability. Therefore, systems offering direct access to a terminal are better than those necessitating a bus shuttle or an automated people mover.

In this context, Dallas would be a valuable case study for future research. The Dallas–Fort Worth International Airport has historically had low-quality transit access (needing a train and two buses from the city center, with no trains on Sundays). In December 2012, DART's Orange Line is to be completed as far as Belt Line station, where there will be a shuttle bus serving the airport (*33*). At the end of 2014, the line will be completed to the airport itself. It will be complemented 2 years later by commuter rail from Fort Worth (*34*). As was pointed out on previously, Dallas Love Field airport has a shuttle bus service from the nearest DART station.

One design issue common to all airport stations (and particularly those where changes of level are necessary) is that of passenger volumes in different directions. When people are coming from a terminal to a station, they come in small groups, in ones and twos. When they are arriving by train at a terminal station, they will leave the train in much larger numbers. The design of the facilities needs to take account of this. A good example can be seen on the Madrid subway, where the platform for trains from Madrid has two escalators up and one down, recognizing the problem of higher volumes of people arriving.

Air passengers tend to have baggage. If there is nowhere else for them to put them, they will be put on seats, between seats, in aisles, and in vestibules. This is not ideal for all kinds of reasons. At the same time, it may not be necessary to provide dedicated baggage space. A multipurpose space for bikes, buggies, and bags, possibly with tip-up seats, can be a valuable alternative, and this has been used on several systems.

MARKETING AND TICKETING

A major marketing challenge to a light rail system serving an airport is that generally airport passengers will be a small proportion of total ridership, not justifying much investment in publicity. This is especially a problem since much of the potential market—inbound air passengers—originates a considerable distance from the system. Therefore, good publicity is needed at the airport.

Another challenge is signage and ticket machines which, at the airport, need to be geared to the infrequent user. This is especially the case if validation of tickets is necessary, as tends to be the case in continental Europe, or if there is a local strongly branded smartcard.

The signage used on Seattle's light rail line is referred to on page 205. An example of excellence can be found at Bremen airport (see page 205).

Another issue is that fares tend to be relatively low, compared with a premium fare Airport Express, and, therefore, some ticket machines either only accept coins or do not accept cards. This is difficult for the inbound passenger coming from another country; coins are not generally available in Bureaux de Change. Therefore, at the airport station it is good practice to offer a range of payment options.

Some railways charge airport passengers a premium fare, although the practice is relatively limited on light rail systems. On page 207 there is a description of the concept (never introduced) for London City Airport. After the Canada Line service started, the local transit agency in Vancouver introduced a premium fare for airport passengers. The premium-fare premium-product RhônExpress Express tram is also described on page 207.

Generally, charging a premium fare for a nonpremium product leads to resentment. RhônExpress is a premium product—limited stop, high quality, exclusive—so a premium fare is acceptable. Utah Transit Authority in Salt Lake City considered the idea at one stage and reviewed the provision of upscale facilities at the airport (for example, a Welcome Center at the interface between airport and transit) as a premium feature to justify a premium fare.

It is natural to want to charge what the market will bear, or to try to recoup the costs of expensive infrastructure, but the concept needs to be sold to users.

The fare structure for light rail systems tends to be geared to the frequent user with products for people like commuters using the same route every day. These are not necessarily optimal for airport-based employees, who are likely to have complex shift patterns. If so, it is likely to be worthwhile to sell a multiride product, like a carnet, offering, for example, 12 rides for the price of 10.

Integrated ticketing with airlines is unusual, and especially so in low-fare low-quality options like light rail. An interesting exception can be found in Germany where it is not uncommon for an air ticket to be valid for travel on the local transit system to an airport on the day of (or the day before) a flight, and from the airport to the city on the day of (or the day after) a flight.

MARKET

Airport railways highlight an interesting patronage paradox. Those who live in the airport's catchment area and are flying out tend to understand the local transit system and be confident using it. However, they do not need it because they are likely to have a car available and are likely to have dispersed origins: their homes. By contrast, those living elsewhere and flying in are less likely to understand the local transit system and be confident using it. However, they need it because they do not have a car available and tend to have concentrated trip ends: the convention center or hotel district (*3*, *4*).

Airport-based employees are a valuable market. Recent research has shown that there can be as many as one employee trip for each air passenger trip to or from an airport (*35*). Good reliable public transport can avoid the need for the high costs of acquisition, insurance, and running a car by the lower-paid, but important, airport employee. Employees can be easier to access for marketing purposes than the air traveler. The majority live locally and can often be reached through their employer or through the need to issue identity badges. Some countries and some employers have policies to promote use of public transport by giving discounted tickets to employees.

Reliability is important, both for the air passenger with a flight to catch and for employees needing to clock in. The service also needs to be attractive, to be the mode of choice rather than the mode of last resort. Therefore, a distinctive livery, logo, and brand are worth investing in.

As with a commuter service to an airport, there is scope for conflict which needs to be managed. Conflicts are between commuters knowing the route and traveling alone with virtually no baggage and air passengers not knowing the route, not knowing where they are going and where to get off, and traveling in larger groups with more bags. They are also likely to need more help with ticket machines (see comments above).

One social benefit which can be conferred by a light rail system is access to jobs. The planned system in Manchester and the light rail to Copenhagen airport both run through areas of relatively high unemployment. Connecting these with the major employment center at the airport has a social benefit as well as being beneficial to potential employers seeking a wider pool of labor.

COMPARISONS WITH OTHER TYPES

IARO identifies six types of passenger railway serving airports: high-speed dedicated, high-speed network, regional, metro, suburban and commuter, and light rail. This section compares a range of available statistics on these, in particular, fares, frequencies, and speeds. The major source is IARO's database, a unique collection of statistics and information on rail connections to airports.

Data availability and quality is a major problem. Speed (time divided by distance) relies on an accurate definition of the nonairport trip end (which could be at one of a number of downtown stops) and the distance between there and the airport (which can come from transit authority documentation or, less reliably, from the Official Airline Guide). Fares and frequencies are available from published sources, but are not always current. The fare per kilometer again depends on distance; fare levels will vary with the purchasing power of the country as well as local policies. Mode share statistics rely on published sources which may not give as much information about the population (all trips to and from an airport or air passengers only, for example) or the survey method (gate count, sample questionnaire survey) as one would like.

Maximum, minimum, and average figures for fare (local currency converted on June 12, 2012, to UK £/km), off-peak frequency and speed (km/h) for five types of airport railway have been extracted from the IARO database. Statistics for airports on national and international high-speed networks are so variable that they were considered not worth including.

The Airport Express has the highest figures for fare and speed, with the average fare being £0.31/km (range is £0.80 to £0.10); the average frequency being 2.8 trains/h each way (range: –6 to 1); and speed averaging 94.6 km/h (maximum 225, minimum 45).

Metros have a lower fare (average is £0.14/km, with a maximum of £0.31 and a minimum below £0.01); a higher frequency (5.7 trains/h each way; maximum 12 and minimum 12); and a much lower average speed (average 41.7 km/h; range 64 to 12).

Suburban or commuter services have an average fare of £0.21/km (maximum £1.66, minimum below £0.01). Frequencies average 3.8 trains/h each way (15 to 1) and speeds average 53 km/h (107 to 13).

Regional services are between the two, with a greater variance reflecting their wider range. Average fare is £0.25/km (maximum £0.60, minimum £0.04); frequencies average at 2.5 trains/h (from 8 to 1); and average speed is 59 km/h (ranging from 152 to 12).

Finally, light rail has an average fare above both metro and suburban at £0.23/km, ranging from £0.78 to £0.04; frequencies average at 5.6/h each way (ranging from 12 to 3); and speeds average at 31 km/h (52 to 8). Understandably, speeds are lowest for this type.

The maximum fare for a light rail system is found on Okinawa. The maximum speed on the express tram is found at Lyon–St. Exupéry.

A comparison of mode share would have been valuable, but there are so few statistics available that a reasonable comparison is just not possible.

KEY ISSUES AND LESSONS LEARNED

Light rail can provide good service between a city and an airport, in particular with good in-town distribution, high frequencies, low but reasonable (and consistent) end-to-end journey speeds, and reasonable fares when compared with other types of airport railway.

The good in-town distribution, the network, probably makes them better (especially for employees) than the bare statistics imply. An Airport Express or regional service will typically call at one or two stations downtown; light rail can serve the entire core.

Within the light rail classification, a range of solutions from tram to fully segregated fully automated light metro has been developed.

Planning conflicts and constraints can affect the quality of service: examples can be seen in Los Angeles, Phoenix, and Seattle.

Light rail can unlock development potential which, in turn, can contribute to its funding (the cases of Portland and Pisa) and can fit where heavy rail cannot (Glasgow and Leeds–Bradford).

The market and marketing are a challenge.

CONCLUSIONS AND FURTHER RESEARCH

Light rail certainly provides a feasible solution to the problem of airport access. It is probably more of value to employees than to air passengers, but this is an important market and such a service will increase the size of the labor pool as well as removing traffic from airport roads and car parks.

It can be attractive to air passengers if it is reliable, goes where they want, and is well designed. It can have an impact on airport performance (the London City Airport case) and can highlight station design issues (the Madrid escalators).

Available statistics show the limitations of the statistics available. Ridership, mode share, satisfaction, and viability are all uncertain and highlight a valuable area for future research. It would be valuable to know more about mode share, for system design purposes. It would be valuable to know what factors affect ridership of light rail systems to airports, and, in particular, the influence of a stop adjacent to a terminal compared with one needing another mode. Again, this will help with system design. Viability is less important, because transit systems generally tend not to be self funding, but it would be useful to know the financial contribution of airport passengers to the operating ratio, and, in particular, to understanding the factors which could improve this.

The RhônExpress is interesting: a dedicated high-speed light rail line between a city and its airport. It would be valuable to understand how it is perceived and the characteristics of its patrons and of those who choose not to use it.

System characteristics are always a challenge. Adding an airport to the system adds to the challenges. An understanding of the impact of the resultant compromises on passengers and their satisfaction would be valuable.

There may be a problem of mission creep, if a system tries to perform too many functions and meet too many demands (an urban commuter transport system, a service for airport employees accessing their jobs, air passenger transportation).

Conflicts between different types of passenger (commuter and air passenger) may need to be managed by design.

There are two areas where the value of the system usefully could be quantified. One of these is the local impact on the airport. How does it affect the demand and need for parking space, for example? This can be controversial, given the value of parking revenue (and car hire concessions) to some airports, and also the high cost of providing parking, in terms of space, structures, opportunity costs, and road space needed.

Another is the impact of the system locally: saving fuel, CO_2, and accidents.

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Intermodal Connections with Light Rail in Phoenix, Arizona

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This paper will focus on METRO's (Valley Metro Rail, Inc.) experiences regarding how people connect to the existing 20-mi (32.2-km) light rail system in Phoenix, Arizona. METRO will share information from a recently completed onboard survey and other field research that identifies how people are accessing light rail, including access by bike, bus, automobile, and walking. Also, this paper will cover bus linkages that were created as part of the light rail project. Several new linkages are also occurring, such as the recently implemented limited-stop bus service and an automated people mover connection to Sky Harbor International Airport that will open next year. In addition, METRO is developing a streetcar project in Tempe that will connect to light rail. Future light rail expansion and streetcar opportunities are also being studied and will be briefly discussed.

INTRODUCTION

The purpose of this research project was to develop an understanding of what makes the Phoenix region successful with regard to exceeded expectations of transit passenger ridership. In almost 4 years of service, the Valley Metro Rail, Inc. (METRO), light rail system has fared well in a hot, car-centric, and relatively low-density environment with ridership far exceeding initial projections. Part of this ridership success relies heavily on effective intermodal connections as it serves the cities of Phoenix, Tempe, and Mesa. This paper describes the multimodal connections available to METRO light rail users in the current system and planned enhancements that will positively impact ridership.

METRO LIGHT RAIL

METRO is the brand name for Valley Metro Rail, Inc., a nonprofit public corporation charged with the design, construction, and operation of the region's light rail system. The cities that participate in the light rail system each have a representative on the METRO Board of Directors. Currently, this consists of Phoenix, Tempe, Mesa, Glendale, and Chandler. In 2012 the Board, alongside the Board of Directors of Valley Metro Regional Public Transportation Authority (RPTA), the operator of multicity bus transit in the Phoenix metro area, voted for a single chief executive to be in charge of both METRO and Valley Metro RPTA. This symbolized a shift towards a more integrated regional transit system in the Valley.

Central Phoenix–East Valley Light Rail Line

The Central Phoenix–East Valley light rail line is the newest element of the region's transit system. In 2008, service began on the $1.4 billion (2008 U.S. dollars), 20-mi (32.2-km) light rail segment connecting the cities of Phoenix, Tempe, and Mesa (Figure 1). The light rail starter line opened on time and within budget on December 27, 2008 (*1*).

The light rail line serves several major destinations along the corridor including downtown Phoenix, Arizona State University's (ASU) Tempe and Downtown Phoenix campuses, Sky Harbor International Airport, major sporting facilities, schools, museums, and other activity centers. The system features 28 stations, primarily located in the center of existing roadways, nine park-and-rides with more than 3,600 total spaces, and six transit centers.

The current light rail runs along a corridor that was previously occupied by the most popular bus route in the Valley, the Red Line. The Red Line route ran on approximately 15-min peak-hour headways (*2, 3*). METRO replaced the core segment of the Red Line with the 20-mi starter track. The future planned extensions will extend the light rail to the same terminuses of the original Red Line and beyond. The light rail connects many of the major destinations the original Red Line served at 12-min peak-hour headways.

METRO operates 365 days a year, 20 h a day, Sunday through Thursday, and almost 24 h on Friday and Saturday. Trains arrive every 12 min during the weekday peak period; every 15 min during the Saturday peak; and every 20 min during all other hours, Sundays, and holidays.

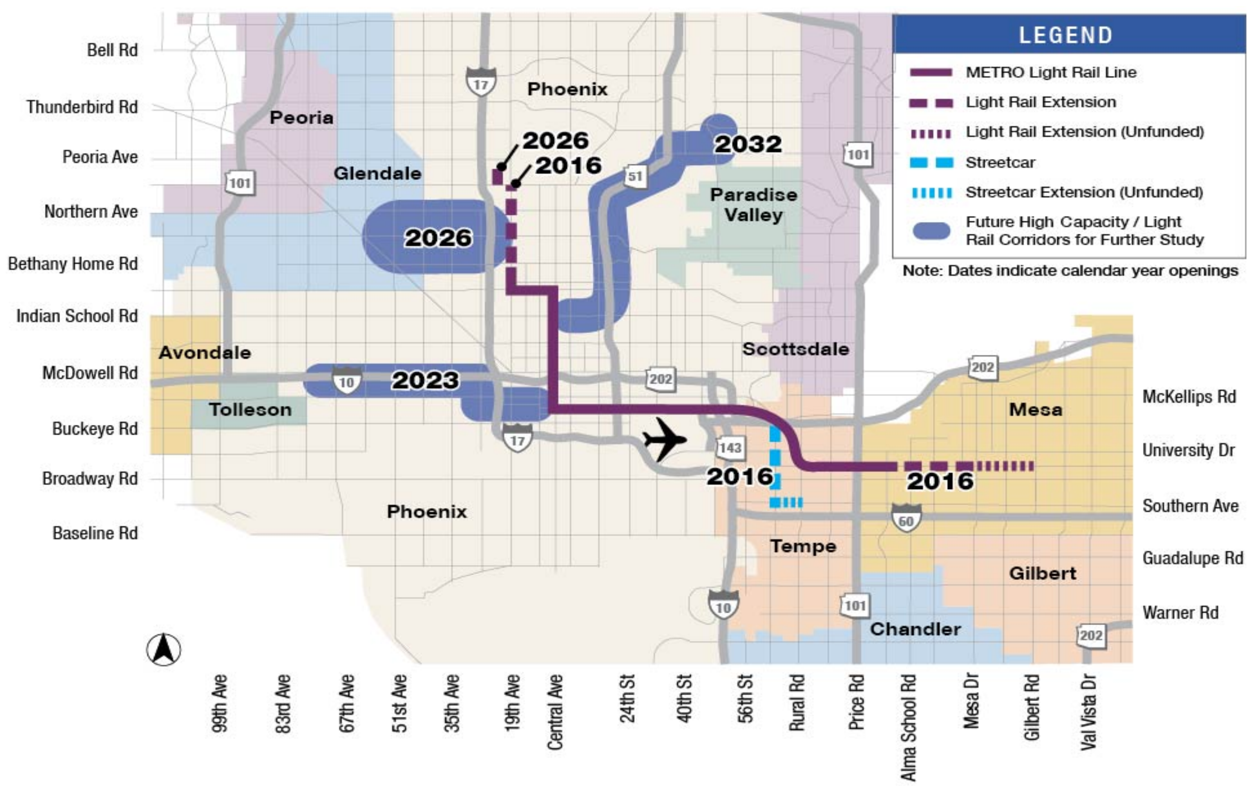

FIGURE 1 Central Phoenix–East Valley light rail line and future expansion.

In 2011, METRO served 13.2 million riders, an increase of 4.3% over 2010. METRO served an average of 40,712 weekday riders, 31,008 Saturday riders, and 20,930 Sunday riders in 2011 (*4*). As of FY 2011, the light rail's farebox recovery rate was 33% (*5*).

Future System Expansion

The Regional Transportation Plan (RTP), approved by Maricopa County voters in 2004, identifies an additional 37-mi (59.5-km) of future high capacity–LRT (HCT–LRT) corridors to be implemented by 2032, which are currently in various stages of planning, design or construction (*6*). The future HCT–LRT corridors serve the most densely populated areas of the Phoenix metropolitan area and are planned to add capacity in heavily traveled commuter corridors. Each corridor will rely on multimodal connections to provide superior transit service throughout the region. This will include an integrated system of connections to existing transit centers featuring regional and local bus routes, pedestrian and bicycle access, and automobile connections through new park-and-rides.

INTERMODAL CONNECTIONS

Transit Centers

Providing connections to regional transit centers along the light rail plays a pivotal role in the successful ridership experienced by the system. The transit centers along the light rail each play a distinct role in the system by providing passengers with seamless connections through efficient and user-friendly service. During the planning phase of the light rail project, METRO coordinated with partner cities and transit agencies to make sure bus and light rail complemented each other's service. This was a critical piece to implementing a system that was designed to replace the Red Line bus route, the most successful bus route in the metropolitan Phoenix region. A total of 14 bus routes were modified to connect to light rail as a measure to improve transit service (*7*).

Central Station

A major bus and rail transportation hub is Central Station in downtown Phoenix. Central Station accommodates eight local bus routes, the downtown circulator (DASH), Phoenix's RAPID commuter bus service, Valley Metro's Express Bus service, METRO light rail, and offers both bike racks and lockers. Located in one of the most dense job centers in Arizona, Central Station is a crucial transfer point or terminus for many commuters. This station offers bike lockers, shading, and public art that make the space both functional and aesthetically attractive. Central Station is close in proximity to many of the downtown financial services, government services, ASU's Downtown Campus, and the Phoenix Convention Center.

Tempe Transportation Center

The Tempe Transportation Center (TTC) is a key transit center along light rail and was recently published as an exemplary case study in the International Association of Public Transport 2012

Interchange Hubs in the Urban Environment as a best practice example of an intermodal hub. Located directly adjacent to the ASU campus and within walking distance to downtown Tempe, the TTC, a Leadership in Energy and Environmental Design (LEED) -certified facility, connects local buses and neighborhood circulators to light rail. One of the popular amenities at the TTC is the Bicycle Cellar, a local business that provides indoor storage for up to 112 bicycles, bicycle rentals, lockers, repair and maintenance services, and shower facilities (*8*).

Bus Services

One Pass Policy

One aspect that makes intermodal connections easy between light rail and bus is Valley METRO's one-pass policy. A one-way pass only covers one ride in one direction on light rail or bus and costs $1.75. If a user plans to transfer or return on transit, they can purchase an all-day pass for $3.50 that works until 2:59 a.m. of the next day on all local busses, LINK, and rail (*9*). Since fares for light rail and bus are paid for with one pass, transferring between rail and bus services is easy. In addition, Valley METRO offers multiple types of passes that allow users to save money by purchasing 3-day, 7-day, and 31-day passes. Valley Metro also has a program with employers that allow them to offer transit cards to their employees at a reduced rate and another program with local universities and colleges that allow students to purchase a reduced fare card for the semester.

Ridership Trends

According to FY 2012 annual ridership report, there were 71,043,488 bus boardings and 13,553,490 light rail boardings, with light rail ridership steadily increasing with each year of operation (Figure 2) (*10*, *11*). Approximately 45% of Valley METRO's local bus routes have transfer points to light rail (*9*). Local bus headways range from every 10 min for the most popular route, Route 29 serving Thomas Road, to every hour for some of the less-frequented or more rural routes. However, headways are generally between 15 to 30 min for most routes. Increasing the frequency of local bus routes could make for more convenient connections to light rail and further increase ridership. Valley METRO is currently trying to restore the level of bus service that existed before the Great Recession. Bus ridership experienced decline during FY 2009 and was stagnant through 2010 and 2011 largely due to cuts in service because of the economic downturn. However, light rail captured a significant portion of bus ridership simultaneously. It is significant to note that in 2009 only seven bus routes experienced ridership growth from 2008. Six of those routes connected with light rail (*12*). Furthermore, bus ridership has rebounded in 2012 and looks as though it will continue to rise.

Transit services in the Valley have traditionally been fairly limited during the weekends and holidays resulting in lower average weekend ridership compared to average weekday ridership. Since METRO operates late-night light rail services on Fridays and Saturdays as well as enhanced services during special events, weekend ridership is much higher than before the light rail began operations. Between 2007 and 2011, weekend transit ridership grew 22%. In part, this can be attributed to the introduction of light rail service in December 2008 and added late night weekend service on light rail in June 2009 (*13*).

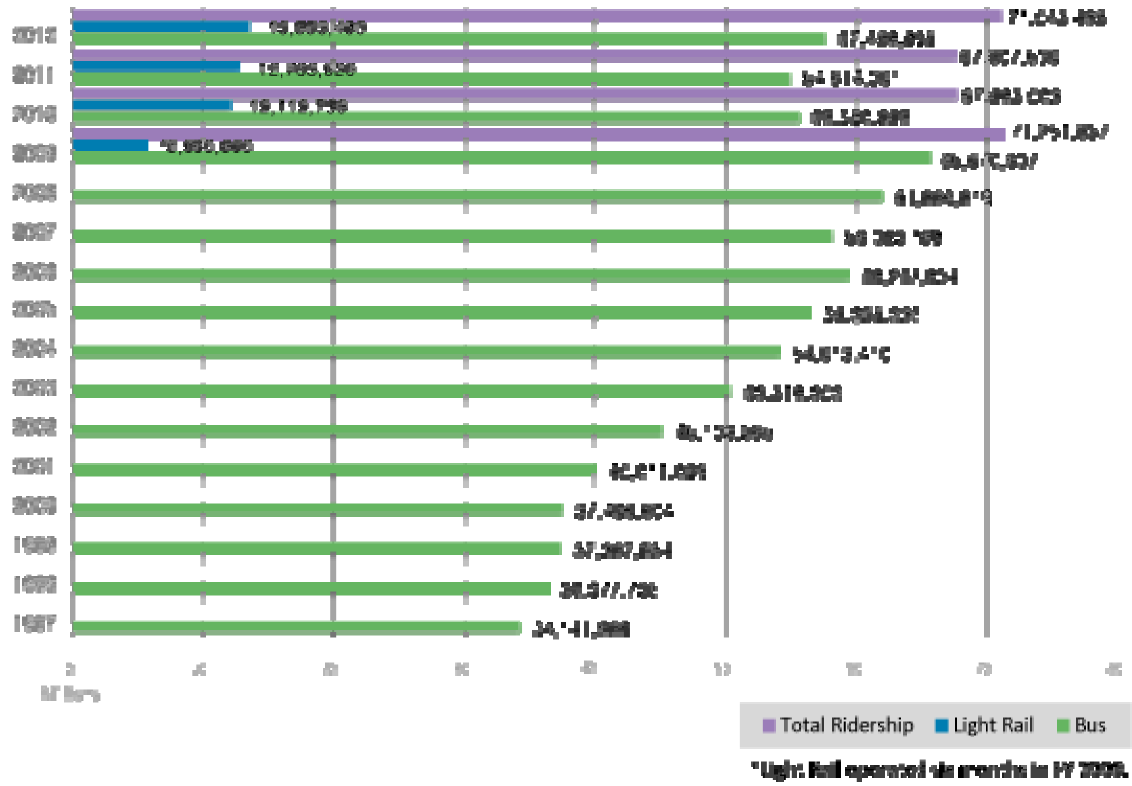

FIGURE 2 Fiscal Years Annual Ridership, 1997–2012.

NextRide

Valley METRO also operates the NextRide electronic service. It was initiated in fall of 2010 to provide customers with quick access to next train and bus schedule information using phone or Internet access. The system is quite simple, using route and stop numbers posted at bus stops and light rail stations, providing schedules for specific routes.

RAPID and Express Service

The majority of RAPID and Express service users are commuters that work in downtown but live in areas that are not served by the rail. These services pick up commuters from outside the urban core and then use freeways to quickly access downtown Phoenix. The RAPID service is completely paid for and operated exclusively within the boundaries of Phoenix. It operates only during peak hours but at headways as low at every 10 min. The Express service is operated by Valley METRO and offers a similar service. However, the Express service only offers a few buses, usually no more than three, that operate at longer headways. Both of these services operate one way and bring commuters to downtown Phoenix in the morning and return them to the outlying areas in the evening. There are some commuters that work in midtown or other areas of the Valley that use this service to reach Central Station and then complete their trip with light rail. All the RAPID and Express routes converge with at least one light rail station.

LINK Bus Rapid Transit Service

One of the unique intermodal connections is the LINK, the only operating bus rapid transit (BRT) -lite service in the region. As the name suggests, the LINK routes were designed to connect the light rail system with the outlying areas of the east and southeast Valley. The LINK does not have dedicated right-of-way or elevated stations like BRT service on the Cleveland, Ohio, Healthline or in Curitiba, Brazil. However, the buses provide a light rail vehicle feel through a combination of a sleek exterior design, low-floor boarding, Wi-Fi access, and signal priority. There are currently two LINK routes utilizing eco-friendly state-of-the-art buses that connect to light rail at the end-of-line Sycamore Transit Center in Mesa (*14*).

Although seen as an important transit investment, the LINK service has not reached its full potential because of recent funding constraints. This has adversely affected service frequency, therefore, timing connections with light rail service can be challenging. Peak-hour service is limited to 15-min headways for the Main Street route and 25-min headways for the Arizona Avenue route. Off peak service is 25-min headways for both, and night service is 30-min headways and 60-min headways, respectively. This can make timing transfers between the light rail and LINK difficult. This is, of course, a deterrent for users because it can result in inordinately long waits. To maximize the full benefit of the LINK BRT-lite service it will need to include improved headways to ensure a seamless transition to light rail.

Neighborhood Circulators

Another popular form of bus transit in the Valley is circulator busses. Multiple cities have circulator systems but the largest is Tempe's Orbit system which operates five separate routes with 15- to 30-min headways in both directions on the route. All of these routes are free to users. The routes have some fixed stops but in general work as a flag stop service. All of the routes converge at the TTC where commuters can access bus and rail.

Bike–Transit Integration

Bicycle connectivity is an important contributor to ridership along light rail. Bicycles are allowed on light rail and four bicycle racks are located in the center section of each vehicle. Each vehicle is clearly marked by bicycle symbols on the train windows that show riders the doors nearest to the bicycle hangers inside the trains. Bike hangers are first-come, first-served. If the bicycle hanger on the train is full or if riders are unable to load their bicycle into the hanger, they may stand with their bicycle as long as they do not block the aisle or doorway. If the train is crowded, riders carrying a bicycle may be required to wait for a less-crowded train before they can board. Riders are responsible for loading and unloading their own bicycle. For safety reasons, operators cannot leave the cabin to provide assistance.

The existing station area bicycle parking offers a total capacity for 536 bikes along the Central Phoenix–East Valley light rail alignment. Currently there are 25 bike lockers available between two stations, Central Station and end-of-line Main Street–Sycamore Station. Station platforms and adjacent sidewalks offer 243 total bike racks.

Park-and-Rides

Park-and-ride is an intermodal connection that works effectively in areas that are highly auto-dependent. In the Phoenix metro area, park-and-rides are parking lots generally owned and operated by cities that commuters can park at and take transit from. METRO currently has nine park-and-ride locations including one at each of the end-of-line stations. The park-and-rides near the end-of-line stations are very popular as they allow riders that live too far to bike or walk access to the light rail.

There are also park-and-rides for bus areas but they are used significantly less than park-and-rides for light rail. In fact, 11% of light rail users accessed the light rail by driving alone. This may be attributed to the fact that light rail users generally make more money than bus users, and a larger percentage of rail users own cars than bus-only riders (*15*).

A unique example of a public–private venture is the McClintock and Apache park-and-ride, located in Grigio Metro multiuse center. This transit-oriented development features a ground-level, indoor storage area with 38 bicycle racks and 300 park-and-ride spaces monitored by a METRO security kiosk.

Walking

According to the onboard survey, approximately 70% of light rail passengers accessed the train by walking. Of users that used bus or train for their commute, more than 88% accessed transit by walking (*15*). Thus, walking is still a critical part of many transit users experience. Cities in the Valley are taking greater steps to improve pedestrian amenities including wider sidewalks and more shade. Shade provided by trees is gaining more prominence because of the additional cooling benefits they provide beyond the benefits of inorganic structures. By creating a more walkable environment, the cities are making infrastructure that makes transit easier and more enjoyable to use.

METRO also recognized that sufficient shade and related amenities are critical to growing and retaining ridership. Thus, METRO stations have canopies that create lots of shade during midday hours to help keep riders cool. The stations also feature walls that create shade during the morning and evening. The walls are made of slotted metal that allow air to flow through and permit visibility for safety purposes. Along these walls, bougainvillea desert vine plants grow on metal lattice which creates green cooling. The larger the plants become, the more effectively they will cool the area around them. All stations are also equipped with drinking fountains that allow people to rehydrate between segments of their journey; one station in downtown even has a solar-powered cooling system that blasts cold air on users waiting to board the train.

Provision of good pedestrian amenities on routes to light rail stations has undoubtedly encouraged pedestrians to walk to the train. This mode of access is used by the majority of individuals that access the train. Thus, most riders access transit by walking; good pedestrian amenities near light rail stations are probably a large contributing factor to the high ridership experienced by METRO. Having water fountains at stations and other amenities further encourages active forms of transport to stations because users know water is available.

Sky Harbor Airport Connection

During the original planning phase, the light rail alignment was located away from Sky Harbor International Airport and its four terminals because it was cost-prohibitive to build a subway under the airport and maintain reliable travel times between Mesa, Tempe, and Phoenix. It was always the intent to have a separate airport connection to serve the passengers using the system to access the airport as an origin or destination. A free bus shuttle service that provides stops at all four of the airport terminals is currently in place to provide light rail riders transportation to and from the airport from the 44th Street–Washington Station. Approximately 1,200 people a day use this service that operates 7 days a week.

The free bus shuttle will be supplanted by the Phoenix Sky Train, a fully automated elevated passenger train that will provide a direct connection from the airport to the 44th Street–Washington Station. This state-of-the-art transportation facility will serve as a new gateway that will feature LEED-certified facilities, an air-conditioned overpass walkway, and off-site flight check-in capabilities.

This project has two phases. The 1.7-mi (2.7-km) Phase 1 segment is expected to be complete in first quarter of 2013 (Figure 3). This segment will serve Terminal 4 and a large economy parking lot. Phase 2 will open in 2017 and extend the train an additional 3.2 mi (5.1-km) to serve the remaining airport terminals and rental car center.

Upon completion, it will take approximately 5 min for passengers to travel between the 44th Street Station and Terminal 4, with trains arriving as frequently as every 3 min. Over 6 million passengers are expected to ride the train in the first year of operation, with an average of 16,000 passengers per day (*16*).

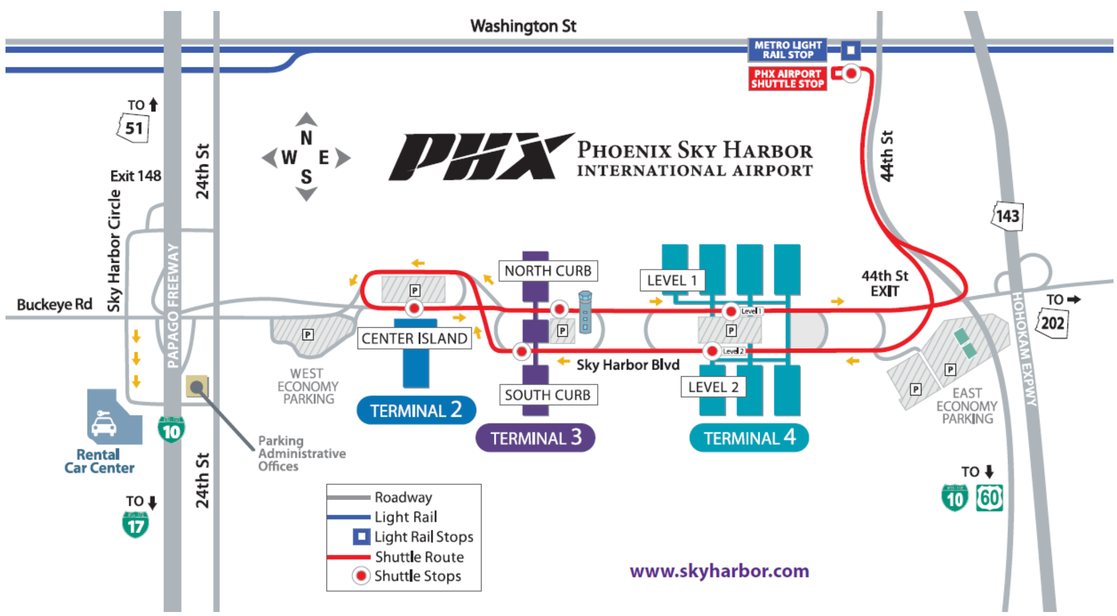

FIGURE 3 Phoenix Sky Train Phase I.

Tempe Streetcar

The Tempe Streetcar is a 2.6-mi (4.2-km) modern streetcar system that will provide additional transit service through downtown Tempe and the ASU Tempe campus. The Tempe streetcar project is scheduled to open in 2016 and will provide a seamless transit connection to light rail. The project will enhance pedestrian movement through downtown Tempe as stops will be spaced approximately every ¼ mile. The in-street running streetcar will serve Mill Avenue, an urban thoroughfare serving the downtown Tempe area that exemplifies a desirable pedestrian environment surrounded by local shopping, restaurants, and offices.

In an effort to complement an already successful urban area, design of the streetcar project takes into consideration multimodal connections. Already served by a successful system of local bus circulators, careful consideration of connecting to the existing transit network was of utmost importance. Additionally, while not a typical feature of several modern streetcar systems, METRO intends to allow bicycles on the streetcar vehicles and will implement bicycle storage and lock-up facilities near stops. Bicycle lanes will be maintained along the streetcar alignment and will be constructed in a manner that will not impede movement at stops.

INTERMODAL RIDERSHIP TRENDS

Onboard Survey

Light rail riders often utilize many different transportation modes to access destinations, making light rail part of a truly intermodal transportation network. From October 2010 to February 2011, Valley METRO conducted a transit onboard survey to collected data from transit users on 100 bus routes and all light rail stations. More than 4,213 were completed by light rail passengers. Those surveys were intentionally timed throughout the day to capture different users and demographics. Sixty percent of the responders were interviewed during peak hours while the other 40% were interviewed during off-peak hours.

METRO is built to be part of a truly intermodal system and the survey revealed respondents accessed METRO in a myriad of ways. Of respondents that only used light rail for transit, 78% of respondents accessed light rail by biking or walking. Twenty-one percent light rail only respondents accessed METRO by driving to a park-and-ride location or being dropped off by another driver at a light rail station. However, of respondents that used both bus and light rail for their trip, 93% accessed their first mode of transit by bike or walking and only 7% were either dropped off or drove alone (*15*).

Furthermore, light rail-only users were nearly four times as likely as bus-only users to report they started using public transit in the last 2 years to save money (44% light rail only versus 12% bus only). In addition, respondents that only use buses were seven times more likely than light rail-only riders to start using transit because they lost their car and seven times less likely to be able to complete their trip without transit (*15*). Light rail attracts almost an equal share of riders with zero, one, or more than one vehicle. Seventy percent of passengers that only use light rail own at least one vehicle, where almost 50% of transit users that used just bus or bus–rail indicated that they did not have a vehicle in their household. More than half of bus passengers reported having an income of $25,000 or less, where almost half of light rail passengers said they have an income of $35,000 or more. When asked if they possessed a valid driver license, most of the light rail riders indicated that they did, while more than half of the bus passengers did not (*15*).

All of this data suggests that METRO light rail attracts more choice ridership than Valley METRO buses; choice ridership consists of people that are not dependent on transit but rather opt to use it. As illustrated above, many choice riders do not use the bus system at all. Light rail-only users were three times more likely to use personal automobiles to get to METRO stations than bus-only users were to use an automobile to get to a bus station. This could be in part attributed to the fact there is currently only one light rail line and nearly 100 bus routes; it is more likely that bus users across the Valley can walk to a bus near their origin or destination. Light rail users may live further from the train and need a different mode than walking to access it. However, light rail-only users generally had higher incomes and were significantly more likely to own a car and have a driver's license than bus-only users. This suggests that light rail-only users have more choices for transportation options.

Understanding this ridership trend is significant to METRO's success. METRO predicted that light rail would attract many choice riders and accordingly planned park-and-rides. Had METRO not worked with member cities to provide the infrastructure necessary to accommodate many of the choice riders that use personal automobiles as a mode to access transit, less ridership would have been captured. Realizing this informs future decisions for expansion and has encouraged the further use of park-and-rides to accommodate a significant portion of light rail ridership that prefers to access light rail via personal automobiles.

Another demographic finding revealed from the onboard survey that affected the planning of future light rail growth was how much of METRO's ridership is attributable to students. The largest share of trips generated by light rail-only passengers was home-based college (HBC) trips, as illustrated in Table 1. The percentage of light rail-only users that made HBC trips significantly outnumbered the amount of bus-only riders and bus–light rail riders making similar trips. The biggest share of light rail trips terminate in downtown Tempe, the location of ASU, the largest university in the region. Further research from the survey revealed light rail-only passengers are primarily between the ages of 18 and 24. This evidence further supports the conclusions that the largest single group of light rail riders are college students (*15*).

METRO is currently within walking distance of Gateway Community College, two ASU campuses, and the East Valley Institute of Technology. It is also within biking distance of South Mountain Community College, Rio Salado Community College, and Mesa Community College. To further accommodate this group of transit users, most of METRO's future light rail extensions are planned for areas that have high concentrations of post-secondary educational institutions. The Central Mesa Extension, which is currently under construction, will be within walking distance of satellite campuses of Benedictine University, Wilkes University, Albright College, and Westminster College (*17*).

To encourage the usage of light rail by students, universities are municipalities alike are making infrastructure improvements to help students move between the rail and campus. ASU provides a shuttle service at ASU Tempe which takes students to–from campus to the TTC. Cities like Mesa are improving the pedestrian environment and bicycle infrastructure in their downtown area to further improve students' ability to move between rail and the new educational institutions they are attracting. The onboard survey results have informed policy and encouraged decision makers to make multimodal connections available for students to use transit.

TABLE 1 Trip Purposes, 2011

Trip Purpose	Bus Only (%)	Light Rail Only (%)	Bus–Light Rail (%)	Overall (%)
HBW	33	17	33	31
Home-based other trip	19	18	24	19
Home-based college trip	12	34	11	15
Nonhome based	12	17	14	13
Home-based school trip	11	6	8	10
Home-based shopping trip	8	6	5	8
Home-based medical trip	5	1	4	4
Home-based airport trip	0	1	1	0

Bicycles

Based upon the 2011 onboard survey results, biking as a mode of access or egress accounted for over 9% of the total surveyed METRO light rail boardings. The survey results give great insight into rider demographics for those using bikes in their commutes to light rail stations and identifies how and where riders are using bikes. Sixty percent of bike-to-transit riders are male, and females account for 40%. Biking is very popular among younger demographics, primarily between the 18 to 24 and 25 to 34 age groups, and biking to and from stations is generally highest during p.m. hours and peaks during the a.m. hours from 7:00 to 7:59 a.m. and 10:00 to 10:59 a.m. and during the p.m. hours from 2:00 to 2:59 p.m. and 4:00 to 4:59 p.m (*18*).

The onboard survey results also illustrate the detailed trips patterns of bicyclists. A majority of riders, 72%, biked both to and from light rail. The highest volumes of access occur on the east side of the alignment, primarily at stations located near ASU and the end-of-line station in Mesa (*18*).

The two place types most commonly identified as destinations by riders using bikes were workplace (35%) and college–university (34%). Generally, bicyclists do not travel very far from the LRT alignment to reach their nonhome destinations. Many of the traffic analysis zones indicated as frequent destinations by bicyclists are located within close proximity to the alignment and most contain popular tourist destinations and landmarks (Figure 4) (*18*).

Current Intercept Surveys

In May 2012, METRO deployed a focus survey on bike–transit integration, targeting bike riders using the METRO system. This survey collected qualitative responses from riders regarding their experience with biking to and from stations, storing their bikes on the trains, and storing their bikes at stations or park-and-rides. Riders identified how often they bike, where they bike, what their trip purposes relate to, and made recommendations for how METRO can improve the system to accommodate bicyclists. Nonbikers were invited to comment on their experiences interfacing with bikes and bicyclists onboard the system (*18*).

Of the entire bike–transit integration survey sample, 64% of respondents indicated that they use a bicycle in the access or egress of their trip when riding METRO (*18*). A majority

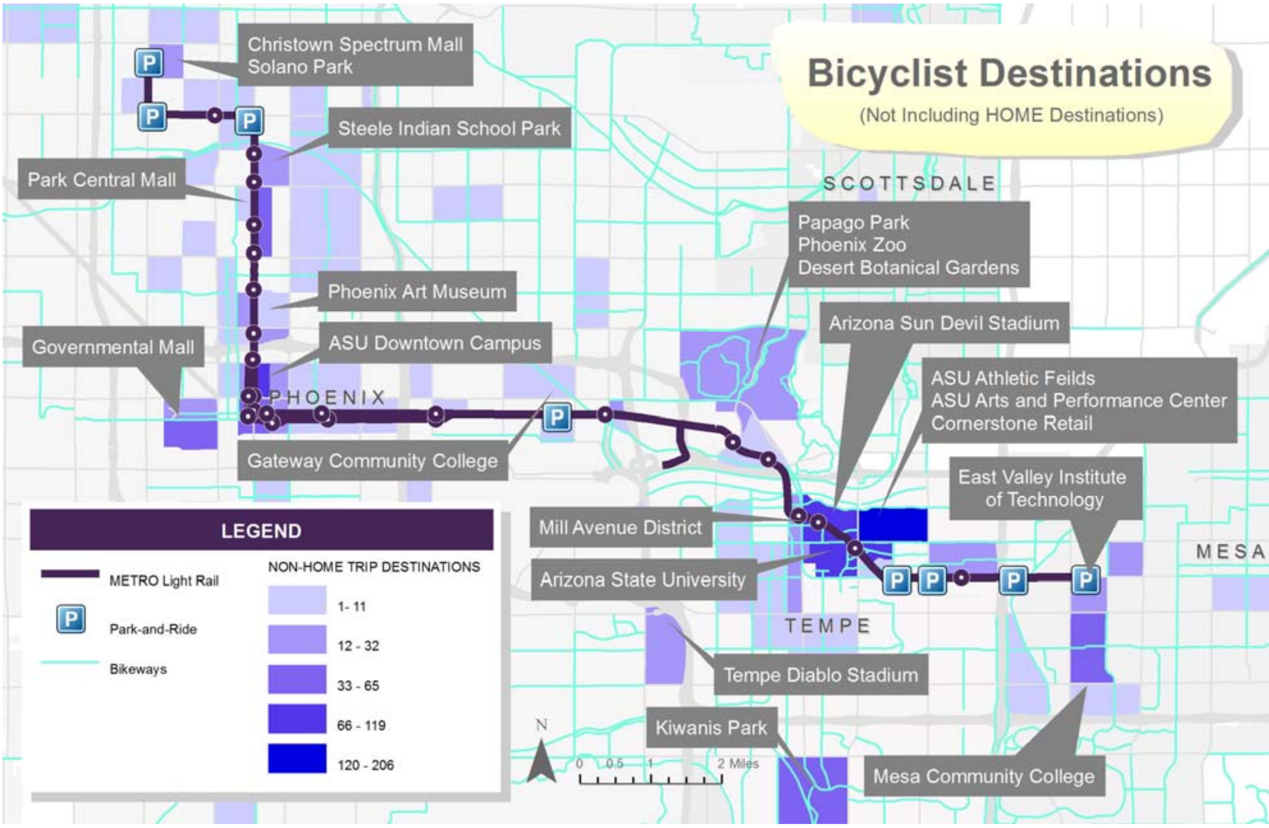

FIGURE 4 Bicyclist destinations (not including home destinations).

of bicycling trips described in the survey are related to work and special event purposes. The most common stations used by surveyed bicyclists include both end-of-line stations, downtown Phoenix, downtown Tempe, and ASU Tempe campus stations.

Most of these bicyclists carry their bike on the train because they need to use their bike to reach their destination. A lack of secure bicycle parking options at stations is another a major factor that encourages bicyclists to carry bikes onboard. Many are afraid that their bike will be stolen or parts will be taken from their bikes if left at a station. In fact, four respondents' bikes were stolen from stations or park-and-ride bike racks. Additionally, some bicyclists are not aware that bike lockers exist or where they can be found, and many bicyclists feel strongly that METRO needs to increase the presence of bike lockers, security personnel, lighting, and cameras. Responses show that many users would be willing to pay a fee rent bike lockers, especially if they are able to rent one for long periods of time.

Some bicyclists have great difficulty using the onboard bike storage hangers due to the height and strength requirements to use the facility. Bicyclists often feel that the space required to perform the hanging action invades the area where riders sit in the bike compartment. Many cyclists board the train at the far end of train and are not able to move through the train to access the bike compartment. For all these reasons cyclists often stand with their bike and block the door causing an impediment to other riders.

According to the survey, bicyclists place a high value on station-area improvements (i.e., increasing connectivity to bikeways and better lighting around stations). The results show that in some cases, riders bike past closer stations to use a station that has better bikeway connectivity, safer roads, or better bike infrastructure. Attractive stations areas, the opportunity for additional physical activity, and increased train capacity influence their decision to bike to a station further away.

Bike–transit integration poses positive and negative impacts to riders. While many riders are able to access the METRO light rail and live a healthier lifestyle with the integration of bikes at stations and on trains, this poses clear capacity and circulation constraints on the METRO light rail vehicles. Bicycle storage facilities onboard the METRO light rail are insufficient at times, especially during peak hours and special events.

CONCLUSIONS

Successful Trends

METRO light rail has well exceeded all system projections. The 20-mi light rail starter line served 13.2 million riders in 2011, exceeding the prior year by over 4%. Weekday ridership grew by 17% between 2009 and 2011 (*10*). The introduction of light rail had a positive effect on the ridership of the total transit network, boosting the growth of weekend transit ridership. The light rail's ridership success can be attributed to intermodal connections that accommodate the needs of riders living in an auto-dependent and sprawl-heavy desert environment.

Innovative measures, such as the NextRide electronic service and all-encompassing transit centers, address the multimodal transportation needs of the Valley and provide riders with reliable transfer connections to and from light rail. Additionally, pedestrian-friendly amenities and bike–transit integration efforts at METRO stations, park-and-rides, and transit centers have allowed riders to truly embrace the active transportation aspect of riding the transit system, with 78% of the respondents accessed light rail by biking or walking (*15*). Pairing light rail service with RAPID, Express, and LINK bus service provides a truly regional connection between suburbs and employment centers, and bike parking and park-and-rides give METRO riders more choices about how to customize their trip based on their own needs.

Challenges

Budget shortfalls resulting from the Great Recession required recent cuts to express and local bus service across the Valley. As the economy improves and local revenues come back METRO, riders can look forward to increased service frequencies and bus route restorations that are integrated with light rail operations. Meanwhile, METRO is taking steps to evaluate other areas of improvements. In 2012, METRO actively surveyed light rail riders' overall experience with the intent of improving current service and capturing new riders. Forward-looking efforts aim to solve current capacity constraints and challenges resulting from offering integrated multimodal service. For example, light rail vehicles often carry more bikes than they were designed to hold causing vehicle circulation and mobility device user conflicts. METRO took a fresh look at bicycle parking options that would alleviate constraints in the 2012 bike–transit integration study. METRO is also studying the feasibility of offering amenities such as WiFi and passenger information services that allow for seamless transfers between bus and light rail and encourage transit application development for smartphone users.

Moving Forward

As a part of the regional transit network, METRO plans to expand the high-capacity transit corridors and provide new options for multimodal connections. As soon as 2013, the existing light rail line will provide platform access to Phoenix Sky Train, a direct connection between light rail and Phoenix Sky Harbor Terminal 4. In 2016, METRO will introduce modern streetcar service in Tempe at the nexus of ASU and downtown Tempe, increasing patron, student, and resident trips to these highly frequented destinations.

METRO will continue to work with local jurisdictions to enhance transit-supportive land use and pedestrian connections to the light rail system. The existing and planned linkages coupled with a sensitive approach to accommodating rider's needs continue to facilitate the growth of light rail ridership as METRO moves into the future.

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Community Decision Making

Noise and Vibration Issues of Modern Streetcars

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Streetcars have been making a comeback in the United States and there are a number of modern streetcar projects in various stages of development in cities across the country. Typical characteristics of modern streetcar operations include sharing the right-of-way with vehicular traffic and speeds below 25 mph. Therefore, they are expected to have minimal noise- and vibration-related issues. However, in assessing noise and vibration impacts for several projects it has been found that there are cases where noise and vibration can present significant issues. Examples include streetcar routes in close proximity to recording studios, theaters, concert halls, and university research facilities, and routes on streets with low traffic volumes and relatively low existing noise levels. This paper presents some of the noise- and vibration-related lessons learned from streetcar projects in New Orleans, Tucson and Tempe, Arizona, and Washington, D.C. It also provides guidelines for identifying and mitigating potential vibration issues and discusses vibration mitigation approaches for embedded track.

INTRODUCTION

The success story of the Portland modern streetcar in reviving the local businesses in the last 10 years has been credited with a newfound interest in streetcar projects across the United States (*1*, *2*). Some examples of streetcar projects that are currently in preliminary design or under construction are the Tucson Modern Streetcar line (Arizona), the New Orleans Loyola Avenue line, the New Orleans French Quarter Streetcar Expansion, the Tempe Modern Streetcar alignment (Arizona), the Anacostia Streetcar alignment (Maryland), H Street–Benning Road alignment (Washington, D.C.), and the Los Angeles Streetcar project (*3–7*). Because most of the modern streetcar projects share right-of-way with vehicular traffic, operate at relatively low speeds of 15 to 25 mph, and are in busy central business districts, they are expected to have negligible noise and vibration issues compared to light rail systems. Experience shows that streetcar projects have much in common with light rail projects from a noise and vibration perspective, because the main sources of noise and vibration are fundamentally the same for both systems (*8–12*).

One difference between the two systems is that streetcar alignments seldom have gated grade crossings and rarely employ wayside warning bells at crossings. Audible wayside warning bells can be an important source of localized noise impact on light rail transit (LRT) projects. Also, wheel–rail noise on streetcar systems typically is lower than on LRT systems because streetcars often operate at a maximum speed of 25 mph. However, it is not possible to dismiss all potential for noise and vibration impacts at sensitive receivers when impacts are based on FTA criteria (*8–13*). The goal of this paper is to discuss potential noise and vibration issues associated with streetcar systems, describe the available mitigation measures, and present several case studies that illustrate potential noise and vibration impacts from modern streetcar systems.

NOISE AND VIBRATION LEVELS FROM STREETCARS

Noise

For a well-maintained streetcar system, the general trend is that at speeds below 20 mph the noise from propulsion motors, air conditioning, and other auxiliary equipment on the vehicles dominates. Above 25 mph, the rolling noise due to metal-to-metal contact at the wheel–rail interface dominates. This is referred to as wheel–rail noise. The level of wheel–rail noise is generally considered to vary with speed by 30*log(speed). Between 15 and 25 mph a transition of the dominant noise source from the vehicle equipment to the wheel–rail interface occurs. Therefore, it is reasonable to expect streetcar noise to have three regimes based on speed: a slope of 30 log(speed) above 25 mph, a constant sound level at speeds less than 15 mph, and an intermediate slope of approximately 15 log(speed) between 15 and 25 mph.

Noise measurements were performed on the Portland streetcar system at three different sites. The measurements at sites 1 and 2 were in June 2007 and the measurement at site 3 was in July 2011. The measurement at sites 1 and 3 were performed at 50 ft from the track centerline. At site 2 there were two tracks separated by 15 ft. The microphone at this location was located 50 ft from the near track centerline. The results of the noise measurements are shown in Table 1. The average maximum streetcar noise level at site 3 was 71.1 dBA for an average speed of 14 mph. The measured noise levels and the average streetcar speeds at sites 1 and 2 were higher than at site 3. Some key observations based on a careful analysis of the streetcar noise spectrum plots presented in Figure 1 are:

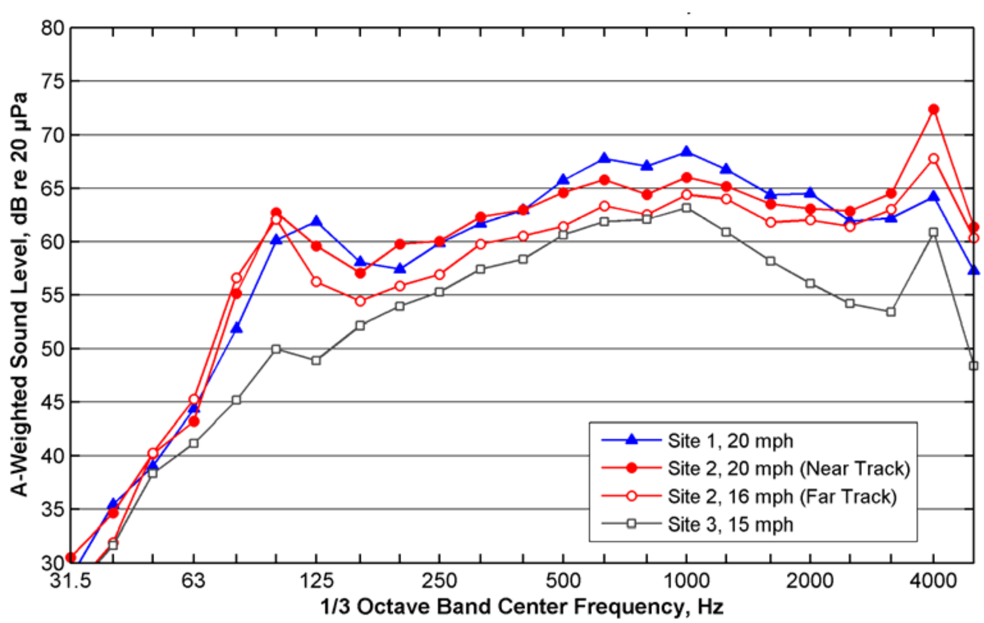

FIGURE 1 Measured streetcar noise level from Portland, L_{max}.

TABLE 1 Overall Noise Levels, Portland Streetcar Measurements

Train	Speed (mph)	Distance of Microphone to the Track (ft)	L_{max} Sound Levels (dBA)
Site 1, June 2006 (1-car trains)			
Train 3	20	50	79.3
Train 4	19	50	76.6
Train 5	17	50	75.0
Train 6	21	50	75.3
Train 7	16	50	72.1
Train 8	20	50	75.7
Train 9	24	50	77.0
Average, Northrup	19.6	50	76.7
Site 2, June 2006 (2-car trains)			
Train 3	20	50	77.9
Train 5	19	50	76.6
Train 6	23	50	78.0
Train 9	20	50	77.6
Train 4	16	65	76.2
Train 7	18	65	75.0
Train 8	15	65	74.1
Average, near	20.5	50	77.6
Average, far	16.3	65	75.2
Site 3, July 2010 (1-car trains)			
Train 6	13	50	70.3
Train 7	15	50	71.9
Average (15 mph)	14	50	71.1

- Sites 1and 2 showed a peak between 80 and 125 Hz that is believed to be caused by rail corrugation.
- Site 1 showed the highest noise level between 500 and 2,000 Hz. The microphone at this site was 50 ft from the track but it was relatively close to two tall buildings. Reflections from the building probably increased the train noise by 2 to 3 dB.
- Noise levels at site 3 were substantially lower. The tracks were fairly new at this site and in relatively good condition, which could be the reason for the lower noise levels.
- All of the noise measurements have a peak of 4 KHz. With the available data it is not clear whether equipment noise contributed to this peak. The spectral peak at 4 KHz increases the overall level at site 2 by about 2 dB. Site 2 was on a curve and the strong peak at 4 KHz could have been caused by the wheel flange contacting the gauge face of the rail or slip-stick interaction of the wheel tread and the rail head.

Based on the Portland measurement, the measured L_{max} for streetcar noise at a reference distance of 50 ft from the track centerline are:

- 72.0 dBA at 15 mph and
- 74.7 dBA at 25 mph.

Reasonable speed adjustments for the maximum streetcar noise levels (L_{max}) are:

- Speed-independent below 15 mph;
- 12*log(speed) between 15 and 25 mph; and
- 30*log(speed) above 25 mph.

Based on the measured L_{max} at 25 mph and the 30*log(speed) adjustment, the streetcar L_{max} at 40 mph is estimated to be 80.8 dBA. This streetcar reference noise level is comparable to the reference noise level for light rail vehicles at 40 mph on embedded tracks. The assumed relationship between streetcar L_{max} and speeds is shown in Figure 2.

Vibration

The measured streetcar force density level (FDL) for two different streetcar vehicles in Seattle and three different sites in Portland are shown in Figure 3. The FDL represents the vibration

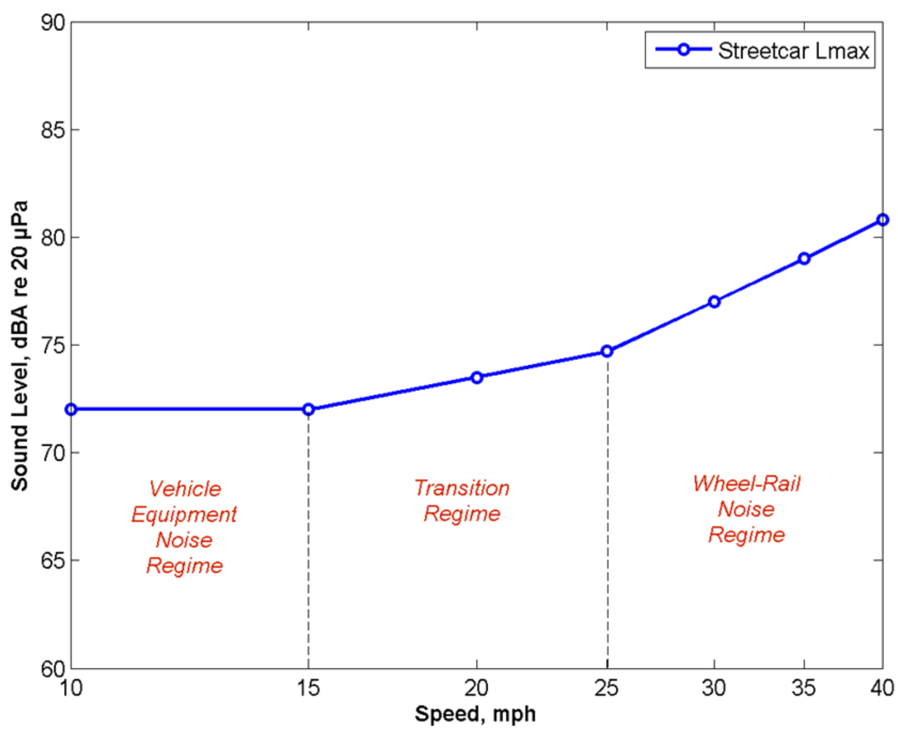

FIGURE 2 Speed dependence of modern streetcar L_{max} noise levels.

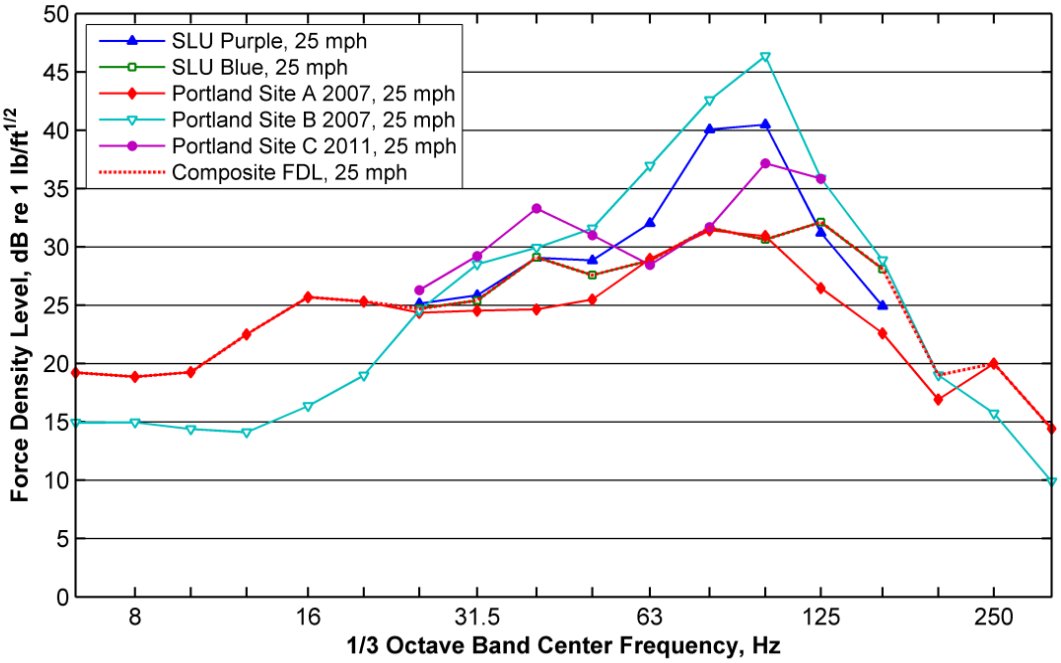

FIGURE 3 Speed dependence of modern streetcar L_{max} noise levels.

energy input by the trains to the ground. To predict train vibration at a receiver, the FDL is combined with the propagation characteristics of the local geology. Higher FDL would lead to higher train vibration. The key points from the streetcar FDL measurements are

- Both in Seattle and Portland, similar vehicles provided very different FDL spectrum indicating potential variations in the wheel–rail interface.
- The streetcar FDL varied widely between 40 and 125 Hz. Much of this variation is likely to be due to rail corrugation at one site in Portland and problems with the wheels for one of the Seattle vehicles.
- Because the rail roughness did not show dominant unevenness at any particular frequency, the difference in FDL between the purple and blue vehicles in Seattle is most likely due to problems with the wheels of the purple vehicle.
- It is feasible to keep the FDL at a minimum level between 40 and 125 Hz through the maintenance of an optimal wheel–rail interface.

A composite streetcar FDL was derived by combining the Seattle blue car FDL between 25 and 125 Hz with the highest available FDL outside this frequency range. It is noteworthy that the blue car FDL was selected over the site A measurements from Portland as the baseline FDL between 25 and 125 Hz because detailed data was available for the measurements in Seattle. For site A in Portland no rail roughness data was available.

NOISE AND VIBRATION ISSUES ASSOCIATED WITH STREETCARS

Noise

Streetcar Operations

This is the normal noise from the operation of streetcars and includes noise from steel wheels rolling on steel rails (wheel–rail noise) and from propulsion motors, heating, ventilation, and air conditioning systems, and other auxiliary equipment on the vehicles. A primary assumption made in most noise projections is that the rail and wheel surfaces will be well maintained and relatively smooth. Most streetcar systems have either an in-house or contracted wheel truing facilities to maintain the wheel profile and keep the wheel tread smooth. However, it is relatively uncommon for streetcar systems to have an ongoing rail grinding program. It is noteworthy that deterioration of the rails after a few years of use can potentially lead to an increase in noise levels unless periodic rail grinding is performed.

Traffic Noise

Streetcar alignments typically share the right-of-way with vehicular traffic and sometimes will alter existing traffic patterns, which will affect community noise levels. Streetcar projects generally result in minimal changes in traffic patterns and volumes in the project area. In such cases, changes in traffic noise are insignificant and can be ignored. One exception is when there will be a property acquisition that will result in demolishing existing buildings between the roadway and sensitive (typically residential) receivers. This can reduce the acoustic shielding for noise sensitive receivers and cause noise levels to increase, which may result in noise levels exceeding the FTA noise impact threshold.

Audible Warnings

Streetcars are usually equipped with horns and bells as audible warning devices. The horns are used to alert pedestrians and motor vehicles of a potential safety risk in the same manner as on buses. Horns are used infrequently enough that they do not need to be included in the noise analysis. The bells or gongs, however, may be used on a regular basis at street crossing or stations and therefore must be included in the analysis of noise impacts for sensitive receptors within approximately 100 ft of where the audible warnings will be sounded on a regular basis.

Special Trackwork

Modern streetcar tracks are constructed of continuously welded track that eliminates the clickety-clack noise associated with older rail systems. One exception is special trackwork for turnouts and crossovers where two rails must cross. A fixture called a frog is used where rails must cross. Wheel impacts at the gaps in the rails of a standard frog can cause the noise levels near special trackwork to increase by approximately 6 dB. Typically, sensitive receivers that are located within 100 ft of a special trackwork have a high potential for noise impacts.

Wheel Squeal

Wheel squeal may be generated when steel-wheel transit vehicles traverse tight radius curves. It is very difficult to predict when and where wheel squeal will occur. A common guideline is that there is the potential for wheel squeal at any curve with a radius less than approximately 400 ft. Wheel squeal can usually be controlled through the use of either lubricants or friction modifiers.

Ancillary Equipment

For a typical streetcar project, the only ancillary equipment that has the potential of causing noise impacts is traction power substations (TPSS). On modern TPSS units, the cooling fans are the only significant noise source. General guidelines are to locate the TPSS units at least 50 ft from the closest residential land use and position the cooling fans so the noise is directed away from sensitive receptors. This, in combination with noise limits in the procurement documents, will usually avoid noise impacts.

Vibration

Streetcar Operations

Streetcar operations create groundborne vibration that can be intrusive to occupants of buildings that are located close to the tracks or may interfere with sensitive research equipment. This is particularly important for residential land uses that are located within 50 ft of streetcars. Typical conditions that may lead to exceeding the FTA criteria for vibration impact are speeds above 25 mph, inexpensive building construction that amplify vibration, and efficient vibration transmission caused by the local geology.

Streetcar vibration may be annoying to building occupants, but the vibration is almost always well below the risk thresholds used to protect even the most sensitive and fragile historic structures from damage. Therefore, the criteria for vibration impact are based solely on minimizing human annoyance. Groundborne noise and vibration from streetcars may approach the FTA impact thresholds for “special buildings” such as concert halls, recording studios, theaters, and research equipment at speeds above 15 mph and distances less than 100 ft from the streetcar tracks.

Special Trackwork

The groundborne vibration near special trackwork increases by approximately 10 dB due to the wheel impacts at the gaps in the rails and the noise increases by approximately 6 dB. It is almost guaranteed that there is potential for vibration impact when crossovers will be located within 50 feet of residences.

MITIGATION APPROACHES

Noise

Typically, noise impacts from streetcar operations are caused by banging noise at crossovers and squeal noise at tight radius curves. Using well-designed flange-bearing frogs for crossovers is the most effective means of eliminating noise impacts from special trackwork. It is common on streetcar systems for the frogs to be flange bearing. That is, there is a short ramp before and after the gap where the load is transferred from the wheel tread to the wheel flange. If the ramps are too short, the load transfer is quite abrupt and will generate substantial noise. Flange-bearing frogs with longer ramps and preferably a spiral transition zone can eliminate most of the wheel–frog impacts that cause high noise and vibration from special trackwork. A well-designed flange-bearing frog requires a minimum ramp slope of 1:20, which allows a smooth transfer of the load from the tread to the flange. This frog design will minimize and can eliminate the increase in noise caused by the rapid transfer of load.

Common approaches to controlling wheel squeal include:

- Applying a friction modifier to the railhead or the wheel tread,
- Applying lubricant to the gauge face of the rail or the wheel flange, and
- Optimizing the wheel and rail profiles. Using resilient wheels and maintaining the tracks will help control wheel squeal; also, periodic wheel truing will maintain an optimum profile and can help minimize wheel squeal.

It is noteworthy that sound walls are not usually a mitigation option for streetcar projects. In contrast to light rail systems, streetcar systems are usually integrated into busy urban areas where sound walls cannot be incorporated into the design. Therefore, it is important to incorporate mitigation strategies such as well-designed flange-bearing frogs and control for wheel squeal into the project.

Vibration

A number of different approaches are available to reduce levels of groundborne vibration from streetcar operations. These measures range from very simple approaches such as stiffening the floors at the receivers to very expensive measures such as placing the entire track system on a concrete slab that is supported by springs (floating slab track). The most appropriate mitigation strategy for a project depends on the amount of mitigation required and the frequency range in which the predicted impacts occur. Potential vibration mitigation measures for embedded track systems are

- Resilient mat. Resilient mats are similar to ballast mats that are designed to be placed under ballast and tie track. Some embedded track designs have used a ballast mat layer under the concrete track slab as a vibration mitigation measure. A typical resilient mat consists of a 3- to 6-cm thick elastomer pad that is placed under the track slab. In essence, the resilient mat is used to create a low-cost floating slab. This approach can be an effective vibration control approach at frequencies greater than 31.5 Hz.

- QTrack Slabs. QTrack is a proprietary system for reducing vibration levels on an embedded track system. It has been used on European trams and LRT systems and appears to have promise as a vibration mitigation approach for embedded track. It has been installed but not yet tested on new LRT systems in North America. QTrack is a fastenerless, continuously supported track with rubber profiles decoupling the whole rail from its environment. The QTrack consists of a high-resilience pad underneath the rail base that acts as the spring and a rubber boot that encompasses the rail. The potential concerns for lateral stability of these fastenerless systems is addressed through careful design to ensure stability that is comparable to mechanically fixed rail. QTrack can provide effective isolation above 25 Hz and, according to the supplier, can be engineered to provide attenuation that is comparable to ballast mats and other resilient mats. The advantage of this system is that the elastomeric material stiffness's can be tailor-made and the vibration isolation performance can be tuned to meet the specific project requirements.
- High-resilience boot. A common embedded track construction procedure is to place the rails in a rubber "boot," position the rails, and then pour concrete around the boot. The rubber boot provides electrical isolation of the rails and provides sufficient resilience that movement of the rail during operations and movement resulting from thermal expansion and contraction does not cause the concrete to crack. In the standard configuration, the rail boot results in a fairly stiff track system. It is sometimes feasible to reduce the track stiffness by using a thicker and softer material for the boot. However, it is unlikely that a softer boot would provide sufficient vibration isolation except for segments where the predicted vibration levels exceed the impact threshold at frequencies of 60 Hz and higher. Alternative approaches to increase the resilience of embedded track include using poured materials (e.g., Icoset) and the equivalent of booted track using three separate pieces to enclose the track instead of a single boot.
- Tire-derived aggregate (shredded tires; TDA). This approach consists of building the track on top of a layer of TDA. Although this approach has not been used for embedded track, it has been successfully used by light rail systems in Denver and San Jose, California, to reduce vibration from sections of ballast and tie track. A 12-in. layer of TDA was used for both the Denver and San Jose installations and all indications are that those designs are functioning as intended. Analysis indicates that TDA can be an inexpensive alternative for resilient mats.
- Floating slab track. A floating slab consists of a concrete slab supported by elastomer or steel coil springs that are in turn supported on a concrete foundation. For embedded track, the rails would be embedded in the spring-supported slab using the same basic design as used for standard embedded track. The frequency range at which a floating slab is effective depends on the thickness of the slab and the stiffness of the springs. Most North American floating slab systems use rubber pads that are 12 to 18 in. in diameter supporting a concrete slab that is 12 to 24 in. thick. Floating slabs are very effective at reducing vibration levels; however, they are very expensive and there are challenges in designing them for shared right-of-way systems such as streetcars. There are systems that have been used on European trams and LRT systems that diverge from the typical North American floating slab system that consists of natural rubber "hockey pucks" supporting a concrete slab track system.

EXAMPLES OF NOISE AND VIBRATION IMPACTS ON MODERN STREETCAR SYSTEMS

Research Facilities

Material Science Microscopes

The Tucson modern streetcar alignment passes through the University of Arizona campus and is close to the Materials Science and Engineering Building (MSE). The primary concern at the MSE building was interference to the nanotechnology research facilities from groundborne vibration related to streetcar operations (*8*). Our analysis showed that none of the microscopes housed in the building at the time of the study would be affected by the streetcar vibration, however, there was potential for interference to a future high-end microscope. Two approaches were considered to mitigate the vibration. The first approach was to use a special low-vibration track system for the section of the streetcar tracks near the building. The second approach was to move the MSE microscopy group to a location on campus that is sufficiently isolated from roadways and the proposed streetcar alignment so that ambient vibration levels would be lower. The second approach was implemented and has worked very well for all the stakeholders.

National Optical Astronomy Observatory Optics Lab

The Tucson modern streetcar alignment was modified in 2010 after the completion of a final environmental assessment (*9*). The realignment of the streetcar track required additional noise and vibration analysis related to the National Optical Astronomy Observatory (NOAO). One of the primary concerns was streetcar vibration affecting the interferometer equipment in the Optics Lab (Figures 4 and 5). It was determined that if streetcar vibration exceeded the ambient vibration when the air handling system was turned off, it would be likely to interfere with the interferometer measurements. The justification for this very strict limit was that NOAO scientists commonly experienced problems with existing vibration even during nighttime hours when activities in the building and traffic on nearby roads were at a minimum. Our analysis showed that streetcar vibration would be below the VC-E curve (the strictest vibration criteria curve provided by the FTA), but would exceed the ambient vibration in the Optics Lab when the air handlers were switched off (Figure 6). The tests with the air handlers on and off indicated that it was possible that low-frequency airborne sound was the source of the interference. However, it was not feasible to confirm whether structureborne vibration or airborne sound was the source of the interference. Because it was difficult to conclusively determine whether streetcar vibration levels would affect the interferometer tests performed in the Optics Lab, a menu of potential mitigation options including track-based mitigation were provided to the design team. Upgrading the interferometer equipment so that it is less sensitive to environmental vibration was determined to be the most cost-effective means of mitigating potential vibration impacts. A new interferometer with advanced technology that is not sensitive to vibration was jointly purchased by the project and NOAO for a cost that was substantially less than virtually any track-based vibration mitigation measure would have been. This approach successfully eliminated streetcar vibration as a potential impact and allowed the interferometer tests to be performed at any time of the day. An added bonus was that the supplier of the equipment was a Tucson-based firm.

FIGURE 4 Vibration measurement positions for NOAO Optics Lab in Tucson (*9*).

(a) (b)

FIGURE 5 (*a*) Optics Lab interferometer and (*b*) the accelerometer locations (*9*).

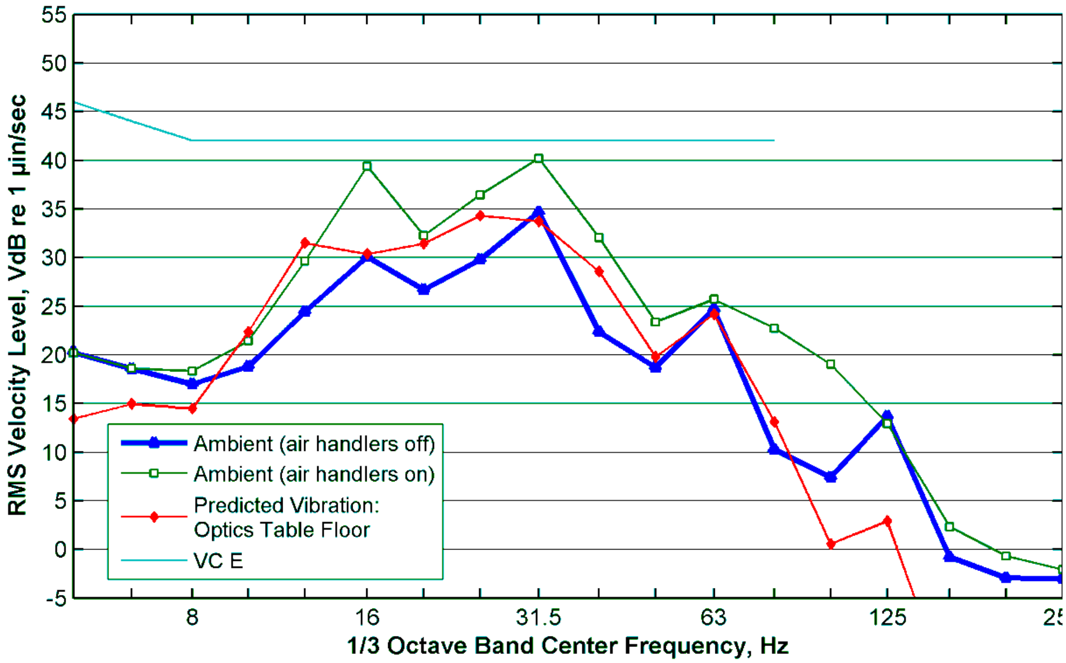

FIGURE 6 Predicted vibration spectra based on thumper testing at the NOAO Optics Lab (*9*).

Recording Studios, Theaters, and Concert Halls

The New Orleans Regional Transit Authority (RTA) designed the Union Pacific Terminal–Loyola Avenue line from the UPT to the Canal Street in 2010–2011. The project is currently under construction using funding from the Transportation Investments Generating Economic Recovery (TIGER) grants from the federal government (*4*, *10*). The UPT–Loyola Avenue line is approximately 1.5 mi long and junctions with the existing Canal Streetcar line. The alignment ends at the starting point of the French Quarter loop streetcar expansion project on North Rampart Avenue. Where the Loyola Avenue line meets the Canal Streetcar line, there are multiple crossovers with special trackwork that use flange-bearing frogs (Figures 7 and 8). Our measurements at the existing Canal Streetcar line showed that the frogs increased vibration by approximately 8 dB.

Groundborne noise and vibration impacts from the Loyola corridor were assessed for three theaters and the future South Rampart Entertainment District. The assessed theaters were Saenger, Loew's State, and the Joy. Saenger Theater, Loew's State Theater, and the future South Rampart Entertainment District were assessed as concert halls and the Joy Theater was assessed as a movie theater, which is its most recent use and is assumed to be its probable future use.

The FTA criteria for groundborne vibration and noise impact consider concert halls and movie theaters to be special buildings requiring more strict vibration criteria. FTA's vibration impact criteria have lower impact threshold criteria for concert halls than for movie theaters. Our analysis showed that groundborne vibration was likely to exceed the FTA impact thresholds at Saenger Theater and Loew's State Theater (Figure 7). There was potential for groundborne noise from the streetcar operations to exceed the FTA impact threshold at Loew's State Theater. However, use of well-designed flange-bearing frogs with longer ramps that have a more gradual transfer of the load was recommended to substantially reduce the impacts that cause high noise

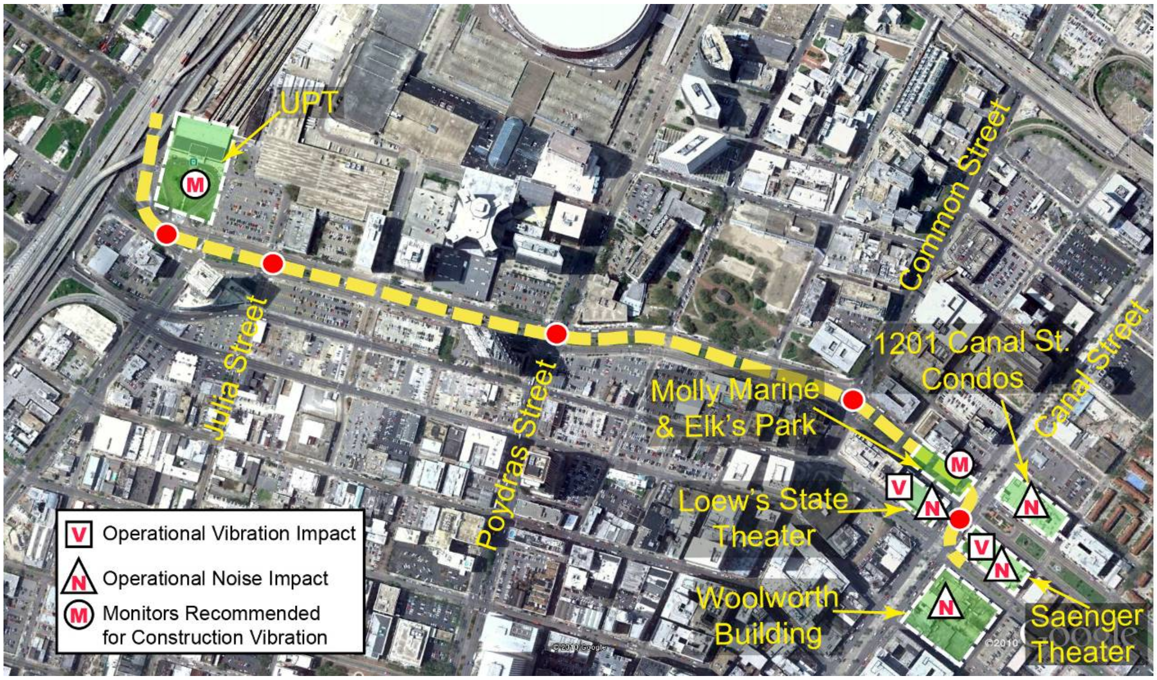

FIGURE 7 Predicted noise and vibration impacts on the New Orleans UPT–Loyola Avenue streetcar alignment (*10*, *11*).

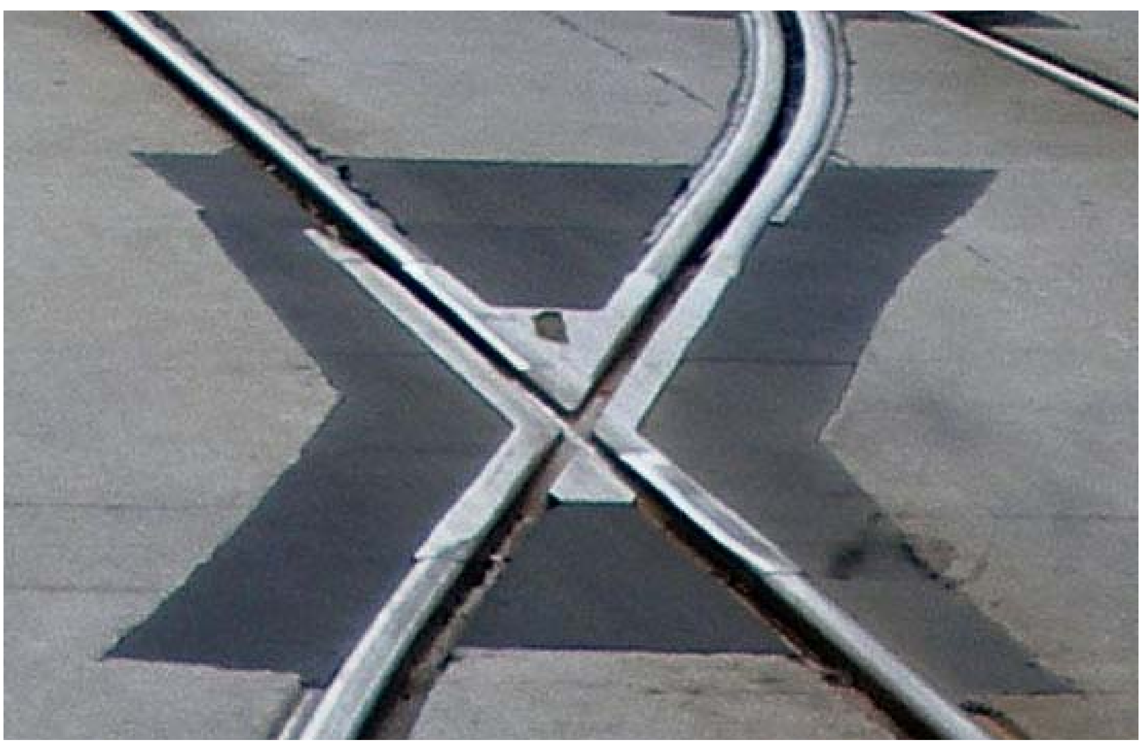

FIGURE 8 A frog on existing Canal Line with a short ramp (*10*, *11*).

and vibration from special trackwork. No further mitigation was necessary to eliminate the predicted impacts.

Residential Land Uses

Typically residences are not affected by groundborne vibration generated from streetcar operations. But for residences located south of Broadway Avenue on the Tempe streetcar alignment, several residential dwelling units are located within 50 ft of the proposed tracks and the operational speed of the streetcar is planned to be 40 mph (Figure 9) (*12*).

Predictions using the FTA Detailed Vibration Analysis procedure showed that there is potential for groundborne vibration impacts at these residences (Figure 10). The conditions that appear to have contributed to predicted vibration impacts at residences are (*a*) the relatively high streetcar speeds, (*b*) receivers within 50 ft of the closest track, and (*c*) efficient ground vibration propagation. This underlines the fact that streetcars are no different from light rail trains in their ability to generate vibration at higher speeds and closer distances. For the Tempe streetcar project, the recommended mitigation options for vibration impacts include lower speeds or use of high-resilience mats under the tracks such as QTrack supplied by CDM-Novitec or ballast mats used on ballast and tie track. The design team has since reviewed the options and held discussions with the stakeholders, including the owners of the affected residences, to arrive at the most acceptable design parameters. The project is expected to start construction in early 2013.

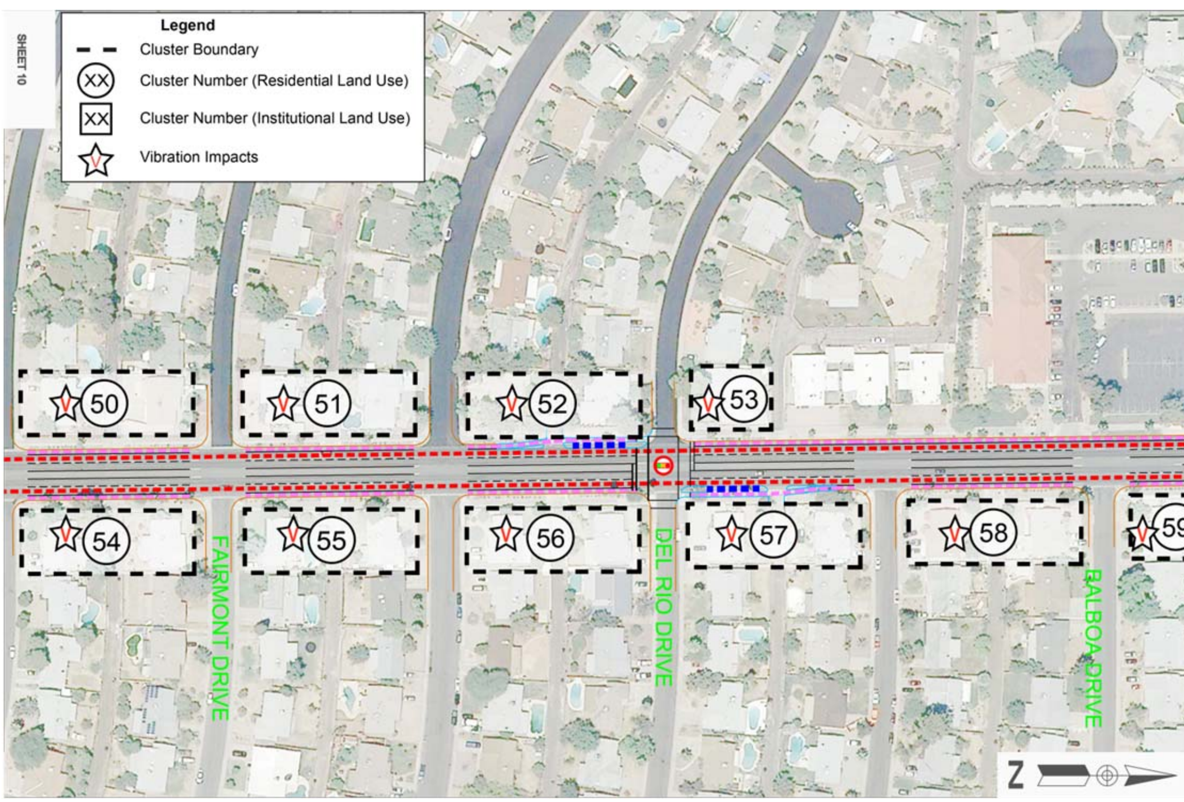

FIGURE 9 Predicted vibration impacts at residences along a proposed alternative for Tempe streetcar (*12*).

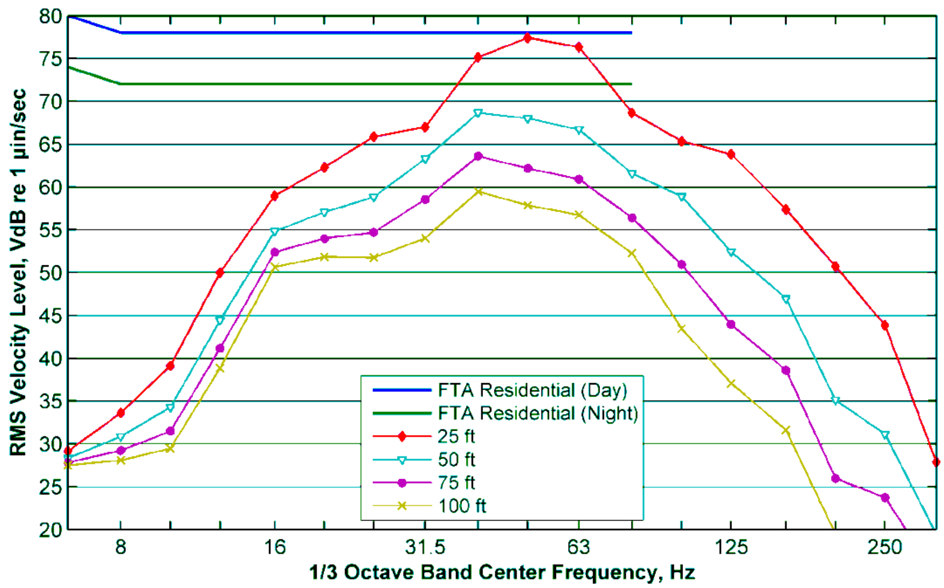

FIGURE 10 Predicted streetcar vibration spectrum at 40 mph for Tempe streetcar (excludes safety factor and building amplification) (*12*).

RAIL ROUGHNESS DATA FROM EXISTING STREETCAR SYSTEMS

Wheel and rail surfaces are never completely smooth and their unevenness causes acoustic excitation. Roughness is the term used to refer to the surface unevenness. The frequency of acoustic excitation created by rail roughness depends on the wavelength of roughness and the streetcar speed. Depending on the frequency of excitation, high levels can occur either in the noise or vibration regime. The mathematical relationship is

$$\text{frequency} = \frac{\text{velocity}}{\text{wavelength}}$$

In the above equation, wavelength is the length of roughness on the rail or wheel. For streetcars traveling at 15 mph, 2-in. (51-mm) roughness wavelength translates to excitation at about 130 Hz. Longer wavelengths of rail roughness lead to lower frequency excitation and higher speeds will cause higher frequency excitation.

The rail roughness was measured on the Seattle streetcar and the Portland streetcar systems. Figures 11 and 12 are photographs taken during the roughness measurements in Portland.

The results of the measurements are provided in Figure 13. The roughness levels are represented in decibels with reference to 1 µ in and plotted against the wavelength of the rail roughness expressed in millimeters. The measured roughness levels are plotted with the ISO 3095 spectrum, the rail roughness standard used in Europe (*14*). Roughness levels exceeding the ISO standard indicates that that it may be possible to reduce noise and vibration levels through grinding to smooth the rail head.

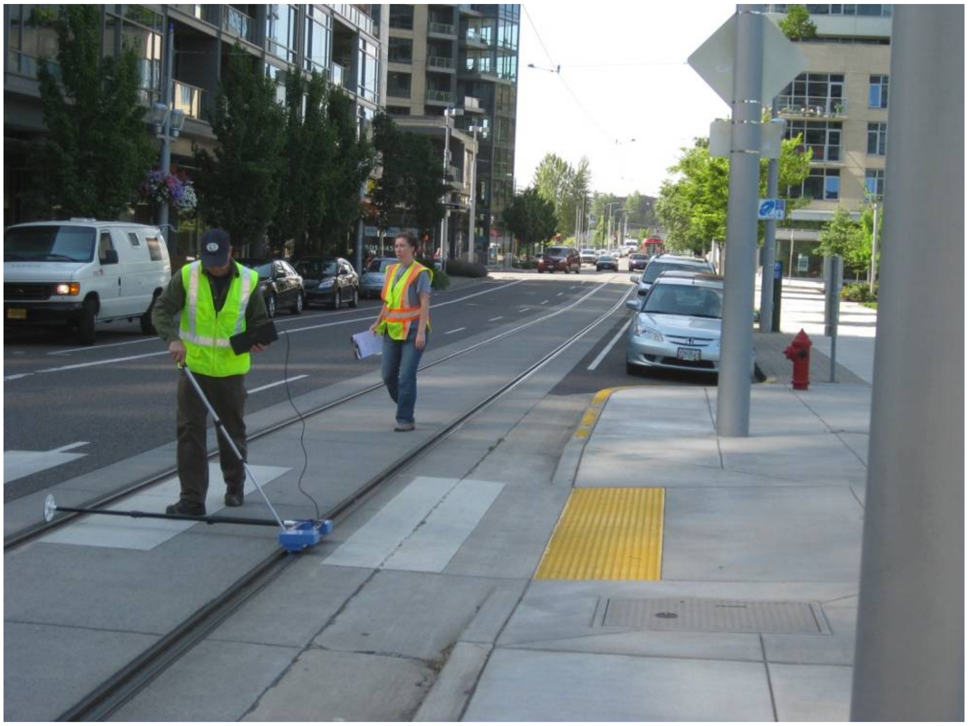

FIGURE 11 Rail roughness measurement in Portland streetcar tracks (*12*).

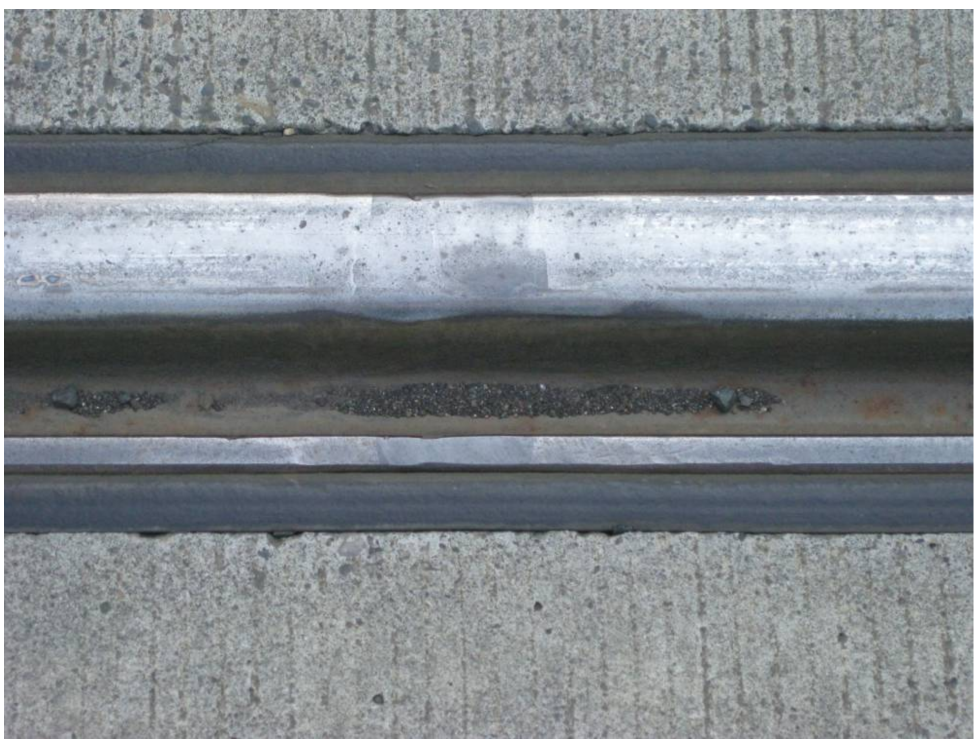

FIGURE 12 Rail condition in Portland (*12*).

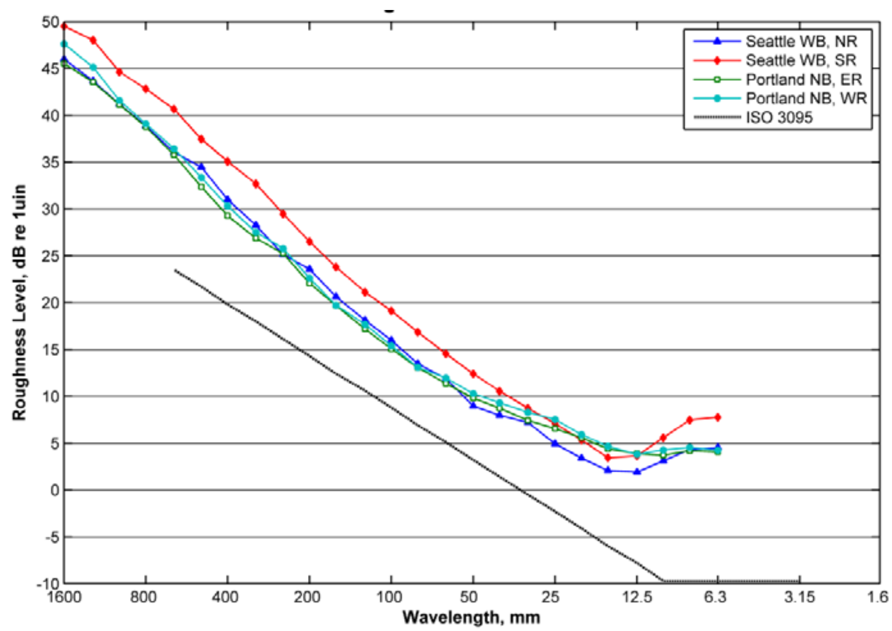

FIGURE 13 Rail roughness measurement results (*12*). (Note: WB = westbound; NR = north rail; SR = south rail; NB = northbound; ER = east rail; WR = west rail. ISO 3095 = recommended roughness limit.)

The key points from the roughness measurements shown Figure 13 are

- The rail roughness at both Portland and Seattle were higher than the ISO 3095 standard across the spectrum.
- The roughness results in Portland and Seattle are remarkably similar. This indicates their high roughness levels are not an anomaly and may be representative of streetcar systems in general.
- Because the measured roughness spectra is a smooth curve and does not show any peaks, the acoustic excitation from the rough rail surface can be expected to be a broadband excitation.
- There may be potential for reducing streetcar noise and vibration for any new streetcar project by implementing a track maintenance program that maintains the rail roughness to levels below the ISO 3095 standard.

CONCLUSIONS

The key conclusions are as follows:

1. Because streetcars share the right-of-way with vehicular traffic and operate at relatively low speeds, streetcar operations on tangent tracks usually do not lead to noise or vibration impacts. However, there is potential for impact if the streetcar alignment passes near

facilities that are particularly sensitive to noise and vibration, such as theaters or research facilities.

2. If streetcars run at higher speeds (such as 40 mph), the noise and vibration levels will be comparable to LRT systems and the potential for impact will increase.
3. Noise mitigation options exist for special track conditions such as crossover and tight radius curves. These are common sources of high noise levels from streetcar operations. It is important to identify these issues before the system is constructed so that appropriate mitigation options can be included in the design.
4. For vibration-sensitive equipment that may be affected by streetcar operations, mitigation of vibration at the equipment may be more cost-effective than employing track-based solutions.
5. When necessary, track-based mitigation options are available for streetcar vibration impacts. Although traditional floating slab track designs used in light rail systems are not usually feasible for streetcar alignments because of cost, alternate mitigation systems with nearly comparable performance are available.
6. An optimal wheel profile combined with smooth rails can minimize noise and vibration levels. It is noteworthy that employing rail grinding programs as part of routine track maintenance could minimize noise and vibration complaints due to deterioration of the rails over time.

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Baltimore Red Line Process Is a Model for Civic Engagement

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The Red Line, a 14-mi light rail line, currently in preliminary engineering phase, is much more than a transportation project. It will be a driver for community and neighborhood development, a way to improve the environment across Baltimore City, and a model for responsiveness and civic engagement. The Red Line will bring more employment opportunities, business ventures, and local investments to keep the city moving forward. It will connect the region's largest employers to the downtown business and residential communities of Baltimore City. Woodlawn is home to the headquarters of two federal agencies and more than 12,500 government workers. The Red Line project creates quick, efficient transit along a congested, transit-deficient route. Public participation is key to implementation. The train's route is roughly the same as the uncompleted end of Interstate 70, which was defeated by a "freeway revolt" in the 1970s. Hundreds of homes were taken by eminent domain and residents relocated. Scars from this contentious period remain today in the form of two disjointed highway stubs and a lingering distrust for large projects. Baltimore City's Red Line Community Compact defines the success of the project and requires early public participation and engagement, beginning at the planning stage through construction. Baltimore City Department of Transportation in coordination with the Maryland Transportation Administration has engaged community leaders, businesses, institutions, and organizations in a conversation about how to maximize the benefits of the Red Line. Some of the accomplishments as identified in the Community Compact include getting a state law passed that prohibits the involuntarily taking of homes for construction of the Red Line, a job study that identifies the type of education, training, and skills necessary for the Red Line construction, and the creation of an Economic Empowerment Office to create a pipeline for job training, contractors, and entrepreneurs.

INTRODUCTION

The Baltimore Red Line first appeared on a map produced in 2002 by the Baltimore Rail Plan Advisory Committee, which studied the rail transit needs of Baltimore (*1*). The Red Line was chosen for implementation because its route is very congested, connects major employment and residential areas, and is presently absent of light rail and rapid transit. Baltimore routinely ranks in the top 20 in studies of the United States' most congested cities (*2*).

The community involvement process employed by the City of Baltimore's Office of the Red Line is unique in both its duration and scope. The Community Compact is a trailblazer and serves as a model throughout the transportation industry. Currently, there are no other identifiable transit projects in the United States with this type of early and extensive public engagement.

COMMUNITY COMPACT

Former Baltimore Mayor Sheila Dixon sought to be out front in the community engagement process. It was her opinion that a large-scale, coordinated, early start to the process was critical to ensuring the public's support of the project.

Because the Red Line will be constructed and operated by the Maryland Transit Administration (MTA), Mayor Dixon sought to ensure that the input of Baltimore's City residents would be heard and valued. She created the Mayor's Red Line Project Coordinator position in January 2008. The role of the Red Line Project Coordinator is to serve as the liaison to the MTA, elected officials, city agencies, and the communities along the corridor in an effort to keep the project moving forward.

Baltimore's unique community engagement process began with Mayor Dixon's Red Line Summit in May 2008 where the focus was on the benefits of the Red Line and not the mode (i.e., bus rapid transit, light rail transit, or heavy rail), nor the specific alignment. More than 300 community, business, and advocacy group leaders met and engaged in a conversation about how to maximize the benefits of the Red Line project.

The product of the summit was the Red Line Community Compact, a unique document outlining the goals of the project and strategies to achieve them. The Red Line Community Compact defines the success of the project and requires early public participation and engagement, from planning stage through construction. Baltimore City Department of Transportation (DOT), in coordination with the MTA, has engaged citizen community leaders, businesses, institutions, and organizations in a conversation about how to get the most out of the Red Line project. The Community Compact serves as a "road map to implementation of the project to make sure that the desires of the public are met."

Some of the accomplishments of the Community Compact include passage of a state law that prohibits the involuntarily residential displacement for construction of the Red Line, a job study that identifies the type of education, training, and skills necessary for the Red Line construction and the creation of an Economic Empowerment Office to create a pipeline for job training, contractors, and entrepreneurs (*3*).

The Community Compact is a collaborative effort, and it is a living document. Its principles create guidelines for how the project will generate jobs, economic opportunities and enhance neighborhoods. Each year, an annual report is released by the DOT that displays the Red Line's progress in a checklist format; that is, it shows which Compact goals have been achieved, which are in progress, and which have yet to begin (*4*).

In the summer of 2008, the City of Baltimore DOT, the Department of Housing, the Department of Planning, and other stakeholders brought together residents and experts to draft detailed principles and strategies for achieving the goals of the Red Line Community Compact.

Key community leaders participated and offered support for the Red Line at the Community Compact signing ceremony in September 2008. At the Compact signing ceremony, there were more than 60 signatories that agreed to the goals of the Compact and understood that the strategies will require further discussion, planning, and negotiation. The support for the Community Compact did not imply support of any specific mode or alignment for the Red Line, as the locally preferred alignment had not yet been approved. However, support for the compact did represent support for a common vision of success for the project as a whole.

Following the signing of the Compact, community engagement was widespread and constant. In summer and fall of 2008, Mayor Dixon, along with residents, DOT, Planning, Housing, and MTA, held a number of neighborhood walking tours along the corridor. This allowed a two-way conversation to take place between stakeholders and officials about the Red Line's potential impact on neighborhoods. The mayor was afforded an opportunity to learn first-hand the concerns and opinions about the Red Line in each neighborhood affected by the project. The presence of other city agencies on the walking tours was essential to help identify and develop transit-oriented development (TOD) opportunities. Outreach to the various churches along the corridor was critical, as many members do not necessarily live in the corridor itself. Forming relationships with the corridor's clergy meant the addition of well-respected Red Line ambassadors that have a weekly audience.

Throughout the planning process, the Red Line team has participated at various neighborhood and city festivals as well as Artscape, the largest free music and arts festival in the United States, which takes place annually in Baltimore. Promotional materials with the distinctive Red Line logo were handed out. Having "Red Line" on items like buttons, bags, fans, umbrellas, and water bottles has provided very efficient, long-lasting advertising.

In fall 2008, additional walking tours were held specifically in the historic areas along the route. Unlike many organizations that typically did not come to the table until later in the process, the goals of the Compact allowed the Red Line to become partners with historic organizations early in the planning process. The historic walking tours were facilitated by Baltimore Heritage, a nonprofit historic preservation organization that is involved in preservation planning and advocacy, heritage education, and technical assistance. Historic preservation was identified in the Compact as a project goal, and several historic neighborhoods associations have publicly supported the Red Line project.

In October 2008, with assistance from several business groups and nonprofits, the city DOT and MTA took a number of Baltimore residents and business leaders on a tour of the transit systems of Los Angeles, Phoenix, Seattle, and Portland. Stakeholders were given the opportunity to see and learn about the vehicles, maintenance facilities, stations, and operations of these cities' systems, some of which were currently under construction. DOT and MTA also facilitated peer-to-peer meetings for business leaders about the impacts of construction and mitigation techniques. Upon returning to Baltimore, residents presented their experiences to their communities as well-informed, transit-literate Red Line ambassadors.

"Making the Red Line Green" was identified in the Compact as being important to the community and as a result, the City's Red Line team developed a health impact assessment (HIA). DOT sought to gain insight into important health and environmental issues faced by residents along the corridor. Data in this study clearly demonstrated the health benefits of the Red Line, especially to low-income communities in the corridor with higher incidences of health problems (*5*). The HIA summarizes current health conditions for the population living in the Red Line corridor, illustrates links between transportation and health in Baltimore, and recommends specific design features and mitigation strategies to maximize the project's capacity to achieve better health.

As the community participation process moved on, the Red Line Community Compact Steering Committee and four subcommittees were formed. The purpose of these committees was to implement the goals and strategies of the community compact, track implementation, and engage community members and local experts to develop detailed plans to carry out strategies.

Baltimore, like many other U.S. cities, was the site of "highway revolts" in the early 1970s. Mostly low-income and minority citizens were displaced from their homes and the communities for the purpose of building the eastern end of I-70. I-70 was stopped at the city's western border; however, the eastern end of the expressway was constructed despite this. Submerged below street level and extending 1.5 mi west of downtown before an abrupt ending, this section of expressway is known colloquially as "The Ditch" and "The Highway to Nowhere." Communities were severed in two; most of the neighborhoods on either side of this expressway have been in economic peril for decades.

Due to the history of using eminent domain for the Highway to Nowhere, displacing residents was not an option. The mayor would only support an alignment that would not take any homes. As a result, community leaders and the city DOT, along with state delegates and MTA, helped to get Maryland House of Delegates Bill 426 passed. This bill put into law that no residents would be involuntarily displaced for the construction of the Red Line. This was an action from a direct response to the Community Compact. The Compact clearly "reject any alternatives which require involuntary residential displacement as a result of the project."

A goal of the Compact is to employ community liaisons to coordinate and disseminate information among agencies, contractors, residents, and businesses and provide rapid response when issues occur in the construction stage. To the extent possible, liaisons will be hired from affected communities. However, it became evident to DOT and MTA that it would be more effective to bring aboard liaisons in the planning stage to develop relationships and to help communities understand the project. In April 2009, MTA hired five community liaisons, three of which live along the corridor. They currently serve as ombudsmen to the community. Liaisons are the face of the project and they are charged with hearing and allaying concerns about the project while educating stakeholders. Liaisons work for MTA but coordinate with the city's Red Line Office, as both MTA and the city continue to keep their promises in the Compact.

In an effort to identify opportunities and benefits available now to corridor residents, the city's Red Line team coordinated with MTA to implement a farmer's market at the West Baltimore MARC commuter rail station, which will be a major transfer point for Red Line commuters using the train to commute to Washington, D.C. Many different partners teamed up with DOT and MTA to highlight opportunities for sustainable and creative use of the West Baltimore MARC station space and showcase the health benefits of the Red Line. The farmers' market was a huge success and has continued and remains an annual event dedicated to bringing fresh food to one of Baltimore's "food deserts" or areas without easy access to fresh, healthy foods (*6*).

The city's Red Line team is always looking for new and different community engagement tools. Beginning in 2009, community leaders hosted Red Line house parties, or informal gatherings of residents for questions-and-answer sessions at their respective homes. The Red Line team shared facts and maps, and brainstormed ideas related to the project. The characteristics of small group communication lent themselves well to clearly communicating the benefits and opportunities of the project.

The city's Red Line team also coordinated with independent businesses along the Red Line corridor to hold social hours at local restaurants and cafes. The goal was to target residents who do not belong to community organizations; these include many who rent their homes, especially younger residents. It was important to DOT to have their support because studies show that young adults are more interested in transit and less in auto ownership than in previous generations (*7*).

As a vehicle for meeting the Compact's goal of increased safety for people of all ages, funds from the city's Safe Routes to School program were targeted and allocated to schools in the corridor that needed improvements to safe access. This is another example of the Red Line working proactively to facilitate positive impacts before construction has even begun.

To give the Red Line a sense of permanence and inevitability, high-quality printed metal signs were installed by DOT at the proposed station locations that said "future home of the Red Line," with an "estimated time to downtown" printed thereupon. This created a sense of place in Red Line station areas, informing the public where they would be, and giving the public an opportunity to think about how this station location is accessible to them.

It was necessary to continue to educate the community on best practices, case studies, and learn from other transit agency about similar projects like the Red Line. The city took a delegation to Rail~volution, an annual conference focused on building livable communities with transit, to learn about current light rail transit practices. The delegation returned to Baltimore with tools to adopt innovative approaches to the Red Line and associated TOD.

As part of the city and MTA's working with local educational institutions to promote transportation-related professions for young people, as identified in the Compact, the Red Line team partnered with the ACE (Architecture, Construction, and Engineering) Baltimore mentoring program. This program is designed to give students an opportunity to explore career possibilities in the building professions (*8*). The ACE program used the Red Line as a basis for student projects in 2010 when students from the area learned how to design a community-friendly transit station.

DOT sponsored the Open City Challenge, a unique project which encouraged people to think differently about the Red Line. Partnering with MTA, *Urbanite* magazine, D Center Baltimore, and Maryland Institute College of Art, the project called for creative and innovative ideas to turn construction of the Red Line into a positive experience for the community, featuring cash prizes. Proposals poured in from all over the world from a mix of participants, including architects, designers, art students, and Baltimore locals (*9*).

CONCLUSION

The Red Line is scheduled to enter into final design phase in fall 2013. Extensive public engagement will continue, with a focus on maximizing the benefits for the residents that live, work and play along the Red Line corridor. DOT will continue to keep the promises made in the Community Compact, maintain existing relationships with stakeholders while forging new ones, and ensure the community's support and excitement for this vital project.

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Light Rail Transit, Streetcars, and Transit-Oriented Developments

Light Railways and Busways as Key Driver for Sustainable Urban Development

Swedish Experiences with Transit-Oriented Development

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Sustainable urbanism and good placemaking revolve around creating and maintaining sustainable and attractive places by reviving planning and urban design paradigms and by experimentation and innovation. The transports play a crucial role in the sustainable urban endeavor and expectations for wide accessibility and networking are very high. The challenge today is to integrate and improve the efficiency and effectiveness of urban and transport systems and the transports have to fulfill the ongoing demands for enhanced efficiency, comfort, safety, and speed, as well as the environmental factors in the light of global climate change and the energy crisis. One emphasis has been on public transports and transit-oriented development (TOD), compact cities and urbanity-empowering public transports like light railways or light rail transit (LRT) and bus rapid transit (BRT) with its busways as key drivers for sustainable neighborhoods. TOD in a Swedish (European) perspective is by no means a new idea. Three cases of newer light railway and busway projects (Stockholm, Gothenburg, and Norrkoping) are explored in this paper and they are seen through a historical overview of TOD experiences in Sweden. We also investigate and draw attention to the values of placemaking and sustainable urbanism via the advantages and disadvantages of the urban and regional public transport systems and TOD principles.

Sustainable urbanism and good placemaking revolve around creating and maintaining sustainable and attractive places by reviving urban planning and design paradigms, by experimentation and innovation, and by building synergies between the old and the new. The transports play crucial role in the sustainable urban endeavor and the expectations for wide accessibility are very high. The challenge today is to integrate and improve the efficiency and effectiveness of the urban and transport systems and the transports have to fulfill the ongoing demands for enhanced efficiency, comfort, safety, and speed, as well as the environmental factors in the light of global climate change and energy crisis. One solution is transit-oriented development (TOD) or compact cities with urbanity-empowering public transports like light railways or light rail transit (LRT) and bus rapid transit (BRT) as key drivers for sustainable neighborhoods. Transit, a shortening from mass transit, is an American catchall for public transport (*1*) while TOD is a policy to synchronize urban planning and development with public transports. Peter Calthorpe, who introduced the catchy coinage in the beginning of the 1990s, defines TOD as design or development of moderate and high-density mixed-use urban areas at strategic points along the regional public transport system (*2*).

The European parallel to the American TOD is roughly the compact city. It is advocated by the European Commission and is central in the European sustainable cities debate since the 1990s. The vibrant and lively compact city and the contained and ecological green city are two sustainable urban concepts. The compact city favors architectural heritage by respecting rather than imitating the old, greater diversity by mixed uses, particularly housing in inner city areas, and solving urban problems within existing boundaries of the city without extending its periphery (*3*). The argument is that density and diversity are more likely to result in people living close to work places and services that are required for the everyday life (*4*). The ambition of the compact city is also to make the private car an option in cities rather than a necessity (*3*) by creating integrated, intermodal transport systems that fully exploit the potential of public transport (*5*). There are numerous experiments of compact neighborhoods during the last 20 years throughout Europe with a paramount accent on multimodality and urbanity.

TOD as policy to synchronize urban planning and development with public transports in a Swedish and European perspective is by no means a new idea. There is wide body of knowledge and heuristics about public transport systems, cities, and their interplay. We focus in this paper on three cities with newer light railway and busway projects (Stockholm, Gothenburg, and Norrkoping) in a historical overview of TOD experiences in Sweden.

PRINCIPAL PUBLIC TRANSPORT CITIES

The cities throughout the history were shaped by transport technologies and the mobility of their citizens. We made a simplified categorization (Table 1) to describe and cluster the public transports infrastructures as technologies with similar effect on cities.

There are basically three technologies:

1. Public transports on streets (buses and trams);
2. Completely separated, either elevated or on the ground (heavy railways or busways); and
3. Underground (subways), contributed by a hybrid of the three: public transports partially separated on ground (light railways or busways).

The categories are unorthodox and open for further discussion. Heavy means always full separation regardless if it is a bus or rail system, whereas the light attribute describes partially separated systems.

The designation X shows the anchor where (X) ranges of the various public transport infrastructures and their position as public transport technologies shaping cities. Two technologies

TABLE 1 Public Transport Technologies Through Infrastructures (Designed with K. Kottenhoff)

	On Streets in Traffic	Dedicated Lane on Streets	Partially Separated on Ground	Fully Separated on Ground or Elevated	In Tunnel or Underground
Bus line	X	X	(X)		
Light busway		(X)	X	(X)	
Heavy busway			(X)	X	(X)
Tramway	X	X	(X)		
Light railway	(X)	(X)	X	(X)	(X)
Heavy railway				X	(X)
Subway					X

tend to concentrate over specialized infrastructures and excel either on the urban (public transports on streets) or regional scale (fully separated on ground or elevated public transports), whereas the underground public transports excel both on the urban and regional scale. The hybrids, public transports partially separated on ground, also tend to have a wide span claiming both domains.

Each technology enables distinctive urban and regional growth pattern and unique placemaking. The public transports on streets accelerate the urban life and enable elongation and interweaving of the cities along the bus lines and tramways. The fully separated public transports orchestrate discontinuity of urban fabric and regional existence as temporal convergence of distant places—the railways disperse and fragment the city in its region. The public transports underground strengthen the polycentric agglomeration of the existing cities by adding speed, capacity, and concentration; the subways connect urban nucleuses in a network. Analogically, there are four public transport cities (Figure 1):

1. The elongated and interwoven city of buses and trams;
2. The railway city of pearls;
3. The networked city above the underground; and
4. The compact city along the light railways and busways.

The four public transport cities are fuzzy models for TOD, each with its own history and future.

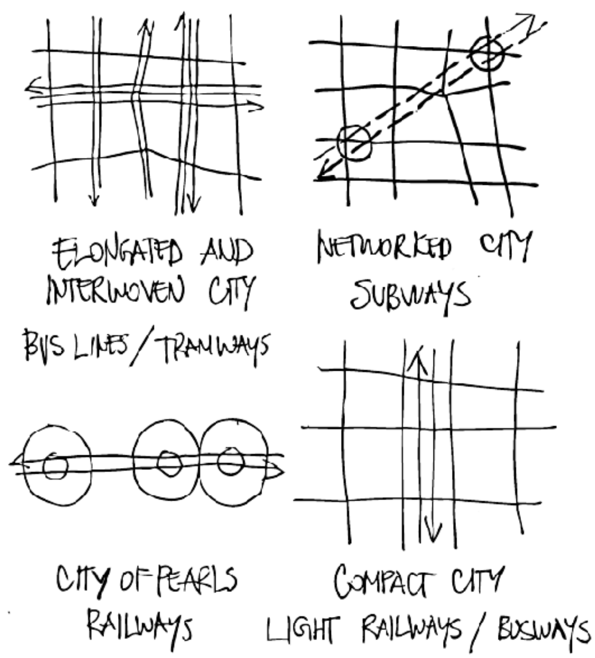

FIGURE 1 The public transport cities.

PUBLIC TRANSPORT CITIES IN SWEDEN

The public transports facilitated accelerated urbanization in Sweden from the 1830s, but with different impacts in Stockholm, Gothenburg, and Norrkoping. The three cities developed differently. Stockholm and Gothenburg developed as dominant cores in their regions, whereas Norrkoping shared its region with Linkoping. Stockholm continuously developed a variety of public transports (Figure 2) and expanded along the railways and subways, which slowly urbanized its region with satellite cities, whereas Gothenburg and Norrkoping concentrated within the range of the tramways and jealously kept them. The tramways became uncompetitive when the e-motorways interconnected entire Sweden in the 1970s and the urban life lost its attractiveness compared to the prospect of living in a peaceful and scenic landscape. The population dropped in the urban cores and the cities dispersed. Stockholm annexed its satellite cities and developed new ones, whereas Gothenburg sprawled in its region. While both Stockholm and Gothenburg had strong growth, Norrkoping had much slower regional growth (Figure 3) and it competed for population with Linkoping. As a consequence Norrkoping has had almost no change in urban population in the past 40 years.

The compact city and urban living advocacy from the 1990s inspired urban developments in Stockholm and Gothenburg and their urban populations slowly recuperated. Gothenburg reached its urban population level from the 1970s in the 2000s, while Stockholm started to grow rapidly.

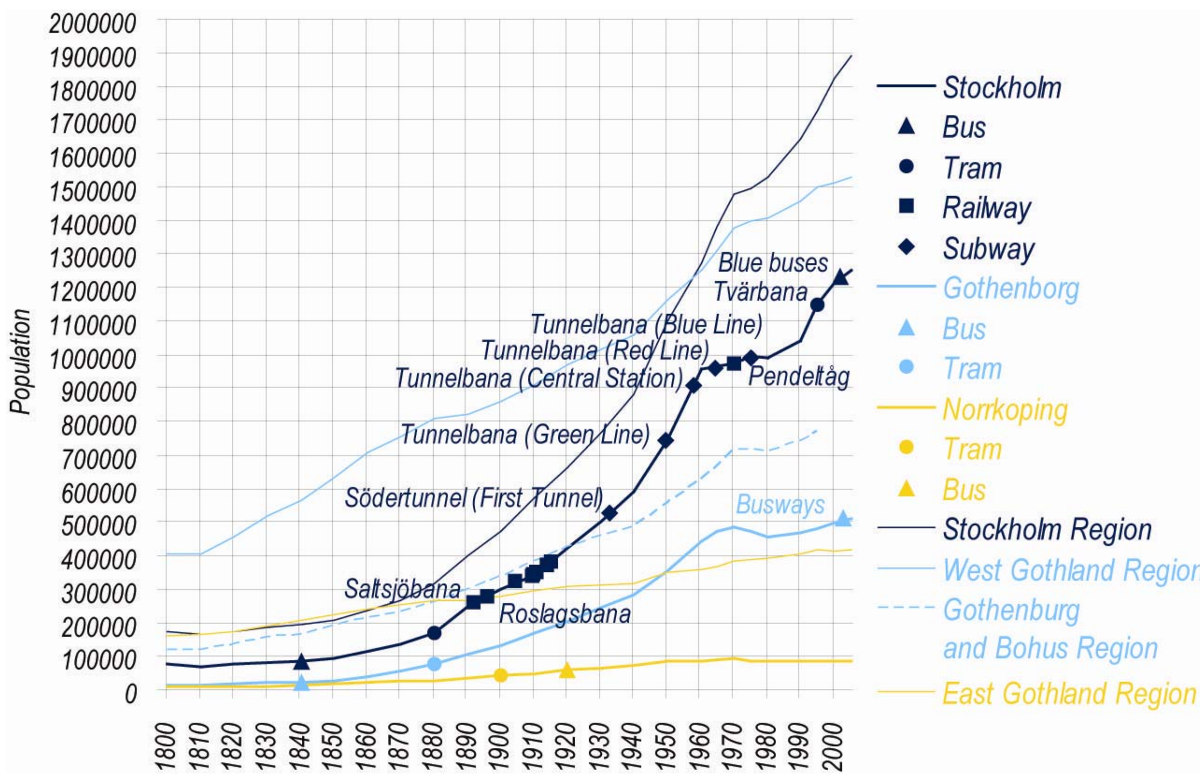

FIGURE 2 Population growth in Stockholm, Gothenburg, and Norrkoping and the public transports.

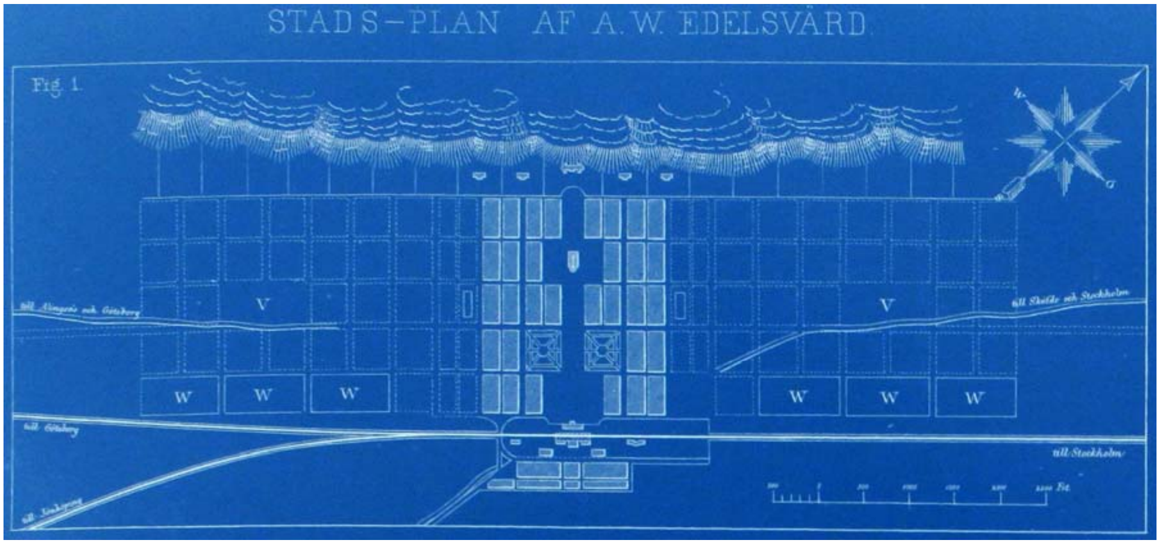

FIGURE 3 Adolf Wilhelm Edelsvärd's ideal city–urban plan from 1859 in *Tidskrift för Byggnadskonst och Ingenjörsvetenskap*.

Buses and Trams Elongate and Interweave the Cities

The horse-drawn buses or omnibuses (hästomnibussar) were introduced in the 1830s and horse-drawn trams (hästspårvagnar) rolled in at the end of the 1870s. Only Stockholm, Gothenburg, and Malmo had horse-drawn tramways. In the 1900s the trams (spårvagnar) were electrified and nine Swedish cities developed tramway networks. Most of the tramways were removed in the 1950s to 1970s and replaced with motorbuses (motorbussar).

The omnibuses, cable cars, horse cars, trams or streetcars, motorbuses or common buses, trolley buses or trolleys are basically modifications of the same public transport technology and if we consider capacity and speed they did not change dramatically. Hindered by the traffic on the streets, they are slow, reaching averagely 10 to 20 km/h (7 to 13 mph). The bus lines and tramways are optimally 7 to 8 km (5 mi) long. The longer lines are not unusual, but they are not attractive within the travel time budgets. Their lack of speed is compensated by a longitudinal attractiveness, urbanity, and wide access to the general public by shortening walking distances. They add vibrancy on streets, provide pleasant urban vistas, and create mobile public spaces. The buses and trams as public transports on street elongated and interweaved a continuous amoebic city. The streets with public transports were and often remained as very attractive directions in the city.

Buses and Trams in Stockholm

The omnibus arrived in Stockholm as inspiration from Paris and Copenhagen in 1835 and reached its peak in the 1870s when the first trams were introduced. Even though the tramways exchanged bus lines, the central line on Drottningatan, one of the main streets in Stockholm, was continuously operated by omnibuses and motorbuses even in the heyday of the trams in the beginning of the 20th century. The buses carried more than 1 million passengers in 1900 (*7*, *8*). At the end of the 19th century, the electric railway became more fashionable than the horse-drawn omnibuses and noisy motorbuses. Stockholm became a stage where several tramway and railway companies competed for turf. There were nine tram and three bus lines in the 1920s and they shaped and interweaved the urban core of Stockholm. Five tramways and one bus line extended outward and elongated the city to a radius of 8 to 10 km (5 to 7 mi). Stockholm grew from 75,000 to 300,000 inhabitants from 1830 to 1900 (*6*). The inner city, where the buses and trams operated, continued growing until 1940 when it reached its maximum of 470,000 inhabitants (http://www.statistikomstockholm.se/).

The directions of the historical bus lines and tramway are basically the main promenades in Stockholm today. The buses and trams follow the urban activity along the main streets, but at the same time they facilitate the formation of urban promenades with attractive frontages and façades. Drottningatan in Stockholm is an attractive shopping street where buses traversed and where the trams accelerated and enriched the urban life on streets like Hornsgatan, Sveavägen, Kungsgatan, and Odengatan. The trams were declared obsolete in the 1930s with the emergence of a new generation of motorbuses. In a visionary modernization they were replaced with the trains of the Tunnelbana (the subway system in Stockholm) and motor buses from 1933 to 1967. Today there are trunk lines with blue buses that perpetually traverse the main streets and operate on the historical tramways. The blue buses orbit the urban core of Stockholm and complete the radial network of subway and railway links. There are also feeder lines with red buses that circulate the smaller streets in meandering fashion. The buses today compete with walking or cycling. Their average speed is around 15 km/h or 10 mph. The buses give acceleration to walking and quick refuge from the cold, better comfort for astonishing urban outlooks, and vibrancy on the street.

Trams in Gothenburg and Norrkoping

Gothenburg and Norrkoping are the only two Swedish cities that kept their tramways. But they had very different histories. Gothenburg had accelerated growth and continuously extended its tramways. Norrkoping stagnated and reduced its tramway network.

Gothenburg experienced rapid industrialization in the second half of the 19th century and it spread out of the spiky city wall in the 1860s. The trams facilitated expansion outward from the end of the 1870s, supported by boats and ferries crossing the river (Götaälv) on the north. In the 1900s there were six lines within a radius of 5 km (3 mi) and the city grew compactly along these lines. As in Stockholm, the streets along which the tramways operated created attractive promenades (Västra and Östra Hamngatan or Vasagatan) that connected the main squares and neighborhoods. Gothenburg diligently extended its tramways and neglected fast public transport links. The average speed of the Gothenburg trams is 15 to 25 km/h (10 to 17 mph) and they extend roughly 10 km (7 mi) in all directions.

Under the pressure of accelerated motorization the city experienced very strong regional growth and rapid urban decline. The dispersed city achieved staggering mobility with people living over 80 km (50 mi) from the city center today (*9*), far beyond the reach of the trams.

Norrkoping had a dense urban core already in the 18th century. It was an old industrial center on a river regulated with dams to power factories since the 17th century. The city grew slowly from 10,000 in 1800, to 40,000 in 1900, to 80,000 inhabitants in 1960 (*6*). Norrkoping elongated northeast and southeast along the tramways, which opened in the 1900s, and developed compactly within a radius of roughly 5 km (3 mi). The tramways concentrate the development along and enriched the urbanity and charm of Drottningatan, the main street in the city.

Railways Introduced the City's Suburbs

In the 19th century, the railways were exciting revolutionary technology of speed, schedules and timetables, wagons and compartments, classes, and tickets. Unlike the typical bus and tram stops on the streets, the train stations were nodes, pearls on an impenetrable string. They were placed at distances that prevented overlapping buffers and gave total control over accessibility. The city of pearls was motivated by monopolistic entrepreneurship that targeted twofold gains. The developers bought almost worthless land on the periphery, laid railways, and designed suburbs. The buildings were sold or leased, while the fares were bringing continuous and lucrative profits.

Because of their speed, the railways created a hierarchy of access and desirability that linked urban pearls scattered over wide distances. The city of pearls can theoretically extend radial over 100 km (70 mi), creating a string of subordinate nodes, gravitating suburbs, and suburban centers.

Edelsvärd's Ideal Railway City

The railways inspired many urban planners and architects. Adolf Wilhelm Edelsvärd was an architect who made a model of an ideal city with a railway station in its core in 1859. Edelsvärd's city (Figure 3) was functionally divided. It had an urban core of public buildings (hatched blocks) with a picturesque boulevard as an axis. The sequence of public spaces started with a square in front of the railway station, parks on both sides squared with church surrounded by court and other public buildings, and ends with an amusement park or Tivoli. The industries (W) were located along the railway, while the houses were located on the wings. Each housing block (hollow blocks) were around 120 m (400 ft). There were 12 houses in each block with 30% to 40% building coverage. In the core of the housing quarter there was a square (V) (*10*).

Railway Suburbs in Stockholm

Stockholm was the only city in Sweden that developed a metropolis structure and the pattern of urban satellite as pearls on strings was visible already in the 1930s. Its suburbanization started in the 1890s and the garden suburb was the realistic counterpart to Edelsvärd's city. The tramway and railway companies who competed for turf in the city also bought land in the countryside and laid suburban railways to profit on increasing land values (*11*). They developed garden suburbs similarly as in many British and American cities that achieved copious fame as cities of villas (villastäder) in Sweden (Figure 4).

The entrepreneurs quickly understood that railways dramatically increase land values and that the garden suburbs are very attractive. The battle for turf in the city expanded to the countryside around Stockholm and there were two entrepreneurship models in suburbanization. Sometimes the development and railway companies cooperated, where one company laid both railways and developed land. Djursholmsbana (or Roslagsbana today) is a railway that connected Djursholm, one of the first garden suburbs with a terminus on the north of the city. One company was running the trains and extended the railway network northward while another company planned and developed suburbs along the railway. Other companies had funds to invest both in

FIGURE 4 Collage of photographs from Djursholm, the city of villas on the north of Stockholm, and Roslagsbana, the suburban railway, from the end of the 19th century and today. [Source for the historical photographs: Stockholm's Spårvägsmuseum (Stockholm Transport Museum.]

the development of railways and land. Knut Agathon Wallenberg was a banker and politician who both financed the Sältsjöbana, the suburban railway that terminated in Slussen, and developed a string of suburbs eastward (*12*). The suburban railways with speeds of 40 km/h (25 mph) and over are competitive with the cars even today. The journey to the center of Stockholm with the Roslagsbana is 10 min and it takes only 13 min to drive the same distance.

ABC Suburb and City

The ABC suburb and city were functional replication of the railway suburb. ABC city stands for arbete (working), bostad (housing), and centrum (center) and is much inspired and critical to Le Corbusier's urbanism and the functional city in his *Athens Charter*. The ABC principle was also inspired by the advocacy for polycentric metropolis and neighborhood planning in Lewis Mumford's *Culture of Cities* (*13*). The metropolis structure was described by Mumford (*14*) and recognized by Sven Markelius, the planning director in the city of Stockholm, who established it as a model for future development. The ABC principle was actualized either as suburb or a satellite city, a cluster of suburbs. The suburb as a pearl (Figures 5 and 6) has urban sectors that should represent a Stockholm in miniature, where the satellite city lays an array of smaller satellites and suburbanizes the suburbs (Figure 5). Markelius (*15*, *16*) argued for larger suburbs with at least 50,000 inhabitants and various building typologies to support housing preferences. The satellite city of pearls was a response to that problem. Markelius produced both the visionary overture *Future Stockholm* (*Framtida Stockholm*) and the unbinding *Generalplan för Stockholm 1952*, which shaped the ABC principle and what the ABC suburbs are in Stockholm today.

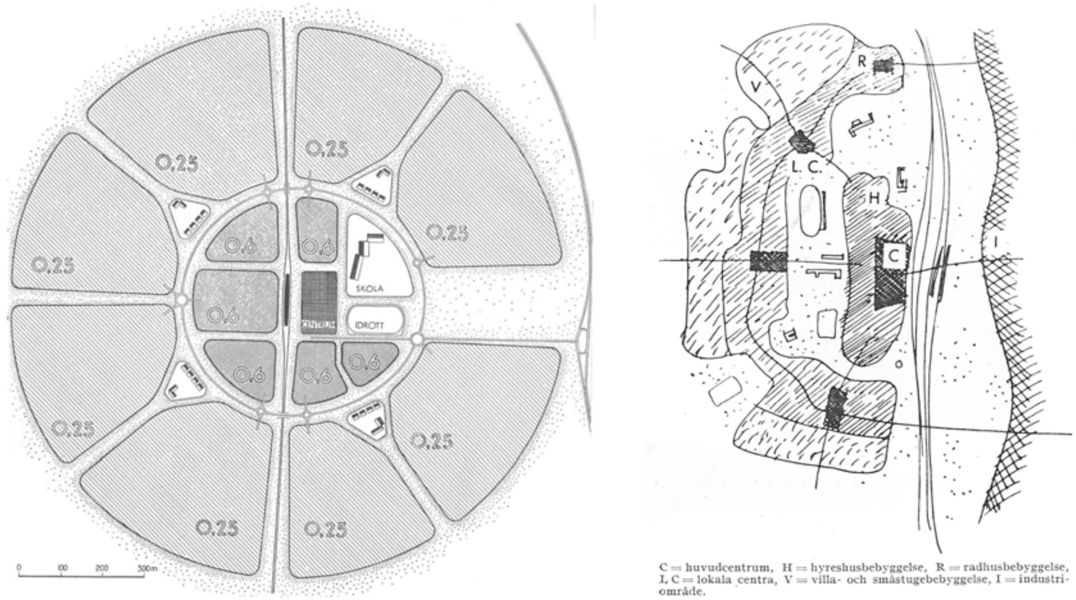

FIGURE 5 Suburb as pearl from *Future Stockholm* (*Framtida Stockholm*) in 1945 on the left (the numbers represent the floor area ratios of the housing districts) and the satellite city by Markelius on the right from *Byggmästaren 1945*. (C = main center; LC = local center; H = multifamily housing; R = row housing; V = villas; I = industries.)

FIGURE 6 Collage of photographs from Vällingby, the first ABC city, from the 1950s and today. The photographs of the center (the C element in ABC) are on the left; on the right are the photographs from the diverse residential areas (the A element in ABC) surrounding the center. [Source: Stockholm's Spårvägsmuseum (Stockholm Transport Museum).]

The Stockholm metropolis model is one of the most successful TODs. Despite the high motorization in the Stockholm region (400 cars per 1,000 inhabitants) the share of public transport is very high, especially during rush hours (almost 70%). The centers in the ABC suburbs or cities act as public transport nodes, where the diversity and density of the ABC city attracts passengers and balances the public transport demand between the satellites.

Stockholm's Underground Network

The subways are the heart of the metropolis hierarchy. They connect feeding railways or extend as railways outward. Terribly expensive, they preserve the city above and protect the traditional urban fabric and historical heritage. They rival or outperform any surface transport in congested urban cores and they do not cause visual impacts as the elevated systems do. Nevertheless, they affect the vibrancy of urban life by networking the places above. They act much like the diagonals of Rome or the baroque European capitals, just invisible to the city above.

The debate about Stockholm's underground network opened in 1913 in the heyday of the railways, when Wallenberg suggested tunnels under the city that connect the suburban railways that terminated on the urban fringes. The hybrid system of subways and railways adopted the name Tunnelbana. The first tunnel opened in 1933 and the central station in 1957 (*17*).

Stockholm's Tunnelbana is the heart and the main arteries of the metropolis hierarchy, while the buses are the capillaries that feed the urban tissue. It also networks the ABC cities and original railway suburbs and generates more than 1 million passengers each day in a region of more than 2 million. The average speed of the system is 30 to 40 km/h (20 to 25 mph) and it extends to a radius 15 20 km (10 to 12 mi) from the central station. The Tunnelbana system is additionally strengthened with branches of a commuter trains (Pendeltåg).

COMPACT CITIES ALONG LIGHT RAILWAYS AND BUSWAYS AS SUSTAINABLE EUROPEAN CITIES

The light railways emerged as a compromise between tramways and railways in the 19th century as systems partially on the street and partially fully separated. Many, especially in American cities, developed along light railways or interurbans in the end of the 19th and the beginning of the 20th century. Los Angeles had the most extensive railway network in the world, which at its peak in the 1920s, had more than 1,600 km (1,000 mi) of interurban railways connected with over 320 km (200 mi) of tramways.

Compact city advocacy in the last 20 years in Europe revived the model of a city with partially separated public transportation services (light railways and busways) that enable the urbanity. Stockholm and Gothenburg have started experiments with sustainable neighborhoods having light railways and busways as structuring urban elements, whereas Norrkoping extended its tramways as partially separated in order to renew, diversify, and intensify the neighborhoods along.

Hammarby Sjöstad and the Tvärbana in Stockholm

Hammarby's Sjöstad (Waterfront City) evolved as a sustainable city model in the 1990s. It is a redevelopment of an abandoned industrial zone located south from the inner city district of Södermalm. The neighborhood winds along an ideally sized light railway corridor and it replicates the façades and urban form of Södermalm. The northern waterfront developed a pattern of quasi-enclosed urban blocks in the early 1990s to maximize the lake views that mirrored on the southern waterfront.

The green esplanade of the Tvärbana, the orbital light railway, is the backbone of the neighborhood. This 37-m wide urban corridor collects pedestrians, bikers, trams, buses, and cars in clearly defined linear stripes. The median tramway is partially separated from car traffic and fenced by a longitudinal park. The bicycle lane is placed between the car lane and a strip of on-street parking. The sidewalks are the last strip having direct contact with the commercial frontage of the buildings. The politicians wanted a true urban feel (stadsmässighet) along the esplanade, as in the inner city.

The city planning office pursued a policy of less private cars and higher share of public transport and had heavy restrictions on parking places. These measures were subverted by the development companies who had problems selling the apartments. Some apartments were sold in a package with a new car and soon there was a problem with parking.

The neighborhood also attracted younger affluent families with high demand for mobility and wide accessibility and the slower light railways and the extra transfer seemed like a worse alternative than the car. The neighborhood was not directly connected to the subway or railway lines but the people needed to make transfer through an old grayish industrial area on the west that felt like leaving the city and returning back. To solve this problem the newest debates are about extending the Tunnelbana towards Hammarby Sjöstad and further to Nacka.

The Tvärbana opened the industrial fringe of Stockholm for development. There is ongoing extension of the Tvärbana northwards towards Solna (Figure 7) which already inspired infill projects and redevelopments in Sundbyberg and Ulvsunda, besides Hammarby Sjöstad (Figure 8).

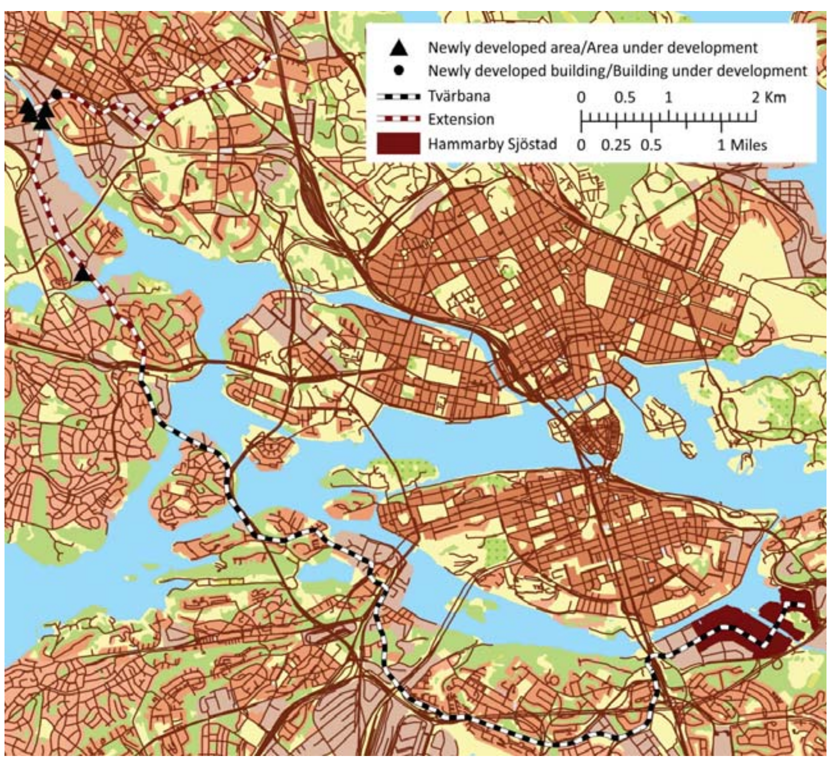

FIGURE 7 Urban development along the Tvärbana.

FIGURE 8 Cityscapes from Hammarby's Sjöstad and its main esplanade on the top four photographs and ongoing urban developments in Sundbyberg on the right and in Ulvsunda on the left of the bottom four photographs.

Norrkoping's Tramway Extension in Hageby

Norrkoping is one of only two Swedish cities, with Gothenburg, that has kept its tram system over the years. There are two tram and four urban bus lines in the city and the trams handle almost half of all the passengers that use the urban public transport. The city opened a 4-km (more than 2 mi) extension of the tramway to the southern suburbs of Ljura, Hageby, and Navestad in 2011 (Figure 9).

The extension should make these suburbs more attractive and sustainable and inspire new urban infill projects. The tram extension connects Ljura, a housing area from the 1950s, Hageby Centrum, a 1960s shopping center that terminates in Navestad, a housing area from the 1960s. Navestad has two housing complexes called Golden Ring and Silver Ring that were upgraded in the 1990s. To diversify Navestad, there are plans for more retail, housing, and public spaces. The tramway extension will have 10 stops laid on grass, which reduces noise. The simultaneous development along the tramway extension was the renovation of Hageby Centrum (Figure 10). New developments are expected in the following years.

Gothenburg's Busway in Norra Älvstranden

Gothenburg and its region have been the industrial center and largest port in Sweden since the mid-1900s when Götaverken, Lindholmen, and Eriksberg, three of the world's biggest shipyards, opened on the north shore of Götälv (the wide river that separated the city from the industrial

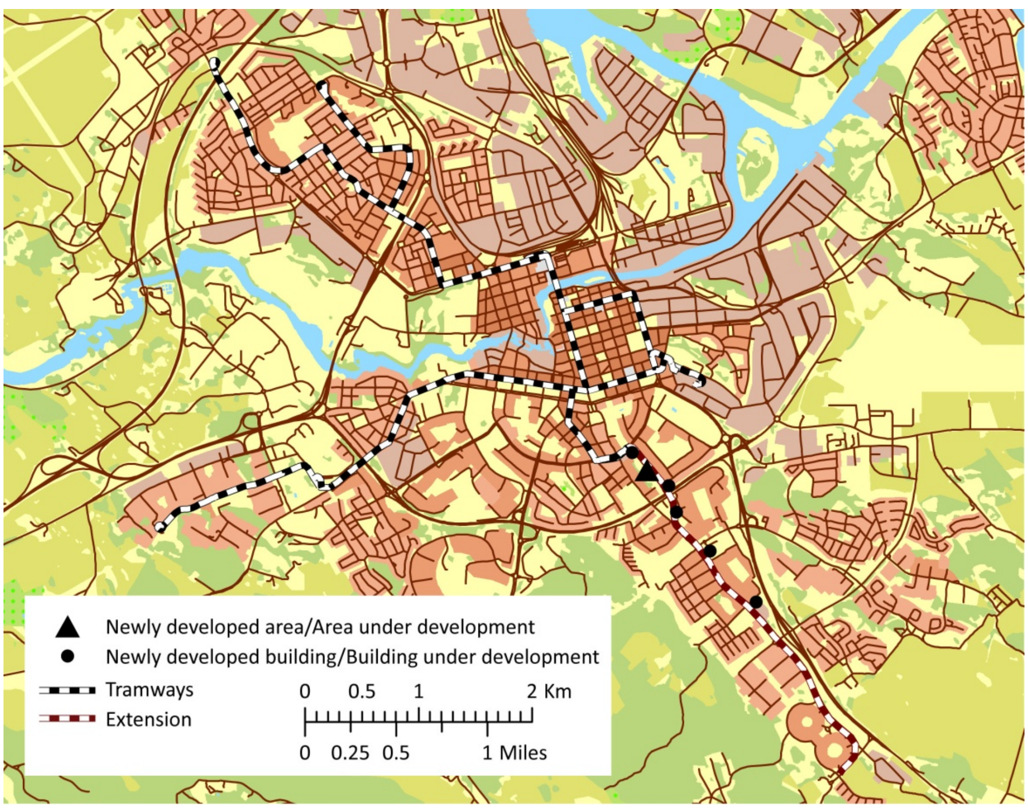

FIGURE 9 Urban development along Norrkoping's tramway extension.

FIGURE 10 Photographs of the newly developed Hageby center (Mirum Galeria from 2012), a newly developed building, and a new area assigned for development in the fall 2012.

zone). The manufacturing power further strengthened when Volvo formed at the end of the 1920s. But since the 1970s, Gothenburg suffered from the deindustrialization that heavily hit the northern industrial waterfront. The industrial area gradually emptied and the city assigned the northern waterfront (Norra Älvstranden), between the Götälv Bridge in the east and Älvsborgs Bridge in the west, for development. Large portions of the land are owned by the city and the renewal started in the 1990s with quite heterogeneous and fragmented development. Eriksberg, an early development, much like the northern waterfront opposite of Hammarby Sjöstad, displays a pattern of quasi-enclosed urban blocks opening prospects on Götälv, still closing up towards the streets to achieve an urban feeling. The more recent developments show less urban attitude, using more building typologies associated with the modernist era, but still focusing on maximizing water views (Figures 11 and 12).

Göteborg kept and carefully developed its tramway system in the city limits from 1879, but there was no agreement of a tram extension along the waterfront. Instead, the city and the public transport authority decided for a system of busways adopting the motto “think railways,

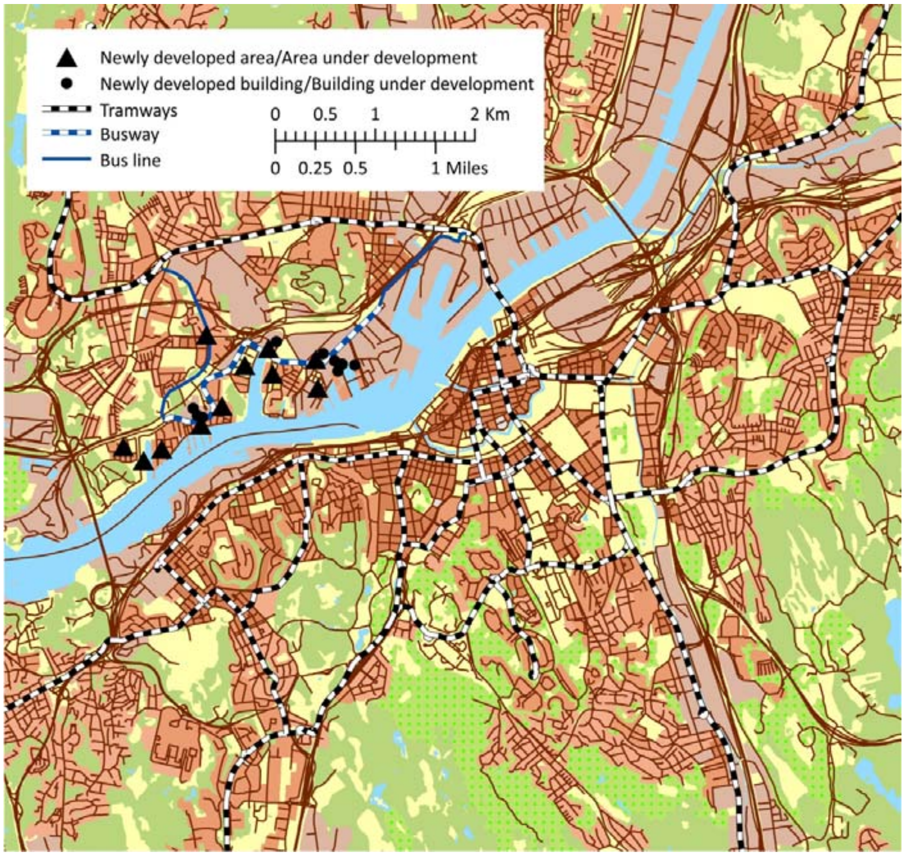

FIGURE 11 Urban development along Gothenburg's busway in Norra Älvstranden.

FIGURE 12 Photographs of the busway and the developments along Gothenburg.

run buses," which also influenced the emergence of blue buses in Stockholm. The busways in Gothenburg however on some parts have been developed on a grand manner and served by double-articulated buses. Lindholmsallén (Lindholm's Esplanade) is extremely wide (almost 90 m or 300 ft), including separate bus lanes in the middle, a wide longitudinal park with double tree lines, double car lanes, another green stripe, single tree line, two-way bicycle lane, and a separate sidewalk. The urban development is slow, but ongoing. It is located mainly on the waterfront. The dense development around public transport nodes is yet to come in this part of the Norra Älvstranden. The esplanade today feels very open and empty.

The waterfront is also served by Älvsnabben (River Quick). It is a popular ferry line within the public transport system, connecting five stops on the northern and two on the southern (city centre). Two departures per hour in rush hours is not very much, but it is about to increase in the near future. The Älvsnabbare (River Quicker) shuttle is, as its name suggests, a quicker shuttle line connecting Lindholmen on the north shore to Rosenlund on the southern shore, every 6 min in rush hours. Since spring 2011, traveling on Älvsnabbare is free of charge. Similar ferry line free of charge exists in Hammarby Sjöstad, which was introduced instead of a bridge between the southern and northern waterfront.

LIGHT RAILWAYS AND BUSWAYS AS DRIVERS FOR URBAN DEVELOPMENT

The rapid urbanization was essential to integration of the public transports in the cities in the 19th and early 20th century. Cervero argued that public transport redistributes rather than produces growth (*18*) and the public transport cities were both product and driver for urban concentration around public transports. The urbanization and population growth are prerequisites for urban and regional development, whereas the public transport stops and lines are one of many urban attractors.

Even though Stockholm, Gothenburg, and Norrkoping had different urbanization and growth patterns there are new developments, infill developments, or redevelopments along the new light railways or busways in the three cities. The busways in Gothenburg as partially separated public transport systems equally added value and triggered developments along the light railways in Stockholm and Norrkoping.

Compact City and TOD

Urban planning includes rules and models. The rules for procedures for conceiving and generating space and models are prototypes, a model space, or a model of space (*19*). When we talk compact neighborhoods or TODs, it seems that the models prevail. We see a wide replication of a similar urban model of sustainable neighborhood not only in Gothenburg and Stockholm, but in cities in Germany, Holland, France, and Great Britain. It is a model of a dense and diverse neighborhood along an intermodal boulevard as main axis. The question is, do we have to think in models and replicate them when sustainability escapes blueprints?

Urbanity and Multimodality Advocacy

Every age imprinted itself on the cities. The public transports dominated the 19th century and the beginning of the 20th and the private car dominated the 20th century. Each age reflected on the planning paradigms, urban models, or regulations. Mixing urbanity or multimodality of public and private transports prevails in the sustainable cities debate today.

The urbanity is widely highlighted and pursued today both by the compact city and TOD models. The urban advocacy works in Sweden where we can see recuperation and population growth in the larger cities like Stockholm and Gothenburg. However, it evades the smaller cities which have stagnating urban population but experience population growth in their regions. Without urban growth it is difficult to integrate the public transport systems into the cities. There is a need for a louder advocacy for urban living and public transports especially in the smaller cities, which are as sprawling as the larger ones, but almost completely dependent on the private car.

The multimodality is also loudly advocated, especially among planners and the light public transports seem to dominate that stage. The light infrastructures of BRT and LRT are disadvantaged compared to the fully separated systems. They are too slow (20 to 25 km/h or 13 to 15 mph) to compete with the private car on regional scale. To enable competitive light public transports like BRT and LRT in the regions there must be incredibly strong policies restricting car access and urban containment. There is an ongoing project about the Tunnelbana in Stockholm at KTH, the Royal Institute of Technology, and the preliminary results from the traffic models and simulations show that if the tramways or light railway remained instead of the Tunnelbana, the number of daily passengers would decrease between 50% (within inner city), 70% (to the inner city), and 75% (through the city from north to south). The results are from the lectures and seminars held by Börjesson and Jonsson.

The motorization rate is not as strong a factor as the competitiveness of public transport systems. In Stockholm's region, there 398 cars per 1,000 people and it is slightly lower than in Västra Gothland's region with 457, but the public transport share is more than double. There are in average 357 annual journeys in Stockholm's region compared to 144 in Västra Gothland.

Placemaking and Networking Places

There are two important scales, of walking distances that define place and neighborhood and of motorized mobility that enables our city life. If the hierarchical combination of public transports that establish a metropolis is one solution for competitive public mobility, placemaking is one solution for livable cityscapes.

Placemaking is about communities and processes, not about completed models. It is about the human scale, citizen perspective or view inside of cities in urbanism. Gehl's "in between buildings" describes lucidly the prospect within. It started as a loud critique of modernism, the architect's perspective from the top and its city grandiose in the end of the 1950s. Whyte and Jacobs wrote *The Exploding Metropolis or the Death and Life of Great American Cities* and the view inside was entangled in Cullen's *Concise Townscape* and Lynch's *Wayfinding and Imageability*. The argument was that "the city is for humans, not for a race of giants playing a new kind of chess" (*20*) and places, districts, or neighborhoods must be developed within neighborhoods and to human scale. The development of Pearl District in Portland, one of the most famous and successful American TODs, is an example of placemaking through action plans, proactive planning, and community involvement instead of finished or defined models (Figure 13). By living, planning, and designing together the community enjoys its urbanity and diversity today. In this ongoing urban process the neighborhood and public transport entangled together and the Portland Streetcar became a driver for urban development. Namely, in 10 years there was $3.5 billion invested along the line.

Without placemaking and gradual integration of the public transport in the city, urbanity evades TOD and the tramways and light railways do not guarantee vibrancy and livability. In South Waterfront, a new development in Portland, we see exciting, but finished new architecture, great integration of urban design and public transport, but without real feeling of a place that exists in the Pearl District. Second and very important, Portland Streetcars are urban public transport system and cannot compete regionally with the cars. That is why the share of public transport in the Pearl District is low. The Portland Streetcars are only a downtown alternative and the people have regional existence. It is not only important to make places, but also to network these places in the region with competitive public transports.

FIGURE 13 The vibrant urban life and a tram stop in the Pearl District and newly developed South Waterfront and the Portland Streetcars terminus.

CONCLUSIONS

We show in this paper that there is a long history and tradition of integration of public transport in urban and regional planning and some old models and operators worked fine. The two operators are basically placemaking and networking places, or pursuing livable and sustainable places in continuous process of change and adaptation while superimposing metropolitan systems that interconnect these places into regional hierarchy. Citizens today have regional existence that sometimes extends over 80 km (50 mi) and the public transports must reach and serve these urban edges. Stockholm is an example of where the public transports make this regional hierarchy with variety of technologies and modes. It is not always necessary to have one choice, one model, and one system that can be replicated. In practice, partially separated public transport systems like light railways or busways thrive on the wide infrastructural coverage and are advocated universal solutions. But how efficient are these systems if they are be compared with innovative combinations of old or new public transport systems that excel in urbanity and mobility, on urban or regional perspective?

The synchronization of these universal public transports and cities is possible and implies two approaches that are not exclusive. The first is basically the compact city that revolves around policies of containment and preservation of the urban fringes as green wedges or agricultural land. In the smaller cities the LRT and BRT systems can act as mobility systems if the regional accessibility is somehow restricted. It is a very challenging endeavor, since many European and American cities developed extensive road hierarchies along the e-motorways or the Interstate Highway System, which enables excellent car access almost anywhere in their regions. The second solution is to enact a public mobility hierarchy even in the smaller cities, a metropolitan system with wide regional accessibility brought by attractive and speedy public transport infrastructures like heavy railways or busways and urban mobility by slower, not less attractive, bus lines, tramways, light railways, or busways. Again, it is a challenge to superpose an expensive public network over the extensive road hierarchies.

In the end, for gradual and continuous placemaking, there is a need to consider the disadvantages and desirability of the different public transport infrastructure on the urban scale. The effect of the different public transports and infrastructures on cities is often forgotten. Various public transport infrastructures have different attractiveness and permeability around stations and along lines. There are desirability cores that are important urban catalysts, inducers and drivers for urban development.

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Light Rail as the Catalyst for Ottawa's Transit-Oriented Development

Planning for Sustainable Growth

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INTRODUCTION

The City of Ottawa, Ontario, Canada, is the nation's capital city as well as its fourth largest city with a population of nearly 1 million. It is a carefully planned municipality with a strong federal government presence and influence leading to a high quality of life. Ottawa has a broad socioeconomic and age profile, and a continuous demand for high quality municipal services, including public transit. In response to this situation, transportation and mobility was identified as a strategic priority within Ottawa's 2011–2014 Term of Council priorities and the ensuing City Strategic Plan. This priority formalizes the expectation to provide reliable and sustainable public transit service while also providing an appropriate land use mix in and around transit stations (*1*). This paper should be considered as a road map of plans, policies, and steps taken to support Ottawa's commitment to becoming a leader in Canada's transit-oriented development (TOD) efforts. It demonstrates Ottawa Light Rail Transit's (OLRT) role in providing for the city's growing transit needs through efforts to support and implement modal shift and advancing TOD principles. An overview of the ongoing amendments to planning-related documents in support of the OLRT project will be given. Finally, a high level review of current and proposed land use planning initiatives will be discussed to illustrate how existing and future TODs are influenced by transit choices.

PROJECT BACKGROUND

The decision to introduce light rail in Ottawa was the product of extensive research, strategic planning, and consultation with industry experts. In 2009, the city hosted a technology forum which brought together representatives of manufacturers and transit agencies to discuss the merits and drawbacks of various modes based upon the goals that include the ability to accommodate the planning horizon within the Transportation Master Plan (TMP) planning horizon; its fit within Ottawa's urban environment; the minimization of capital and lifetime operating and maintenance costs; and the need to be a service proven so as to minimize implementation risk while maximizing operational efficiencies (*2*). In this vein, the city's population is expected to grow from 923,000 in 2011 to 1,135,800 by 2031 (*3*).

Phase One of the OLRT project will span 12.5 km and 13 LRT stations. Moreover, 2.6 km of this alignment and three stations will be part of an underground system through downtown which was built to alleviate transit operational issues due to congestion. The majority of the LRT system will involve the conversion of bus rapid transit (BRT), a first in North America. Construction begins in early 2013 with revenue service expected in early 2018. Core project objectives include fostering TOD, maximizing mobility, and delivering the project on time and within budget. Secondary objectives are aimed at changing commuter behavior, increasing the quality of integration of OLRT with all modes of travel, and reducing automobile dependency and overall vehicle miles traveled. As construction approaches, the project must deliver on expectations that light rail is the solution to efficient and effective public transit, while also laying the groundwork for complementary TODs along the system and stations. Statistically, Ottawans already embrace available public transit offerings—taking transit 100 times annually on average—more than residents in any city of comparable size in North America (*4*).

This $2.1 billion public–private partnership (P3) project is a first step in realizing the vision articulated in Ottawa's TMP, which calls for more than 40 km of new electrified light rail to be built over the next 20 years. P3s are becoming a common method of procuring large, complex infrastructure projects in Canada and across the globe. By bringing the private sector into the design, maintenance, and operation of an asset, the government sponsor is able to leverage the private sector's expertise and innovation to increase the efficiency of their procurement process and reduce costs.

In Ontario, these types of procurements are overseen by Infrastructure Ontario (IO) with the goal of engaging private sector expertise in a manner that will help eliminate cost and schedule overruns, better coordinate and increase accountability through the design, construction, and long-term maintenance phases of public projects, and make long-term infrastructure investments that will support the provincial economy. Three recent examples of P3 projects are the following:

- The Montfort Hospital (Ottawa), a $173 million build–finance project in partnership with the EllisonDon Corporation that the province estimates resulted in $19.4 million in savings (8.1%).
- The Ottawa Hospital Regional Cancer Program, a $113 million build–finance project in partnership with PCL Constructors Ltd. to upgrade the cancer care facilities at the Queensway–Carleton and Ottawa hospitals. The province estimates $7.9 million in savings (11.79%) at the Ottawa Hospital and $10.7 million (11.73%) at the Queensway–Carleton.
- Durham Consolidated Courthouse (Oshawa), a $334 million design–build–finance–maintain project in partnership with the Access Justice Durham consortium. The province estimates savings of approximately $49 million (12.79%) (*5*).

These examples show that P3s are a proven means of maximizing efficiencies and cost savings. From the perspective of the OLRT project, it is anticipated that these savings will be replicated while also vastly improving service and connectivity throughout the system. The successful planning and management of the LRT project means that residents and transit users can look forward to a host of anticipated economic and environmental benefits, as identified in the city's strategic plan, including $100 million in annual transit operational savings and sizable reductions in fuel consumption, greenhouse gas emissions, air contaminants, and the usage of road salt among others.

This paper is premised on a series of broad assumptions as follows:

- The OLRT project will be a long-term stimulator of TODs.
- Ottawa's aging population will be attracted to public transit and be a growing segment of the city's transit ridership.
- Increased density: the zoning bylaw has been, and will continue to be, modified to reflect TOD potential. This will enable and the confirmation of higher densities and mixed uses on based on a station-by-station analysis.
- Connectivity: the implementation of the Cycling Master Plan and related Walkability Plan, together with OLRT, will be embraced by residents and lead to a measurable change in modal split. And
- The creation and implementation of 13 TOD plans will be supported by their respective communities and therefore yield desirable outcomes.

WHAT IS TRANSIT-ORIENTED DEVELOPMENT AND WHY IS IT RELEVANT TO OTTAWA?

TOD is as much an approach to thinking as it is an outcome of planning, transportation, and land use policy. Properly conceived development is achieved through addressing the six Ds of transit-oriented communities: destinations, distance, design, density, diversity, and demand management (*6*). TOD is formally defined as "a walkable, mixed-use form of development typically focused within a [600–800 metre] radius of a Transit Station—a Light Rail Transit (LRT) station or Bus Rapid Transit (BRT)." Higher density development is concentrated near the station to make transit convenient for more people and encourage ridership. This form of development utilizes existing infrastructure, optimizes use of the transit network, and creates mobility options for transit riders and the local community. Successful TOD provides a mix of land uses and densities that create a convenient, interesting, and vibrant community for local residents and visitors alike (*7*).

This means that growth will be directed towards key locations with a mix of housing, shopping, recreation, and employment in locations that are easily accessible by transit and that encourage walking or cycling as a result of destinations being conveniently grouped together. Additionally, future development, whether in new communities or in established areas suited to accommodate growth, will be compact and efficient from a servicing point of view.

TODs have the potential to generate economic and environmental benefits for a city or community. Ottawa is taking advantage of two broad trends that will support successful implementation of TOD in the city: the role and influence of P3s and the aging population. With regard to the former, as mentioned above, the city must work to gain buy-in from private sector businesses, developers, and other partners who together must work to generate development that is in the public interest as well as measurable changes in individual travel choices.

While many successful examples exist, Washington, D.C.'s Navy Yard West Metrorail Station is particularly applicable to Ottawa's interest and context because of its preservation of heritage elements and the fact that the development was initiated by the introduction of major infrastructure that would draw people to the area. The construction of a new baseball stadium along the Anacostia waterfront helped lead to the consequent development of over 260,000 ft^2 of office space and associated additional parking spaces. Benefits experienced as a result of the development were many, including increased station capacity from 5,000 people per hour to 15,000 people per hour and the added office space that will become the new headquarters of the

U.S. Department of Transportation and the other organizations that moving to the Waterfront District (*8*).

The second trend mentioned above is a sociodemographic phenomenon as the aging population in the city calls for a shift in the planning and delivery of housing, infrastructure, and services. The following snapshot of social and demographic statistics pertaining to Ottawa's older adult population illustrates this trend:

- In 2006, 100,875 seniors were living in Ottawa, representing 12% of all residents. Seniors represent the fastest growing age segment.
- The population of seniors will more than double between 2011 and 2031 to a projected 253,950 individuals. In 2031, more than one in five residents will be over 65.
- Between 2011 and 2031, the 74 to 84 age segment will experience the largest overall growth rate (*9*).

The chart and table below (Table 1 and Figure 1) show that Ottawa's population, by 2031, will be extremely diverse and have a higher percentage of those 85+ than ever before (*10*).

TABLE 1 Population Projections, Subgroups of Senior Population, Ottowa, 2011–2031

	2031	Growth 2011-31	Growth %
Population 65+	254,000	135,900	115%
Immigrant	77,400	40,000	106%
Francophone	47,600	26,000	109%
Aboriginal	3,300	2,700	415%
On low income	15,700	8,300	113%
With disabilities	44,500	24,000	116%
Living in rural area	30,900	20,000	183%

Source: Hemson Consulting, 2010

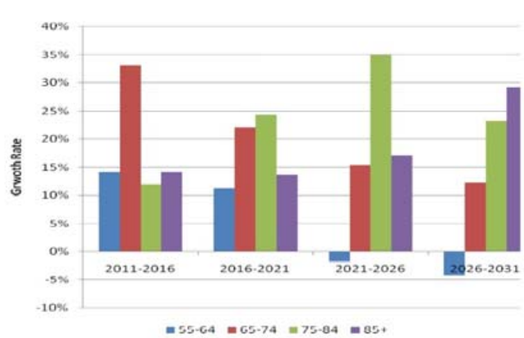


FIGURE 1 Projected growth in population age 55 and over, Ottawa, 2011–2031.

Considerations of these statistics are important factors in TOD planning as they have implications for service planning, maintenance, and delivery. As many choose to "age in place," the potential for a high percentage of seniors in the oldest age bracket to be independently carrying out their daily activities is increasing. The housing industry is already adapting to this trend. Declines in average family household size paired with an aging population and multigenerational families means that demand for housing is expected to grow faster than the population itself, although this anticipated future demand will be concentrated in smaller units in the form of condominiums and apartments. For instance, in 2010 singles represented 34% of the housing start market compared to a 30% share in the apartment–condominium category. Similarly, in 2000 single-family homes represented 63% of the city's housing starts while apartments–condos accounted for a mere 4% (*11*). These statistics show a clear shift in both household size and associated buyer preference. The pressure on public transit providers to adapt service and plan for the future is just as great, thus the value of TOD communities: allowing residents to safely and independently navigate their surroundings with relative ease. Ottawa is at the cusp of this shift in development policy and regulations and there is recognition that only through strategic and supportive planning can transit-oriented communities gradually be created. The OLRT project office together with other city departments are planning proactively to respond to the challenges and opportunities that this new reality creates.

A FOUNDATION FOR SUCCESSFUL TODs

Strategic and Supportive Planning for Transit-Oriented Communities in Ottawa

- OLRT is guided and informed by a series of strategies, plans, studies, and initiatives that are intended to lay the foundation for successful TODs, a shift initiated by the introduction of OLRT.
- The individual and cumulative importance of this planning and development work is underscored within the city's Origin Destination Survey Data and the TMP, respectively.
- During the morning peak nearly 62% of residents traveled by automobile compared to about 21% by transit, 9% by walking, 2% by cycling, and 6% by other modes.
- By 2031, the population is projected to grow by 30%. Over the same period, the city's goal is to increase the proportion of people who use public transit from 23% to 30%. Coupled together, these factors are expected to increase overall transit ridership by 78%, from 93 million trips a year to 164 million trips a year in 2031 (*12*).
- In response to the identified need for improved public transit in the short and the long term, the city is initiating a series of complementary, coordinated planning and development studies spanning the next 5 years:
    a. Official plan update;
    b. Zoning bylaw review;
    c. TMP update;
    d. City of Ottawa's TOD guidelines;
    e. Environmental project report;
    f. Community design plans (CDPs);
    g. OLRT pedestrian and cycling study; and
    h. TOD plans.

Each piece will be summarized below with a particular focus on the significance of each projects individual importance as well the collective impact of the projects when packaged together.

Official Plan Update

Ontario's Planning Act provides that a municipality must review its official plan every 5 years. An update of the Official Plan (OP) is required to set the stage for other land use regulatory reviews. One of the review areas pertains to advancing TOD at light rail stations. This review will result in changes to official plan policies and changes to departmental planning processes in support of TOD. While the current OP gives guidance for the planning of TOD areas (for example, by setting targets for intensification, establishing design priority areas, increasing cycling and walking mode shares, and reducing vehicle parking rates) the policies need to be more proactive and prescriptive to enable liveable communities, along with a higher density and mix of uses than is currently identified (*13*).

Zoning Bylaw Review

The zoning bylaw provisions are being reviewed and amended as necessary to implement the city's TOD policies and reflect the emphasis on intensification in the OP. Changes will be proposed for Council approval if current zoning is not supporting TOD in specific locations or if specific policies are not being implemented as intended or as effectively as they could be. For example, amendments will be made to permit the range of uses contemplated in the OP and to permit the uses along the transit corridor associated with the construction of the OLRT system. The 2014 OP will contain new TOD policies and zoning will be amended to support any new policy directions taken by City Council.

Transportation Master Plan Update

The Ottawa TMP identifies the transportation facilities, services, and policies that will be implemented to serve a projected population of 1.14 million people by 2031. It sets the direction for day-to-day transportation programs and provides a basis for budget planning that is consistent with the growth management policies of the OP. The TMP provides guidance in the preparation of TOD plans by setting out "active transportation" polices that support walking and cycling as desirable modes of travel, not only on the road network but also on multiuse pathways. The TMP is being updated in parallel with the OP for approval in 2014 to ensure both are strategically aligned.

City of Ottawa Transit-Oriented Development Guidelines

These TOD Guidelines identify five distinct characteristics of transit-oriented communities:

- Medium- to high-density development located in a compact form within a 10-min walking circle surrounding a transit stop or station;
- Inclusion of a broad mix of uses supporting people wanting to live, work, and play within a single community;

- Allow people to make the majority of their daily or weekly trips without using a car;
- Walkable and pedestrian-oriented design; and
- Reduction in demand for parking inside the 10-min walking circle around the station.

These guidelines form a strategic approach for an integrated approach with corporate agendas that blend transit planning and service considerations with urban planning, a particularly important partnership as the city expands its rapid transit network with the goal of increasing transit ridership when opportunities for TODs are presented. The guidelines were developed to provide direction to the design and review processes for plans of subdivision, site plan control, rezoning, and OP amendments; to assist in the preparation of TOD studies, new community design plans, or secondary plans for undeveloped or redeveloping communities; and to complement design considerations in approved community design plans or existing secondary plans (*14*).

One example of the successful implementation of TOD Guidelines relates to the Escarpment Area District Plan. The plan's recommendations are as follows:

- Land use: additional street-level retail and commercial uses are encouraged to offer a diverse mix of activities, opportunities, and local services.
- Open spaces: the blend of large formal open spaces, smaller community parks, and similar opportunities for green space, pedestrian connectivity, and the natural heritage of the escarpment itself will undoubtedly to appeal to local and regional visitors and interests.
- Mobility and circulation: supporting a pleasant pedestrian and cycling environment. A more equitable balance of modal transport will be achieved through the establishment of a strong hierarchy of routes and the addition of new pedestrian connections.
- Built form: emphasis is placed on preserving views and sunlight, reducing shadow impacts, maintaining privacy, and eliminating blank walls and inactive frontages while also showcasing mixed pedestrian usages to revitalize the streetscape.

Environmental Project Report

The Environmental Project Report itself is a formal representation of the credence given to sustainability in its most holistic sense. The report (2010) details the process used to define, develop, and evaluate the OLRT project. It outlines the environmental impacts the project presents and assesses mitigation options. This report identifies the core project benefits, each representing a strong linkage to at least one pillar of sustainability. They are as follows:

- Improving mobility, reducing travel times, and increasing safety, reliability, and efficiency;
- Expanding public access and ridership;
- Reducing greenhouse gasses and other emissions; and
- Contributing to sustainable municipal development and land use planning (*15*).

Community Design Plans

The city is committed to working with communities to ensure that significant change is integrated into the existing fabric of neighborhoods and supported, to the greatest extent possible, by area stakeholders. To date a series of CDPs have been completed across the city, with others planned for the future. An example is the Escarpment Area District Plan (EADP). The area is situated in close proximity to the OLRT's future LeBreton Station, which is situated on traditional Algonquin First Nation territory and is themed to reflect this:

> The Escarpment Area District Plan…establishes a new benchmark for high-rise built form in the city that is more pedestrian-friendly and results in a visually appealing development in contrast to the traditional slab-style building that has characterized the downtown since the 1970s. A more slender "point tower" form will help preserve views and access to sunlight, substantially reduce shadow impacts, maintain privacy and eliminate blank walls and inanimate facades. As well, a new central park will provide needed public green space to serve the residents of this western downtown area….Three public agencies own most of the lands within the area—the City of Ottawa, the National Capital Commission and the Ottawa-Carleton District School Board (*16*).

The EADP is a good example of TODs being integrated into the planning fabric of the city, as it is served by a key downtown station, while also displaying the complexity of balancing the needs and interests of multiple stakeholders with issues of heritage designation and other such land issues. Data demonstrates continued development within this district. Within an 800-m radius of LeBreton Station a total of 109 development applications have been processed between January 1, 1999, and August 21, 2012 (this figure excludes smaller developments like additions to a home). This development trend is expected to continue, giving strong market conditions for condominiums, supporting office space, and retail.

OLRT Pedestrian and Cycling Study Conducted by Capital Transit Partners

The Pedestrian and Cycling Study (2011) identifies opportunities to enhance the pedestrian and cycling conditions and community linkages to OLRT stations based on existing networks and passenger movements. For the overall transportation system to function efficiently and to encourage users, the pedestrian and cycling systems must link seamlessly with the LRT network. Pedestrian and cycling permeability will encourage people to utilize the transit system and reduce overall dependency on passenger vehicles.

Transportation-Oriented Design Studies and IBM Smart Cities Grant

The city is undertaking TOD studies, a specialized form of CDP for all of the stations located outside the central area, by 2014 in advance of the targeted 2018 start of LRT revenue service. The city is planning for well-designed, compact neighborhoods that promote public transit by employing effective urban design techniques in the planning and design of the communities surrounding the stations (*17*).

At present, three TOD Studies are underway at the Ottawa Train Station, St. Laurent Shopping Centre Station, and Cyrville Road Station. Ottawa is one of only two Canadian cities selected for the IBM Smarter Cities Challenge this year, a US$50 million grant program. IBM's in-kind consulting services will assist in outlining the future development along the OLRTcorridor, in particular those areas surrounding the Ottawa Train, St. Laurent Shopping Centre, and Cyrville Road stations. However, the results of this project will be universal in nature such that the recommended strategies could be applied to other stations along the OLRT corridor.

The city has recently undertaken land use planning studies for the neighborhoods around each of the three stations that will act as a framework to guide growth over the next 20 years. Plans, however, are only as successful as their implementation. The challenge facing the city is to determine how best to stimulate development around these light rail stations in accordance with the study findings. There is a need to determine how to build market interest such that new residents desire to live, work, and play in these new destination neighborhoods. IBM will develop a marketing plan that is intended to attract residents, business, industry, tourism, and education to the area surrounding the three transit stations. This marketing plan will include strategies and actions to attract development along with the associated costs that will form the basis for an implementation plan for the next 20 years. To showcase the city as a well-planned and liveable city and to ensure greater success, IBM's plan can be transferable to development areas surrounding all other light rail stations as well as to other municipalities.

Five central area stations for the OLRT project have an average density of 330 jobs and people per gross hectare within 800 m of the stations. Conversely, the eight stations located outside the central area have a significantly lower average density of 60 jobs and people per gross hectare within the same radius. The stations located east of the central area are located in generally auto-oriented communities that have been developed since the 1950s. The stations west of the central area include many large undeveloped or underdeveloped parcels of land.

TOD studies geared to stations outside of the core propose that the zoning be amended to support densities in the range of 200 to 400 residents and employees per gross hectare. The net densities (site specific) will range from 250 to 400 people and jobs per hectare depending on the proximity to the LRT station and property size (*18*). One of the city's biggest challenges is how to promote development around these three stations. It is difficult to tell when development will occur or even whether it will occur. However, the existing zoning generally permits transit-supportive densities; the existing development has an existing density of between 50 and 60 people per gross hectare. The proposed densities will increase the number of people inhabiting and working in these areas by a minimum of approximately 300% to 400% which will provide the market with some of the incentives it needs to develop along the LRT corridor.

Table 2 compares OLRT and Metro Vancouver Rapid Transit average and medium densities, within an 800-m radius of stations. This data substantiates the viability of the OLRT in Ottawa. As indicated, Ottawa's average existing density across all future LRT stations is 164 jobs and people per hectare; a measure that is comparable to Metro Vancouver's established Expo and Millennium Lines at 196 and 63, respectively, as well as the future Evergreen Line which will enter revenue service in 2016 and presently reports a density of 65 jobs and people per hectare. Looking forward, in light of Ottawa's planned transit-oriented communities, this positions the city well to successfully support Phase 1 of the light rail project.

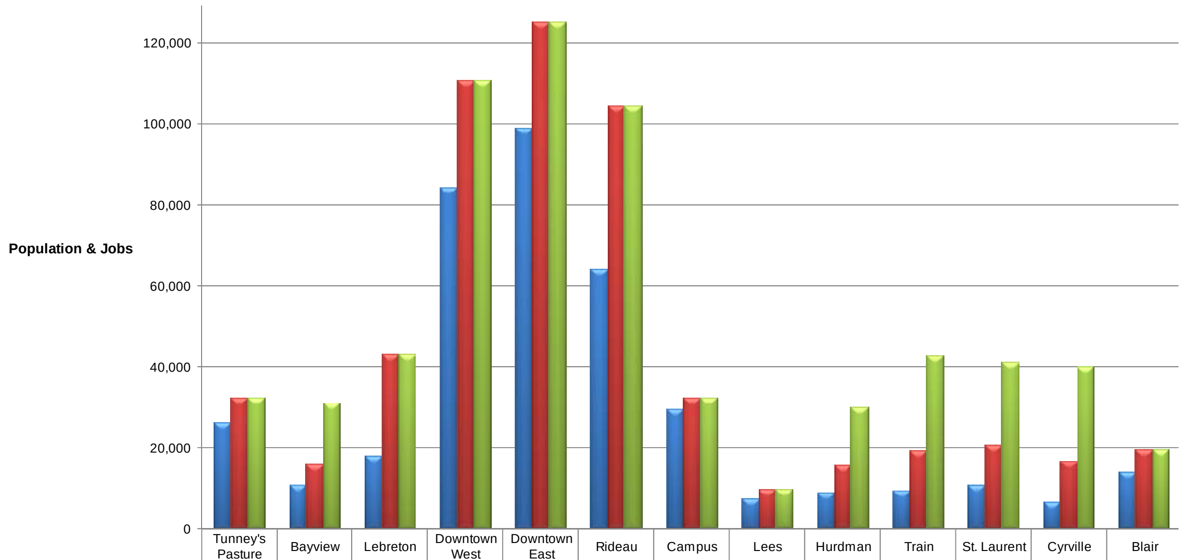
TABLE 2 City of Ottawa and Metro Vancouver Density Comparison, 800 m from Stations

Density Category[a]	OLRT Stations[b]	Evergreen Line Stations[c]	Expo Line Stations	Millennium Line Stations	Canada Line Stations
Population/ha (average)	37	45	71	37	52
Population/ha (median)	38	21	65	33	36
Employees/ha (average)	127	20	125	26	124
Employees/ha (median)	46	14	35	21	47
Total population + employees/ha (average)	**164**	**65**	**196**	**63**	**177**
Total population + employees/ha (median)	**69**	**55**	**100**	**54**	**83**
Total population + employees/ha (min)	33 (Cyrville)	27 (Port Moody Central)	14 (Scott Road)	20 (Braid)	4 (Templeton)
Total population + employees/ha (max)	575 (downtown east)	132 (Lougheed)	721 (Burrard)	132 (Lougheed)	712 (Waterfront)

[a] Each of the station buffers (radius 800 m from given station) is drawn independently and consequently there is overlap with the neighboring station buffer(s). The 800-m radius in gross hectares (excluding water features).
[b] Not in service until 2018.
[c] Not in service until 2016.
SOURCE: City of Ottawa, Planning and Infrastructure, Rail Implementation Office, and Rail Planning Branch. Data compiled by TransLink.

From a business development point of view, the graph in Figure 2 depicts existing 2011 data pertaining to projected gross future population and employment growth, highlighting potential for TODs around select stations along the alignment.

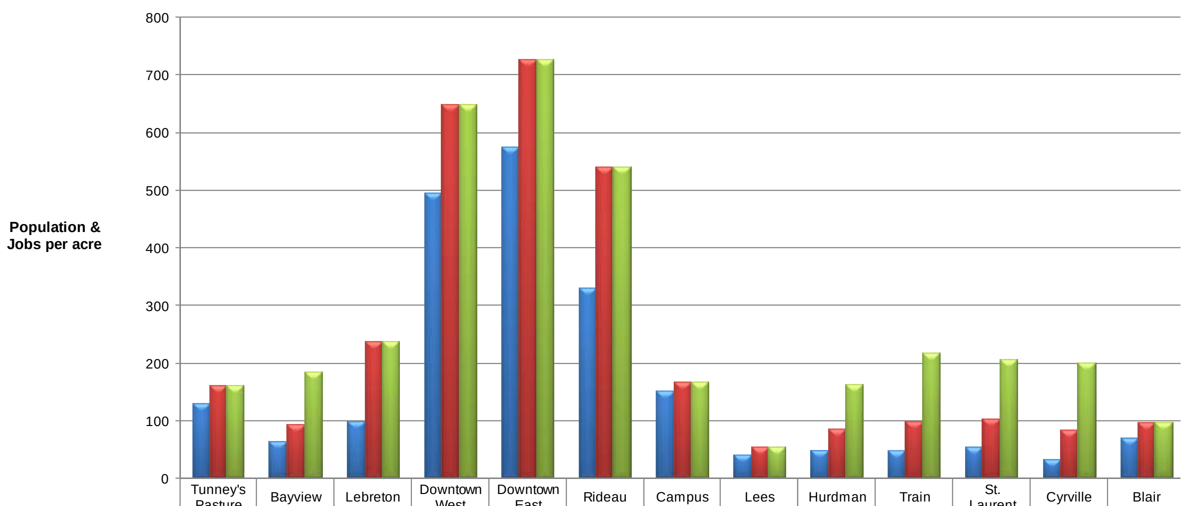
By contrast, the graph in Figure 3 displays existing and projected population and employment densities showcasing future TODs around select stations. This also depicts projected growth at full development potential. These figures provide a visual reference indicating that projected densities can successfully support TOD implementation, though ongoing consultation will be required from a business perspective to ensure sufficient buy-in from this group to help support and stimulate successful implementation and return on investment.



	Tunney's Pasture	Bayview	Lebreton	Downtown West	Downtown East	Rideau	Campus	Lees	Hurdman	Train	St. Laurent	Cyrville	Blair
2011 Pop'n + Jobs	26,229	10,570	17,806	84,338	99,142	64,011	29,471	7,268	8,792	9,226	10,625	6,527	13,861
2031 Pop'n + Jobs	32,400	15,700	42,900	110,800	125,200	104,400	32,300	9,600	15,500	19,200	20,600	16,500	19,500
Future Build-out (Pop'n + Jobs)	32,400	31,000	42,900	110,800	125,200	104,400	32,300	9,600	29,800	42,600	41,100	40,100	19,500

Source: 2012 City of Ottawa, Planning and Infrastructure, Rail Implementation Office, Rail Planning Branch

FIGURE 2 Existing and projected densities within a 800-m catchment of stations.



	Tunney's Pasture	Bayview	Lebreton	Downtown West	Downtown East	Rideau	Campus	Lees	Hurdman	Train	St. Laurent	Cyrville	Blair
2011 Pop'n + Jobs/ha	130	63	99	494	575	330	152	41	48	47	53	33	69
2031 Pop'n + Jobs/ha	161	93	238	649	727	539	166	54	85	98	103	82	97
Future Build-out (Pop'n + Jobs/ha)	161	185	238	649	727	539	166	54	164	217	205	200	97

*The 800 metre radius in gross hectares includes roads and green spaces
Source: 2012 City of Ottawa, Planning and Infrastructure, Rail Implementation Office, Rail Planning Branch

FIGURE 3 Existing and projected population and employment densities showcasing future TODs around select stations.

LINKAGES BETWEEN CITY OF OTTAWA TOD PLANNING, BUSINESS DEVELOPMENT STRATEGIZING, AND SURROUNDING FEDERAL LAND

530 Tremblay Road

In an effort to maximize the economic benefits that have been experienced by other North American cities, the City of Ottawa's Business Development Strategy (BDS) team has been approaching landlords, developers, retailers, and landowners since September of 2010 to explore and promote the economic opportunities associated with TODs as a means of further supporting the city's intensification objectives. Key objectives of this strategy are to:

- Heighten awareness of the OLRT project;
- Facilitate connections between the target audience and the city so as to initiate development agreements;
- Encourage the participation of the target audience in mutually beneficial projects;
- Further enhance the existing transit system; and
- Explore creative means through which to optimize Ottawa's future LRT system.

A currently developing TOD involving a federal government department and a large shopping center in Ottawa East illustrate the challenges and opportunities that this type of development presents:

> The proposed activities for Phase 1 of the project are: The construction of two to three office buildings totaling between 90,000 m² to 105,000 m² together with a parking facility in the form of an underground and above ground parking structure. The construction of a pedestrian bridge…crossing over Highway 417 connecting to the St. Laurent transit station. (*19*)

Moreover, the site has optimal TOD potential and timelines that work well with the OLRT project. One appraisal estimates that "there is room for about 200,000 m² of office space accommodating 11,000 employees, plus roughly 900 residential units" (*20*).

Land in the vicinity of the OLRT St. Laurent Station (Figure 4) is classified according to a range of uses including: commercial, office, residential, and industrial among others as displayed in the pie chart shown in Figure 5.

The short-, medium-, and long-term potential for community building and economic benefits, among others, appear to be overwhelmingly positive. From a business perspective LRT makes an attractive amenity to prospective tenants while also greatly increasing the volume and frequency of ridership and visitor traffic to the mall. Similarly business and landowners in the vicinity are provided an opportunity to have early involvement and input into the design process, with the potential for future linkages to be developed south of Highway 417.

Core elements of Ottawa's TOD plans pertaining for St. Laurent station include the following:

1. A new pedestrian overpass will be developed by Public Works and Government Services Canada as part of the first phase of redevelopment of the 530 Tremblay Road site. This pedestrian overpass is a critical component towards achieving modal splits in favour of transit for the 530 Tremblay Road site. The overpass should connect into a new building on the 530

FIGURE 4 Land in the vicinity of the OLRT St. Laurent Station.

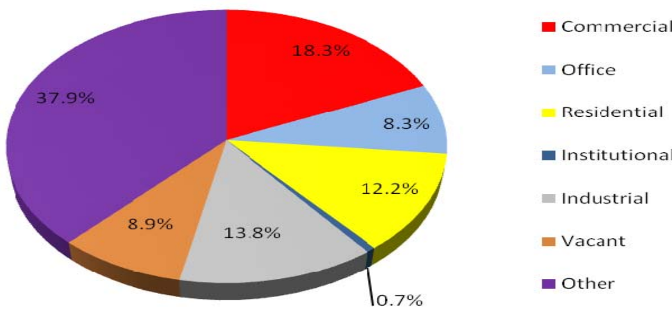


FIGURE 5 St. Laurent station land uses within a 800-m radius.

Tremblay Road site and may connect into a new building on the St. Laurent Shopping Centre site in the future.

2. The Coventry Road sidewalk, from Belfast Road to St. Laurent Boulevard, will be widened and realigned to support the relocation of municipal services and utilities as well as expansion of the St. Laurent Shopping Centre site. Sidewalks should be developed along both sides of Coventry Road upon its reconstruction.

3. The portion of sidewalk located on the 530 Tremblay Road site will be widened and realigned to create more frontages along the street and reorganize the development parcels within the large site. Sidewalks must be located along both sides of Tremblay Road upon its reconstruction. Tremblay Road in this area is a priority street with an active frontage area.

A combination of similar projects across multiple sites will, over time, generate shifts in both individual travel patterns and the larger-scale economic and related benefits experienced throughout the city that are more characteristic in cities where TODs are well established and supported.

LRT IN OTTAWA

Projected Benefits and Key Markers and Markets of Success

As demonstrated in the discussion above, LRT has considerable potential to generate significant benefits across economic, environmental, social, and cultural spheres. For example, a study on LRT for the City of Hamilton, which reviewed the experience of cities around the world, found that the positive impact on property values is higher for rail systems than any other transit mode. The study shows that having an LRT station nearby can add as much as 6% to the value of residential properties in the area. The value of commercial properties near LRT stations can increase by as much as 14% (*21*). For additional details about the full scope of projected benefits associated with the implementation of the OLRT system, please visit the following website: www.ottawalightrail.ca.

Similarly, it is abundantly clear that LRT is an effective and lasting stimulator of economic growth, something that the planning of the OLRT project hopes to not only replicate, but serve as a Canadian leader in this regard. The following North American cities embody this reality:

1. In the 10 years after implementing the light rail-based Dallas Area Rapid Transit System in 1999, development in the city attributed directly to the new system totalled \$4.26 billion (*22*).
2. In Minneapolis, the Hiawatha Light Rail line had 11,931 housing units and 1,054,436 ft^2 of commercial space under construction or planned within a ½ mile of its track before the line even opened (*23*).
3. In Arlington County, Virginia, the city's metro rail system has transformed its economic base through TOD. The project has spurred approximately 40 million ft^2 of development so far, and the area around each station has an urban feel. From 2002 to 2006, land values in the Rosslyn–Ballston Corridor grew 84%, from \$2.18 billion to \$4 billion (*24*).

While the above-mentioned benefits generate excitement surrounding potential benefits to be realized through Ottawa's future LRT system, Ottawa's road to success is just beginning.

CONCLUSION

With revenue service opening in 2018, the window of opportunity is now upon the city to continue its work to help others understand and capitalize upon the opportunity before them. Collective action and benefit is a core means of sustaining success. The result? Strong support for, and the expansion of both light rail and TODs in Canada's capital through the development and implementation of policies, regulations, and corporate strategies that encourage TOD.

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Understanding the Level of Integration of Light Rail Transit into Communities in the Denver Region

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While many studies evaluate travel behavior associated with specific elements of transit-oriented development (TOD) with varying conclusions, most assess built environment factors in isolation, preventing a comprehensive understanding of the interrelated nature of the fabric of transit-oriented communities. Our research begins to address this gap by accounting for the "level of integration" between transit and the built environment. We aim to identify key factors associated with integration as a first step towards developing composite measures that account for level of integration. As a means of testing the level of integration concept, we also assess the importance of various integration factors in explaining the travel behavior of station area residents. We evaluate areas served by light rail transit (LRT) in the Denver, Colorado, metropolitan area. In studying Denver, we provide much-needed insights into "second-generation" light rail systems in cities characterized by auto dependence. We develop four final models in order to identify those variables that best explain four travel outcomes: car ownership, vehicle miles traveled, and use of LRT and alternative modes. The explanatory variables included in the models represent those that are most important for consideration in future measures of integration. Three variables appear to hold the most promise: miles of bicycle facilities, pedestrian shed (the percent of the area within ½ mi of stations that can be walked along the network in ½ mi), and access to other amenities. Results of our analysis also clearly indicate that sociodemographic variables and self-selection effects must be accounted for in future investigations of the effects of level of integration. While the variables used in the present analysis are helpful in exploring the viability of a level of integration measure, they do not represent perfect measures. Future work will develop more-nuanced composite measures of integration and will test the effects of these measures on travel behavior using more sophisticated modeling techniques. Ultimately, we expect that station areas with characteristics representative of high levels of integration between transit and the built environment are more likely to foster positive travel outcomes.

INTRODUCTION AND BACKGROUND

While transit and what we now call transit-oriented development (TOD) has been a staple in the United States since well before automobiles existed, TODs did not start receiving significant attention from the research community until the late 20th century. At that time, the majority of reports and research papers are best categorized as general assessments or critiques of TODs (*1*–*4*), or efforts to understand the impact of the transit system on adjacent land uses (*5*, *6*). Since then, research questions have primarily related to how transit and land use influence travel behavior (*7*–*10*). This line of inquiry aims to understand the travel behavior of people living near TODs that are characterized by certain types of adjacent built environments. Research often asks whether station-area residents exhibit the behaviors that transit advocates hope to see, namely whether residents use light rail transit (LRT) with increased frequency, drive less, own fewer cars, or walk and bike more often. Because transit infrastructure and associated development often require substantial investment, this strand of research provides important insights to decision makers.

A large body of literature exists on the relationship between travel behavior and the built environment. Ewing and Cervero (*11*) provide a comprehensive overview of these studies, which have employed increasingly sophisticated methods, models, and measurements (*11*). However, despite years of such improvements, there is still considerable debate concerning findings. On one hand, abundant studies suggest that the built environment significantly impacts travel behaviors (*12–21*). On the other hand, the elasticities of the significant findings are generally small (*12*). Several studies have found no significant impact (*16*, *22*) and researchers often attribute significant results to sociodemographic differences more than those related to land use or transit (*23*). Moreover, many studies finding significant influence of land use on travel behavior do not account for issues of self-selection, thereby undercutting the validity of findings. When these studies are dismissed, the seemingly high ratio of studies finding significant influence to those that do not find significance drops even lower (*24–28*).

Despite somewhat inconsistent findings, the existing research generally suggests that TODs are supportive of the beneficial travel behaviors espoused by transit advocates. It appears that transit, in combination with certain built environment characteristics, is positively linked to less driving, increased transit use and active transportation, and fewer household automobiles. Researchers have continued to deconstruct measures of the built environment to the point where studies such as the meta-analysis study conducted by Ewing and Cervero are able to calculate pooled elasticities of individual built environment variables (*11*). For example, the weighted average elasticity of transit use with increasing intersection density is found to be 0.23 based upon four studies identified by Ewing and Cervero (none of which, in this example, account for self-selection).

While we could conduct a study that adds to this grand list of literature—by marginally improving upon a methodology, accounting for self-selection, or investigating a second-generation system such as light rail in the Denver region—we intend to step back from efforts to assess built environment factors in isolation. Our literature review makes it clear that, even after almost two decades of research, it is still difficult for travel behavior researchers to fully understand outcomes by simply placing isolated transportation, land use, and sociodemographic variables into a model and accounting for as many potentially confounding factors as possible. TODs and the people that live near them are infinitely more complex than they have generally been given credit for. In reality, many variables are highly interrelated and therefore need to be considered as such in order to begin to realize appreciable differences in terms of travel behavior and quality of life outcomes. We conceptualize the harmony between isolated variables as the level of integration between rail transit and the fabric of the community. A lack of integration may indeed be contributing to the fact that many of existing TODs in the United States are considered to be underperforming (*29*, *30*). In order to begin to fill what we think is a considerable research gap, and eventually develop a quantitative set of metrics, this research aims to better understand the level of integration between transit and the surrounding built environment. We ultimately expect to find that the more integrated a transit system is with its surrounding community, the more that benefits related to travel behavior and the broader goals of livability and sustainability will be realized.

In order to begin identifying possible means of measuring level of integration with respect to transit and community design, we considered some common definitions of TOD and found that current notions of TOD do not explicitly account for level of integration. For example, Boarnet and Crane focus on intensifying development around the stations and define TOD as "the idea that land near rail transit stations should be developed or redeveloped in ways that encourage the best use of the transit system and that leverage the public investment in rail transit" (*31*). In the book *The New Transit Town*, Dittmar et al. add a bit more in terms of land use specifics by defining TOD as "a mix of uses, at various densities, within a half-mile radius around each transit stop" (*29*) while Calthorpe takes a step further with respect to land use by suggesting that the TOD "concept is simple: moderate and high-density housing, along with complementary public uses, jobs, retail and services, are concentrated in mixed-use developments at strategic points along the regional transit systems" (*32*). While these definitions differ slightly, their main themes focus on land uses in terms of both variety and density. Other perspectives, such as the one espoused by the Center for Neighborhood Technology, stress the need for "high levels of pedestrian and bicycle accessibility," but the concept of integrating the transit system into the community fabric is rarely acknowledged (*33*).

Bernick and Cervero provide one notable outlier to standard TOD definitions. Preferring the term "transit village," they describe their concept of TODs as places where the built, social, and economic environments "embrace and evolve" around the transit system (*34*). They state "the transit village is about increasing choice—opening up more options in how to travel, where to live and work, places to go, and how to spend one's free time" (*34*). They argue that transit villages must emerge from our large-scale infrastructure investments in order for transit to become fundamental to transportation in the United States. Our research considers Bernick and Cervero's description as fundamental to our efforts in measuring the level of integration between rail transit and the built environment. While there might be some level of agreement in terms of how specific TOD elements may or may not contribute to positive travel outcomes, there is clearly a need to better understand how built environment characteristics should be integrated with the transit system and the surrounding community in order to maximize travel and quality-of-life benefits. The present research aims to quantify these concepts using a set of factors that examine the level of integration of transit stations in the Denver Metropolitan region with respect to the fabric of surrounding communities.

Although many studies have tested some of the same variables that we employ, very few studies have specifically investigated the issue of integration. In one very recent study, Calimente (*35*) identifies 10 indicators of integration—transit ridership; quality of service (frequency, hours of service, passenger load, and cost per passenger); mode share from travel between home and station; the number of mode connections; the number of auto and bicycle parking spaces provided at stations; housing and population density; property values within and beyond 500 m of the station; quality of streetscape design; pedestrian safety; and crime rates—and evaluates them using descriptive comparisons of several stations in Tokyo, Japan (*35*). While Calimente provides a reasonable conceptual basis for possible measures of integration, the research fails to identify those factors which best explain travel behavior outcomes. Furthermore, the focus on Tokyo limits generalizability to most North American cities, which tend to have vastly different patterns of land use and transit service.

Our research aims to expand the understanding of factors that contribute to integration between transit and the community and begin to examine how the consideration of level of integration might improve our understanding of travel outcomes. To do so, we evaluate areas served by light rail in the Denver metropolitan area. In studying Denver, we provide much-needed insights into second-generation LRT systems in cities characterized by auto-dependence.

Therefore, our research is widely applicable to many auto-oriented North American cities with, or contemplating the implementation of, rail transit. The Denver Metro Region is home to 2.7 million people with more than 50% growth predicted by 2035 for an expected population of 4.2 million people (*36*). Three of the eight counties in the Denver Metro are currently served by a 35-mi, four-corridor LRT system with 36 stations. The first corridor was implemented in 1994, followed by three others in 2000, 2002, and 2006. The existing system connects downtown Denver with the Five Points Business District (north of downtown), Auraria Campus (which serves as the home of three higher-education institutions), Denver Union Station in Denver's Lower Downtown district, the Pepsi Center and Sports Authority Field at Mile High sporting centers, and communities in the southwest and southeast of the Denver Metro. Twenty-five of the 36 existing stations are located in the city and county of Denver (CCD), which are selected here for analysis. In 2004, voters approved funding for 122 new miles of rail, 18 mi of bus rapid transit, and 57 new rapid transit stations as part of the FasTracks Program which is currently in the planning and construction phase. Once completed, FasTracks will constitute one of the country's largest investments in rail transit (*37*). Our research is therefore particularly timely, as planners and policy makers begin to approach the design of TODs and surrounding communities in the Denver Metro, as well as in communities across the United States that share characteristics with Denver. In developing a better understanding of the level of integration between rail transit and the community fabric, our research begins to shed light on ways in which positive travel and quality of life outcomes might be optimized in communities investing in rail transit.

RESEARCH QUESTIONS

This research aims to identify key factors associated with the integration of transit and the community fabric in order to contribute to the development of measures accounting for level of integration. In order to test the level-of-integration concept, we also assess the importance of various integration factors in explaining the travel behavior of station area residents. We define three categories of integration measures:

- Built environment characteristics,
- Transit level of service (LOS), and
- Access to amenities such as grocery stores, restaurants, schools, and other destinations.

The analysis also includes several sociodemographic variables commonly associated with travel behavior, as well as variables that account for possible self-selection effects. We hypothesize that a range of variables associated with the level of integration between LRT and the community are important in explaining travel outcomes. We also expect that sociodemographic variables will be important to travel behavior, as has been shown consistently in previous research. The variables identified through the present analysis will provide a basis from which to develop more nuanced composite measures of integration. Future research will link these composite measures to travel behavior using more sophisticated modeling techniques. Ultimately, we expect that station areas with characteristics representative of high levels of integration between transit and the built environment are more likely to foster positive travel outcomes.

DATA AND METHODS

In this analysis, we develop a series of models in order to identify those variables that best contribute to the quantification of level of integration and explain a variety of travel outcomes. Four travel outcomes related to car ownership, vehicle-miles traveled (VMT), regular use of LRT, and regular use of alternative modes of transport. The purpose of the research is not to assess the effects of specific variables on travel behavior; rather, we intend to identify the range of variables that are important in explaining a variety of travel behavior outcomes and could be important as part of a level of integration composite variable. Therefore, the outcome variables assessed here are not meant to exhaustively capture all aspects of travel behavior. They instead provide a range of possible travel outcomes from which to test the level of integration concept and identify those factors that are most important in explaining travel outcomes. As shown in Figure 1, a total of 12 independent variables related to level of integration in three categories are included in the analysis: built environment characteristics, transit LOS, and access to amenities. These integration variables, along with several other measures meant to account for sociodemographics and possible self-selection effects, were used in an iterative model-building process resulting in a final best-fit model for each of the four travel outcomes. The variables included in each of the final models are identified as the measures that are most important to future analyses evaluating the integration between rail transit and the fabric of the community. Data and methods employed in the present study are described in more detail in the following section.

Data

Independent Variables: Level of Integration Measures

We evaluate three categories of variables associated with the level of integration between LRT and the fabric of the community developed using a variety of data sources.

Built Environment Factors Six variables measuring characteristics of the built environment are included. All were developed using geographic information system data obtained from the CCD and the regional transportation district in fall 2011. The variable "pedestrian shed" represents the percent of the total area within ½ mi of a station that can be reached by walking along the network for ½ mi. Higher values for pedestrian shed are expected to increase the level of integration. The variables "park-and-ride parking spaces" and "park-and-ride bicycle spaces" represent the total number of parking spaces available at the LRT station for automobiles and bicycles, respectively. We expect that less auto parking and more bicycle parking will contribute to higher levels of integration. The variable "walkability index" is an index measuring the quality of walking facilities within 1 mi of the station. The index was created following the methodology outlined by Frank et al. (*38*). Four measures are included in the index: net residential density (number of households per acre of residential land use), retail floor-area ratio (total retail building square footage divided by retail land area square footage), intersection density (number of intersections per acre), and land use mix (a normalized value where 0 indicates single use and 1 indicates even distribution across five uses). The index is a composite score of summed *z*-scores of the four measures, with intersection density weighted twice that of the other three measures. The variable "miles of bicycle facilities" indicates that number of miles of on-street

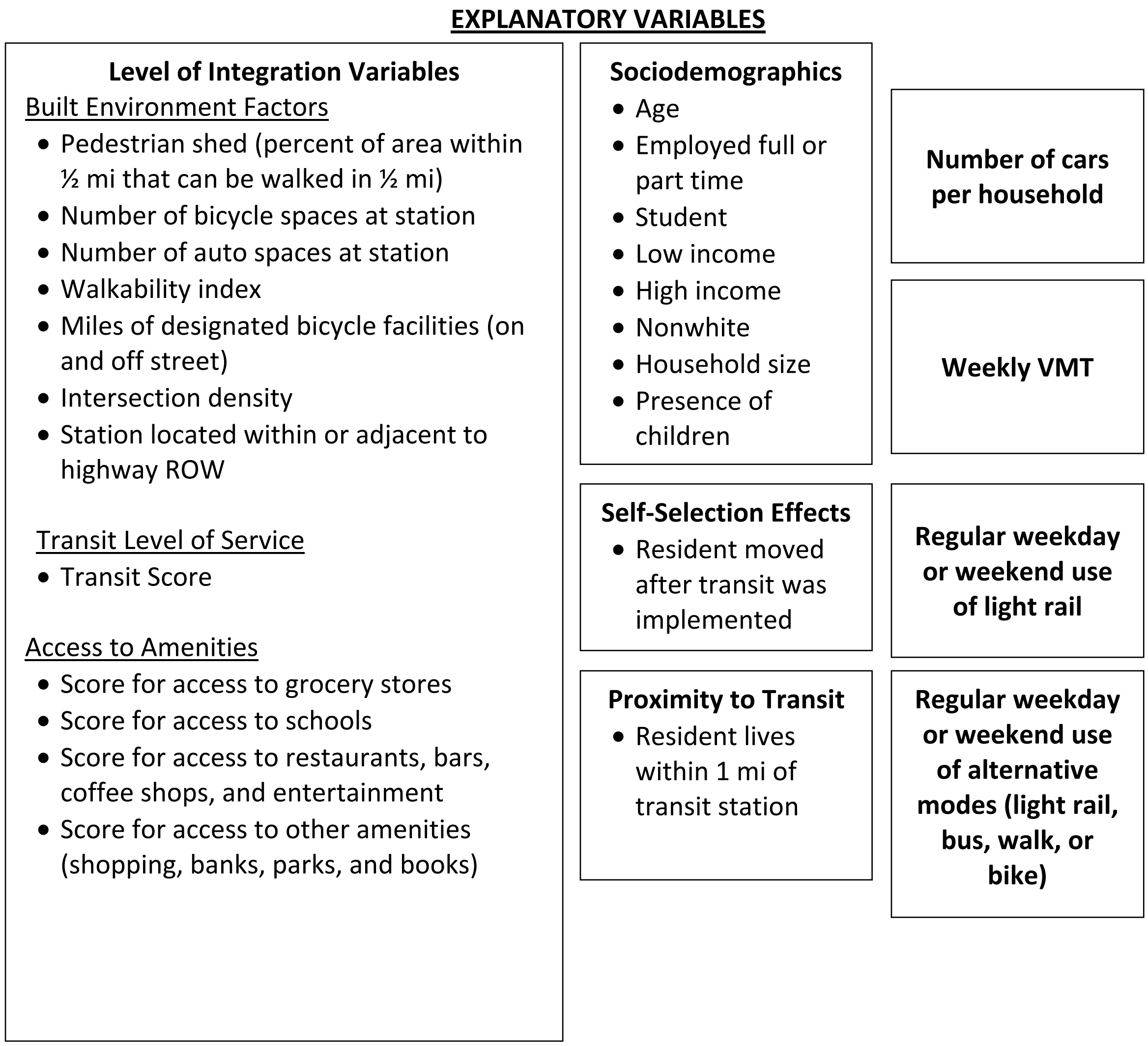

FIGURE 1 Explanatory and outcome variables.

and off-street bicycle facilities within 2 mi of stations. Higher values for walkability index and miles of bicycle facilities are expected to contribute positively to the level of integration. The variable "intersection density" represents a commonly used measure in walkability research (*39*). Intersection density is calculated as intersections per square mile in the area within 1.5 mi of the station. Higher intersection densities are expected to be associated with higher levels of integration. The final built environment variable, "highway ROW," is a dummy variable indicating whether the station is located within or adjacent to U.S. Interstate or highway right-of-way (ROW). We expect that stations located outside of highway ROW will exhibit higher levels of integration.

Transit Level of Service Transit LOS is measured through the variable "transit score," which is derived from Transit Score, a patent-pending measure developed by Walk Score that assigns a score based on how well a location is served by public transit on a scale from 0 to 100 (*40*). The algorithm accounts for three factors: the distance to the nearest transit stop(s), frequency of the route(s), and type of route(s) with heavy and light rail weighted more heavily than bus service (*41*). While not a perfect measure, in combination these factors serve as a strong indicator of the usefulness of transit at a particular location. Higher transit scores are expected to be associated with higher levels of integration.

Access to Amenities Destination accessibility is widely acknowledged to be an important factor in assessing travel behavior (*13, 16, 21, 25*, *42*). While both local and regional accessibility is likely to affect travel behavior in station areas, the present study is focuses on accessibility to local amenities (i.e., amenities within station areas. Further work is required in order to integrate measures of regional accessibility. Variables accounting for walking access to four categories of amenities—grocery stores, schools, food and entertainment, and other amenities—are derived from the Street Smart Walk Score and included in analysis (*42*). Walk Score uses data from several sources to calculate scores for nine different amenity categories based on the number of destinations in each category and the street network distance to those destinations (*43*). The amenity scores included in the present analysis were selected because of their importance to the level of integration between transit and the community. Research shows that walk accessibility to grocery stores is strongly associated with walking behavior (*44*). Research similarly identifies restaurants and bars, as well as coffee shops and entertainment businesses to be common walking destinations (*43*, *45*). We therefore use the score for grocery amenities as one variable ("grocery score"), and the combined scores for restaurants, bars, coffee shops, and entertainment as another variable ("food and entertainment score"). Walk Score also recognizes schools as important walking destinations, the score for which we include as "school score." The remaining four categories calculated by Walk Score—shopping, banks, parks, and books—are included in the variable "other score." We expect that higher scores for all categories of amenities will be associated with higher levels of integration.

Independent Variables: Sociodemographic Controls

Six sociodemographic variables are also included in order to account for individual characteristics commonly associated with travel behavior. These variables were obtained from a survey of residents in the Denver Metro undertaken in spring and summer of 2011. A mail-out–mail-back survey tool was distributed to randomly selected households in two counties, Denver and Arapahoe, which contain 34 of the 36 LRT stations. The survey effort achieved a response rate of 14%, with more than 250 responses. The survey included questions related to housing, household, and sociodemographic factors, as well as about travel behavior both before and after LRT was implemented, or before and after the resident moved to the neighborhood. Attitudes related to travel, land use, and the environment were also queried. The present analysis includes data obtained only from those respondents residing within 2 mi of the 25 LRT stations located in the CCD, a sample of 124 surveys. The analysis presented here includes several measures developed based on survey data including dummy variables accounting for full- or part-time employment ("employed"), status as student ("student"), and annual household incomes less than \$25,000 ("low income") and more than \$100,000 ("high income"). Persons of color are also identified through the dummy variable "nonwhite." The number of individuals reported to live together as part of the same household "household size" is also included, along with the respondent's age ("age"). A dummy variable for the presence of at least one child under the age of 18 ("presence of children") is also included.

Independent Variables: Self-Selection and Proximity to Transit

Possible effects of self-selection are also accounted for through the inclusion of the dummy variable "moved after transit." Self-selection describes the phenomenon in which households choose to live in a neighborhood expressly to satisfy their desired travel behavior. For instance, self-selection exists when a resident wishing to commute to work by light rail chooses (self-selects) to live in a neighborhood served by light rail. Self-selection is considered to be important to travel behavior research because the impact of transit access and the built environment may be over-estimated when individual's residential location and travel preferences are not accounted for (*46*, *47*). Through their review of 38 empirical studies, Cao et al. (*47*) identify nine methodological means for addressing self-selection, ranging from simply asking respondents whether their travel and land use preferences influenced their residential location decision to rigorous joint and structural equation modeling techniques. We follow the most straightforward approach by accounting for whether respondents moved to station areas after the implementation of transit service. Although the survey tool did not directly ask about preferences guiding residential location decisions, we are still able to identify whether status as an in-mover has an effect on travel behavior outcomes. If final best-fit models include the variable, it is possible that self-selection may affect the outcome variables. If the model does not include the variable, self-selection effects are not likely. It should be noted that accounting for self-selection is most important in studies that aim to precisely estimate the impact of policies governing the built environment and land use on travel behavior, fuel consumption, and emissions (*46*). Although it is important to account for self-selection in all travel behavior research, it is less important in the present analysis since we are primarily interested in understanding the key factors involved in explaining travel outcomes, not in specifically estimating the effects of variables on travel outcomes.

A final dummy variable, "within 1 mi" identifies those survey respondents that live within 1 mi of a transit station. The variable is included in order to account for whether respondents living within 1 mi of stations exhibit different travel outcomes than those living between 1 and 2 mi from stations.

Dependent Variables

Four outcome variables derived from survey data are assessed in this analysis:

- Number of cars available within a household ("number of cars");
- Weekly VMT ("weekly VMT");
- Binary variable identifying individuals who report using LRT regularly on weekday or weekend days ("LRT use"); and
- Binary variable identifying individuals who report using "alternative" modes (LRT, bus, walking, or biking) regularly on weekday or weekend days ("alternative mode use").

Each of these variables are derived from responses to questions in the survey tool. The first two variables were directly asked in the survey [How many motor vehicles are available for regular use by the individuals in your household?" "About how many miles per week (both work–school and nonwork–nonschool trips) do you usually drive (car or motorcycle)?]. The latter two variables are derived from questions that asked respondents to indicate whether if they use light rail regularly on average weekdays and weekend days. For those who did not report using light rail, another question asked if they regularly use other modes on average weekdays and weekend days.

Methods

Data for respondents residing within 2 mi of the 25 LRT stations located in the CCD was employed in the analysis, with the individual respondent as the unit of analysis (n = 124). Only stations located in CCD are analyzed due to a lack of available data for other areas in the metro. A series of best-fit models were developed in order to identify the variables related to level of integration that best explain the four travel behavior outcome variables. Ordinary least square (OLS) regression was used to model continuous dependent variables ("number of cars" and "weekly VMT") and logistic regression was used to model the binary variables ("LRT use" and "alternative mode use"). All models were fit iteratively using *R* statistical software. The best-fit OLS models were selected based on adjusted R^2 statistics, while logistic models were selected based on Akaike information criterion (AIC) statistics. Best-fit models are used to identify the integration factors, sociodemographic controls, and possible self-selection effects that best explain each of the four dependent variables.

Spearman's ranked correlation coefficients for nonnormal distributions were tested for all pairs of independent variables to identify sources of multicollinearity. Pairs of explanatory variables with correlations 0.60 and higher were flagged and prevented from being jointly present in final models. Five pairs meeting this criteria were identified: "school scores" and "intersection density" (rho = 0.78); "food and entertainment score" and "transit score" (rho = 0.65); "other score" and "highway ROW" (rho = –0.62); "pedestrian shed" and "intersection density" (rho = 0.62); and "miles of bicycle facilities" and "highway ROW" (rho = –0.80). The variable in each of these pairs that provided the most explanatory power was retained in the models, while the remaining variable in the pair is omitted such that none of the pairs exhibiting multicollinearity are included jointly in the final best-fit models.

RESULTS

Results from the four final best-fit models are presented in Table 1.

DISCUSSION OF RESULTS

While findings are not entirely conclusive, our research provides insight into the key factors that should be considered in future analyses of the level of integration between rail transit and the community fabric. These observations are outlined below for each level of integration variables, sociodemographic factors, and self-selection effects.

TABLE 1 Best-Fit Model Results

Independent Variables	Regression Coefficients (*standard error*) for Dependent Variables											
	Model 1: No. of Cars			Model 2: Weekly VMT			Model 3: LRT Use			Model 4: Alternative Mode Use		
Intercept	1.285	(*0.421*)	**	254.730	(*70.858*)	***	–11.887	(*5.248*)	*	0.546	(*2.076*)	
Level of Integration Variables												
Built Environment Factors												
Pedestrian shed		—		–1.220	(*0.399*)	**	0.107	(*0.039*)	**		—	
Park-and-ride parking spaces		—		–0.040	(*0.024*)			—			—	
Park-and-ride bicycle spaces	0.017	(*0.006*)	**		—		0.132	(*0.046*)	**		—	
Walkability index	–0.152	(*0.126*)			—			—			—	
Miles of bicycle facilities		—		-52.071	(*2.234*)	***	1.651	(*0.872*)		1.045	(*0.468*)	*
Intersection density		—			—			—			—	
Highway ROW		—			—			—			—	
Transit LOS												
Transit Score		—			—			—			—	
Access to Amenities												
Grocery score		—			—			—			—	
School score	–0.043	(*0.410*)	**		—			—			—	
Food–entertainment score		—		1.789	(*1.059*)			—			—	
Other score		—		1.886	(*1.837*)		–0.207	(*0.075*)	*	–0.167	(*0.078*)	*
Sociodemographic Controls												
Age	–0.001	(*0.005*)			—		–0.065	(*0.040*)			—	
Employed		—			—			—		–0.171	(*0.844*)	
Student		—		–58.748	(*26.862*)	*	5.951	(*2.161*)	**		—	
Low income		—		–22.129	(*20.380*)		2.555	(*1.214*)	*	17.917	(*1386.4*)	
High income		—			—		3.646	(*1.259*)	**		—	
Nonwhite		—		503.380	(*16.105*)	**	–6.183	(*2.907*)	*	–2.968	(*1.218*)	*
Household size	0.387	(*0.069*)	***		—		–0.034	(*0.393*)			—	
Presence of children		—			—		1.976	(*1.382*)		0.997	(*0.782*)	
Self-Selection Effects and Proximity to Transit												
Moved after transit		—			—		1.151	(*0.986*)			—	
Within 1 mi		—		16.060	(*12.028*)			—			—	
Degrees of freedom	112			97			81			82		
Adjusted R^2	0.291			0.203			NA			NA		
AIC	NA			NA			77.316			104.24		

NOTE: no. = number; NA = not available; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Key Level of Integration Factors

Several integration variables appear to be important to numerous travel outcomes. Miles of bicycle facilities is included in the three of four models with higher numbers miles associated with lower weekly VMT and higher likelihoods of LRT and alternative mode use. Access to other amenities (shopping, banks, parks, and books) is also included in three of the models (weekly VMT, LRT use, and alternative mode use). This finding suggests the need to disaggregate the other amenities scores in order to disentangle the effects of each category. The percent of total area within ½ mi of a station that can be reached by walking along the network for ½ mi (variable "pedestrian shed") is an important explanatory variable, with larger pedestrian sheds linked to lower VMT and higher likelihoods of using LRT. The number of bicycle spaces at stations is important to number of cars and LRT use. Three pairs of variables also appeared in multiple models. "Miles of bicycle facilities" and "other score" co-appear in three models, while "pedestrian shed" and "miles of bicycle facilities" and "pedestrian shed" and "other score" appear as pairs in two models. The fact that these three variables hang together in the models implies possible utility in grouping them as part of a future level of integration composite variable.

Variables that appear in the models seldom or not at all are also noteworthy. Intersection density, presence of station within or adjacent to highway ROW, transit score, and access to grocery amenities appear not to be important in explaining travel outcomes, as none appear in any of the four models. The lack of explanatory power for intersection density and grocery amenities is particularly surprising, since previous research suggests that both are important predictors of nonmotorized travel. Both "intersection density" and "highway ROW" were subject to concerns about multicollinearity, which could have affected their inclusion in final models. The number of parking spaces at park-and-ride stations, walkability index, access to schools, and access to food and entertainment amenities also appear to hold little explanatory power, with each only appearing in one final model. These variables need to be revisited in order to understand whether they are measuring the phenomena of interest. In particular, it may be important to account for additional parking factors including the presence of on-street parking, parking costs, and parking occupancy rates.

For the most part, integration variables followed our a priori expectations with variables related to increased walk- and bike-ability and access to amenities associated with travel outcomes thought to be beneficial: decreased car ownership, decreased weekly VMT, and higher likelihoods of LRT and alternative mode use. However, there are some notable instances in which the relationships between integration variables and travel outcomes do not follow expectations. Curiously, an increase in the supply of bicycle spaces at park-and-ride stations is associated with higher levels of car ownership. However, this finding has limited implications since the variable contributes little to an understanding of how integrated a station area is. Results also indicate that several of the amenity scores are related to travel outcomes in ways that defy expectations. The "other" (shopping, banks, parks, and books) amenity score is particularly difficult to account for with results suggesting that higher levels of access to "other" amenities are associated with higher VMT, and lower likelihoods of using LRT and alternative modes regularly. Similarly, higher scores for food and entertainment and school amenities are associated with higher VMT. These relationships suggest that more nuanced methods of measuring access to amenities should be developed and assessed. It should be noted that although the direction of the above relationships do not follow expectations, the inclusion of the variables in the final best-fit model suggest that they merit further inquiry as possible measures of level of integration.

Key Sociodemographic Factors

All the sociodemographic factors tested appear to be important in explaining travel behavior outcomes, with all but two (“employed” and “high income”) appearing in at least two of the four models. “Low income” (annual household income less than $25,000) and “nonwhite” appear to be most important with presence in three models, while “age,” “student,” and “presence of children” all appear in two models. Sociodemographic variables are particularly important in explaining regular LRT use, with seven of the eight factors included in the final best-fit model. Results of our analysis clearly indicate that sociodemographic variables must be accounted for in future investigations of the effects of level of integration.

Self-Selection and Proximity to Transit

Possible effects of self-selection were tested in the models through inclusion of the dummy variable “moved after transit.” This variable is important in explaining only one outcome variable—regular use of LRT—with results suggesting that residents who moved to station areas after implementation of transit are more likely to use LRT. This finding makes sense, since it is understandable that in-moving residents may have selected their residential location based on its proximity to transit and thus are likely to use LRT. Therefore, it is apparent that self-selection should be accounted for in future efforts that seek to measure and assess level of integration. Failure to do so may over-estimate the impact of integration on travel behavior outcomes, particularly if future research aims to precisely estimate the impact of policies encouraging integration between transit and the built environment.

The variable “within one-mile” was included in the analysis with the assumption that residents living within one-mile of transit stations may exhibit different travel outcomes than those living between one and two miles from stations. This variable is only included in one final model (assessing “weekly VMT”) suggesting that it is of limited utility in future integration analysis. Interestingly, residents living within one-mile of stations are associated with higher VMT, which runs counter to a priori expectations.

CONCLUSIONS

While countless studies evaluate travel behavior associated with various elements of TOD, most assess built environment factors in isolation, preventing a comprehensive understanding of the interrelated nature of the fabric of transit-oriented communities. We take a different approach by aiming to understand the elements that contribute to the integration of rail transit and the built environment, and how varying levels of integration may affect travel outcomes and quality of life more broadly. In the present research, we identified the key integration factors that will contribute to the development of measures accounting for level of integration. The variables used in the present analysis were developed based on readily available data in order to explore the viability of a level of integration measure. Although they do not represent perfect measures, they help us in moving towards a deeper understanding of the factors contributing to integration.

Future work will develop more-nuanced measures for integration factors, particularly in those cases in which unexpected and counterintuitive effects on travel outcomes in the present analysis. In particular, the measurement of access to amenities should be reconsidered. While the measures derived from Street Smart Walk Score provide a good starting point and appear in several of the models, results are inconsistent. Further work should also account for regional accessibility. Future research will also aim to develop composite measures of level of integration, and will test the effects of these measures on travel behavior using more sophisticated modeling techniques. In sum, this research expands knowledge around the factors that contribute to the integration of transit and the community fabric, particularly in cities characterized by auto-dependence with second-generation LRT systems, such as Denver. The present analysis begins to shed light on the ways in which positive travel and quality of life outcomes might be realized and optimized in communities investing in rail transit, and provides a foundation upon which future research will continue this important work.

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Traffic Engineering Innovations for Light Rail Transit and Streetcars

Leveraging Subsurface Utility Engineering Data for Utility Safety on Light Rail Transit Projects

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The Subsurface Utility Engineering (SUE) process provides valuable utility facility information that can be leveraged to full extent for light rail projects. A proper understanding of the SUE process helps mitigate problems of utility relocation costs, utility facility safety, and project schedule impacts. In practice, many issues combine to the missed opportunities for dealing with utilities on light rail projects. They are (*a*) stigmatism of SUE as potholing of utilities; (*b*) inexperienced junior engineers assigned to deal with utility issues; and (*c*) missed avoidance, mitigation, or value-engineered solutions to utility conflicts. This report outlines the proper SUE process and how to properly leverage the utility data collected via this process. Critical leveraging solutions include: collection of good utility data by following ASCE 38-02 standard guidelines; use of conflict matrices to manage conflicts; integration of required utility work into light rail construction staging; allowance of every opportunity to bid on utility work under contract; and following through on utility as-built information through construction.

Subsurface utility engineering (SUE) relies on talented individuals with strengths in all aspects of design and construction for both project owner and utility owner infrastructure. Properly executed the SUE process grossly reduces damage risk while streamlining the whole utility effort and promoting good relations and cooperation among all project stakeholders (Figure 1).

For the record, SUE is a comprehensive and complex engineering process to

1. Systematically identify, characterize, map, and document underground utilities in accordance with Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data (Standard CI/ASCE 38-02, American Society of Civil Engineers, Reston, VA, 2002, 20 p);
2. Coordinate (and sometimes mediate) the inclusion of all utilities, both underground and above ground, within design and construction of a civil project; and
3. Engineer and promote optimal, often innovative and nonstandard, resolutions to utility conflicts while embracing a mandate to hold paramount the public welfare.

Arising in the 1980s, the SUE process highlighted a standardized methodology to better collect and depict buried utilities, which was eventually adopted and published as Construction Institute of ASCE (CI–ASCE) 38-02. Perhaps the most significant contribution of the CI–ASCE standard is the development of a formalized procedure for qualifying and designating the general quality of the depicted individual facilities. In the past, lacking a means to assess the basis and quality, the designer simply had to regard a depicted blue dashed line as gospel for where the city water main was buried and let the contractor make adjustments as necessary. There was not a standard means to assess whether the alignment was transcribed from schematics by the

FIGURE 1 Here is a simple example of installing offset manholes to maintain access to an existing 84-in. storm main left in place below a light rail. A main thrust of SUE is integrating qualified data with design and construction to engineer protect-in-place strategies for existing utilities. The SUE process promotes damage prevention, cost and schedule reduction, commerce interests, and above all, the public welfare.

computer-aided drafting and design operator, "witched in" by the public works maintenance person and picked up by a surveyor, or detected by a qualified operator using geophysical methods and accurately tied to project control. There also was not any means to gauge completeness, and nobody was given full responsibility to collect, check, and validate the data set, nor were there defined qualifications for conducting this task. The results have been, and unfortunately continue to be, expensive and often disastrous. But CI–ASCE 38-02 is changing all of that and providing excellent opportunity to raise the bar for the latter two parts of the SUE process listed above: the leveraging aspect.

Table 1 summarizes the four quality levels (QL) designations included in the CI–ASCE standard.

TABLE 1 CI–ASCE 38-02 QLs for Depicting Facilities in Accordance with SUE Protocol

QL-D	QL-D is the most basic level of information for utility locations. It comes solely from existing utility records or verbal recollections, both typically unreliable sources. It may provide an overall "feel" for the congestion of utilities, but is often highly limited in terms of comprehensiveness and accuracy. QL-D is useful primarily for project planning and route selection activities.
QL-C	QL-C is probably the most commonly used level of information. It involves surveying visible utility facilities (e.g., manholes, valve boxes) and correlating this information with existing utility records (QL-D information). When using this information, it is not unusual to find that many underground utilities have been either omitted or erroneously plotted. Its usefulness, therefore, is primarily on rural projects where utilities are not prevalent, or are not too expensive to repair or relocate.
QL-B	QL-B involves the application of appropriate surface geophysical methods to determine the existence and horizontal position of virtually all utilities within the project limits. This activity is called "designating." The information obtained in this manner is surveyed to project control. It addresses problems caused by inaccurate utility records, abandoned or unrecorded facilities, and lost references. The proper selection and application of surface geophysical techniques for achieving QL-B data is critical. Information provided by QL-B can enable the accomplishment of preliminary engineering goals. Decisions regarding location of storm drainage systems, footers, foundations, and other design features can be made to successfully avoid conflicts with existing utilities. Slight adjustments in design can produce substantial cost savings by eliminating utility relocations.
QL-A	QL-A, also known as "locating," is the highest level of accuracy presently available and involves the full use of the subsurface utility engineering services. It provides information for the precise plan and profile mapping of underground utilities through the nondestructive exposure of underground utilities, and also provides the type, size, condition, material, and other characteristics of underground features

CI–ASCE 38-02 standard guidelines require professional engineering certification. Individuals sealing data submittals must provide direct oversight with all data acquisition, processing, and quality assurance measures, and assume direct responsibility in accordance with local state statutes for professional engineers. Adherence to CI–ASCE standards along with the use of records research, geophysical methods, vacuum excavation, and land survey combined in a phased approach and guided by professional judgment, has often been regarded as the essence of SUE. However, SUE does not end after utility data has been collected and depicted in accordance with CI–ASCE 38-02 standard guidelines, rather, that is where the leveraging, or the "E" part, really comes into play through:

1. Systematic conflict identification with proposed infrastructure construction activities (e.g., proposed light rail section crosses a buried telecommunication duct) (Figure 2);
2. Mitigation of conflicts and risk by means of modifications to proposed infrastructure (e.g., proposed rail alignment design is adjusted to avoid the telecom duct);
3. Vacuum excavated test holes to accurately analyze spatial latitude (e.g., proposed light rail alignment cannot be moved, but perhaps the rail section can be modified so both rail and telecom duct can coexist);

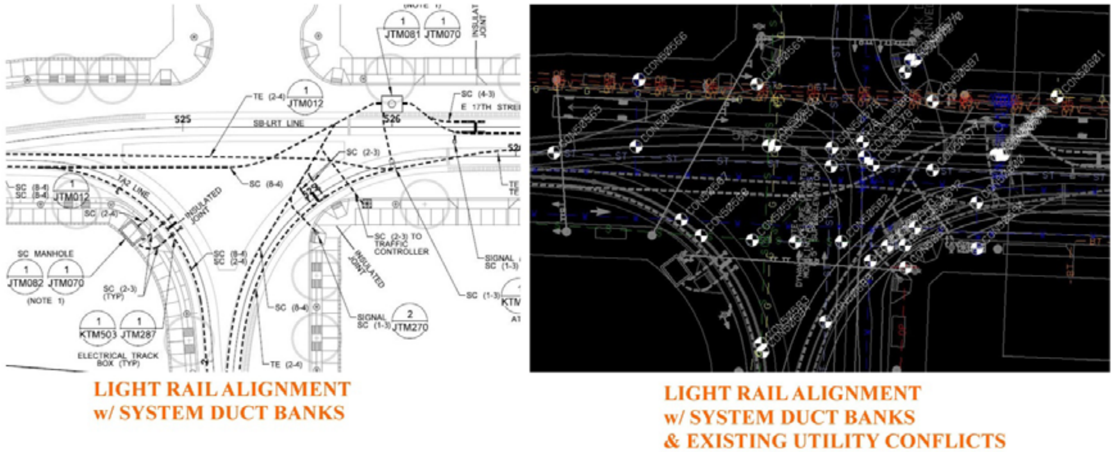


FIGURE 2 Example of conflict identification along proposed light rail using CI–ASCE 38-02 data. (Data courtesy of the Columbia River Project in Vancouver, Washington.)

4. Conflict workshops to brainstorm, assess, and negotiate viable alternatives (Should telecom duct be moved or can proposed rail section be modified and constructed in safe manner that maintains the integrity of both proposed and existing infrastructure? Will the telecom duct be safe from future damage? What lead time is required for the telecom owner to execute either option? What rules must be followed by the contractor to assure work is performed in safe and sound manner?);
5. Selection of resolutions based on objective criteria that places the public welfare above all other interests. Risk, cost, schedule, disruption, and constructability implications all must be assessed, and all stakeholders should be allowed to participate in the solution process with reasons for or against documented (e.g., project owner approves modified light rail section provided telecom company pays for additional design and construction costs; or telecom company approves of modified light rail section provided contractor adheres to construction and inspection criteria and service disruption is avoided);
6. Preparation of agreements which define conditions for utility work or work conducted in close proximity to existing infrastructure;
7. Preparation of construction bid documents that completely define parameters to which the contractor must adhere and conditions for the work, promote value engineering, and minimize risk; and
8. Contractor oversight, regular coordination meetings, as-built documentation, and work approval during construction.

A major pitfall in the SUE process occurs when responsibilities for utility management are relegated to junior level or otherwise inexperienced staff who do not have training or background to work with private utilities to assure their interests, and that of the public, are best served. This is exasperated when (because of inexperience) utility relocations (which are the least creative means for resolving utility issues) are mandated in a wholesale style, sometimes on short notice, without regard to cost, customer service disruption, schedule, or operational disruption to the utility owner. Another pitfall is failure to include SUE data on construction plans or explain the usage of 38-02 data to the contractor candidates during pre-bid job walks.

Data acquired in accordance with 38-02 guidelines must be leveraged to achieve value throughout the entire project development and delivery process, benefiting all stakeholders, most notably the public.

To properly administer the SUE process and optimally leverage SUE data one must do the following:

- Convince project management to allow utility data to be collected in strict accordance with CI–ASCE 38-02 standard guidelines. Good decisions can be made provided good data is available.
- Do not treat the utility effort as an administrative task that ends upon the signing of the utility agreements.
- Treat utility infrastructure with deserved respect, realizing utilities exist because of public demand and serve the public interest. Realize the taxpayer and rate payer are the same.
- Have utility engineering, coordination, and management performed by talented staff who understand
  - Civil infrastructure engineering (e.g., roadway geometrics, light rail, traffic, hydraulics, noise wall, geotechnical, safety, right-of-way, bridge and structural design) and project delivery processes (e.g., design–bid–build, design–build, and construction management–general contractor construction); and
  - Utility design and construction (e.g., power, natural gas, telecommunication, water and sanitary mains, and distribution and services).
- Use utility conflict matrices to manage identified conflicts from cradle to grave, in other words until the construction has been completed and the utility work, or work immediately adjacent to existing utilities, is approved (Figure 3).

Conflict Number	Resolve By Date	Alignment	Features in Conflict		Description	Created by
50023		Washington Street	LRT | TriMet | Light Rail Transit: Rail Section	GVLVNW 104631 | Northwest Natural Gas | Gas Utilities: Valve	Conflict imported without a description.	cgreer@umsi.us on 3/26/2012 3:17 PM
50024		Washington Street	LRT | TriMet | Light Rail Transit: Rail Section	ELINPUD524 | Clark County PUD | Electric Utilities: Buried Power Line	Conflict imported without a description.	cgreer@umsi.us on 3/26/2012 3:17 PM
50026		Washington Street	LRT | TriMet | Light Rail Transit: Rail Section	STMHCV 78700 | Vancouver | Storm Drainage: Manhole	Conflict imported without a description.	cgreer@umsi.us on 3/26/2012 3:17 PM
50027		Washington Street	LRT | TriMet | Light Rail Transit: Rail Section	WVLVCV 104408 | Vancouver | Water Utilities: Valve	Conflict imported without a description.	cgreer@umsi.us on 3/26/2012 3:17 PM
50028		Washington Street	LRT | TriMet | Light Rail Transit: Rail Section	WVLVCV 104408 | Vancouver | Water Utilities: Valve	Conflict imported without a description.	cgreer@umsi.us on 3/26/2012 3:17 PM

FIGURE 3 Example of systematic management of conflict information using a conflict matrix application.

When identifying utility conflicts, realize utilities in close proximity to proposed construction may be at risk and therefore should be considered to be in conflict and handled with appropriate standard of care to avoid damage. Make the conflict resolution effort include deriving clever protect-in-place alternatives that mitigate impact to existing infrastructure.

- Realize identified utility work, such as relocations and protect-in-place alternatives, must be carefully integrated with the mainline construction staging. SUE engineers are well postured to assume responsibility and provide the vigilant standard of care necessary for this activity.
- At every opportunity, allow the prime contractor candidates to bid on utility work in a competitive environment which promotes value engineering. This creates a win-win-win situation:
  - Contractor is in charge of utility work, nets more work, and can include utility work within the mainline schedule;
  - Utility owner gets work performed under competitive bid environment, often for less cost than if performed independently; and
  - Project owner is not tasked with orchestrating and managing the relocations of independent utilities, nor does the project owner get hit with delay claims because third-party utilities have not moved as scheduled.
- The utility effort does not end until the construction effort has been successfully completed, final as-builts submitted, and the work approved.

While not comprehensive, the above list highlights some activities within the SUE process that hold paramount the public welfare, a professional responsibility of every registered engineer. Utilities, of course, are critical to the public welfare. After all, the rate payer and taxpayer are one and the same, and utilities serve commerce as well as represent commerce and we as a country have painfully been made aware these past few years of the importance of commerce to our society.

Leveraging of SUE data engages all stakeholder groups, and they in turn learn how proper use of SUE data can be to their benefit during the coordination of project impacts to utilities. Designers will assess SUE data to reduce impacts–damages to existing utilities or to find safe area for relocation. Contractors will reduce contingency in their bids by understanding the SUE utility information QLs and instigate utility-related value engineering in their planning. Excavators will work safely around utilities during construction. Utility owners will have a systematic means for (*a*) proactive and early involvement in the project planning and design; (*b*) codeveloping resolutions that reduce risk to their infrastructure and services; and (*c*) reliable and cost-effective programming of required activities involving their facilities. Project owners will realize overall risk, cost, and schedule reductions to their projects and witness excellent cooperation and rapport between all parties to the work. The net effect is a process that best serves all stakeholders, public and private alike, accordingly best serves the public welfare.

ACKNOWLEDGMENTS

Columbia River Crossing; the TRB Utilities Committee (AFB70); and Drew Markewicz, The RBA Group.

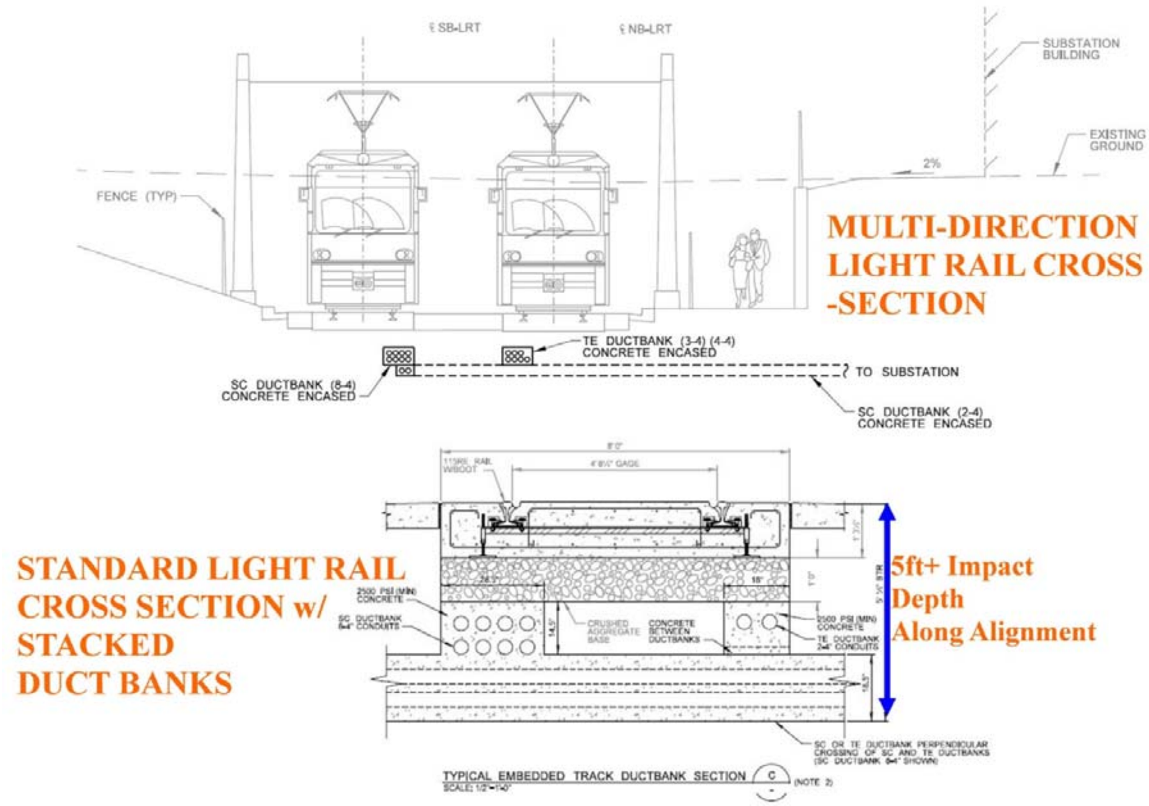
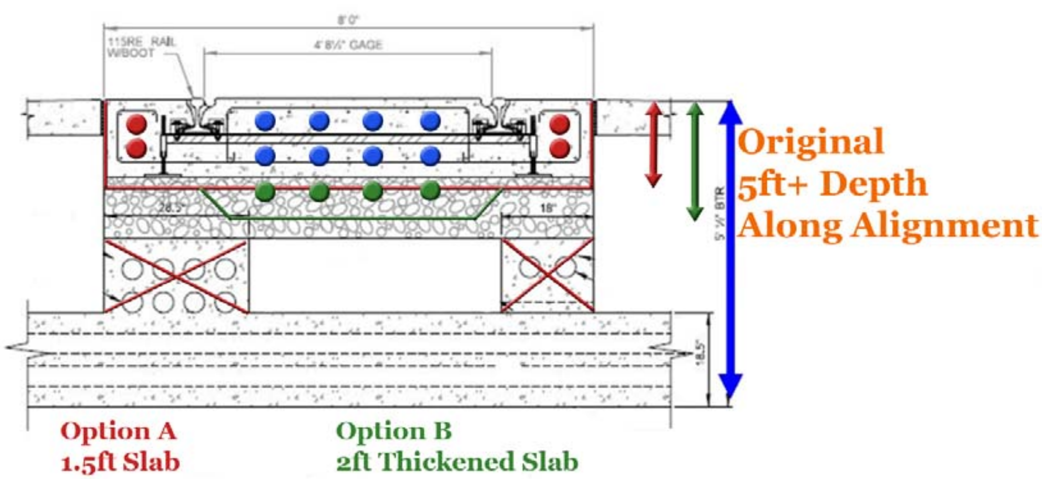


FIGURE 4 Example of typical light rail section.



Possible Design Combination to Reduce
Light Rail Impact Depth to < 3ft

FIGURE 5 Conceptual modifications to light rail sections which explore precast solutions to decrease impact depth and span existing buried infrastructure

Traffic Engineering Innovations for the Sugar House Streetcar Project

LYNN JACOBS
Fehr & Peers

Recent years have seen the rebirth of streetcar as a transportation mode in our communities. Urban streetcars enhance walk, bike, and other transit trips, which enables these trips to be extended over a greater distance and thereby make nonvehicular mode choices more desirable. The Salt Lake City area has been a hotbed of activity for this resurging technology with several projects under development. The Sugar House Streetcar project, which began construction in 2012, is the first modern streetcar line to be implemented in Salt Lake City. Urban streetcars fill a different role in our communities than other forms of rail transit, and therefore have a different set of operating characteristics. It is critical to understand these differences when evaluating traffic conditions and developing what often are unique and innovative traffic engineering design solutions. Given the application of streetcar, there are often competing interests that need to be addressed to find workable solutions. It is important to involve stakeholders while developing innovative solutions to ensure that the final design is effective. This paper outlines a multimodal approach which was used to determine the best solutions at locations where the streetcar will interact with other modes such as adjacent vehicular and trail facilities. The approach relies on the application of a range of design standards and microsimulation analysis to develop and refine traffic engineering solutions that are integral to the streetcar traffic design.

INTRODUCTION

Recent years have seen the rebirth of streetcar as a transportation mode in our communities. Urban streetcars enhance walk, bike and other transit trips, which enables these trips to be extended over a greater distance and thereby make nonvehicular mode choices more desirable. The Salt Lake City area has been part of this resurging technology, with several projects under development. The Sugar House Streetcar project, which began construction in 2012, is the first modern streetcar line to be implemented in Salt Lake City.

The Sugar House Streetcar alignment extends from the TRAX light rail transit (LRT) station at 2100 South in South Salt Lake to the east, terminating at McClelland Street in Salt Lake City as shown in Figure 1. Unique to this project, the streetcar will operate in a primarily semi-exclusive right-of-way (ROW) with 14 at-grade crossings (including two alleys), shared with a planned multiuse trail for the majority of the project's length. Towards the western end of the project, the streetcar will share ROW with a new street that is planned to be constructed as part of Central Pointe, a mixed-use city-sponsored redevelopment project. Due to this unique alignment, this project provides an opportunity to evaluate traffic control measures in a variety of operational scenarios.

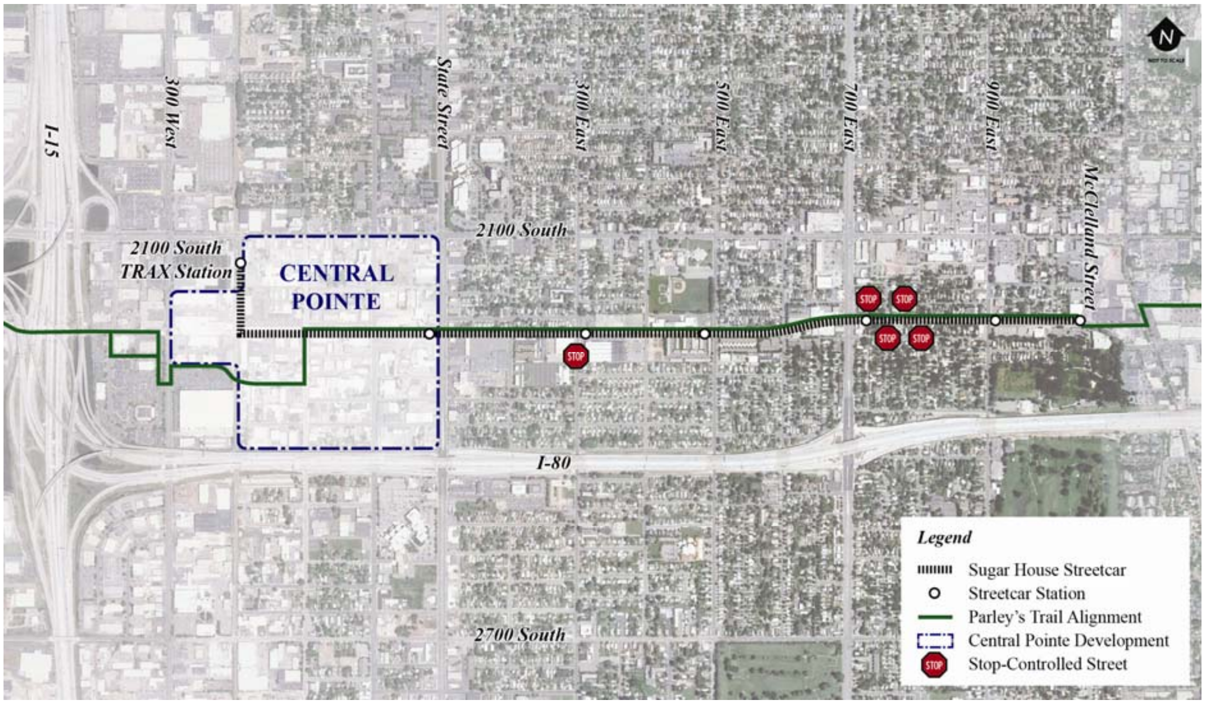


FIGURE 1 Sugar House Streetcar alignment.

As stated in the project's environmental assessment (EA) (*1*), the project's purpose is to

- Contribute to reduced automobile congestion and improved mobility on 2100 South;
- Provide multimodal travel choices in the study area;
- Increase mobility for short-range trips in the study area, especially pedestrian trips;
- Provide connections to the regional transportation network, including the regional transit network; and
- Provide a transportation improvement that is pedestrian friendly, is compatible with surrounding neighborhoods, and supports community and economic redevelopment.

This paper will highlight the differences between traditional LRT and streetcars, evaluating differences in

- Purpose,
- Operating characteristics, and
- Traffic control design.

PURPOSE OF THE STREETCAR PROJECT

The purpose of the Sugar House Streetcar project, as described in its EA, is fundamentally different from the majority of LRT projects. The primary purpose of traditional LRT is typically to move large quantities of people quickly and efficiently, while the primary purpose of streetcar is typically to

- Develop an environment that spurs economic growth;
- Serve as a "walk extender"; and
- Service the "first and last" mile of a transit trip.

Local municipalities and governments often view streetcars as an opportunity to renew and revitalize the area around the corridor. As a result, more emphasis is placed on the type of environment the streetcar is developing. While other forms of LRT also can spur economic development, the type of development is often different in nature. For traditional LRT, with larger distances between stations, the focus is on station area development. For a streetcar with closely spaced stations, corridorwide development becomes a possibility. The Sugar House Streetcar project illustrates this effect in at least two instances. The first is the development of the Parley's Trail that is planned to run parallel to the streetcar and within the project ROW from its eastern terminus to West Temple (Figure 1). This 8-mi multiuse trail will connect other regional trails in the area. While separate projects, the streetcar will serve to bring more trail users to the area just as the trail will serve to bring more transit users to the system as a whole. The second example is the city-sponsored redevelopment of Central Pointe (Figure 1). South Salt Lake is working through a redevelopment process of the area immediately adjacent to the streetcar corridor, leveraging this transportation investment to improve their city. Large redevelopment opportunities exist at two intermediate stations to create the possibility of a corridor of development leading to the existing and expanding Sugar House business district. These examples illustrate planned developments that have been advanced by the introduction of the Sugar House Streetcar project.

Streetcars serve to extend walking trips. People who live within close proximity to the streetcar alignment will now be able to walk to the streetcar and connect to destinations that are normally further than they would be willing to walk. This serves to reduce auto-based trips, as well as serve users who are unable to use autos.

Similar to being a walk extender, the streetcar also serves as a transit extender. Destinations beyond the first and last mile (or even half-mile) of a transit station are often inconvenient to reach without a car, deterring potential transit users. Streetcars can be used to lengthen the coverage area of a transit station by connecting a greater number of origins or destinations that lie outside the typical walk shed to the larger system of transit service.

Streetcars are often referred to as buses on rails as it provides a similar function to typical bus service. The benefit of streetcars are to provide a sense of permanence and predictability. This philosophy of treating streetcars like buses on rails should be used to inform decisions during the design process. Streetcars should be treated less like trains and more like buses.

STREETCAR OPERATING CHARACTERISTICS

Since the purpose of streetcars is so fundamentally different from traditional LRT, the way it operates is also unique. Some of the unique operational characteristics of streetcar that affect design include the following:

- Acceleration and braking characteristics,
- Surrounding environment,
- Operating speed,

- Stop frequency and design, and
- Streetcar interaction with other transportation facilities and modes.

Since streetcars are often a different vehicle than other LRT systems, they may have distinct acceleration–braking characteristics. For the Sugar House Streetcar project, a typical TRAX LRT vehicle is planned to be used. However, the Sugar House Streetcar will operate at a lower maximum speed and will consist of a single-train vehicle, which makes its acceleration and braking characteristics different than other TRAX projects in Utah (with higher speeds). While rail vehicles have different braking and acceleration characteristics than a bus, a slower-moving streetcar would not need as much distance to accelerate or decelerate as a faster moving train. Each design application has project-specific operating characteristics for the design vehicle that is affected by vehicle design, weight, speed, coefficients of friction, etc. These unique features should be taken into account when performing traffic control design. Acceleration and deceleration impact traffic engineering parameters such as stopping-sight distance and signal timing design as well as design decisions such as choice of control devices.

Streetcars can operate in a different environment than other types of LRT. In fact, streetcars are being used as a tool to spur redevelopment and change environments. The Sugar House Streetcar project will operate in primarily residential areas consisting of smaller detached single-family homes. Other parts of the corridor also have areas that could rapidly change from large lots into attractive destinations. Since the environment is so different when compared to an industrial or commercial land use, care was taken in the design of the Sugar House Streetcar project to ensure that the project would be compatible with the character of the neighborhood.

Streetcar operating speed may be lower than typical LRT. This is largely due to the nature of streetcar's goals and objectives. Typical LRT is designed to move large masses of people quickly over a distance of 5 mi or more. On the other hand, urban circulating streetcar enhances other modes (walking, cycling, and transit) by connecting origins and destinations within a smaller catchment area. The Sugar House Streetcar is designed to operate with a maximum speed of 25 mph. However, other streetcar designs may have higher operating speeds. This may happen when the streetcar will be operating in mixed-flow with traffic that is operating at speeds greater than 25 mph. In that situation, the streetcar may be designed to operate at the same speed as other traffic on the roadway. In this way, the streetcar could be treated similar to other vehicles. Conversely, it is common for traditional LRT projects to have a maximum operating speed of up to 55 or 65 mph. This paper will focus on the Sugar House Streetcar project, which will operate as an urban circulator with lower speeds.

As the streetcar is designed to primarily extend walking trips or provide connectivity to the first and last mile of a transit trip, it is usually designed with more frequent stops than typical LRT. The Sugar House Streetcar project has stop spacing of one stop every two blocks, making it highly accessible to the entire neighborhood along its length. This frequency of stops also drives the need to operate the streetcar at a lower design speed. Also, care has been taken to ensure that the station platform areas are designed to be consistent with the community context.

These unique operating characteristics play a critical role in the way streetcars interact with other transportation facilities and modes. For example, the Sugar House Streetcar project interacts with the following:

- Other transit facilities (TRAX 2100 South Central Pointe station, bus routes),
- Arterial roadways (State Street and 700 East),

- Minor residential streets of varying speeds and volume,
- Pedestrian plazas (being developed concurrently with the project), and
- Multiuse trail (Parley's Trail) running parallel with the project alignment.

TRAFFIC CONTROL DESIGN

Even though streetcars' operating characteristics vary significantly from other forms of LRT, the current design standards do not differentiate between the two. For example, traffic control for all forms of LRT is covered by chapter eight of the FHWA *Manual on Uniform Traffic Control Devices 2009* (MUTCD) (*2*). Section 8A.01 paragraph 9 states that

> LRT is a mode of metropolitan transportation that employs LRT vehicles (commonly known as light rail vehicles, streetcars, or trolleys) that operate on rails in mixed traffic (shared lanes with autos), and LRT traffic that operates in semi-exclusive rights-of-way, or in exclusive rights-of-way. Grade crossings with LRT can occur at intersections or at midblock locations, including public and private driveways. (*2*)

This paragraph indicates that streetcar is viewed exactly the same way as traditional LRT in the MUTCD. Since streetcar has such unique operational characteristics, forcing the requirements for a traditional LRT system may be counter to the purpose and environment of streetcars.

The Sugar House Streetcar design had to reconcile these discrepancies, while still providing a design that met all applicable standards. The top three design issues faced during the project were

- Pedestrian and cyclist control elements,
- Grade crossings control devices, and
- Analysis requirements.

Pedestrian and Cyclist Control Elements

Streetcar is frequently built in pedestrian- and bicycle-friendly environments, which helps to serve the purposes of this mode as described previously. Streetcar and pedestrian accessibility are inexorably tied. Therefore, it is important to provide adequate and safe multimodal facilities. This may result in improvements that are more than the minimum requirements. For example, the Sugar House Streetcar project and Parley's Trail project will include the following pedestrian–bicycle amenities:

- Pedestrian bulb-out areas at many of the crossings to reduce pedestrian crossing distance across roadways and serve as traffic calming devices (Figure 2);
- Traffic control signals being installed for the streetcar will also serve pedestrians and cyclists when the train is not there;
- Landscape amenities;
- Pedestrian plaza areas; and
- Streetcar platform design.

The Sugar House Streetcar had to accommodate pedestrian crossings from the parallel trail facility. However, pedestrians could not be expected to wait up to 15 min for a train to arrive to make their crossing. For this reason, the pedestrian crossings had to be accommodated at the same location, but not necessarily at the same time as the streetcar crossing.

At stop-controlled intersections, pedestrians using the trail have the right-of-way at all times. Auto traffic is required to stop and yield to both the train and the trail users.

At signalized crossings, pedestrians use the same signal equipment provided for the streetcar to actuate a signalized crossing as shown in Figure 2. Trail users would be required to actuate the signal and wait for the signal to provide a red indication for autos and a pedestrian walk indication to give them the right-of-way.

At major arterial crossings (700 East and State Street), the pedestrian accommodation is still under consideration. Pedestrians may be allowed at-grade like other signalized intersections on the corridor, or complete grade separation (pedestrian bridge) may be required.

While each streetcar project requires attention to developing pedestrian-friendly amenities, there is limited guidance on how effective these amenities really are. Further study should be done to quantify the effectiveness of pedestrian improvements in a streetcar context to:

- Improve safety,
- Increase ridership, and
- Spur economic development.

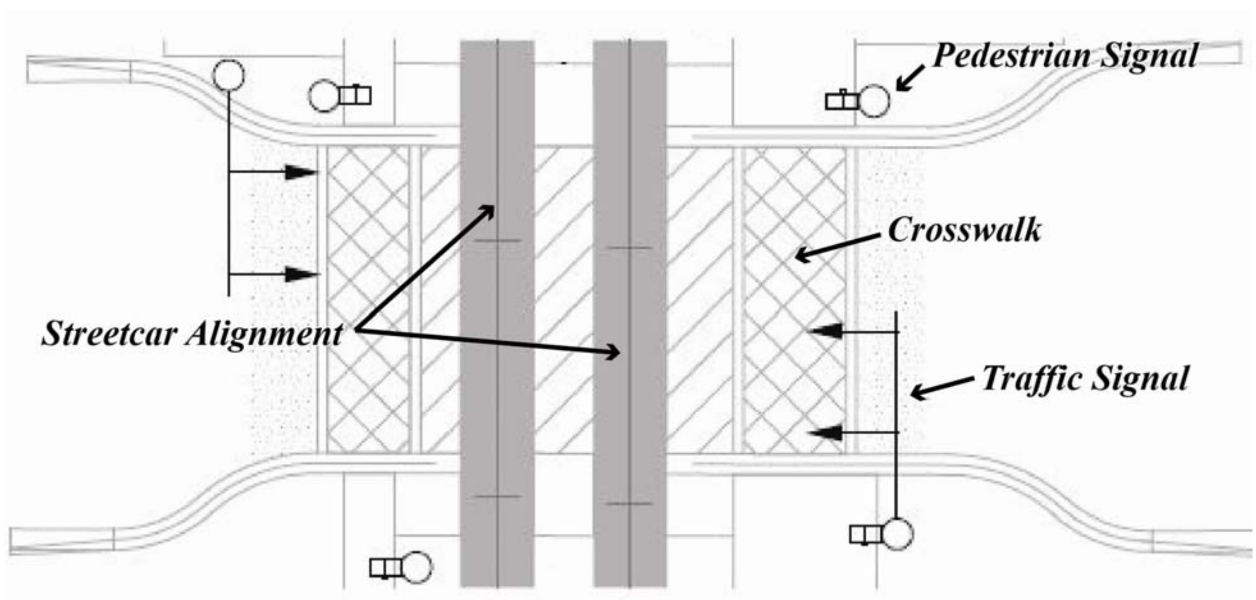


FIGURE 2 Typical signalized crossing.

Grade Crossing Control Devices

One of the biggest challenges in designing the Sugar House Streetcar project was to determine what control devices would be used at street crossings. The project team spent a great deal of time and effort evaluating options and selecting the most appropriate control device. For the Sugar House Streetcar project, the Utah Department of Transportation (DOT) had jurisdictional oversight of all grade crossings, regardless of the jurisdiction where the crossing would be located (city or Utah DOT facility). The Sugar House Streetcar project consists of 14 at-grade crossings as follows:

- Five South Salt Lake roadways,
- Seven Salt Lake City roadways (including two alleys), and
- Two Utah DOT roadways.

Design required coordination between these three agencies and the Utah Transit Authority (UTA). Since Utah DOT has jurisdictional oversight, they developed a surveillance memorandum outlining the required control elements. The surveillance memorandum serves as an official record of traffic control elements to be implemented at each railroad crossing and is developed by the agency with oversight jurisdiction. In the case of the Sugar House Streetcar project, the surveillance memorandum was developed by Utah DOT. This surveillance memorandum was reviewed and refined during early stages of the design process. These refinements generally consisted of instances where the preferred control devices were not consistent with streetcar operations or the built environment. Traffic control devices allowed by the MUTCD are generally grouped into two categories:

- Passive warning devices and
- Active warning devices.

However, there is limited guidance on when each of the devices is appropriate in unique situations. The MUTCD identifies that there is no "one-size-fits-all" solution for LRT crossings in Section 8A.03. Because of the large number of significant variables to be considered, no single standard system of traffic control devices is universally applicable for all highway–LRT grade crossings (*2*).

Thorough analysis of the grade crossing should be completed to understand operational impacts of the crossing. As different control devices have varying operational features, comparative analysis of the operational impacts of each proposed control device can be completed to inform design decisions.

Passive Warning Devices

Passive warning devices consist of a stop or yield sign with a cross-buck assembly. The guidance in the MUTCD provides some direction on when passive control devices may be used:

> The uses of only STOP or YIELD signs for road users at highway-LRT grade crossings should be limited to those crossings where the need and feasibility is established by an engineering study. Such crossings should have all of the following characteristics (*2*):

A. The crossing roadways should be secondary in character (such as a minor street with one lane in each direction, an alley, or a driveway) with low traffic volumes and low speed limits. The specific thresholds of traffic volumes and speed limits should be determined by the local agencies.

B. LRT speeds do not exceed 35 mph.

C. The line of sight for an approaching LRT operator is adequate from a sufficient distance such that the operator can sound an audible signal and bring the LRT equipment to a stop before arriving at the crossing.

D. The road user has sufficient sight distance at the stop line to permit the vehicle to cross the tracks before the arrival of the LRT equipment.

E. If at an intersection of two roadways, the intersection does not meet the warrants for a traffic control signal as provided in Chapter 4C.

F. The LRT tracks are located such that highway vehicles are not likely to stop on the tracks while waiting to enter a cross street or highway.

Passive warning devices are only allowed under these specific situations; however there may be examples where these requirements are not consistent with streetcar operations. For instance, a streetcar could be traveling in mixed flow with other traffic with the speed limit posted at 35 mph. Under the current standard, all driveways and stop-controlled intersections located along the corridor would no longer be allowed to remain as stop-controlled intersections, but would be required to include an active warning device. This would be contrary to the philosophy that streetcar should be treated like a "bus on rail." Implementation of a new bus line on the same corridor would not result in a change to the control devices; therefore, implementation of a new streetcar should not necessitate these changes either.

For the Sugar House Streetcar, only five crossings were deemed to have low enough volumes to be controlled by a stop sign. No specific volume threshold was identified. Instead, consensus was reached among the stakeholders that these five crossings (alleyways, dead-end streets, and minor roadways) were of sufficiently low volume to allow the use of passive warning devices. The guidance in the MUTCD does not provide specific volume thresholds for identifying when it is appropriate to use passive versus active warning devices. Instead, it leaves determination of these volumes to local decision makers. For other applications, the MUTCD does provide specific volume thresholds (i.e., signal warrants). More specific guidance could be helpful in determining the most appropriate control device at minor crossings. The locations selected for stop signs (as shown in Figure 3) were 400 East, Lake Street, 800 East, and two alleyways.

Active Warning Devices

Examples of active warning devices include flashing light signals, traffic signals, and automatic gates.

The MUTCD guidance states that active warning devices should be used when LRT speeds exceed 35 mph. Section 8C.05 states that

> Highway-LRT grade crossings in semi-exclusive alignments should be equipped with automatic gates and flashing-light signals (see Sections 8C.02 and 9C.03) where LRT speeds exceed 35 mph. Option: Where a highway–LRT grade crossing is at a location other than an intersection, where LRT speeds exceed 35 mph, automatic gates and flashing-light signals may be installed.

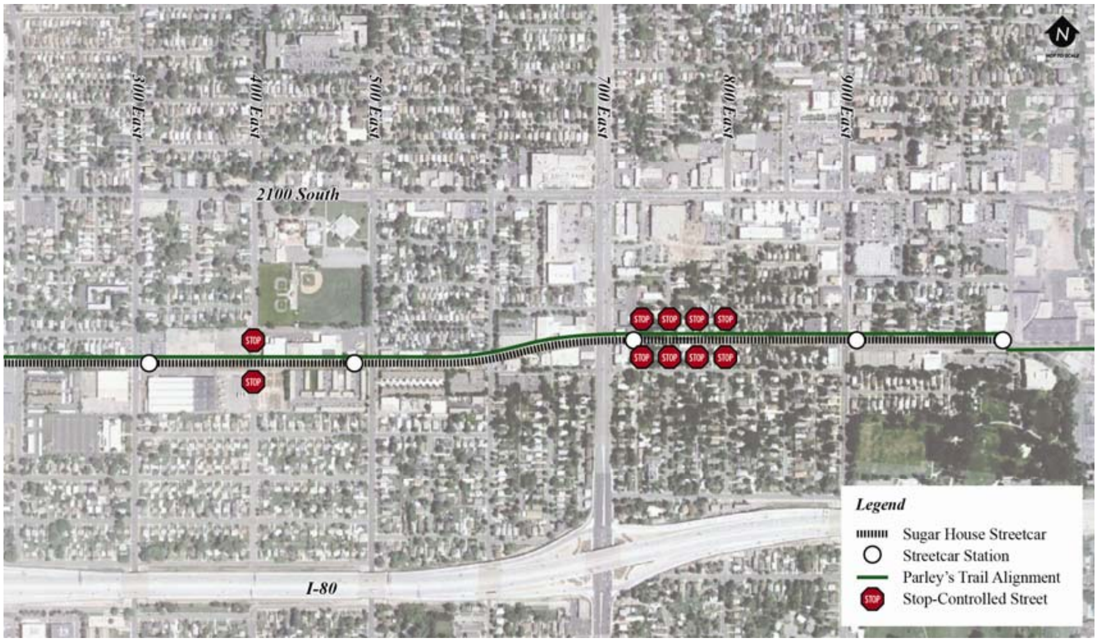


FIGURE 3 Stop-controlled intersections.

> Traffic control signals may be used instead of automatic gates at highway–LRT grade crossings within highway–highway intersections where LRT speeds do not exceed 35 mph. Traffic control signals or flashing light signals without automatic gates may be used where the crossing is at a location other than an intersection and where LRT speeds do not exceed 25 mph and the roadway is a low-volume street where prevailing speeds do not exceed 25 mph. (*2*)

Given the example illustrated in the passive warning device section, streetcar implementation on a roadway with the streetcar operating in mixed flow with a 40-mph posted speed limit would actually require automatic gates and flashing light signals at every minor street and driveway crossing. This would represent a large capital investment as well as impacts to the minor street traffic operations. These impacts make it more difficult and expensive for streetcar to be constructed.

The requirement is also somewhat vague. For a streetcar traveling at 25 mph and crossing a roadway where the prevailing speed exceeds 25 mph, the guidance does not provide a clear indication of whether gates are required. The crossing at 700 East provided the most challenge in determining the most appropriate application of control devices. Many options were considered at this location including:

- Actuated crossing gates;
- Traffic signal with advance warning beacons;
- Actuated crossing gates in combination with a traffic signal; and
- Grade separation of the pedestrians.

Ultimately it was determined that the traffic signal with advance warning beacons would be the most appropriate control device. However, further detail for how crossings with LRT with speeds between 25 and 35 mph should be treated would be useful. Further guidance should also be provided for how to control crossings with various roadway speeds.

When gated crossings are used, it is difficult to accommodate pedestrians safely. The MUTCD does allow for a hybrid of gates with a traffic signal that can be used to serve pedestrians, but this can cause driver confusion and result in higher crash rates. As part of the analysis for the Sugar House Streetcar project, a comparative safety analysis was performed for nine similar locations in Utah:

- Four that were controlled by gates (primarily located in suburban areas),
- Four that were controlled by traffic signals (primarily located in urban areas), and
- One location that was a hybrid of the two: gates controlling the LRT crossing and signals controlling the pedestrian crossing (located in a suburban area).

Figure 4 shows how the number of crashes at the three crossing types compared when normalized by average annual daily traffic (AADT). This data includes a summary of all reported incidents within ¼ mi of the crossing over a 3-year period. There was sufficient data to perform a more detailed statistical analysis, but it is clear that the hybrid location in this instance experienced much higher crash rates than the other two types of control treatments. The signalized locations were also generally located at urban locations with more complex operations than the gates, which may explain the higher crash rate reported for signals when compared to gates.

The higher crash rate identified at the hybrid crossing could be explained by drivers trying to process too much information. As a driver approaches the crossing, they could see that the gate arms are up and miss looking for the signal.

As mentioned previously, streetcar projects typically generate higher levels of pedestrian and cyclist activity. Failing to safely accommodate the increase in pedestrian traffic would create an environment contrary to the goals and purposes of streetcar. Signals provide a clear advantage in that they simultaneously accommodate all modes without grade separation or other special treatment of pedestrians. Further guidance should be provided for accommodating all modes at streetcar crossings.

Audible Warning Devices

The MUTCD requirement outlined in Section 8C.03 states: If flashing-light signals are in operation at a highway-LRT crossing that is used by pedestrians, bicyclists, and/or other nonmotorized road users, an audible device such as a bell shall also be provided and shall be operated in conjunction with the flashing-light signals.

This indicates that in a typical streetcar environment, where the crossings are to be used by pedestrians, bicyclists, and/or other nonmotorized road users, active warning flashers are required to have an audible device installed. This may make sense for a majority of LRT crossings where the LRT vehicle is traveling at a high rate of speed in a more commercial–industrial land use setting, but can be difficult to implement in a typical streetcar environment where the majority of adjacent land uses are residential or mixed-use. Additionally, the lower operating speed and reduced braking distance of a streetcar may make this requirement unnecessary. Finally, many streetcars are also equipped with built-in audible devices that can be actuated by the driver at crossings, making the audible devices on the flashing light redundant.

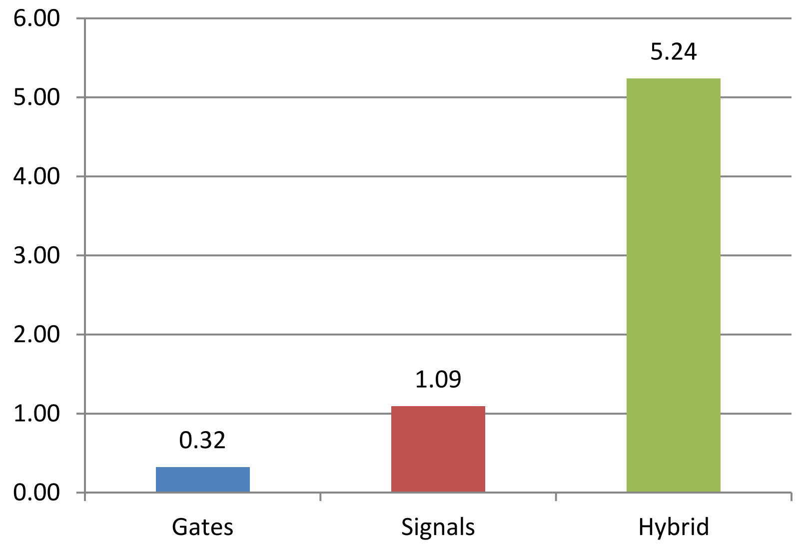


FIGURE 4 Crash rates per 1,000 AADT. (Note: Analysis protected by 23 USC 409.)

For the Sugar House Streetcar project, a number of medium volume roadway crossings were considered for active warning flashers, but the audible warning device requirement was not acceptable to some of the project stakeholders due to noise concerns in the neighborhoods. One example of this situation was the grade crossing at 800 East. As shown in Figure 5, the area surrounding this crossing is primarily residential. Any audible warning would be heard throughout the entire neighborhood. At these locations, other control devices (passive stop control or actuated traffic signals) were selected when an active warning flasher may have resulted in less delay or lower construction costs. This is an example of where the initial surveillance memorandum was further refined in an effort to meet streetcar goals and criteria, while still complying with all applicable standards.

Analysis Requirements

For important regional highway facility crossings, detailed operational analysis should be completed identifying impacts of design decisions. The level of detail required in the analysis should be determined based on the level of complexity of the situation being evaluated and the required level of confidence in analysis results. For example, if a streetcar is operating in mixed flow with no level of transit signal priority, the operations have fewer complexities than a semi-exclusive grade crossing with full pre-emption, and a lesser detailed analysis may be adequate. In order to correctly evaluate streetcar operations, it is important that the analysis methodology

1. Correctly replicates the control operations and
2. Includes multimodal evaluation of impacts to the streetcar, autos, and nonmotorized modes.

FIGURE 5 800 East.

Traditional analysis methodologies such as delay calculations outlined in the *Highway Capacity Manual 2010* (HCM 2010) typically do not account for the complex traffic operations that can be associated with some streetcar crossings. Traditional analysis methodologies also typically do not account for multimodal evaluation, but instead rely on auto-based delay and level of service (LOS). Industrywide efforts are being made to improve our ability to make decisions from a multimodal perspective. Analysis completed for streetcar projects should include these new standards.

For the Sugar House Streetcar project, microsimulation analysis was performed to identify the impacts at the two major arterial crossings of 700 East and State Street. These are both complex semi-exclusive grade crossings. The analysis was performed to understand:

- Operational impacts of controlling the crossings with gates or signals on the roadways and the streetcar;
- Operational impacts of providing at-grade pedestrian crossings concurrent with the streetcar crossing; and
- Pedestrian delay implications of allowing pedestrians to cross 700 East in one or two stages.

The results of this analysis helped to inform design decisions about the implications of various traffic control approaches. The analysis showed that a two-stage pedestrian crossing would result in slightly less delay for vehicles but a significant increase in delay for pedestrians. The analysis recommended a one-stage pedestrian crossing based on the multimodal approach.

For a thorough understanding of the limitations of each analysis methodology, FHWA has put together a set of documents entitled “Traffic Analysis Tools” that provides excellent coverage on the appropriate use of all analysis tools. However, the multimodal LOS definitions outlined in the HCM 2010are still lacking in the ability to articulate the operational nuances of streetcar operations. For example, the intersection pedestrian LOS defined in the HCM 2010 is based on both pedestrian delay and space available at the crossing. Since delay and available space may not have the same weight in the eyes of users, further refinement of this approach may be useful. For the Sugar House Streetcar project, decision makers were more interested in delay than how much room the pedestrians had to wait for their crossing. For this reason, pedestrian delay was presented. User delay may also be a useful metric that is not outlined in the HCM methodology.

CONCLUSION

The re-emergence of streetcars in our society has created a need for more detailed guidance and standards for streetcar design and implementation. This is due to the fact that streetcar is currently held to the same standards as traditional LRT even though it has different purposes and operational characteristics. Further design guidance should be provided for:

- Pedestrian accommodation,
- Traffic control device selection, and
- Analysis methodology.

By their very nature, streetcars bring an increase in pedestrian activity. This increase in pedestrian use requires additional design accommodation. Providing pedestrian amenities creates an environment where the streetcar can be successful; however, there is limited design guidance on the best way to accommodate pedestrians in this environment, especially at grade crossings. Further research should be done to quantify the benefits of various pedestrian amenities on safety, ridership, and economic development in a streetcar context.

While the current standards generally provide enough flexibility to implement streetcar, more mode-specific guidance is needed. Streetcar is a form of LRT, but since it has such unique goals, purposes, and operating characteristics, the umbrella requirements currently in place for all forms of LRT do not always make sense. Specifically, further guidance should be provided on:

- Streetcar operating in a mixed-flow condition;
- Streetcar operating between 25 and 35 mph; and
- Streetcar grade crossings in residential and mixed-use environments.

The tools exist for proper streetcar analysis, but care must be taken to select the correct methodology. The analysis approach should correlate to the specific operations being analyzed as well as the level of confidence required in analysis results. Additionally, multimodal analysis metrics should be used to understand the trade-offs of design decisions associated with each mode.

ACKNOWLEDGMENTS

The Sugar House Streetcar project has been made possible through a joint partnership between the UTA, Salt Lake City, and South Salt Lake. The Utah DOT has provided jurisdictional review of the at-grade crossings. It is being funded in part by a Transportation Investment Generating Economic Recovery federal grant.

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1. Sugar House Streetcar Environmental Assessment. FTA, U.S. Department of Transportation, 2010.
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Modern Roundabout Makes Preferred Alignment Possible for TRAX *Light Rail in Salt Lake City*

BILL BARANOWSKI
Roundabouts USA

In 2003 the University Light Rail Extension project in Salt Lake City constructed an innovative, replicable solution to a problem that could constrain light rail and streetcar projects in many other locales. The strongly preferred track alignment was down the centerline of the street, but that alignment was prevented by the requirement at the University of Utah main vehicle entrance to accommodate heavy left-turn traffic. There was no practical way to run the tracks through the proposed intersection. The novel solution was to simply replace the existing unsignalized intersection with a modern roundabout. The track alignment bisects the roundabout and allows the busy left-turn movement to flow with little or no delay. The author was the lead designer and was inspired by light rail and streetcar examples from Australia and Europe. This paper includes a description of the design of the roundabout with the light rail crossing located in the center. It describes the operational and safety history of the intersection over the past 9 years.

BACKGROUND

The original section of light rail constructed in Salt Lake County is the 15-mi north–south line between Sandy City and Salt Lake City completed in December 2000. Main Street to University of Utah TRAX line includes two sections. The first section, shown in red in Figure 1, is located on 400 South–500 South between Main Street east to the Rice–Eccles Stadium on the University of Utah campus. It was completed in 2001.

The second section shown in light blue at left in the figure, is the Medical Center light rail extension at the University of Utah campus. It begins at the Rice–Eccles Stadium Station and follows South Campus Drive and Wasatch Drive for 1.4 mi. The extension includes three stations and three major intersections.

The Medical Center light rail extension opened on September 29, 2003. In 2009 it was reported that 33% of the university campus trips were made via light rail. There is an existing shortage of parking on campus that provides an excellent opportunity for growth in transit ridership. The map in Figure 2 shows the Medical Center Extension.

Several alternative light rail track alignments within the existing roadway corridors were proposed along with station locations, intersection control options, and pedestrian crossing locations. The design of the new stations and intersections allowed for existing and future traffic needs along the 1.4-mi extension.

The roundabout intersection described in this report is located at South Campus Drive–Campus Center Drive between the Stadium station and the South Campus station. This intersection is one of the major entrances into the campus with over 2,000 vehicles per hour during both the a.m. and p.m. peak travel periods.

The light rail system in Salt Lake County has expanded since 2003 to include 24 additional stations with new links to South Jordan, West Valley City, Draper City, and the Salt Lake International Airport.

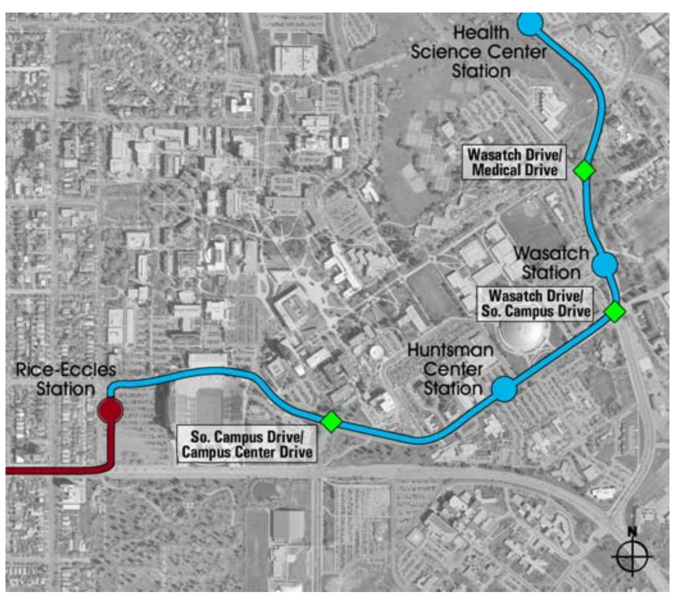

FIGURE 1 University of Utah light rail project stations.

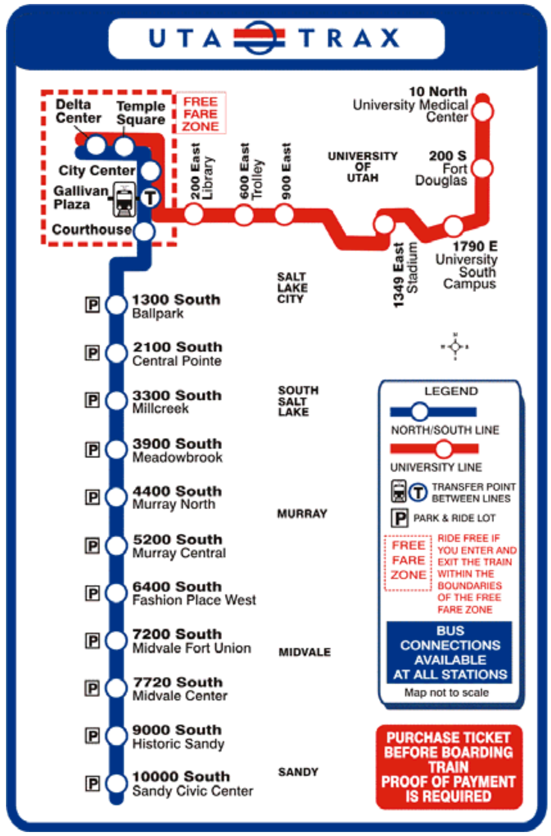

FIGURE 2 2003 TRAX system map.

THE PREFERRED TRACK ALIGNMENT

Several alternative light rail track alignments within the existing roadway corridors were proposed along with station locations, intersection control options, and pedestrian crossing locations. The designer was asked to review the proposed track alignments, analyze three key intersections and to give recommendations for the placement of the tracks and stations.

Center-running track is an operational advantage over side running on South Campus Drive. The track crossings are reduced to only those at signalized intersection locations. This has eliminated nine potential gated crossings on the north side of South Campus Drive. Right-in–right-out access is maintained for the driveways on both sides of South Campus Drive. Two lanes of traffic are provided on each side of the tracks east of the roundabout and one lane of traffic is provided on each side west of the roundabout (Figure 3). Automobile traffic is strictly controlled as vehicles are allowed to cross the tracks only at gated crossings, signalized intersections and the roundabout. Center running tracks allow the continued operation of the Campus Shuttles and Utah Transit Authority (UTA) transit bus stops on both sides of South Campus Drive near the Library and the Huntsman Sports Center. The roundabout option makes center-running light rail possible and is preferred over the traffic signal option because of its superior level of service (LOS).

The change in track alignment on South Campus Drive from side running to center-running improved access and operation of the campus shuttles and UTA buses running on both sides of the tracks. The roundabout allows center running light rail and enables left turns by automobiles in all directions at this key intersection. The photos below (Figure 4) show where the tracks shift from side running to center running west of the Stadium.

INTERSECTION ANALYSIS: ROUNDABOUT AND TRAFFIC SIGNAL COMPARISON

Before the roundabout was constructed, the intersection of South Campus Drive and Campus Center Drive was a T-intersection with South Campus Drive along the top of the T running east–west. Yield signs controlled traffic at the top of the T. Bypass lanes existed at the two

FIGURE 3 Roundabout in the snow looking west towards the stadium.

(a) **(b)**

FIGURE 4 (*a*) Side-running to center-running transition point west of roundabout intersection; at-grade crosswalk has been removed; and (*b*) pedestrian undercrossing west of roundabout intersection at transition point.

corners and across the top of the T. This intersection is one of the major entrances to the campus with about 2,000 vehicles per hour in both the a.m. and p.m. peak travel periods.

The south leg is Campus Center Drive, which connects to 500 South–Foothill Boulevard, which is a major six-lane east–west arterial connecting downtown Salt Lake City to I-80 to the south. The 500 South intersection is located 320 ft to the south and is controlled by a traffic signal with heavy double left-turn traffic towards the roundabout. The two light-rail tracks run in the center of South Campus Drive (the top of the T) with one lane of vehicle traffic in each direction to the west of the intersection and two lanes of vehicle traffic in each direction to the east of the intersection. The dual-lane bypass that existed before the roundabout conversion was retained in the new intersection (Figure 5).

Computer analysis and simulations were prepared to show the traffic impacts with the center running TRAX line on South Campus Drive at the intersection with Central Campus Drive. The two alternatives considered included a roundabout with bypass lanes on the southeast corner and a signal-controlled intersection with double left turns in the northbound and westbound directions.

SYNCHRO (traffic signal analysis software) was used to generate the traffic capacity reports for the signal and RODEL (British roundabout analysis software) was used to produce a LOS analysis based on the geometry of the roundabout. Movie-type simulations of vehicles merging and making lane changes were created using VISSIM, a common simulation model that is very effective at modeling both light rail and roundabouts.

Table 1 summarizes analysis comparing roundabout control to traffic signal control.

The analysis found the roundabout option to experience less delay for vehicular traffic and no delay at all for light rail trains. The traffic signal option however, experienced at least twice the amount of delay as the roundabout option during peak traffic periods. In addition, with the traffic signal option the light rail trains would experience a 50% chance of stopping at the intersection to wait for the intersection to clear. Pedestrian crossings are provided at three signalized locations away from the roundabout.

FIGURE 5 South Campus Drive–Campus Center Drive intersection before the roundabout construction. Yield signs control the traffic along the top of the T-intersection. Bypass lanes existed at the two corners and across the top of the T. Because of the existing free movements the change to a roundabout operation was not as extreme for drivers.

TABLE 1 Intersection LOS Comparison: 2020 Turning Movement Volumes (LOS/average delay[a])

	Roundabout		Signal		Signal (dual lefts)	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
Northbound	A/7.8	A/4.8	C/34.6	F/89.6	C/25.1	B/15.1
Eastbound	A/4.2	A/6.0	C/28.8	D/49.3	C/26.9	C/20.7
Westbound	A/4.2	A/7.8	D/37.2	E/55.9	A/7.2	B/11.2
Overall	A/6.0	A/6.8	D/35.3	E/63.4	B/17.6	B/12.6

[a] Does not include TRAX light rail effects.

INTERSECTION LRT CONTROL AND SAFETY

The safety concerns associated with allowing the trains to cross vehicle traffic at the roundabout was solved by installing railroad gates, flashers, and bells on two of the entries and two gates where the vehicles cross the tracks inside the roundabout (Figure 6).

A total of four railroad gates with flashers and bells are provided at the roundabout. Sensors in the tracks allow the gates to go down before a train arrives.

The four gates drop in succession to allow most vehicles already in the circle to exit before the train arrives. After the train leaves the circle, the two gates next to the tracks raise first allowing vehicles coming from the traffic signal to get a head start into the roundabout. The design speed for vehicular traffic in the roundabout is 18 mph. The safety of the intersection is enhanced by the reduced speeds and the lower number of conflict points inherent in the roundabout design.

Light Rail in Nantes, France

The light rail system in Nantes, France, has more than 20 roundabouts with light rail through the center. Boulevard Salvador Allende has nine roundabouts in a row with light rail through the center. None of the intersections are controlled by gates but rather are controlled by traffic signals next to the tracks. In France, gates are usually reserved for crossings of high-speed rail not for light rail. CERTA in France has developed a design guide for using light rail in and near roundabouts.

Light Rail in Melbourne, Australia

The light rail system in Melbourne, Australia, has more than eight roundabouts with light rail through the center. The roundabout that inspired the Salt Lake City project has since 2000 been replaced by a traffic signal controlled intersection and the roundabout has been removed.

Existing versus Future for the Roundabout Intersection

The existing University of Utah roundabout intersection is shown below (Figures 7 through 9). During the 9 years that the roundabout with light rail has been in service the number of auto crashes has reduced by 50%. No light rail–auto crashes have been reported at the intersection. The roundabout experiences minor rear-end or sideswipe–type crashes.

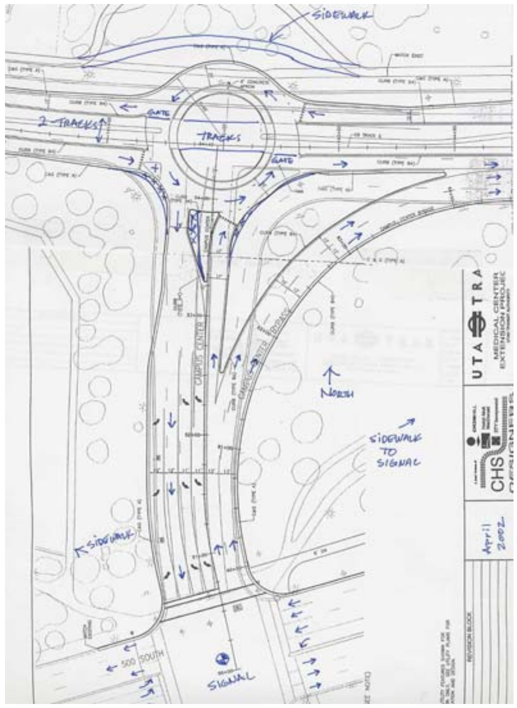

FIGURE 6 Roundabout construction drawing: four gates.

FIGURE 7 Roundabout during winter driving conditions.

Westbound p.m. peak period traffic often backs into the roundabout because of a signalized pedestrian crossing approximately 250 ft to the west. This crossing was originally proposed to be below grade in a tunnel that was not constructed for funding reasons. A tunnel for this pedestrian crossing is recommended to improve the operations and capacity of the roundabout.

(a) **(b)**

FIGURE 8 (*a*) Light rail in Nantes, France, and (*b*) CERTA *Roundabouts and Light Rail Design Guide*.

FIGURE 9 The University of Utah roundabout intersection in 2012. (Note two-lane bypass on the right side.) (Source: Google Maps.)

FIGURE 10 TRAX ribbon cutting, University of Utah, September 29, 2003.

In the future a second vehicle lane that bypasses the roundabout across the north side or top side of the T may be needed to reduce the westbound traffic queues and traffic queues coming from the signalized pedestrian crossing during the p.m. peak periods.

A modern roundabout intersection with light rail running through the center began full operation on September 29, 2003, as part of the University of Utah Health Sciences Center Light Rail Extension in Salt Lake City, Utah (Figure 10). It is located on the University Line between the Stadium Station and the South Campus Station. The roundabout made center-running tracks possible at a major campus intersection. The roundabout is a clear enhancement for the light rail trains as the intersection priority is switched from giving priority to vehicular traffic to allowing the trains full priority.

The use of similar roundabouts with rail crossings was observed by the author on trips to Europe (Nantes) and Australia (Melbourne). These served as the inspiration for the application in the United States. As roundabout usage becomes more common in the United States, creative uses such as this one should be considered. This project was made possible through the cooperation of UTA, the Utah Department of Transportation and the University of Utah.

CONCLUSIONS

The traffic analysis and computer simulations of the study intersection demonstrated the advantages of the roundabout alternative. The roundabout intersection makes center running LRT possible on South Campus Drive. The roundabout gives the light rail trains full priority at the intersection. The low-speed design of the vehicular traffic in and out of the roundabout enhanced the safety of the intersection. The project is an example of how a modern roundabout may improve light rail operations at other locations in the United States.

The Tide
Evolution of Train Detection at Hampton Roads Transit

JAMES PRICE
Hampton Roads Transit

INTRODUCTION

Hampton Roads Transits opened its new light rail system, The Tide, in Norfolk, Virginia, on August 19, 2011. The Tide is 7.4 mi in length and extends from the Eastern Virginia Medical Center–Ft. Norfolk station (EVMC–Ft. Norfolk) to the Newtown Road station at the border of Virginia Beach. The light rail alignment is completely contained within the Norfolk city limits and serves a university, a downtown community college, a city hall and courts complex, a shopping mall, a minor league baseball park, and an entertainment district (Figure 1). It is within walking distance of an active waterfront and maritime museum. Approximately 2.7 mi of the alignment is within the central business district (CBD) and interfaces with 20 signalized intersections. These intersections balance the city's traffic patterns against the scheduled 24-min trip time of the light rail system. Hampton Roads Transit and Norfolk have worked in close cooperation to find the best technology to achieve this goal.

OPERATING CHALLENGES

All train movement in the CBD is controlled by "line-of-sight" operations. Light rail operates at 10-min headways during peak service, 15 min during mid-day and early evening, and 30-min in early morning and late night. During special events, the headways drop to 7 min. The alignment intersects with several primary streets that are particularly important during daily traffic commute times. These streets are needed the most when light rail service is at its peak. Throughout the CBD, light rail trains merge in and out of shared lanes of automotive traffic.

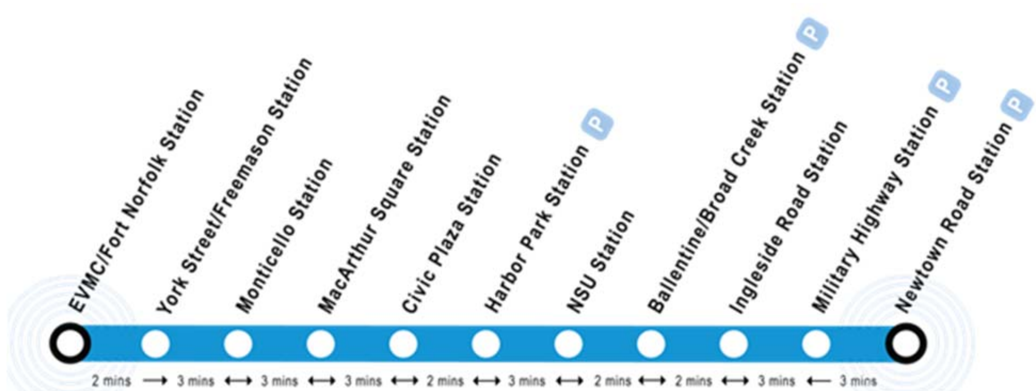

FIGURE 1 The Tide, Hampton Roads Transit's light rail alignment.

The light rail alignment intersects with 12 uncontrolled entries–exits, six uncontrolled pedestrian crossings, and one uncontrolled bike crossing. Finally, the alignment has a number of very tight radius turns (82 ft) that limit operating speeds.

INITIAL DESIGN

The original design of the traffic control interface called for three methods of train detection within the CBD: imbedded induction loops, an infrared detection system, and "end of line" pushbuttons. The imbedded induction loops are in five locations and the pushbutton in one. The vast majority of train detection, therefore, was going to be provided by the infrared detection system. The infrared system is similar to what is being used by fire, police, and emergency medical services vehicles in the Norfolk. Infrared systems have been used in other light rail properties with some success. An infrared detection system has been successfully employed at TRI-MET in Portland. However, during the construction phase concerns were raised that Norfolk's tight radius curves and close proximity to intersections would limit system reliability and would have caused inconsistent train movement within the CBD. This was observed with emergency vehicles within the CBD failing to gain a permissive aspect at certain intersections. Emergency vehicles would proceed with lights and sirens with minimal impact. Light rail vehicles (LRVs) would not have this option. This concern prompted staff to review the design of the traffic management system and quickly realized that there had been no consideration given to the equipment needed to be installed on the LRVs. They also discovered additional wayside sensors were needed to augment the infrared design. Once the oversights had been identified, Hampton Roads Transit considered other options that would avoid increased costs associated with modifying the infrared system. Approximately 18 months prior to the start of revenue service, the infrared detection system was abandoned in favor of radar detection.

Radar Detection

Setting aside the infrared detection system came when much of the civil work in the CDB was advanced beyond any serious modifications. LRVs were already physically present on Hampton Roads Transit property. Any changes to the vehicles would have needed to be performed retroactively. In addition, the project faced severe budget restrictions that required a minimal approach to any design changes. Staff learned that radar detections systems were being used successfully on Minneapolis' Hiawatha Light Rail system and had enjoyed wide acceptance in many European rail systems. Radar detection did not require vehicle modification and very little destructive rework of embedded track or surrounding areas. The equipment and material costs for the radar detection system were under $160,000 and the installation was covered in existing contracts in lieu of the infrared detection system (Figure 2).

The radar detection system uses a transmitter–receiver unit mounted on a pole or structure and pointed along the train path. When a train intercepts the 24-GHz transmission signal, a return echo is detected. This in turn engages a set of contacts that are sent to the intersection's traffic control panel. The device has dip switches which control transmission strength and receiver sensitivity. The individual device can be adjusted for the specific location for optimum train detection. The location of devices was determined by information gathered from the traffic modeling software of light rail and downtown signal operations.

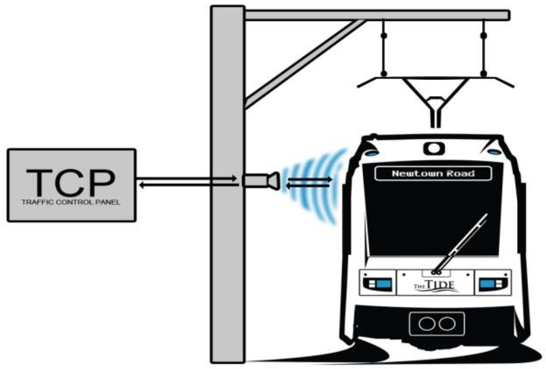

FIGURE 2 Radar detection.

The radar detection system was installed and tested in June, July, and August 2011. The system worked well and consistently. It allowed 24-min trip times while allowing efficient signal coordination, queuing with minimal traffic impact to the city's grid. Trains began moving through the CBD in early July. The radar detection system supported a regular schedule during operator training and the 30-day pre-revenue testing phase. While there were lingering problems, Hampton Roads Transit and the city of Norfolk were satisfied with the radar detection system and felt they could resolve remaining issues with time and experience.

Traffic Control Methodology

The traffic controllers are owned and operated by Norfolk. Based on the traffic modeling software, the city opted to use three different methodologies for allowing train movement through an intersection. These methods are: pre-emption, priority, and continuous cycling.

Thirteen intersections are configured with pre-emption. Upon entry, once a train is detected, the detection signal triggers the traffic controller to pre-empt the current traffic cycle and stop all automotive traffic and provide a permissive aspect to the train (Figure 3). The traffic controller will remain in the permissive state until the train intercepts a second detector on the intersection's exit. The exit detection clears the pre-empt status in the traffic controller and it returns to its normal traffic cycle.

Five intersections are configured with priority. Two of these intersections are in one direction only. These intersections are high-volume traffic arteries, especially at commute times. Upon entry, the train is detected and the train detection signal triggers the traffic controller into a priority subroutine that introduces a train phase into the traffic cycle. Based on when the train is detected relative to the traffic controller's cycle, the arriving train may have to wait to receive a permissive aspect. The traffic controller will retain the train phase until the train intercepts the second detector on the intersection's exit. The exit detection clears the train phase and returns the traffic controller to its normal cycle.

(a) (b)

FIGURE 3 Signal aspects: (*a*) permissive and (*b*) restrictive.

Two intersections are configured with continuous cycling. A train phase is part of the normal traffic controller's program cycle. The controller will provide a permissive aspect to each cycle whether the train is present or not. In both cases, continuous cycling is in one direction only and it is used in locations where automotive traffic shares the same lane as a train.

Technical Challenges

During the first month of operations, the radar detection system began having problems. The radar detection devices began experiencing a wide range of issues, including being overly sensitive, not sensitive enough, or nonresponsive. Operations personnel adjusted the sensitivity and aligned the devices to improve performance. In effect, they made sure the devices were pointed in the right direction to improve performance. The failures and false detections continued but at a reduced rate. False detections in particular have an adverse effect on the operation of the city's traffic controllers. In these instances, the traffic controllers sensing a problem that software could not resolve, switched to "flash" mode of operation. Trains approaching an intersection in "flash" are required to call the operations control center and request authorization to "stop and proceed." As time passed, "stop and proceed" authorizations persisted and have become a serious operating challenge.

Maintenance personnel had a high degree of confidence that the radar detection devices were working as designed, were properly installed, and were adjusted for the environment. Further study revealed that delivery trucks encroaching onto or near the alignment were triggering the devices. Heavy rain also could generate an echo recognized by the detector. Detectors were repositioned to avoid false detection of trucks, but with mixed success. No solution for the rain echo has been found. A heavy thunderstorm and downpour can put every traffic controller into flash operation. Another detection system was needed.

Safety

The primary purpose of the traffic detection system is to allow trains and automobiles to safely coexist in the CBD. The frequency of false detections has limited the effectiveness of the detection system and compromise system safety. The number of unresolved traffic detection problems in May 2012 caused approximately 12 requests for "stop and proceed" authorizations per day (Figure 4). Hampton Roads Transit and Norfolk agree that the current traffic detection system is unacceptable and must be improved.

Radio Frequency Tagging

The City of Norfolk and Hampton Roads Transit turned to a prototype detection system using a radio frequency (RF) detector designed to detect the presence of a "tag" mounted on a train (Figure 5). The system is similar to those used by toll facilities around the county. The tag can be either passive or semipassive (requires batteries) and is mounted on the roof of the train. The RF detector (antenna) senses the presence of the tag from preset variable ranges and can be configured for single or bidirectional detection. The wayside detector is mounted on the same structures as the radar detectors (OCS poles, etc.). The wayside detector has a low operating range, but it is perfect for train detection.

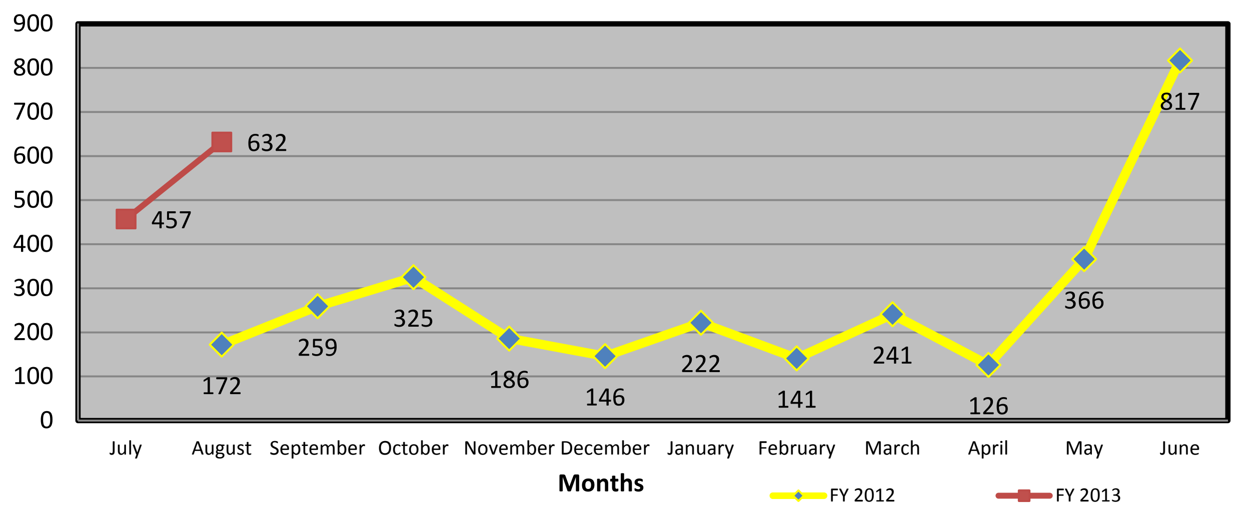

FIGURE 4 Number of false detections.

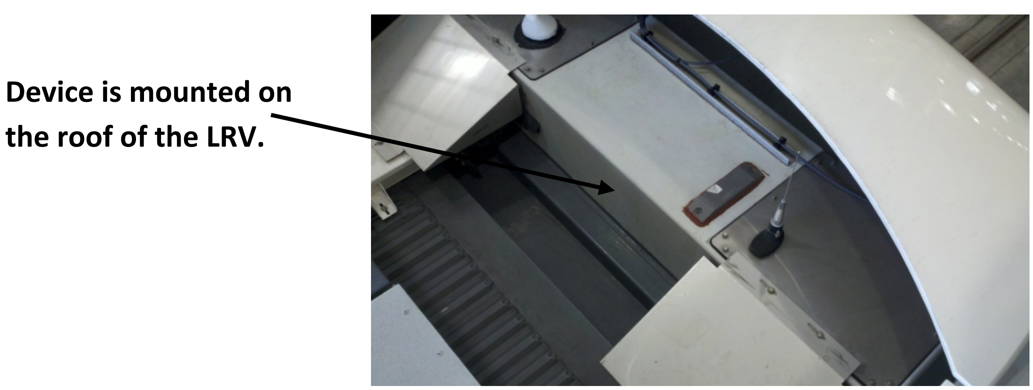

FIGURE 5 RF transmitter (tag).

The prototype test phase was a great success. Intersections outfitted with the prototype RF detection system were highly reliable with zero false detections or failures during the test period. They appear immune to heavy rain. Equipment and material costs are anticipated at $250,000 to $300,000. Hampton Roads Transit and the Norfolk have agreed to implement the RF detection system as soon as procurements will allow. Hampton Roads Transit expects to have the new train detection system in place by the end of fall 2012.

CONCLUSION

The purpose of this paper was to discuss The Tide operating challenges and the evolutionary process train detection has taken during its first year of operation. Hampton Roads Transit and the City of Norfolk have worked together to face challenges and to resolve them. Infrared detection was abandoned during the construction phase. Radar detection was a service proven technology that was relatively easy and inexpensive to install. Radar detection proved to be unreliable in mixed-traffic locations and during periods of heavy rain. The number of unresolved train detections compromised the reliability of the train–automobile traffic control system and lead to safety concerns. Hampton Roads Transit and Norfolk conducted a prototype test of an RF tagging detection system that proved highly successful and plans to implement in 2012. Although The Tide has had no incidents of automobile or pedestrian accidents during the first year of operations, Hampton Roads Transit is committed to the maintenance of its safety record and believes the upgrade to the RF train detection system is vital to its continuing success.

Growing Streetcar Lines from Urban Circulators to Metro Light Rail Transit Systems

Economies of Scale in Operating Costs for Light Rail Transit and Streetcars

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IBI Group

Operating and maintenance (O&M) costs receive less attention than might be warranted, given that they recur each year as part of a transit agency's budgeting process. A number of things can be learned from the annual O&M costs incurred by the existing streetcar and light rail transit (LRT) systems operating in North America. First and foremost among these is that modal average 'unit costs' for O&M can be very misleading. The range in O&M costs per passenger-mile (the most objective overall measure of the cost of providing transportation service per unit of service actually consumed) varies by almost two orders of magnitude (from about 12 cents to almost 6 dollars), and substantial variances exist within individual modes due to the factors mentioned above. For LRT and streetcars, there are some significant economies of scale that drive down the O&M unit costs (per passenger-mile) between very small and very large systems. These can be better understood in terms of passenger traffic density (PTD), system extent (network route-miles), and average commercial speed (ACS). This paper explores these relationships based on data reported to FTA and CUTA (in Canada) for the calendar year 2009, and identifies circumstances under which caution should be exercised in making generalizations about rail O&M costs.

INTRODUCTION

Operating and maintenance (O&M) costs for streetcars and light rail transit (LRT) receive less attention than might be warranted given that they recur each year as part of a transit agency's budget. One reason for the relative lack of attention to O&M costs is that the initial capital costs of electrically propelled rail systems can be quite high, and cost-effectiveness of the initial investment is, and should be, an important consideration. Examination of the initial capital costs of bus and rail-borne systems that are comparable in terms of speed, throughput, and other performance characteristics suggests that a premium of about \$5 to \$7 million (2009 dollars) per route-mile for electric rail technology in the form of trackwork and electric traction elements, independent of the nature of the alignment (e.g., underground, elevated, in exclusive at-grade reservations, or in streets). Using a representative range of effective service lives for these elements (25 to 35 years) and a historic range of discount rates applied for transportation projects (4% to 7% per annum), then rail technology carries an annualized capital premium on the order of \$250,000 to \$600,000 per route-mile per year.

Rail vehicles also typically carry a premium in terms of capital cost per unit of capacity, even when annualized to reflect the much longer service lives of streetcars and light rail vehicles (LRVs). Across the wide range of service levels operated by North American streetcar and LRT systems this can represent an incremental \$3,000 to \$200,000 annually per network route mile.

The additional investment in rail is frequently justified on the basis of rail technology being less expensive to operate, as it in fact is on average. However, in evaluating the overall economic merits of rail technology, it is not unreasonable to consider the extent to which the potential O&M savings may cover the annualized capital cost. That in turn requires an understanding of how those costs can be expected to vary with system characteristics. Considerable caution should be exercised when borrowing cost experience from existing operations or making generalizations about the O&M costs of either streetcars or LRT. The overall favorable impression of rail O&M costs is formed by a number of successful systems whose sheer size determines the average modal performance for both LRT and streetcars. For streetcars, all systems other than Toronto's have much higher unit costs; the top five to 10 light rail systems in terms of passenger-miles (PM) have much lower unit costs than most of the others.

For LRT and streetcars, there are some significant economies of scale that drive down the O&M unit costs between very small and very large systems. These can be better understood in terms of system size (network route-miles or NRM), passenger traffic density (PTD, the ratio of system PM to network route-miles), and average commercial speed (ACS, the ratio of revenue vehicle hours to revenue vehicle miles). This paper explores these relationships based on data reported to FTA (*1*) and the Canadian Urban Transit Association (*2*) for the calendar year 2009, supplemented by information from transit agency websites.

A number of things can be learned from the annual O&M costs incurred by the existing rail transit systems in North America. First and foremost among these is that modal average unit costs for O&M can be very misleading. The range in O&M costs per passenger-mile (the most direct overall measure of the cost of transportation service per unit of service actually consumed) spans almost two orders of magnitude (from about 12 cents to almost $6), and substantial variances exist within modes. Broad statements such as "rail is cheaper to operate than bus" need to be qualified by assuring that such statements are true for the particular circumstances.

The wide range in rail unit costs can be seen in Figure 1, which compares a measure of total system size (PM) and total system O&M costs per PM. Even systems of similar size and traffic density, employing the same mode, can differ by a factor of two in terms of O&M cost. This is where both ACS and the extent of elevated or underground construction have an impact. In order to include the full range of system data (e.g., between the Kenosha, Wisconsin, streetcar and the New York City subway system), a logarithmic scale has been used for both the horizontal and vertical axes in this figure. Streetcars, defined here as operating predominantly in mixed traffic, fall on a continuum of O&M costs with larger LRT systems and even urban rapid transit, designated as heavy rail (HR) by the FTA.

It is also worth observing that bus systems do not exhibit economies of scale to anywhere near the same extent as rail systems; very few bus systems incur O&M costs of less than 45 cents per PM. Figure 1 includes a curve representing the unit cost experience of the average U.S. directly operated bus system relative to system PM. Up to about 10 million annual PM in size, the economies of scale are similar (although rail costs are higher), primarily reflecting changes in average vehicle load. For bus systems, a return towards higher unit costs at the upper end of the size range (over 30 million system PM) is due to traffic congestion (and its attendant lower ACS) in the nation's larger metropolitan areas. All other factors aside, unit costs for rail systems are likely to be markedly higher than for bus at system sizes below 10 million PM, and lower for system sizes over 100 million PM. The value of $0.70 per PM is a convenient benchmark for bus systems, representing an average value for efficiently operated systems of moderate size, operated predominantly with single-unit (12-m or 40-ft) buses.

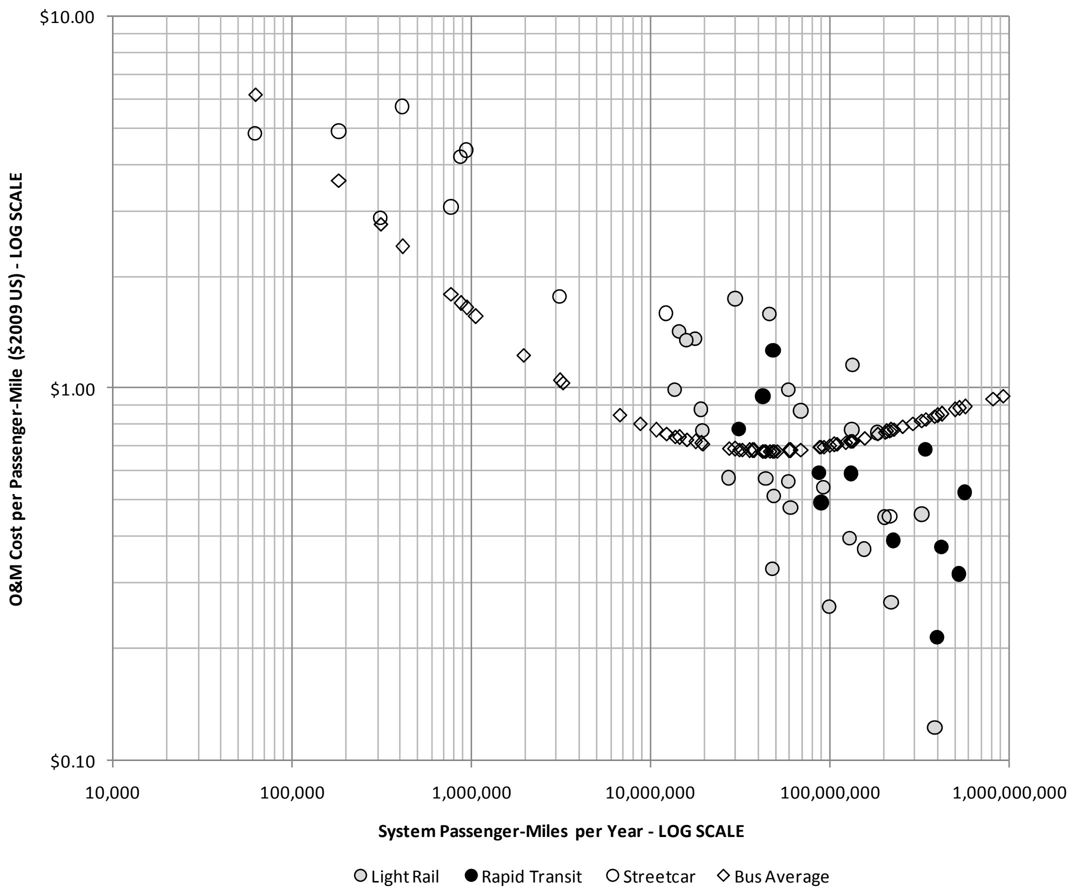

FIGURE 1 Unit O&M costs for calendar 2009 by system size.

ECONOMIES OF SCALE

Higher PTD acts in several ways to bring down unit O&M costs:

- It allows larger vehicles, and ultimately multiple-unit trains of increasing length, to be scheduled at headways appropriate to the service being provided. Operating labor is a large component of transit O&M cost and rail modes can increase the number of passengers carried per unit of operating labor as PTD increases.
- The sometimes substantial nonvehicle maintenance (NVM) costs for the guideway itself, signals and communications, and electric traction systems are spread over a larger number of PM. Although streetcars do not tend to have extensive infrastructure beyond the track and OCS themselves, some LRT systems approach rapid transit in terms of underground or elevated infrastructure. Comparison of the two most extensive underground portions of relatively new LRT (Buffalo, New York, and Edmonton, Alberta, Canada) suggests that underground LRT costs about $1 million per route-mile per year more to operate and maintain than a surface configuration; at the average PTD of 3.5 million for North America's LRT systems, this alone would correspond to $0.29 per PM.

- The basic support facilities and organizational basis typically required to be in the rail business to any extent whatsoever are spread over more PM; this becomes especially noticeable for systems of small physical extent (i.e., less than three NRMs).
- Higher PTD can warrant the provision of reserved street lanes or exclusive rights-of-way to free the transit operation from traffic congestion or delays at traffic signals. The resulting higher ACS will result in more PM being provided per unit of operating labor for the same vehicle or train size.

Figure 2 shows the unit O&M cost per NRM for the urban or local rail modes arrayed against PTD on the horizontal axis. There is a fairly evident continuum visible from streetcars to rapid transit. At the higher-density end, the costs compare favorably with the benchmark bus value as shown. Streetcar systems generally fall at the low end of the density scale, however, and therefore exhibit higher unit costs on that account. That this is a density effect rather than a technological one is borne out by the Toronto Transit Commission's streetcar system, which has a PTD of about 4 million, comparable to many LRT systems.

Figure 2 also includes two curves for reference: one that corresponds to the benchmark bus level of O&M cost for a given PTD and one that represents this amount less an allowance of $600,000 to represent an annualized premium for rail transit as described above. This suggests that a median rail system would attain the benchmark cost level at a PTD of about 3 million (neglecting capital costs), and could cover the capital premium at a PTD of about 5 million.

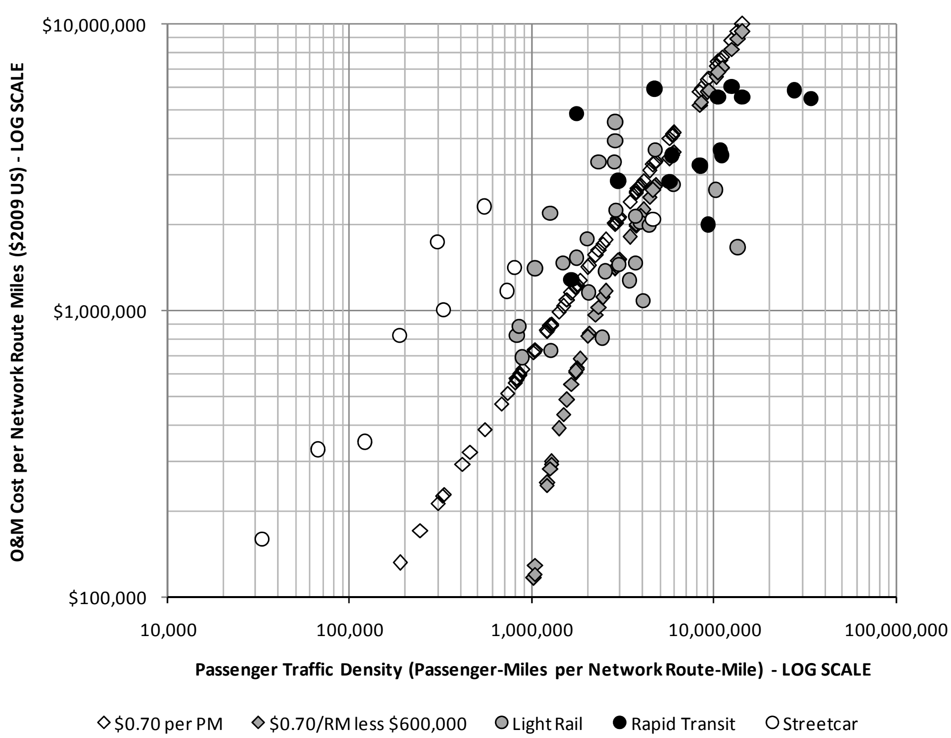

FIGURE 2 Unit O&M cost per NRM versus PTD.

Figure 3 compares unit O&M cost directly with PTD. There is a generally consistent trend, as indicated by a formula in Figure 3 that adjusts for some of the higher infrastructure costs of systems with extensive elevated or underground alignments. The formula suggests that the unit costs increase as the 0.725 power of PTD (i.e., the slope of the trend line through them in log–log space is about 0.725). This needs to be interpreted carefully, because it cannot be presumed to apply to a specific system after it is built. Strictly, this means something like "for a specific system configuration (e.g., network size and number of stations), a system cost-optimized to carry twice the PTD as an otherwise similar cost-optimized system can reasonably be expected to have a total O&M cost only 65 percent higher."

A principal effect of PTD on costs is through the average vehicle load. Figure 4 shows unit O&M cost per PM arrayed against the average vehicle load [system PM divided by system vehicle-miles (VM)]. As might be expected, these costs are generally in inverse proportion to the average load. As a benchmark, Figure 4 also shows the median rail O&M cost per VM ($16.52) divided by the average vehicle load on the horizontal axis. From this figure it can be observed that

- Streetcar systems almost always cost more than the rail median to operate per mile. This can be attributed to their lower ACS, due in turn to in-street running and short distances between stops.
- Rapid transit systems usually cost less than the median, despite their higher infrastructure maintenance requirements. This is due to the relatively high speeds enabled by the investment in grade-separated alignments.

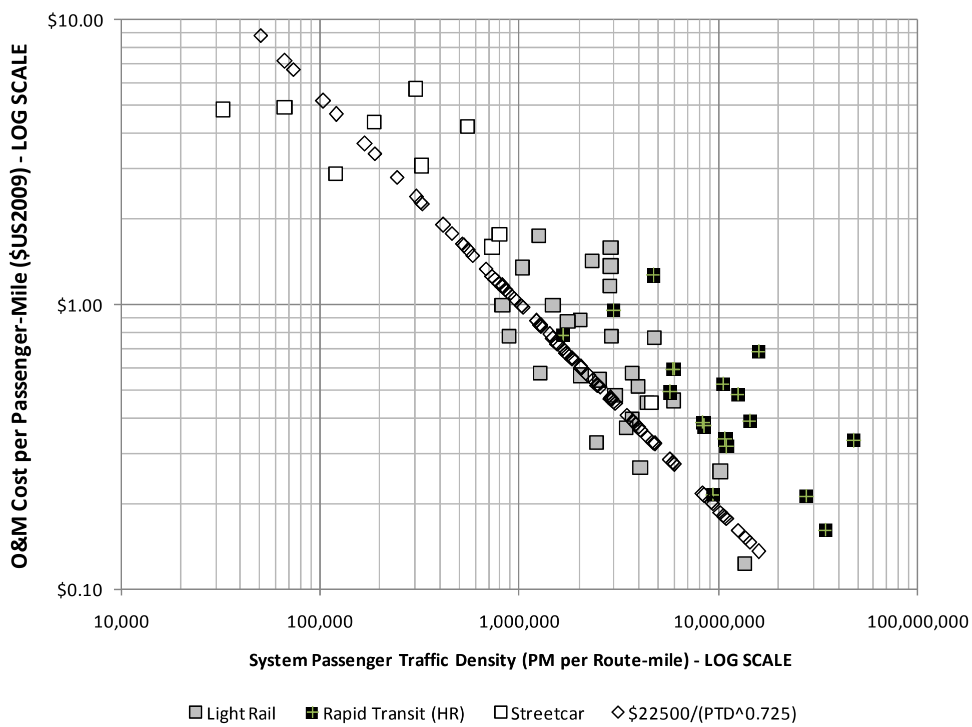

FIGURE 3 O&M cost compared directly with PTD.

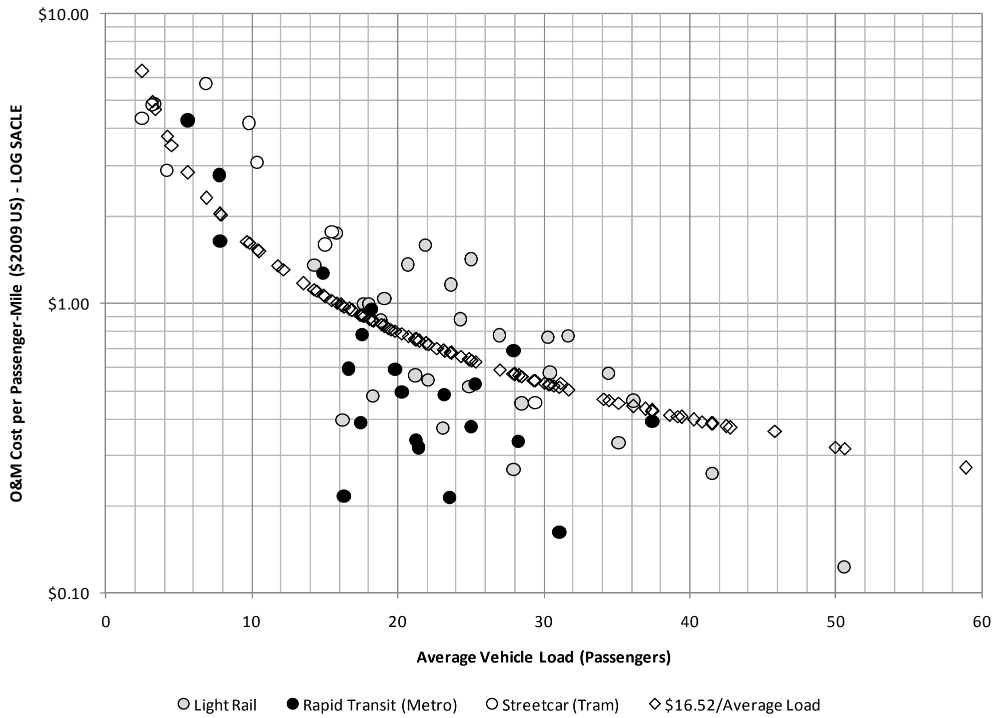

FIGURE 4 O&M costs versus average vehicle load.

- As might be expected, LRT spans these two classes, including some systems more similar to either streetcars or rapid transit than others. As a general rule, the LRT systems exhibiting costs well below the rail median are quite distinct from streetcars, running for substantial distances in reserved rights-of-way at grade without traffic signals. The top five systems in this regard are Calgary, Denver, St. Louis, Salt Lake City, and San Diego.

Figure 5 is intended to show the effects of ACS on unit O&M costs. The vertical axis is the ratio of each system's unit cost to that which would be expected with its actual vehicle load and the median vehicle operating cost per mile ($16.52). This was one to try to isolate speed-related effects from the strong vehicle load effects evident in Figure 4. Although considerable noise remains attributable to differences in regional costs and the extent of underground and elevated construction, the conclusion that speed is a major contributor to efficiency is easy to reach. For reference purposes, points representing the ratio assuming speed is the sole determinant are shown. At low end of the ACS range, the effects of both lower energy consumption and either automation (for a rapid-transit style people mover classified as rapid transit for the purposes of this analysis) or inclusion of some volunteer labor act to bring costs below the level extrapolated based on speed alone.

Since the 1980s, Schumann has been maintaining a distinction between Class I LRTs over 15 mph, and Class II LRTs at lower average speeds (*3*), and this distinction is pretty clear in Figure 5. The Class I LRTs indeed substantially overlap rapid transit, while the Class II systems transition more closely resemble the streetcar systems. Schumann originally defined streetcars as a separate category and, with the advent of modern streetcar systems, there may be merit in re-establishing this grouping which was previously used by the FTA.

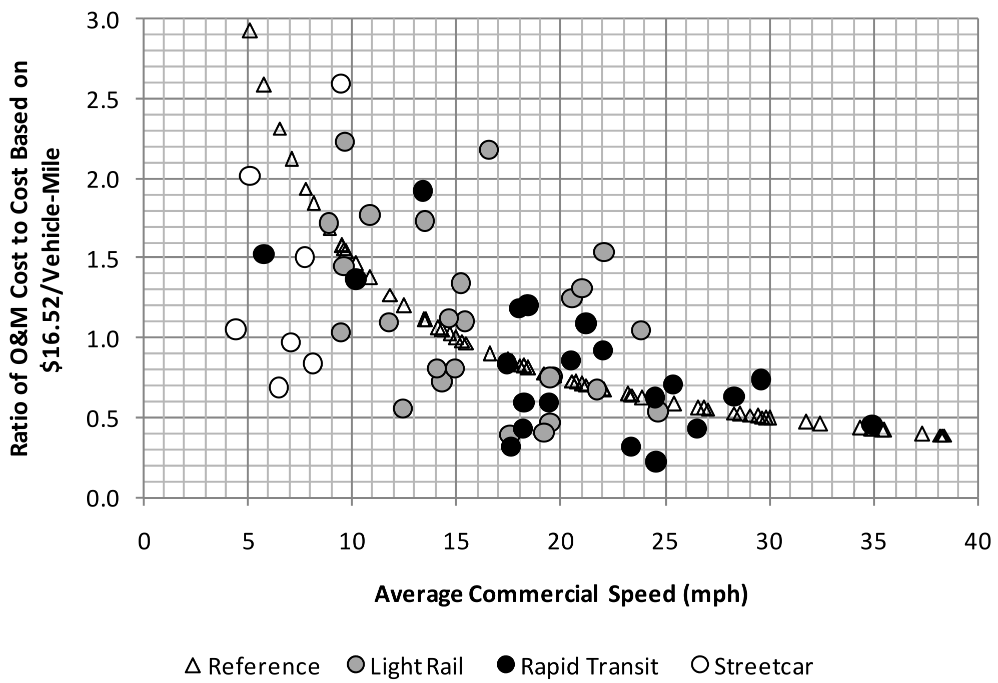

FIGURE 5 O&M cost ratio versus average commercial speed.

OBSERVATIONS

Analysis of the O&M costs of North America's rail transit systems in 2009 suggests that the presence of the following conditions for a proposed LRT or streetcar system may warrant redoubled attention to the O&M costs for the proposed system with respect to possible bus-based alternatives:

- System extent of less than 3 NRMs;
- System size (demand) of less than 30 million PM per year;
- Passenger traffic density (person-miles per NRM per year) of less than 3 million;
- Average commercial speed (revenue hours per revenue mile) of less than 15 mph.

The more of these conditions that pertain, the greater the risk of experiencing costs per PM that may be much higher than the bus benchmark of $0.70. Across all the North American streetcar and LRT systems, the average O&M cost per person-mile in 2009 was $0.54, well below the bus benchmark; including the premium for annualized differential capital costs, this average was likely about $0.67. However, as shown in Table 1, the presence of the factors above is strongly correlated with expectations for O&M unit cost, both with and without the inclusion of a premium for the annualized differential capital costs of rail technology.

This suggests that the average person-mile delivered by North American streetcar and LRT systems does indeed cost less, even including capital, than a benchmark bus. However, the larger and higher-speed LRT systems are the ones that dominate the multisystem average. For these leader systems, with none of the conditions indicated as correlated with high costs, the

TABLE 1 Estimated Unit O&M Cost Performance of Streetcar and LRT Systems

System Group	Average O&M Cost per PM (2009$)	Average O&M Cost and Differential Annualized Capital per PM (2009$)
All U.S. and Canadian LRT and streetcar systems	$0.54	$0.67
Systems with no conditions associated with high costs	$0.30	$0.37
Systems with one condition associated with high costs	$0.62	$0.76
Systems with two or more high-cost conditions	$1.14	$1.38
Systems with three or more high-cost conditions	$1.59	$1.99
Benchmark bus system (single-unit buses predominate)	$0.70	$0.70
Average of six BRTs[a] (articulated buses predominate)	$0.54	$0.54

NOTE: BRT = bus rapid transit.
[a] York Region Transit VIVA, Translink B-98, MBTA Silver Line, Honolulu City Express B, Eugene EmX, and Las Vegas MAX.

unit O&M cost is on the order of one half of the cost of the benchmark bus. For comparison purposes, it should also be noted that for six bus rapid transit (BRT) systems operating predominantly with articulated (18-m or 60-ft) buses, the average cost per PM was about $0.54.

Indeed, at about $0.88 per person-mile (and $1.10 including the capital premium), the median system among North American LRT and streetcar systems is more expensive than the bus benchmark. This reflects the existence of many streetcar systems and some LRTs operating at over $2.00 per PM.

It should therefore not be simply assumed that rail is cheaper to operate than buses when going into an assessment of alternatives. The presence of any of the conditions above should suggest that this may not turn out to be case for a specific instance and it may not be realistic to claim this as being among the benefits of choosing rail without substantiation.

ACKNOWLEDGMENT

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Right-of-Way Treatments to Enhance Light Rail Transit and Streetcar Operations and Aesthetics

Enhancing Neighborhoods Through Streetcar Development in Paris, France

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INTRODUCTION

There has been considerable international interest from both researchers and planners in the development of new light rail transit (LRT) systems in France (*1–3*). Much of this interest has focused on smaller French cities and towns where LRT has acted to substantially transform both mobility and urban form with much reported success (*4–7*). However, it is not true that the development of new and innovative French LRT has only focused on smaller towns. LRT has also been implemented in Paris, the capital of France, with many similar successful outcomes.

This presentation outlines some of the light rail developments in Paris with a focus on urban design transformations that have been implemented as part of light rail development projects. First, an overview of system development is described. Then each of three LRT lines are presented and outcomes illustrated. Environmental features including artwork and general approach are then discussed.

LIGHT RAIL DEVELOPMENT IN PARIS

Light rail development in Paris has focused on the Île-de-France region which is a wider urban metropolitan region surrounding the city of Paris [Note: The city of Paris has an urban population of 2.21 million (2008) while the Île-de-France region as a whole has 11.66 million (*8*).] There are currently four LRT systems, each named T1 to T4. The first three lines are operated by RATP which also operates the Paris Métro and most bus services in Paris. The fourth is operated by SNCF (The French National Railway Corporation). This paper focuses on lines T1 to T3, which are operated by RATP.

A major focus of LRT development in Paris has been improving access and livability of suburbs in the regions ringing the inner Paris region (see Figure 1). New LRT systems have acted to improve circumferential mobility while also improving access to radial transit lines into the inner Paris core areas. A key feature of light rail development in this context is the transforming of streetscapes on peripheral streets and boulevards applying innovative traffic engineering techniques using streetcar system development. Three new streetcar lines, beginning with T1, T2, and T3 (and T4) have already been developed (Figure 1) and form the beginnings of a ring around the city. Line T1 (Table 1) was the first developed in 1992 and is to the north of the city. Line T2 followed in 1997 and lies to the west. Line T3 is the newest and will be the largest covering the eastern and southern parts of Paris.

Figure 2 illustrates the considerable service development program that is underway with Paris light rail. In addition to line extensions, four new lines are planned. The aim is to trigger significant economic development and an entirely new modern appearance for their neighborhoods, brought on by application of a comprehensive approach to traffic engineering, streetscape design, and the insertion of an on-street streetcar system.

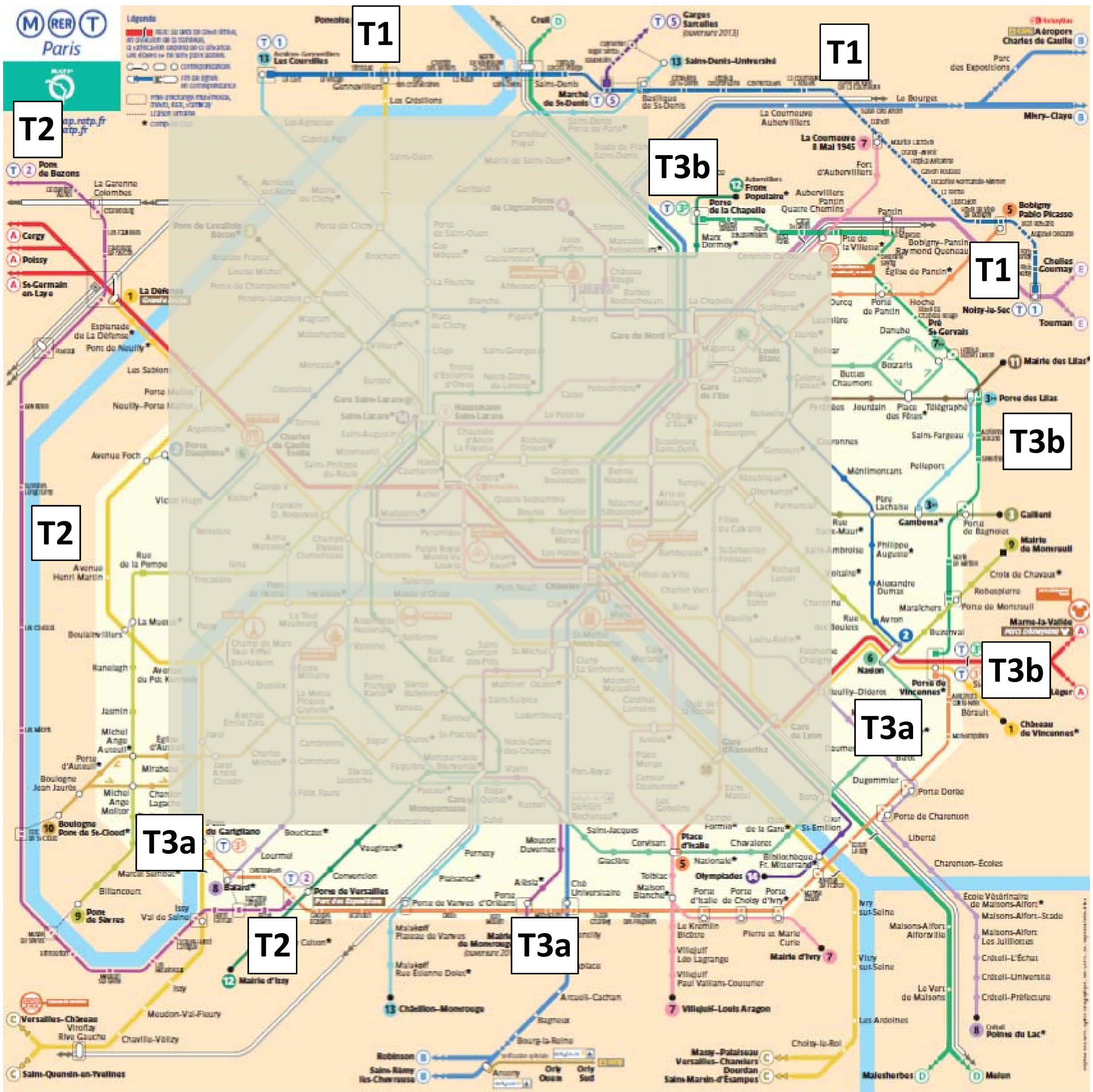


FIGURE 1 T1 to T3 route alignments.
(Note: Central area shaded to highlight fringe routes.)

TABLE 1 Key Features of Paris Lines T1 to T3

Line	T1	T2	T3a
Current termini	St. Denis to Noisy-Le-Sec	Pont de Bezons to Porte de Versailles	3a: Pont du Garigliano to Porte de Vincennes 3b: Porte de Vincennes to Porte de la Chapelle
Year opened	1992	1997	2006
Year extended	2003	2009	—
Length (mi/km)	7.5/12.1	7.2/11.6	4.9/7.9
Stations	26	16	17
Passengers/day	115,000	110,000	130,000
Vehicles	35; Alstom first generation	52; Alstom Citadis 302	21; Alstom Citadis 402

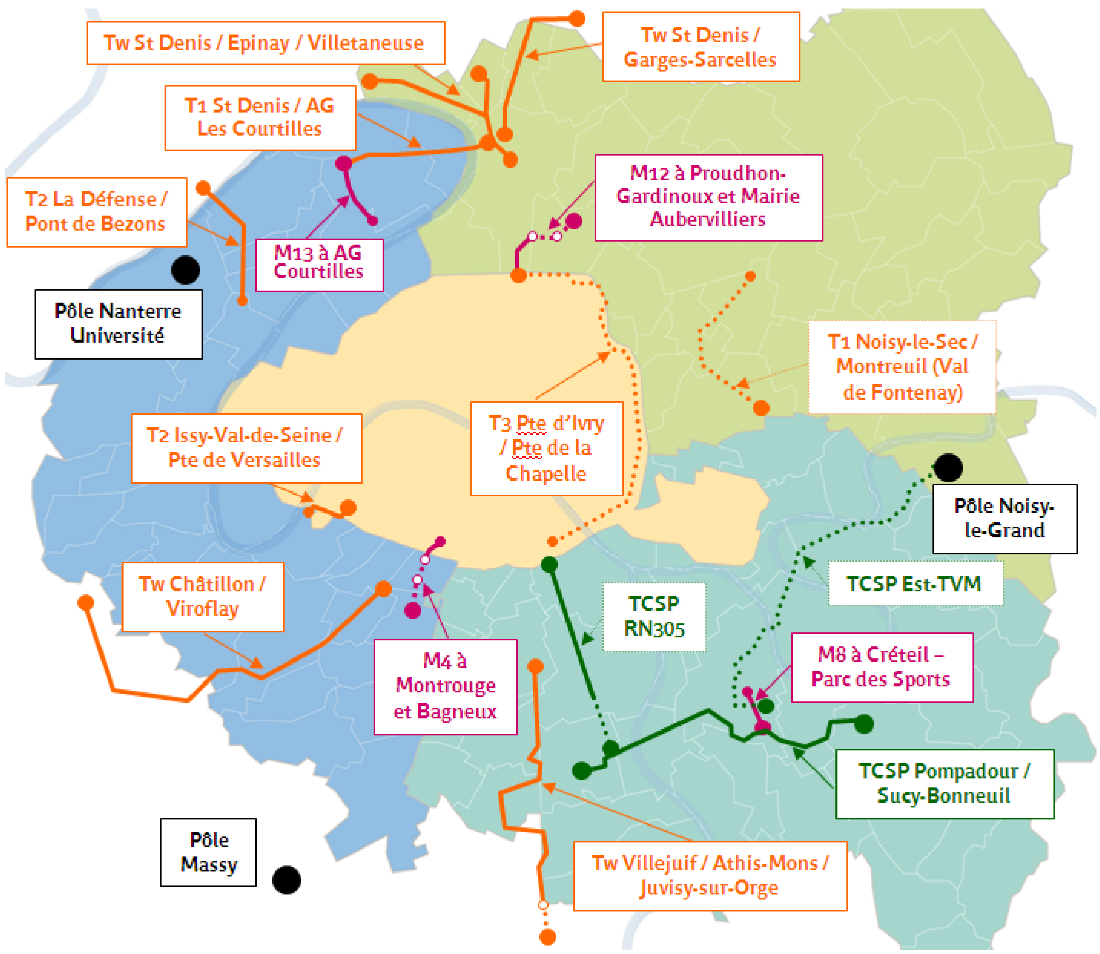


FIGURE 2 LRT development projects in Paris.

T1 LINE

Created in 1992, the T-1 line (St. Denis–Noisy-Le-Sec) (Figure 3) was created to link five municipalities along the northern perimeter of Paris' city limits. Prior to T1, streetcars had not existed in Paris since 1937. The line became a vital transportation connector linking passengers to the radial RER commuter railways (Réseau Express Régional or Regional Express Network) and to Metro lines. There have been two extensions of the line, one in 2003 to Noisy-le-Sac which is in the eastern suburbs of Paris and a western extension which just got underway in 2011. The second was a 3-mi extension with 10 new stations. This extension will support an additional 11.5 million trips per year and is scheduled to open in late 2012.

The T1 line extension to the west, which will cover 4.9 km and serve the cities of St. Denis, Ile-St-Denis Villeneuve-le-Garenne, and Gennevilliers Asnieres-sur-Seine. Its commissioning is planned for late 2012. It will feature new amenities such as new lighting, new pathways, and new vegetation as see in the renderings in Figure 4.

FIGURE 3 Paris T1 Line Tram at a suburban station.

FIGURE 4 Paris T1 Line Tram T1 extension.

T2 LINE

With the success of the T1 line, the T2 line was created in 1997 (Figure 5). The T2 line runs just outside Paris to the west and connects the large Paris business areas of La Defense to Porte-de-Versailles. This used older railway tracks which were rehabilitated and converted for streetcar use as part of the development project. The line quickly gained success and in 2005 the trams were doubled in length by coupling two cars together to carry over 440 passengers. Currently RATP has begun work on a 4.2 km northern extension with seven new stations. The expansion continues in the north to Bridge Bezons. Expected at the end of 2012, the extension will allow the service of Commons Puteaux, Courbevoie, La Garenne-Colombes, Colombes, Nanterre, and Bezons.

Some 58,000 travelers take L2 every day or 19 million passengers per year. The extension will service six towns with some 32,000 residents and 19,000 jobs.

Table 2 itemizes the benefits of the tram extension identified in planning studies.

FIGURE 5 Paris T2 Line Tram: well-lit and open plan stations at night.

TABLE 2 Key Benefits of the T2 Tram Extension

Benefit	Key Data
Faster	A streetcar every 4 min during peak hours, and 7 to 8 min in peak hours Travel between Defense–Bezons in 12 min A velocity of 20 km/h in separate lanes with priority at junctions
More connections	Transilien 24 bus lines RER A (Defence) M1 Metro Line (La Défense)
More comfort	A transportation mode with low noise A mode of transportation fully accessible to the disabled A passenger information system in real time
More availability	A service from 5 to 1a.m.
More security	The soft modes recovery (separation of traffic lanes) A video surveillance system

T3 LINE

Of the T lines covered in this paper, the T3 line is the most modern and unique (Figure 6). It is the only of the lines to enter the core of the central Paris region. Having to build a streetcar line in the middle of Paris proved to be an effort of large proportions. Design had to be such that it complemented the history and culture of the specific alignment chosen. RATP had to innovatively rework vital urban areas including meeting environmental objectives. Extensive trees planting (over 1,000 were planted), grass medians and specially designed outdoor lighting were all contributing attributes to the success of this line. The current extension being built will be one of the largest extensions of a streetcar line.

Each of the three current lines and the planning for the new lines and extensions has included innovative traffic engineering solutions to maintain street safety, to assure pedestrian signage and communication, to permit median streetcar operations, and to promote a new design for the entire streetscape.

The focus in Paris was to have a positive impact on the communities through which the new streetcar line traverses. Promoting a new look and feel and creating the potential for significant new economic development.

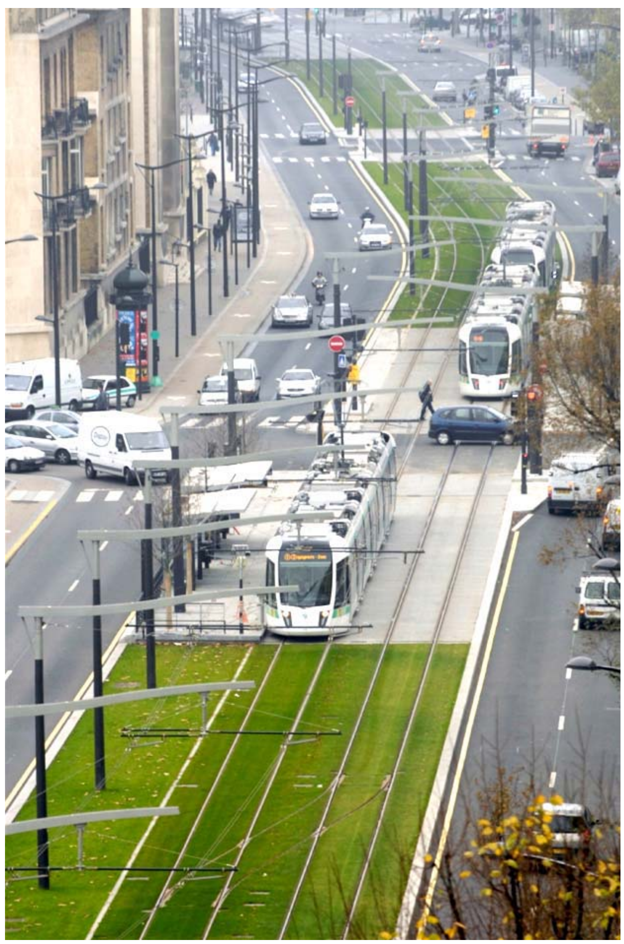
The T3 extension has been an ongoing attempt to reach one goal: How can we improve the life for Parisians and at the same time be an urban link between Paris and adjacent cities? Through the current extension of the T3 line, economic development was ensured through open communication with the general public and businesses in the neighborhoods of the extension. A series of questions were asked to see what they wanted out of their public transportation. The question was answered with the following:

- Meet a growing need for surface transportation ring;
- Improve networking of public transport;
- Improve local service in the east of Paris, and strengthen links with the adjacent municipalities;
- Improve the accessibility of urban transport and pathways;
- Redevelop the urban landscape and the distribution of space.

The T3 extension demonstrates the ability to create a surface transportation ring (Figure 7). The new extension will run in two arcs as noted above. Of the 26 stations that are being built on the T3 extension, 13 connect to Metro and RER lines and 20 of the stations connect to bus lines.

Along with the newly constructed bike path, there will be new “Velib” bike stations added along many station sites (Figures 8 and 9). Some of the large crossings had to be redesigned in order to accommodate the new routes. Traffic lights were changed so that the streetcar will have priority at traffic stops.

(a)



(b)

FIGURE 6 (*a*) Paris T3 Line Tram, grass tracks as part of right-of-way design, and (*b*) Paris T3 Line Tram, intersection, road layout, and right-of-way design.

FIGURE 7 Paris T3 Line Tram alignment.

FIGURE 8 A bike path has been designed to parallel the tracks of Paris T3 Line extension near the station Baron Leroy.

FIGURE 9 Paris T3 Line extension: new bridges and adjacent urban development.

EXPRESSIVE ARTWORK

The artist Mark Handforth created a pink lamp post called "Twisted Star Lampost," which creates a surprisingly beautiful light to one of the main entrances to Paris (Figure 10). The artist, known for his playful diversion of street furniture, reinterpreted mainmast. Located in the center of the Place de la Porte de Bagnolet, the mast of Twisted Lampost Star bends before bursting into a star at the top in a five-pointed umbrella which illuminates at night, the roundabout by a halo of rosy light. This landmark on the route of the extension of T3 is one of 19 art projects that line the route to draw a new landscape.

FIGURE 10 Artistic works enhance the tram right of way near the Paris T3 Line extension.

As part of the art projects developed along the extension of the T3, Ben Langlands and Nikki Bell have dressed the metro station Porte de Vincennes with large glass sculptures that are backlit showing the signal “M.” The shape of these works was chosen in response to the square bases of the columns of Ledoux located on the Place de la Nation (Figure 11). Artists have now chosen the scenario highlighted the work. It now remains to rewrite the software principles used in the backlighting technique.The work “Call and Response” will soon be a landmark night along the prolongation of the T3 tramway, changing color at the rate of arrivals and departures of the tram. It points the users to the underground crossing of the Cours de Vincennes by the subway.

ENVIRONMENTAL APPROACH

On the T3 extension, nearly 3,500 trees will be planted along with other types of vegetation and flowers (Figure 12). Landscaping carried out to mark the extension of the tram will keep with the current vegetation planted along the tramline path. The paths were designed to enrich and to stage the Parisian heritage trees while keeping an urban feel.

A major element of planning for the T3 extensions have been creating an active and attractive streetcape (Figure 13). A holistic approach to the design of the tram aims to improve the quality of the urban landscape. Wider sidewalks, improved accessibility and continuous bike lanes will enhance the urban environment system and make for an easy and effective mode of transportation. RATP will continue to look at innovative designs for all their future extensions as it has proven to be an effectual process in bringing people and transportation together.

FIGURE 11 Artistic works backlighting “M” for Metro at station interchanges near the Paris T3 Line extension.

FIGURE 12 Paris T3 Line Extension—flora.

FIGURE 13 Urban streetscape plans for Paris T3 Line extension.

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Purple Line

Connecting the Nation's Capital Transportation System

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The Purple Line is a proposed 16-mi light rail transit (LRT) line project in the Maryland suburbs of Washington, D.C. The Purple Line is planned to provide improved east–west travel among five major activity centers and access to and egress from intermodal connections with the region's transit system by interfacing with two legs of the Washington Metrorail Red Line, the Green Line, and the Orange Line; all three MARC (Maryland's commuter rail) lines; three separate bus systems; the University of Maryland shuttle system; and Amtrak. This project illustrates how LRT, by connecting these activity centers and intermodal connections, can serve a combination of traditional central business district-oriented and emerging "circumferential" travel markets. The project also illustrates that in planning to serve well-developed major activity centers and interfaces with established rail and bus systems and facilities, LRT's adaptability and flexibility must be exploited to provide convenient and efficient intermodal connections.

PURPLE LINE PROJECT

The Purple Line Project is a planned 16-mi east–west light rail transit (LRT) line between Bethesda and New Carrollton running just inside the Washington, D.C., area's Capital Beltway (Figure 1). The Purple Line will serve five major activity centers just north of Washington, D.C.: Bethesda, Silver Spring, Takoma–Langley Park, College Park–University of Maryland, and New Carrollton. These activity centers are experiencing active development and major projects are planned. The Washington, D.C., region's Metrorail system, the nation's second busiest rail transit system, serves four of these major activity centers while three of these centers are served by MARC, Maryland's commuter rail system. Amtrak services along its northeast corridor connect at one of the centers. The following show the transit services that connect at these major activity centers:

- Bethesda: Metrorail's Red Line (west line) and major bus service hub for the Washington Metropolitan Area Transit Authority (WMATA) Metrobus and Montgomery County's Ride On system;
- Silver Spring: Metrorail's Red Line (east line), MARC Brunswick Line, as well as major bus interface at Silver Spring Transit Center for Metrobus and Ride On;

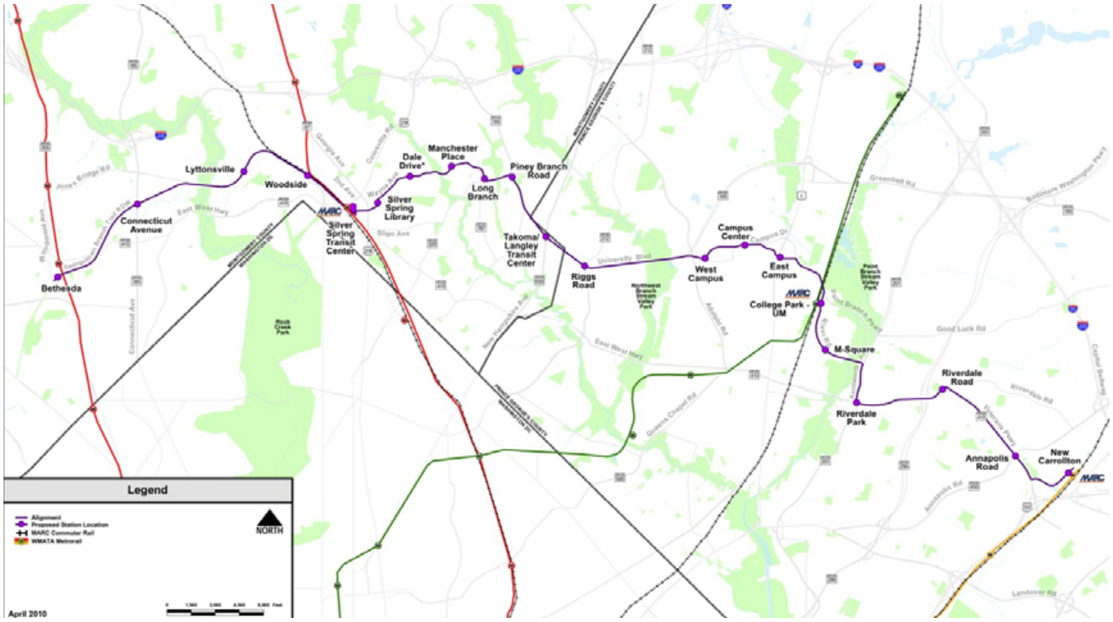

FIGURE 1 Purple Line LRT project.

- Takoma–Langley Park: a planned transit center for WMATA Metrobus regional system, Ride On bus services, and Prince George's County The Bus services;
- College Park: Metrorail Green Line, MARC Camden Line, and the University of Maryland shuttle bus system as well as Metrobus and The Bus; and
- New Carrollton: Metrorail Orange Line terminal, Marc Penn Line, Amtrak Northeast Corridor services, and major bus hub for Metrobus and The Bus.

In addition to these five stations there are another 16 stations serving the residential communities, commercial districts, and institutional establishments between the major activity centers, including three stations serving the University of Maryland with its 37,000 students, 13,000 employees, and visitors. The Purple Line is expected to attract more than 60,000 daily boardings in 2030, with over a third expected to use Metrorail–MARC for some part of their trip, with the Purple Line typically providing the access or egress connection. The project is expected to take 20,000 auto trips off the roads daily. The project is planned to have two maintenance and storage facilities and have a year-of-expenditure capital cost of $1.9 billion with a start of service by the end 2020.

The Purple Line Project is being advanced by the Maryland Transit Administration (MTA), which is part of the Maryland Department of Transportation (DOT). The funding for the project is planned to be 50% from the Maryland Transportation Trust Fund and 50% FTA Section 5309 New Start funds. The project has completed its alternatives analysis–draft environmental impact statement (EIS) and was granted entry to preliminary engineering and final EIS (FEIS) completion by the FTA in October 2011. The MTA continues to explore various procurement, financing, construction, and operating options for implementing the project. Start of construction is planned for 2015.

SERVING THE EMERGING TRAVEL MARKET

Changing land uses in the Washington metropolitan area have resulted in more suburb-to-suburb travel, while the existing transit system is oriented toward radial travel in and out of downtown Washington, D.C. The only transit service available for east–west travel is bus service, which is slow and unreliable because it operates on congested roadways in the corridor between the major activity centers. There is no efficient, reliable, and high-capacity transit for east–west travel in the corridor. The Purple Line would serve transit patrons whose journey is solely east–west in the corridor, as well as those who want to access the existing north–south Metrorail system. The Purple Line would also provide a direct link to the Brunswick, Camden, and Penn Lines of the Maryland MARC commuter rail system and to Amtrak's Northeast Corridor service at New Carrollton.

The Purple Line will principally serve three travel patterns:

- Intracorridor travel. One of the principal travel patterns to be served by the Purple Line is intracorridor trips from people traveling from the residential communities in Bethesda, Silver Spring, Takoma–Langley Park, College Park, and Riverdale–New Carrollton to three major activity centers within the corridor: Bethesda, Silver Spring, and College Park. These trips would be people using the Purple Line to travel from the communities adjoining the major attractions and are not people making lengthy trips across the entire corridor.
- Corridor productions to attractions outside the corridor. Another principal travel pattern would be trip productions from the corridor to attractions outside the corridor. These people would be traveling from the residential communities in the corridor, especially Silver Spring, Takoma–Langley Park, and Riverdale–New Carrollton to Washington, D.C., particularly the D.C. core and northern D.C. There would also be travel north of the corridor along the Metrorail Red Line branches and the Green Line. These trips are expected to be from residential communities in the corridor using the Purple Line for relatively short to moderate length east–west trips across a portion of the corridor to access the Metrorail and north–south bus services to make generally longer trips to D.C. and other attractions along the Metrorail and bus lines.
- Productions outside the corridor to corridor attractions. The third principal travel pattern would be trip productions from outside the corridor to attractions within the corridor as people travel from the residential communities outside the corridor, especially northern and eastern D.C. and other areas south of the corridor, from Glenmont and Laurel to the north, and from Bowie and areas to the east (through the New Carrollton Metrorail Station), to attractions in Bethesda, Silver Spring, and College Park. These trips would be from residential communities south, north, and east of the corridor using the Metrorail and north–south bus services to access the corridor and using the Purple Line for relatively short east–west trips across a portion of the corridor to access the attractions in the corridor activity centers, principally Bethesda, College Park, and Silver Spring.

The travel market that would be served by the Purple Line has two principal components:

1. Traditional travel pattern. Travel from residences in the corridor to the major activity centers in the Washington, D.C., region with some "reverse commute". For this market, the Purple Line would be providing the access link within the corridor to the regional rail and bus system that serves D.C.

2. A series of traditional travel patterns. Travel to the five major activity centers in the corridor (Bethesda, Silver Spring, Takoma–Langley Park, College Park, and New Carrollton) from the residential communities within the corridor or the communities south, north, and east of the corridor. For this market, the Purple Line would be acting as a transit link to these major activity centers from the adjoining residential communities, either as an access link within the corridor or as the distribution link from Metrorail/radial bus services from the community outside the corridor.

PURPLE LINE SERVICE STRATEGY

The corridor has a sizeable population that already uses transit and contains some of the busiest transit routes and transfer areas in the Washington, D.C., metropolitan area. Many communities in the corridor have a high percentage of households without a vehicle, most by household income limitations but some by choice due to availability of transit and other options such as Zipcar. Continued growth projections of population and employment in the corridor indicate that there will be a growing need for corridor transit improvements. The increasingly congested roadway system does not have adequate capacity to accommodate the existing average daily travel demand, and congestion on the existing roadways is projected to worsen as traffic continues to grow through 2030. Many communities in the Purple Line corridor are built out; therefore new road construction or road widening to increase capacity and reduce congestion are not feasible.

North–south rapid transit serves parts of the corridor, but transit users who are not within walking distance of these rapid transit services must drive or use slow and unreliable buses that often operate over circuitous routes to access transit stations. Faster and more reliable connections along the east–west Purple Line corridor to the existing radial rail lines (Metrorail and MARC trains), bus routes, and activity centers within the corridor would improve mobility and accessibility. Enhancing the connectivity of the transit system would improve transit effectiveness, making the system more attractive to a larger number of people.

The service strategy for the Purple Line corridor locally preferred alternative is based on maintaining and enhancing the current transit network, improving travel time and reliability, accommodating long-term demand, expanding coverage and access, and ensuring regional service integration. Elements and actions associated with each of these broad-based guidelines are described.

- The corridor has 75 bus routes operating in the corridor, including 44 routes terminating at one of the four Metro stations. Only 13 provide east–west service with the rest being radial routes that cross the corridor and the proposed LRT alignment. Because of the large number of existing bus routes, the feeder bus network for the Purple Line is already in place. Minor modifications will be made to existing routes to serve LRT stations.
- The Purple Line will provide faster and more reliable service than the bus service currently offers with the construction of a dedicated guideway that will allow the LRT to bypass traffic congestion. Traffic signal priority will help maintain LRT schedules by allowing late trains to move through more signals with minimal delay.
- The LRT will provide greater passenger capacity and will help meet future demand for travel through the corridor.

- The Purple Line, in serving four Metro stations on four different branches of the Metrorail system and all three lines of the MARC commuter rail system, will improve network connectivity by providing an alternative route between branches and by serving the approximately 75 bus routes that operate in the corridor.

MAKING THE INTERMODAL CONNECTIONS

Often tying new LRT lines into existing transportation systems (Metrorail, heavy rail lines, commuter rail lines, and roadways) and facilities (rail, bus, airport, ferry terminals and stations, and associated parking garages) means having to fit into existing environments, such as major activity centers, where there are established buildings and infrastructure. These established transportation terminals and major activity centers, for the same reasons that make them attractive for being served by LRT systems, are also places for additional development, leading to competition for available space and proximity to the transportation passenger activities. LRT, as transit mode, has design and operating characteristics that enable it to be flexible and adaptable in integrating into these situations. It presents planners and designers with choices and trade-offs among cost, service, convenience, and impacts. For example, snaking a LRT line to get the station as close as possible to existing transportation services for convenient connections can result in slow speeds due to tights curves and interference from vehicular and pedestrian activity. So while the walk time may be minimized, the in-vehicle time on the slow-running train offsets this convenience. Providing a straighter (higher-speed) alignment into and out of the station may reduce in-vehicle time for the passenger, but may result in a station further away and a longer walk transfer time. LRT system offers the opportunity to make these choices.

The five major intermodal connections that the Purple Line will have with the corridor's existing Metrorail, bus, and commuter rail system—Bethesda, Silver Spring, Takoma–Langley Park, College Park, and New Carrollton—provide an illustration of these opportunities and challenges presented by existing and planned development and facilities.

In addition to the mobility goals and objectives, the project also is striving to address a number of community and economic development purposes:

- Support local, regional, and state policies and adopted master plans;
- Strengthen and revitalize communities in the corridor; and
- Increase potential for transit-oriented development (TOD) at existing and proposed stations in the corridor as identified in local land use plans.

Both Montgomery and Prince George's counties have land use and zoning tools in place that support TOD and have a number of active projects and initiatives in the corridor. WMATA has active TOD projects at several of their stations while Maryland DOT–MTA is engaged in TOD activities at several of the stations. The opportunities and challenges of providing the desired intermodal connections within the existing and planned development and facilities at the each of the five intermodal Purple Line stations are examined below.

Bethesda Purple Line Terminal Planned South Metrorail Connection

The Purple Line western terminal is located in Bethesda, a major concentration of commercial, residential, and institutional activities, that continues to grow especially to the south and west of the future Purple Line terminal station. In addition to serving the travel market generated by the major development located here, the station is planned to interface with the west leg of the Metrorail Red Line, the bus service hub for the WMATA Metrobus, and Montgomery County's Ride On system. The Purple Line will run along a former railroad right-of-way (ROW) located under two separate buildings and a highway bridge for Wisconsin Avenue, essentially forming a 1,200-ft long, nominally 30-ft wide by 22-ft high tunnel for most of the terminal area, one level below grade. West of the Wisconsin Avenue bridge, the space widens a slight bit. In this tunnel space, the Purple Line must locate the station center platform and fare equipment, passenger access, tracks and associated crossovers and tailtracks, and a connection to the Metrorail Red Line station below. In addition, there is a desire to accommodate the continuation of a Montgomery County hiker–biker trail—the Capital Crescent Trail—through this area. There is planned further development over and adjacent to the extreme west end of the ROW and even possible redevelopment of the existing buildings above and adjacent to the ROW.

The underground Metrorail Red Line Station is located 160 ft below Wisconsin Avenue. Currently, the Metrorail station entrance is located at the north end of the station platform, which connects to the bus transfer facility. The Purple Line alignment crosses perpendicular to and over the Metrorail station platform's south end. Montgomery County, with MTA support, is advancing the design of a new elevator-based south entrance for the Metrorail station. The entrance would connect with the surface but also have connections with the Purple Line station level. Figure 2 provides a schematic illustration of this connection. Notwithstanding the physical space limitation at the Purple Line station level, the connection with the Metrorail Red Line station will be relatively convenient for this major intermodal connection. The bus facility associated with the Metrorail station is located adjacent to the existing north Metrorail station entrance. For the most part, the potential bus transfers with the Purple Line will be lines serving the area to the west and northwest. A surface pedestrian corridor is being established to enable this connection and possible routing of some bus routes to more directly connect with the Purple Line is under consideration.

Silver Spring Transit Center Station

Like Bethesda, Silver Spring is a major concentration of commercial and residential activities. While an older community than Bethesda, Silver Spring is experiencing major development and redevelopment of its commercial core, especially around the transit hub. Historically a station on the Baltimore & Ohio Railroad (now CSX) Metropolitan Branch was located ½-mi south of the current station location for the Silver Spring stations for the east leg of the Metrorail Red Line and MARC Brunswick Line, as well as a major bus interface at Silver Spring Transit Center for Metrobus and Ride On. The Metrorail tracks and center platform are located in the middle, and the CSX tracks on which MARC operates are located on the outside. The MARC service has side platforms outside of the track ROW, which are connected by an overhead pedestrian bridge over the four tracks and WMATA platform.

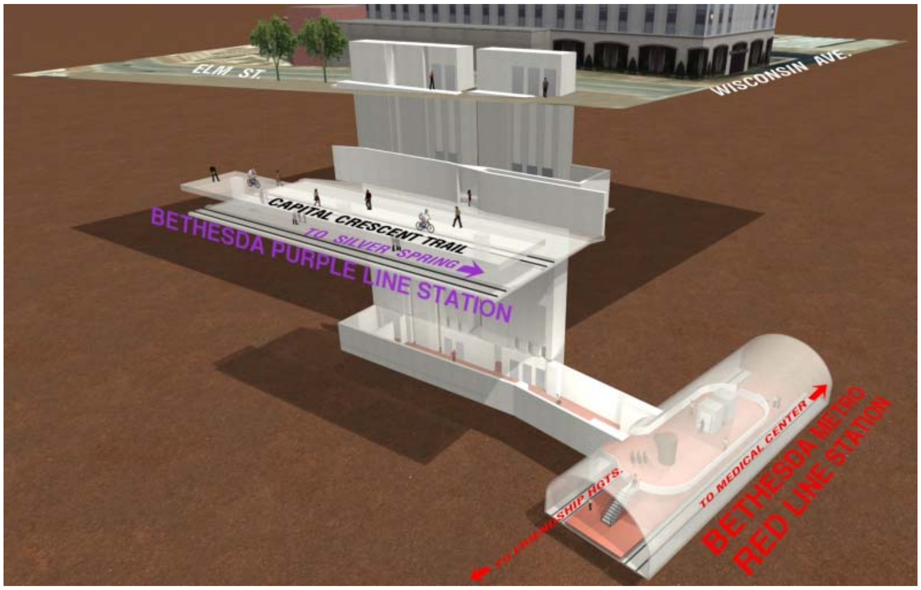

FIGURE 2 Planned Metrorail Red Line Bethesda station south entrance and connection with Purple Line

A new multilevel transit center for the bus services immediately adjacent to the Metrorail and MARC stations is in the final stages of construction. Three building towers are also anticipated adjacent to the other side of the transit center facility. While the area immediately surrounding the transit center and Metrorail–MARC station is developed with commercial and governmental buildings as well as parking structures, major residential development is occurring to the south and north of the complex. The first two levels of the transit center are bus levels. The third level is for kiss-and-ride (K&R) and taxi as well as vehicle access for the future development. Each level has direct street access by virtue of the topography of the site.

The CSX Metropolitan Subdivision ROW, which has the Metrorail Red Line track and station in the middle, is a defining physical feature running nominally north–south through downtown Silver Spring. North of the station it is in a cut. Then the ROW bridges over Colesville Road, the major street defining the northern boundary of the station and transit center. The Metrorail and MARC platforms are one level above the principal street access level where the entrances to the Metrorail fare gates are located. Several parking garages serving the transit center complex are located nearby, but off the site.

The Purple Line is planned to run from the north along the west side of the CSX–Metrorail ROW. It then has to cross over the four sets of revenue tracks and a Metrorail pocket track to get to the east side of the ROW and into the slot provided for the Purple Line station and alignment between the Metrorail station–MARC station platforms and tracks and the new transit center. The vertical clearance requirement over the CSX railroad, the depth of the structure needed to span over the CSX–Metrorail tracks and LRT vertical and horizontal alignment criteria for the S-curve crossing and at the station platform will result in the Purple Line platform being effectively two stories above the level of the Metrorail and MARC platforms and three stories above the street level where Metrorail access is located. A mezzanine below the Purple Line platform facilitates circulation and transfers with the other transit services and a continuation of the planned Capital Crescent hiker–biker trail discussed at the Bethesda station. The vertical configuration is summarized as follows:

Fourth level		Purple Line platform
Third level	Transit center K&R–taxi level	Purple Line station mezzanine Capital Crescent Trail MARC pedestrian overpass
Second level	Transit center upper bus level	Metrorail center platform MARC side platforms
Colesville Road level	Transit center lower bus level	Metrorail access–fare gates

Figure 3 is a rendering of the Purple Line station and alignment structure showing the Metrorail and MARC level and street level below.

While the planned configuration of the Purple Line station will offer full connectivity among the transit services and relatively close physical proximity in plan, the vertical separation of the Purple Line platform relative to the bus, MARC, and especially Metrorail access offers challenges. A possible additional Metrorail platform access directly off the planned Purple Line station mezzanine is under consideration. This would significantly reduce the transfer time and distance. Structural feasibility and cost and funding studies continue for this connection.

Takoma–Langley Transit Center Station

The Takoma–Langley Park area is centered at the intersection of University Boulevard and New Hampshire Avenue. This area is a wedge area between the east leg of the WMATA Metrorail Red Line and the Green Line. The residential community is characterized by very low levels of car ownership and high reliance on bus service for mobility. New Hampshire Avenue is a radial

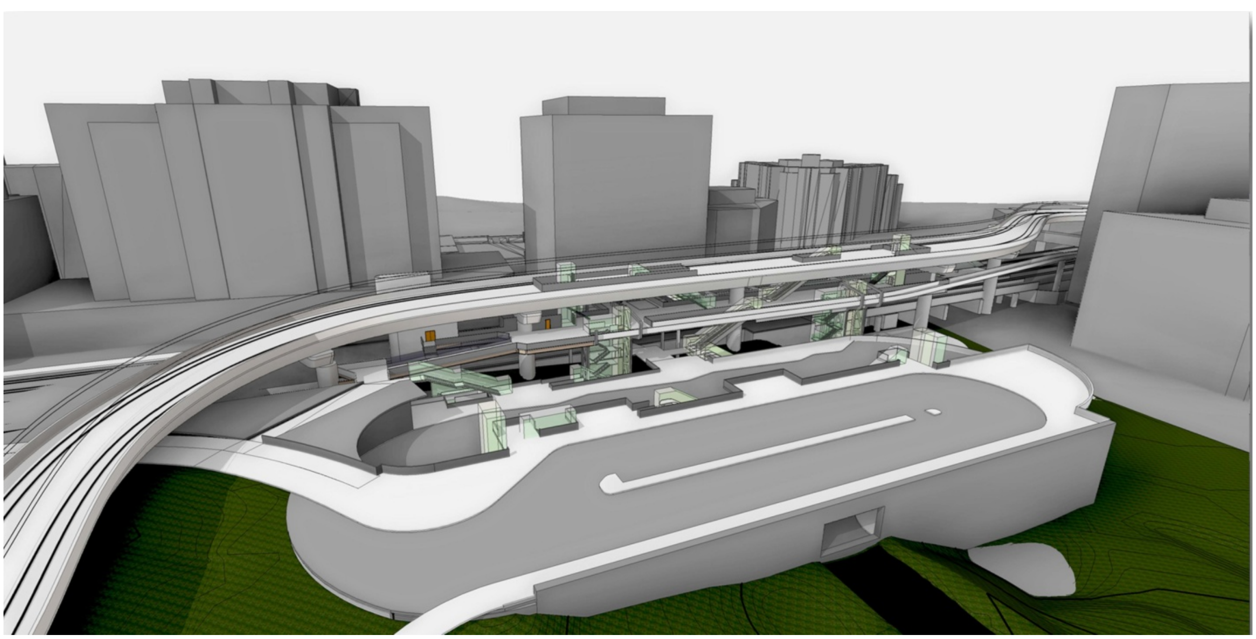

FIGURE 3 Purple Line Silver Spring transit center station.

arterial roadway leading into Washington, D.C., and has a significant amount of bus service running into and out of the District. New Hampshire Avenue is also the boundary between Montgomery County to the west and Prince George's County to the east. Montgomery County's Ride On bus system has several routes that operate along University Boulevard as far east as the New Hampshire Avenue county line and the Prince George County's The Bus system runs a number of routes along University Boulevard as far west as New Hampshire Avenue. At the University Boulevard and New Hampshire Avenue intersection, there is the confluence of all these bus routes with the associated transfer activities. All the bus stops are located along the streets and transferring patrons must often cross one or more busy streets. In order to improve the convenience, safety and efficiency of this transfer activity and bus operations, the Maryland DOT and the two counties are jointly developing an off-street transit center for these bus services and associated passenger transferring. While the surrounding land uses are generally suburban style strip retail commercial and residential garden apartments, future plans foresee more urban higher density commercial and residential developments.

The Purple Line will run along University Boulevard and will have a center platform station in the median of the roadway adjacent to the Takoma–Langley transit center (Figure 4). This configuration does require street-level crossings to access the Purple Line platform from the sidewalks and to transfer between the Purple Line platform and the adjacent transit center. These crossings will be signal protected. While consideration was given to routing the LRT alignment into the transit center site, operational considerations and the proximity of the site and station to a major traffic intersection led to the decision to place the alignment and platform in the median of University Boulevard with the associated pedestrian at-grade transfer connection to the transit center.

FIGURE 4 Purple Line station at Takoma–Langley transit center.

College Park Metrorail–MARC Station

When the Metrorail Green Line was being developed, political and community controversy shifted the line and station away from the University of Maryland's flagship campus at College Park to a location about a mile to the east. At this location, the Metrorail Line runs alongside the CSX and MARC Camden Line and station. The Metrorail fare gates and a pedestrian tunnel below the tracks provide the connections to the Metrorail and MARC platforms. The Town of College Park is west of the station while to the east is the University of Maryland's M Square research park. The station has a substantial bus transfer facility for WMATA Metrobus, The Bus, and University of Maryland shuttle bus services. The shuttle runs a number of lines with a core service being a route that runs at 8-min headways 22 h a day between the center of campus and the College Park–University of Maryland Metrorail station. The station also has a parking garage and a surface parking facility that is the site of proposed transit-oriented residential development. A retail–commercial development is also planned at the station.

The Purple Line is planned to have three stations serving the current campus core and planned campus developments to its eastern and western edges. The Purple Line College Park station will be the next station to the east. The Purple Line will run through the heart of the campus along Campus Drive and take the place of the shuttle route between the campus and the College Park Metrorail station. The Purple Line will have to cross under the CSX–MARC tracks and Metrorail Green Line tracks following an existing roadway underpass. The cost and challenges of widening the underpass (the area has a high water table) has resulted in the Purple Line being planned to run in shared lanes for this section. The Metrorail parking garage is located such that the Purple Line will have to run around this structure instead of immediately alongside the track ROW. The alignment will diagonally cross the Metrorail College Park Station site and will necessitate a reconfiguration of the existing surface bus loop. The Purple Line center platform will be parallel to the Metrorail station platform and tracks and immediately adjacent to the Metrorail–MARC entrances at a level below their platforms. Transfers between the Purple Line, Metrorail–MARC and bus services will be relatively convenient due to their close proximity and only one level change required to reach the Metrorail–MARC platforms. Because of the Purple Line diagonal crossing of the site, the bus patrons will have to cross the LRT tracks at-grade (Figure 5).

The Purple Line platform and tracks, along with a crossover and pocket track needed for train operations serving campus special events, will be located between Metrorail–CSX–MARC ROW and the structured parking for the future residential TOD development on the site of the existing surface parking lot. Because of the economic conditions, the implementation schedule for the development has stretched out and some of the individuals involved have changes. This has resulted in some planning, design, and ROW decisions having to be reaffirmed with the new players, especially need for the pocket tracks and the associated space requirements.

New Carrollton TOD

New Carrollton is an emerging suburban center located at the convergence of several major highways including I-95–I-495 Capital Beltway and US-50 that runs east–west from Washington, D.C., through New Carrollton out to Bowie and Annapolis and the Amtrak Northeast Corridor with Acela and regional intercity service and MARC Penn Line service.

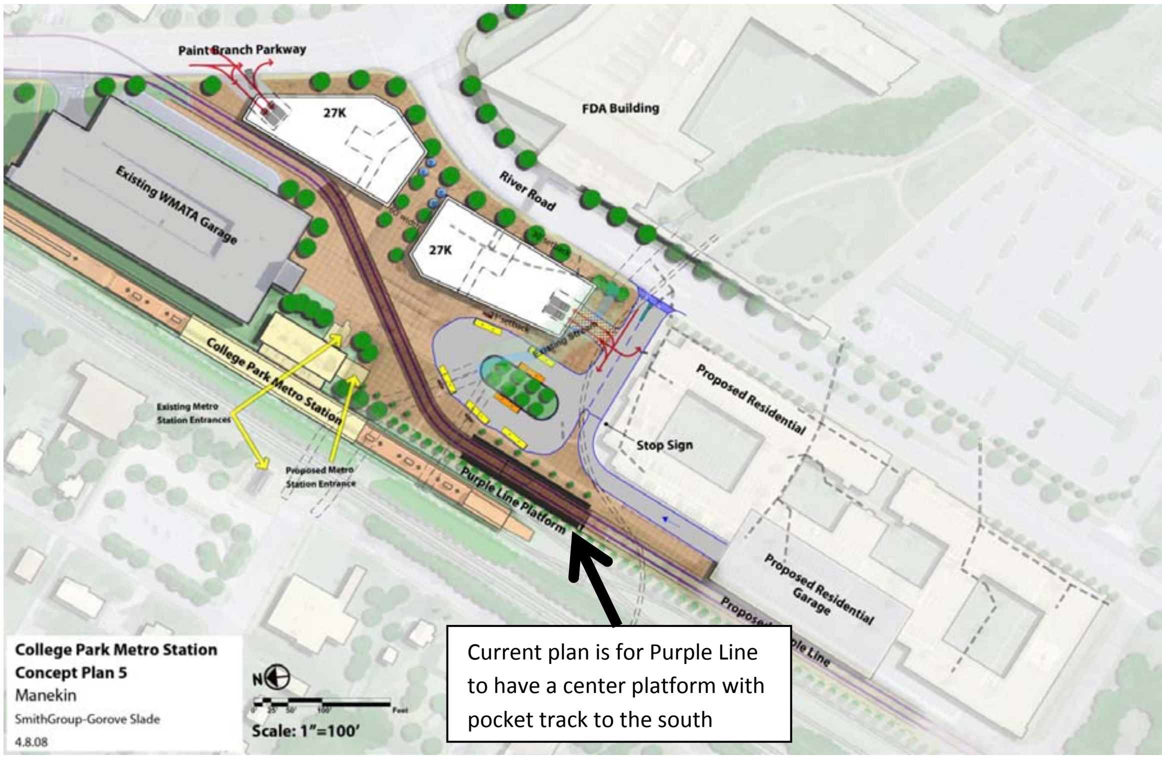

FIGURE 5 Purple Line station at the College Park Metrorail–MARC stations.

Metrorail Orange Line eastern terminus is located here as well. With Metrorail's two tracks and center platform and Amtrak's three tracks and a platform New Carrollton terminal is major bus hub for Metrobus and Prince George's County's The Bus services. The configuration of the roadway and the Amtrak–MARC–Metrorail ROW has resulted in the east side of the station complex being the principal access point, with the major parking and bus facilities here as well as the main entrance to the Amtrak–MARC station and the Metrorail station fare gates. The station facilities are located below the tracks and platforms with access provided via a pedestrian tunnel. This tunnel runs through to the west side of the ROW where Metrorail provide a second set of bus transfer, K&R, and parking facilities.

The area around the station is a mix of station parking facilities, a large Metrorail rail car storage and maintenance facility, traditional suburban office parks, a major electrical utility substation, and some single-family and garden apartment residences. Immediately to the west of the station complex is a major office building, the U.S. Internal Revenue Service (IRS) headquarters, which is connected to the station by an overhead pedestrian bridge. The State of Maryland and WMATA have a major TOD program underway which will create a more town center-type of environment. The main focus of the initial TOD development is on the east side of the New Carrollton station complex but expectations are that the west side will eventually have some TOD. Amtrak has requested that the planning for the TOD and Purple Line accommodate a future fourth track and additional platform for its future high-speed service. This would widen the current rail ROW, pushing the Purple Line station to the west.

The Purple Line will approach the New Carrollton Amtrak–MARC and Metrorail facility from the west along the side of Ellin Road. The alignment has to stay along the side of the roadway to clear the electrical substation mentioned above and then makes an "S-curve" to enter the west side of the Metro station complex where currently the bus, K&R, and parking facilities are located. The Purple Line would have a center platform, crossover and tail tracks, as well as a traction power substation and associated terminal station facilities. Prince Georges County wants the planning for the site to enable a possible future extension of Purple Line. The strip of land between the rail ROW and the Ellin Road is also on the side where Amtrak wants it future track and platform expansion. The WMATA bus, K&R, and parking facilities will have to be reconfigured to accommodate the Purple Line and Amtrak plans. The pedestrian underpass between the east and west sides of the complex, which connects Amtrak–MARC and Metrorail stations and platform, will also likely need modification, as might the overhead pedestrian bridge that connects to the IRS headquarters, as illustrated in Figure 6. In addition there is interest in accommodating future TOD in this area; at a minimum, to create a pedestrian-friendly environment and "sense of place" among all these facilities to accommodate transit and auto vehicles. This will be a lot of facilities to squeeze into a relatively narrow strip of land between the rail ROW and Ellin Road. The Purple Line, WMATA, and TOD teams continue to work together to develop a plan that will accommodate the needs of each, to the degree possible, and will work as a whole. Early in the process, the Purple Line team had to demonstrate the need for the crossover and tail track facilities at a terminal station as well as explain the limitations of the track's horizontal and vertical alignment. A significant step in the collaborative process was the recognition that the modifying the IRS overhead pedestrian bridge would remove constraints that would allow the Purple Line track and platform to be tucked tight along the Amtrak–MARC ROW. This would not only enhance the convenience of the intermodal connections but also would enable the creation of a pedestrian space to act as a mixing bowl for the connections among all the modes on the west side of the complex.

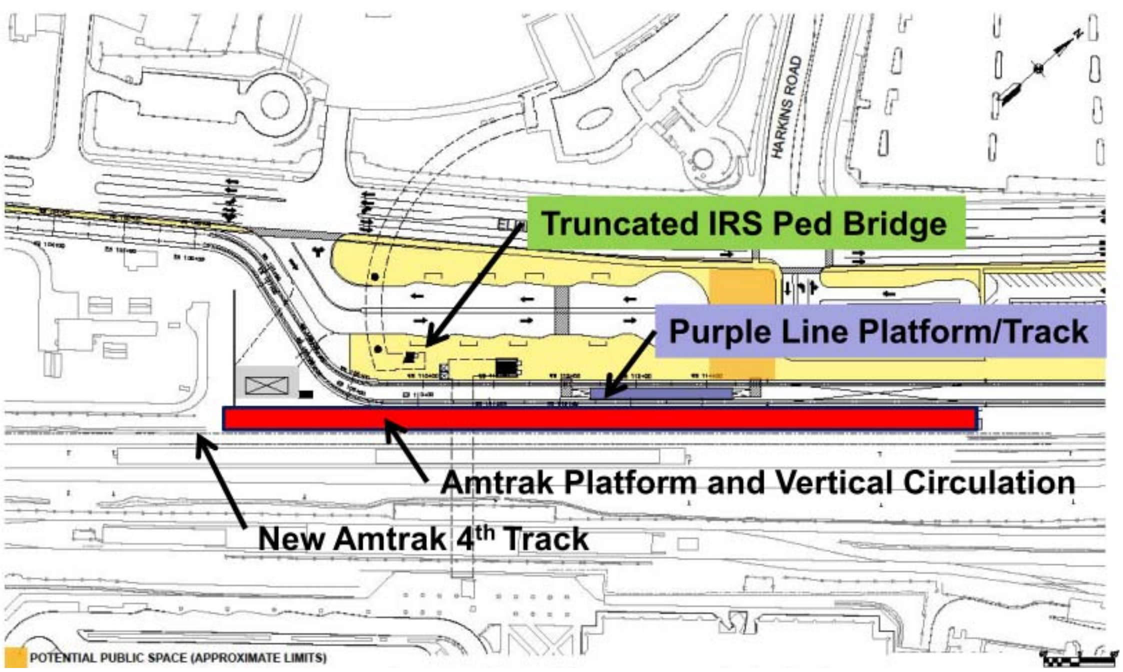

FIGURE 6 Purple Line Station at the Metrorail–MARC–Amtrak Stations (concept plan subject to change).

CONCLUSION

This Purple Line project illustrates how LRT, by providing much-improved access between activity centers and intermodal connections, can serve a combination of traditional CBD-oriented and emerging circumferential travel markets. It is expected that over a third of trips in the Purple Line will involve a least one leg on the Metrorail or MARC system while a significant portion of the rest will involve a leg on one or more of the corridor's bus services. The highly developed land use and transportation infrastructure in the Purple Line corridor provide both many opportunities and constraints for the project's alignment, station facilities, and intermodal connections, as it does on the surrounding existing and planned developments. While sometimes you just have to make do, thoughtful planning can result in good outcomes. The Purple Line shows that in planning to serve well-developed major activity centers and interfaces with established rail and bus systems and facilities, LRT's adaptability and flexibility must be exploited to provide convenient and efficient intermodal connections to serve existing and emerging travel markets.

Appendices

APPENDIX A

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