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Exploring the Land Use Potential of Light Rail Transit

ROBERT CERVERO

ABSTRACT

The potential role of light rail transit in influencing urban growth and revitalizing central city areas is explored. Land use characteristics of cities that have recently built or are planning light rail systems are examined. Specific development strategies designed in response to new or anticipated light rail investments are also reviewed. In order to probe some of the key factors related to the urban development potential of light rail transit, 12 study sites are examined in more detail.

Some 20 or so North American cities have recently built, are building, or are planning to build light rail transit (LRT) systems. The potential impacts of these investments on city form, downtown redevelopment, and urban densities are important to transportation planners. In particular, exploiting opportunities for joint public and private development around station sites will be crucial if there is to be significant land use impact.

By improving access along a corridor, LRT, like any other fixed-guideway system, has the potential to attract and cluster new development around station sites and to rejuvenate declining areas. Because LRT generally has poorer performance characteristics (e.g., in terms of speed and regional coverage) than heavy rail systems, its overall city-shaping abilities could be expected to be less. One might ask, then, what lessons San Francisco's Bay Area Rapid Transit (BART), Washington's Metrorail, and other recent heavy rail investments provide on how LRT systems can be planned and designed to effectively promote regional development objectives? Studies during the past decade have consistently shown that rail transit can have a significant effect on shaping urban form and land uses only if integrated with local prodevelopment policies (1,2). Zoning, taxation, and joint-development incentives are particularly important. Other necessary conditions are a strong regional economy, the availability of land that is easily assembled and developed, citizen support, a hospitable physical setting (in terms of aethestics, ease of pedestrian access, etc.), and the existence of some automobile discouragements (e.g., limits on new highway construction and downtown parking restrictions).

Besides these factors, it is also necessary that an urban setting meet minimum land use requirements to ensure that there is sufficient demand to warrant light rail investments. Pushkarev and Zupan (3,4) have estimated these minimum warrants employing national data on LRT's capital and operating costs, average fare levels, and land use trip generation rates. To justify an LRT line that operates with 5-min headways during rush hour, Pushkarev and Zupan suggest the following minimum thresholds:

1. A cluster of nonresidential activity downtown or elsewhere (e.g., office, retail, hotel) of 25 to 50 million ft^2 of floor space and
2. Residential densities averaging at least 9 dwelling units per residential acre in a corridor of 25 to 100 miles^2.

They conclude that as many as 30 urban areas in the United States are valid candidates for LRT based on these criteria. Some of the recently constructed or planned North American LRT projects are examined in relation to Pushkarev and Zupan's warrants later in this paper.

TWELVE RECENT LRT PROJECTS

Streetcar and trolley lines have existed in Pittsburgh, Philadelphia, Boston, and five other North American cities since the mid-1930s or earlier (5). LRT, essentially a modern-day version of turn-of-the-century streetcar technology, is today being heralded by many as a moderate-cost alternative to heavy rail investments. Indeed, interest in LRT has gained tremendous momentum in recent years. Edmonton's 1978 opening of its northeast line ushered in the first of the recent wave of light rail projects. Calgary and San Diego began their service just 3 years later. New systems are now under construction in Buffalo, Portland, and Vancouver. Some dozen or more other systems and extensions are also at various stages of planning and preliminary engineering. They range in size from Boston's proposed 7-mile Lechmere Extension and Roxbury Line replacement to Denver's 77-mile, 85-station regional system. A number of the new projects and extensions are being proposed in rapidly growing areas, notably San Jose, Sacramento, Orange County, Columbus, Calgary, and Salt Lake City, where the land use and development potential of LRT could be significant.

To explore the urban development potential of LRT, information was compiled on areas that have constructed, are constructing, or are planning LRT projects or extensions from 1978 to the present. (Areas still conducting alternatives analyses or at the pre-route-level planning stage were not studied.) Questionnaires elicited background information from local officials responsible for planning and managing their area's LRT projects and related land use programs. Twelve fairly complete questionnaires were returned from among the 17 sent out. This response rate was considered quite high given the somewhat preliminary nature of some projects. Responses were obtained from Buffalo, Boston, Calgary, Columbus, Denver, Orange County, Pittsburgh, Portland, Sacramento, San Diego, San Jose, and Toronto. In the remainder of this paper various planning efforts being carried out in these 12 areas to assess the urban development potential of LRT are examined.

LRT AND LAND USE PLANNING

Operating and Financial Characteristics

The 12 study sites offer a range of LRT environments in terms of right-of-way, operating, and financial characteristics. From Table 1, it is seen that both exclusive and semiexclusive or mixed-traffic rights-of-way are or will be used to varying degrees.

TABLE 1 Operating and Financial Characteristics of 12 Recently Constructed or Planned LRT Systems

System	Right-of-Way (miles)		Operating Features		Funding Characteristics	
	Exclusive[a]	Mixed or Semiexclusive[b]	Avg Speed[c] (mph)	Peak Headways[d] (min)	Percentage of Capital Costs Locally State Financed	Percentage of Fairbox Recovery[e]
Built						
Calgary[f]	7.0	20.3	8-24	5	100	41
San Diego[g]	0.0	15.9	15-30	15	100	82
Under construction						
Buffalo	5.2	1.2	12-22	6	20	48
Pittsburgh	12.0	12.9	20-35	1-3	20	50
Portland[g]	0.0	15.1	20-45	5-10	15	NA
Toronto	0.5	3.8	12-20	17	100	68
Planned						
Sacramento	5.4	12.9	10-30	15	27	75
San Jose	4.0	15.7	7-30	5-10	49	50
Columbus	1.8	8.7	10-35	7-10	NA	40
Orange County	29.0	12.5	20-30	5-10	NA	70
Denver	54.0	23.0	20-30	5	NA	80
Boston	NA	NA	11-23	3-4	20	NA

[a] Exclusive rights-of-way are those that are or will be totally grade separated, such as subway or aerial structures.

[b] Semiexclusive rights-of-way are those that have some modest entry controls (e.g., curbed or raised median, mall, traffic preemption); mixed rights-of-way involve surface street operation in mixed traffic.

[c] Speed ranges are for downtown sections on the low end to outlying segments on the high end.

[d] Peak headways signify the average minutes between LRT trains during the morning and evening peak periods.

[e] Farebox recovery equals passenger revenues divided by operating expenses. Figures are either actual current rates or anticipated rates.

[f] Includes current system and future extensions.

[g] Data only for existing system. Information on planned extensions is not available.

Buffalo's LRT, for instance, will run underground for more than 80 percent of the 6.4-mile system, whereas Portland's Banfield Line will operate almost totally as a separate surface track, although in mixed-traffic surroundings. Exclusive rights-of-way (e.g., subway and aerial) are currently or will make up roughly 35 percent of the total alignments of the 11 sites for which data were available. Likewise, existing and projected operating speeds and headways differ markedly, from 7 to 35 mph and from 1- to 15-min intervals between trains.

With regard to funding, most projects anticipate receiving substantial federal support to finance construction and capital acquisitions. Only the Canadian systems and San Diego in the United States have used nonfederal sources exclusively for financing capital costs. San Diego, however, is seeking federal aid to help finance future extensions to El Cajon and Point Loma. Finally, existing and projected farebox recovery rates (passenger revenues divided by operating costs) range from 40 to 82 percent; the average for 10 of the systems is just over 60 percent. It is apparent that some LRT operations expect to be heavily dependent on government subsidies to help offset future operating expenses.

Land Use Characteristics

A variety of land uses--residences, stores, offices, and industries--lie within the corridors of all 12 LRT study areas. Urban densities vary somewhat, and some have far greater shares of mixed land uses than others. Data from Table 2 (4, Exhibit 3.13) reveal that residential densities vary from 6 dwelling units per developable acre along Sacramento's northeast corridor to more than 50 in the case of Boston's Lechmere Extension. Most projects meet Pushkarev and Zupan's minimum threshold of nine dwelling units per acre, though several fall below it. Because Calgary averages 40,000 passengers per average weekday with a comparatively low residential density, however, these criteria are only general rules of thumb.

TABLE 2 Land Use Characteristics of Cities with Recently Constructed or Planned LRT Systems (4)

System	Avg Dwelling Units/ Residential Acre Along Corridor of Residential Segment	Downtown Segment		
		Nonresidential Floor Space in CBD[a] (ft^2 000,000s)	CBD Land Area[b] (acres)	CBD LRT Alignment
Built				
Calgary	8	26	500	Mall and subway
San Diego	9	25	1,200	Surface
Under construction				
Buffalo	8	26	900	Mall
Pittsburgh[c]	12	40	400	Subway
Portland	9	25	640	Mall
Toronto[c]	12	3[d]	500	Aerial
Planned				
Sacramento	6	12	640	Mall
San Jose	13	5	640	Mall
Columbus	9	21	550	Surface
Orange County	12	40[e]	4,200[e]	Aerial
Denver	9	36	1,200	Subway
Boston[c]	55	66	640	Subway

Note: Some data from survey responses and local inventories.

[a] Nonresidential includes office, retail, hotel, government, and industrial land uses.

[b] 1983 estimates.

[c] Extension or modernization.

[d] CBD floor space is for the Scarborough Town Centre. Downtown Toronto's nonresidential floor space exceeds 100 million ft^2.

[e] CBD floor space and land area for Orange County are for 10 urban centers of varying sizes, the largest being Santa Ana and Anaheim.

Far fewer areas meet the minimum requirement of 25 million ft^2 of nonresidential floor space in the downtown area. It is significant that Pushkarev and Zupan identified this factor as being the most important simply because there needs to be a substantial and vital central core to attract paying customers. Not counting Orange County, five of the areas fall at or below this mark. Though Orange County has more than 40 million ft^2 of centralized nonresidential floor space, it is spread over 10 subcenters scattered throughout the region. Given the relatively low intensity of downtown activities in some of these areas, it becomes particularly important that concerted land use and joint development planning be carried out if LRT operations are to be successful. The integration of LRT with downtown malls by a significant share of areas is encouraging in this regard.

Possibilities for Urban and Joint Development

LRT officials were questioned regarding the possibilities for urban and joint public and private development around stations. Two-thirds of the officials indicated that LRT was or is being planned as part of a larger downtown redevelopment effort. Light rail is also being coordinated with development and redevelopment activities elsewhere along the corridor in 10 of the 12 cases, according to respondents. It is noteworthy, however, that all indicated that a concerted effort either was or might possibly be initiated to encourage private investment and joint development around LRT stations. Clearly this reflects a strong commitment to private-sector involvement and perhaps an appreciation of the current political mood in the United States and Canada.

Eight of the 12 study areas have used or are strongly considering a variety of specific land use strategies to stimulate private development around LRT stations (Table 3). The most frequently cited strategy involves parking controls--either physically reducing the number of downtown spaces or relaxing minimum requirements in local zoning ordinances. Major capital improvements (e.g., new sewer facilities) and public lease or sale of land were being used or considered for attracting private investment by one-quarter of the areas. Less frequently cited strategies were air rights development, tax increment financing, zoning revisions, provisions for pedestrian amenities, the creation of special transit development districts or authorities, and the granting of density bonuses. It is noteworthy that automobile disincentives, such as parking controls, are being used or considered so extensively, at least in contrast to more positive land use incentives. This undoubtedly reflects the belief that transit ridership can be maximized and a transit-oriented downtown can be more effectively established by limiting automobile entry (via parking restrictions) than by almost any other strategy.

LAND USE ISSUES

The 12 study sites offer unique settings for examining issues regarding LRT and urban development. In this section land use issues surrounding these 12 LRT projects are summarized, focusing on those factors that could prove most important in shaping the urban development outcomes of future LRT investments.

Sites with Existing LRT Systems

Calgary

Calgary's current 7.7-mile LRT system, along with 18 miles of extension, holds considerable land use promise. Calgary itself is a fast-growing city of 620,000 that has enjoyed the spin-off from the oil industry boom throughout western Canada. It functions as a major regional center and, unlike many similar-sized cities, has a well-defined, intensely developed central business district (CBD). One-third of all regional employment (82,000 workers) is in downtown Calgary. Office construction continues around the clock to meet the growing demand for central city location.

Perhaps more than any area, Calgary has embarked on a concerted effort to make the downtown area a truly transit- and pedestrian-oriented environment. The 1981 initiation of LRT services in a downtown mall setting represented just one element of an overall plan to increase by 1990 the share of CBD trips made by transit to 55 percent (5). Other key strategies have involved regulatory parking reforms, the use of density bonuses, and major downtown public investments. Calgary has reduced minimum parking requirements by as much as 80 percent for buildings that connect to light rail stations and also allows cash payments in lieu of parking to help finance public parking structures and pedestrian improvements. During the past decade, downtown parking has declined by 1,000 spaces (even though employment and office floor space have doubled) and the city's downtown transit mode split has increased from 34 to 45 percent (6).

Around outlying stations, Calgary has taken an altogether different approach to parking. To date, 2,000 park-and-ride spaces have been provided. Calgary planners have accepted the low-density, single-family character of residential stations (see Table 2) and realize that automobile access is necessary to make the LRT system work. Although park-and-ride lots could discourage possible apartment and mixed-use development around non-CBD stations (currently 82 percent of all households are single family), relocating parking out of the CBD was considered a higher priority. Private interests helped in the financing of park-and-ride lots under a shared-use plan that gives customers of nearby hotels and shopping centers access during weekends and off-peak hours (7).

Calgary has also revised its zoning ordinance to allow mixed residential, commercial, and office uses within 0.25 mile (400 m) of LRT stations. Moreover, floor-space ratios have been increased by 80 percent within these radii. A creative system of density bonuses has also been designed that permits more floor space for new buildings that provide pedestrian arcades, public open spaces, and direct access to LRT stations. Higher bonuses are granted for

TABLE 3 Land Use and Financing Strategies Employed or Being Considered for Promoting Private Development Around LRT Stations

Land Use or Financing Strategy	City Using or Considering Strategy
Reductions in downtown parking or in minimum parking requirements	Calgary, San Diego, Pittsburgh, Portland, Toronto, Sacramento
Major public investment and capital improvements in station area	Pittsburgh, Portland, Buffalo, Sacramento, San Diego
Public lease or sale of land around stations to private developers	Pittsburgh, Portland, Buffalo, Sacramento
Pedestrian walkways and mezzanines to LRT stations	Calgary, Pittsburgh, Toronto
Air rights developmentabove LRT stations	Calgary, Boston
Tax increment financing	Portland, Sacramento
Revised zoning densities	Portland, Sacramento
Special transit development districts or authorities	Portland, Sacramento

interconnected elevated skywalks, and even higher ones when such facilities are temperature controlled.

Calgary appears to have the essential ingredients for a successful partnership between LRT and downtown: a strong economy, parking controls, and a plethora of development incentives. Having the city's transportation and planning departments under one city jurisdiction has also helped. Though there has been only a modest amount of concerted joint-development activities to date, interest by private investors has remained high. The two planned LRT extensions can be expected to further strengthen the downtown area and the regional transit network.

San Diego

Like Calgary, San Diego is a relatively low density, sprawling city. The 16-mile San Diego Trolley, although not intended to change this predominant land use pattern, has nonetheless been a much-heralded success. The line runs from downtown San Diego (on both exclusive and mixed-traffic rights-of-way with simple loading islands instead of stations) southward along a railroad alignment to the Mexican border. Much of the corridor traverses an industrial belt and unusable scrubland, although several South Bay residential areas are also crossed. The availability of a suitable railroad right-of-way along this corridor has been responsible for much of the system's construction cost savings; however, one condition of acquisition has been that mixed freight traffic be allowed during evenings. Average weekday ridership has leveled off over the past 2 years at about 11,500 (although it is up to 17,000 on Saturdays), yet the farebox recovery rate has remained relatively high at 82 percent (see Table 1). Several major employers are located at the downtown end of the line (e.g., National Steel and Shipbuilding and Rohr Corporation) and at the south end Tijuana provides a steady stream of tourists, laborers, and shoppers. Thus, there has tended to be a near-constant distribution of LRT traffic throughout most hours of the day.

There is little evidence of any positive land use impacts from the trolley to date. Although San Diego's Mass Transit Development Board (MTDB) guidelines officially "encourage, to the extent feasible, the concentration of appropriate development adjacent to stations" (8), because much of the line is in an active freight railroad right-of-way the trolley's development potential is limited. Joint development has been invited by formal requests for proposals and newspaper advertisement inquiries, although no significant progress has been made with prospective investors. Neighborhoods near the stations are already built up, and no significant redevelopment has yet occurred. Although the five southernmost stations all have considerable amounts of vacant land within walking distance, no great increases in residential density are being sought nor are any anticipated. As with Calgary, the availability of 2,000 park-and-ride spaces will probably preserve the automobile orientation of these outlying regions.

As in other cities, San Diego's LRT is seen as playing a supporting, although not a major, role in downtown redevelopment plans. Downtown office floor space increased from 4 million to 6 million ft^2 from 1981 and 1982; an additional 1.5 million ft^2 is currently either under construction or planned. These and other CBD developments are described by MTDB as being coordinated with but not dependent on the trolley.

More ambitious efforts are being made to encourage intensive development around stations on the proposed 17-mile East Line extension, largely because future state aid has been tied to the establishment of such a policy. MTDB's plan for promoting growth along this corridor includes relaxed parking requirements for new developments around stations and influencing private investment via major public improvements, such as the construction of a multimodal transportation center at the terminus of the East Line financed jointly by MTDB and the city of El Cajon.

In sum, LRT is working in San Diego despite relatively low population densities and only modest public interest in stimulating joint development. The availability of an inexpensive right-of-way together with San Diego's fortuitous position as a military, tourist, and international retail center have been the key factors behind the trolley's success to date.

Sites Currently Constructing LRT Systems

Buffalo

Buffalo began constructing its 6.4-mile LRT system in 1979 and hopes to complete the downtown mall segment by late 1984 and the remainder by 1986. Unlike Calgary and San Diego, however, Buffalo is a nongrowth area. Population has declined by 25 percent over the past decade and both downtown retail sales and employment have dropped off as well. Perhaps more than anywhere else, in Buffalo LRT is being looked on as a key and necessary component of a massive downtown revitalization effort. Buffalo's Department of Community Development is the lead agency in an ambitious effort to reverse the exodus of retail stores from the central city and reestablish a vital downtown core (9). The city has already invested more than $70 million in a new downtown civic center, a network of enclosed overhead walkways, landscaping, and the acquisition of properties for open space. Buffalo opted for building a 1.2-mile surface street transit mall, which will be one of the longest anywhere, to make LRT within easy walking distance and a highly visible part of the downtown redevelopment effort.

Responses by private investors to the LRT system and related projects to date have exceeded expectations. During the first year of construction, more than $200 million in private downtown construction was undertaken or announced. One joint development, Main-Genesee, includes two bank office towers and a new 400-room hotel complex located adjacent to a downtown station. Downtown office space is expected to increase by one-third by the time the entire 6.4-mile system is in full operation. Although some have noted that the opening of a new major arterial highway on the eastern edge of downtown might suppress redevelopment efforts by diverting potential LRT users, most community leaders believe that downtown Buffalo has a bright future (9).

Pittsburgh

Pittsburgh has embarked on a major reconstruction and modernization of its 25-mile system, replacing 35-year-old streetcars with new LRT vehicles, upgrading tracks, and building a downtown subway link through an existing tunnel. An underground loop will serve the Gateway Center, a six-building office complex, as well as the Golden Triangle. Two downtown stations, slated to open in late 1984, will have mezzanine connections to downtown streets. Downtown landscaping, public leases of land near the station, and parking reforms are also being used to encourage redevelopment. City officials have also raised long-term downtown parking rates to encourage office workers to commute by transit, whereas the short-term rates have been lowered to stimulate downtown shopping (10). As in Buffalo and Calgary, LRT is being looked on as an integral part of Pittsburgh's downtown redevelopment effort.

Toronto

Toronto is in the process of extending its already heavily patronized LRT system from the terminus of the Bloor-Danforth line to Scarborough Town Centre, one of five suburban municipalities within metropolitan Toronto. The LRT extension is part of a developing civic center in Scarborough where 1.75 million ft^2 of retail and office floor space already exists and another 1 million ft^2 is under construction along with several major hotel complexes.

Unlike Toronto's celebrated heavy rail system, no special land use strategies are being employed to encourage growth along the LRT extension, primarily because a strong market already exists. Still, a pedestrian walkway system is being built incrementally throughout the Town Centre and integrated with the new elevated station. Moreover, parking is being reduced near the station. Overall, the LRT line is expected to reinforce an already vital cluster of office and retail uses in central Scarborough and perhaps stimulate some new residential development as well.

Portland

Portland's 15-mile LRT line will run at grade from the downtown mall eastward to the bedroom community of Gresham. Two historic districts will be crossed and the Memorial Coliseum will be served. Scheduled to open in mid-1986, the alignment, named the Banfield Line, will parallel two freeways much of the way, which will perhaps limit some of its urban development potential.

More than most cities, Portland's economy has been hard hit by the recession, a factor that could affect the LRT's city-shaping role. Still, along with the city's new fleet of articulated buses, LRT is being viewed as an integral part of Portland's long-range comprehensive Downtown Plan. LRT's importance lies more in its possible contribution to improving downtown circulation and enhancing the pedestrian-mall environment than in stimulating redevelopment. Because downtown stations will be simply shelters, any clustering effects of LRT would likely be, in comparison with the situation in other cities, modest.

Because of the abundance of vacant land, much of the joint development potential of the Banfield LRT is in Gresham. The city has prepared a joint development plan calling for tax increment financing, though the plan suffered a major setback in 1982 when Gresham voters rejected the creation of an urban renewal agency. Multnomah County's attempt to form a redevelopment agency to help plan LRT-related growth was similarly rejected by voters. The county has, however, invested $3 million in sewer improvements in several unincorporated areas to stimulate growth. Moreover, it has systematically increased zoned residential densities along the Banfield corridor, whereas multifamily zoning has been restricted outside of it. Minimum parking restrictions have also been eased. Some mixed-use growth is expected, in particular around the Lloyd Center where a large corporate interest has assembled sizable tracts of developable land.

Portland's transit authority, Tri-Met, made an early decision against pursuing joint-development possibilities on its own; instead a separate authority was created for this function. In August 1982, the Transit Investment Corporation (TIC) was formed to manage mixed-use joint development around stations and to influence private capital through various public improvements such as skybridges and open-space enhancement. The five-member, nonprofit corporate board is empowered to incur indebtedness and to negotiate virtually unrestricted joint-development contracts with private investors. So far, the board has been instrumental in stimulating more than 2.5 million ft^2 in new office and retail construction throughout the region. It has also negotiated lease and sale options on land surrounding several stations. TIC is expected to play an increasingly important role in development along the Banfield Line as well as the proposed 12-mile westside extension to Beaverton. Overall, the development potential of LRT in Portland could eventually prove to be significant, despite a stagnant local economy, given the region's strong commitment to comprehensive planning and redevelopment.

Sites Planning LRT Systems

Sacramento

Sacramento is in the final stages of designing an LRT system; construction began in late 1983 and actual operations are scheduled for mid-1985. Unlike most new North American light rail starter lines, Sacramento's LRT will operate on a single track along two close-by 9-mile corridors in the city's northeast. The project is being constructed in lieu of a freeway halted by community protest groups; federal Interstate transfer funds as well as state assistance will be used.

Because of the high concentration of state offices, Sacramento already has a fairly vital downtown for its size, with approximately 80,000 jobs located within 1 mile^2. Though local officials believe LRT will promote positive downtown growth, it is not a formal part of the Master Redevelopment Plan for the CBD. The downtown transit mall is expected to attract private investments; however, developer initiative is being solely relied on.

A special authority, the Sacramento Transit Development Agency, was created in 1981 to manage the system's construction program as well as to prepare a compatible land use and development study. Six of the system's 27 stations have been identified as having high development potential--large vacant and unifiable land parcels, ownership by a few, and strong market. Seven others have been identified as having strong redevelopment potential--transitional neighborhoods with mixed and changing uses and older buildings (11). These 13 areas have been designated special planning areas where residential densities will be raised and minimum parking requirements relaxed. A 10 percent reduction in parking is allowed for nonresidential developments, and an additional 10 percent reduction is granted for projects within 660 ft of an LRT station. Growth around the six targeted development areas will be encouraged by using some combination of density bonuses, tax increment financing, and industrial development bonds. Given Sacramento's strong economy and growth posture, in addition to a local commitment toward station planning, the land use impacts of its LRT system could prove consequential over time.

San Jose

San Jose plans to begin building its 20-mile LRT line in early 1984 with final completion scheduled in 1989. The line will run from the northern industrial zone of Santa Clara through downtown to a southern residential area with a nearby shopping mall and industrial park. A number of major activity centers lie along the corridor, including a major recreational theme park, a commuter railroad station, and several large high-technology industrial plants.

Though LRT connections to these activities suggest a high urban development potential, there are other countervailing influences. One is that San Jose has an unusually small downtown for a city of its size (see Table 2). Of 500,000 total jobs in Santa Clara County, fewer than 15,000 are located in San Jose's CBD. Not unrelated to this is the character of San Jose as a sprawling, automobile-reliant metropolis with an extensive freeway system and abundant free parking. Currently transit accounts for only 1 percent of all trips made in the area (12). Moreover, the LRT line is to be flanked by two new expressways along much of the corridor, which could serve to reinforce the highway orientation and suppress the rail line's development potential. In addition, though the high-technology industry flourishes in the San Jose region, many plants are converting from assembly line production to less labor-intensive research and development activities.

Clearly, the greatest prospects for LRT-generated development are in downtown San Jose. LRT is the centerpiece of the city's intensive downtown redevelopment program. The transit mall, along with density bonuses and various landscaping and amenity improvements, is expected to stimulate retail and office growth. Beyond these strategies, no other joint-development programs are being formally considered, however. Outside the CBD, no density bonuses are being offered nor has any up-zoning occurred. To date, there has been only one major non-CBD development--a mixed office and commercial development near the Oakridge Mall--whose location city officials even partially attribute to the planned LRT line. Planners are hoping, however, that LRT will help curb some of the leapfrogging growth the city has experienced in recent years. Overall, local officials are optimistic about LRT's role in rejuvenating San Jose's downtown, although a radical transformation of the city's predominantly low-density structure is not expected.

Columbus

Columbus is planning a 10.6-mile light rail system running along a railroad right-of-way from downtown to the north. Like Sacramento, Columbus, also a state capital, has a fairly recession-resistant economy. The downtown is growing; more than 6 million ft^2 of office, retail, and hotel floor space have been added in the past 6 years. No specific development strategies have come forth to date as part of the LRT project. Current LRT plans call for extensive park-and-ride facilities around most stations because the proposed railroad right-of-way does not penetrate any major residential or commercial areas. The choice of this alignment on cost-saving grounds might limit the development potential of the project, however.

Orange County

Orange County is planning a regional LRT network to interconnect 10 communities with populations ranging from 40,000 to nearly 200,000. The project is being planned principally to relieve congestion on the county's extensive freeway system. Orange County's LRT setting is unique because of the absence of any major central core, a criterion that Pushkarev and Zupan contend is the most important. Orange County's polynucleated structure closely resembles San Jose's; both are products of the automobile age. Development is booming, however, in downtown Anaheim, Santa Ana, Fullerton, and Garden Grove at a rate of nearly 4 million additional square feet of nonresidential floor space per year. Planners estimate that more than 130,000 jobs are located within walking distance of the LRT corridor. The generally scattered layout of activity centers in Orange County may dissipate any clustering effects of LRT, although the new rail line could function as an important regionwide connector.

Denver

Denver's proposed 77-mile system represents by far the most extensive of the new LRT projects. Though the network focuses on downtown Denver, it will still serve all major employment and activity concentrations in the region. Transit is already an integral component of Denver's downtown: Free shuttle services currently operate along a pedestrian mall and a major multimodal transportation center has just been opened. Though no formal plans exist, special benefit assessment districts and tax increment financing are being explored as ways to help finance the system and stimulate joint development. According to local planners, private investors have shown little interest to date in shared-development concepts, largely because of the absence of a formal implementation plan. The city has begun purchasing abandoned railroad right-of-way in anticipation of building the southeast corridor first; however, the more than $2 billion in capital funding remains the biggest hurdle. If built, the system would be on a par with San Francisco's BART and Washington's Metrorail systems in terms of regional coverage and land use potential.

Boston

Boston is planning an extension of light rail services beyond its Lechmere Station to the cities of Somerville and Medford. However, the extension is expected to play a fairly modest role in shaping future development because of the built-up nature of the corridor. Three redevelopment projects have already been announced for the Lechmere Extension, though, according to local officials, they are not dependent on the LRT line's being built. Overall, the extension could be expected to reinforce an already comprehensive network of light and heavy rail transit in the Boston area.

CONCLUSIONS

Key factors that can be expected to influence the land use impact of LRT are presented in Table 4, along with a summary evaluation of how the 12 study sites rate on these factors. For LRT to have a large-scale impact on urban form, a strong and growing regional economy is an important prerequisite. Over the long run, places such as Calgary, Sacramento, San Jose, and Columbus, therefore, could experience large-scale land use benefits from LRT investments. For some, however, the current automobile-highway system seems so firmly rooted that any major structural changes in urban form would appear unlikely. The development potential of land and a

TABLE 4 Factors Serving as Stimulants and Deterrents for Urban Development

LRT PROJECTS:	STIMULANTS										DETERRENTS								
	Strong and growing regional economy	Local development commitment	Public improvements integrated with LRT	Strong private development interests	Available and assemblable land	Provision of pedestrian amenities	Adoption of various land use incentives	Enactment of parking controls	Creation of special development authority	Major activity centers along corridor	Weak or stagnant local economy	Sprawling, low-density character of the area	LRT aligned along highway or railroad	Park-and-ride could reinforce auto usage	Insufficient residential densities	Small size of downtown area	Much of corridor already built-up	Modest LRT design or terminal features	Small change in regional accessibility
Already Built:																			
Calgary	+	+		+		+	+	+						—	—				
San Diego	+				+					+		—	—	—				—	
Under Construction:																			
Buffalo		+	+	+		+					—				—				
Pittsburgh		+	+			+		+			—						—		—
Portland		+	+		+		+		+	+	—		—					—	
Toronto		+	+	+		+		+									—		
Planned:																			
Sacramento	+	+				+	+	+	+			—		—		—		—	
San Jose	+		+			+						—	—	—		—			
Columbus	+												—	—		—			
Orange County	+			+								—				—			
Denver	+					+							—				—		
Boston																	—		—

NOTES: + means the factor could be expected to have a positive influence on urban development

— means the factor could be expected to impede LRT's urban development and land use impacts

suitable physical setting around LRT stations are likewise important conditions for positive land use changes. In some areas LRT alignments were chosen principally on the basis of minimizing construction costs rather than maximizing development potential (e.g., San Diego and Columbus). In these cases, lines often traverse industrial belts and undevelopable land. Some cities, notably San Jose and Portland, plan to run LRT lines next to or between urban freeways. Though an underlying rationale for building LRT in the first place is to minimize costs, public officials need to recognize the trade-off involved in terms of possibly suppressing longer-range urban development.

Perhaps the strongest development potential of LRT is in downtown areas, particularly where lines are integrated into open pedestrian malls. Buffalo, San Jose, Calgary, and Portland all hope to spark downtown redevelopment with their transit malls. Density bonuses and up-zoning are being used as well in most of these settings to attract private investments. Some joint development and cost sharing with private interests is also occurring (e.g., Calgary), though not on a major scale. A few areas (e.g., Buffalo) are also targeting public improvements around downtown LRT stations as part of the overall redevelopment package. Though these strategies could be a tremendous boon to downtown office construction and retail sales, it should be pointed out that unless an entire region is experiencing growth, such impacts could turn out to be largely redistributive (e.g., taking retail sales from another area).

Parking reforms, such as supply restrictions and easing of minimum requirements, are being used in a number of LRT communities to transform downtown areas into predominantly transit and pedestrian environments (e.g., Calgary, Pittsburgh, and Portland). Park-and-ride lots, however, are being provided at the same time in some of these places to facilitate access to suburban stations. Although these facilities might effectively reinforce the highway orientation of an area, LRT planners seem mindful of the need to provide park-and-ride facilities on a selective basis so as to enhance light rail ridership along suburban corridors. Park-and-ride access also functions as an interim use that can easily be converted to accommodate major land developments if and when a station's market becomes firm.

In closing, the urban development possibilities of LRT appear substantial, though only if other pro development forces exist. Compared with heavy rail systems, LRT projects must be accompanied by various land use incentives and supportive local policies if meaningful land use impacts are to be expected. Unfortunately, much of the emphasis in siting and designing new LRT projects has been placed on minimizing costs, perhaps at the expense of suppressing

LRT's urban development potential by aligning segments along abandoned railroad rights-of-way and freeways. Although the record on LRT in the United States and Canada is still rather short, experiences with rapid rail transit are sobering reminders that a strong regional economy, supportive local policies, and a hospitable station environment are essential if positive and substantial land use outcomes are to occur.

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The Impact of Light Rail Transit on Travel Behavior in Calgary

ARCHIE CHUMAK and DAN BOLGER

ABSTRACT

In May 1981 light rail transit (LRT) was introduced in Calgary between the downtown and the southern part of the city. An extensive 2-year monitoring program of the impact of LRT on the transportation system has been conducted by the city, the results of which are reported. The methodology consisted of a series of before-and-after surveys, which included conventional traffic counts, speed and delay studies, and an on-board survey. An important component of the study was a home interview survey. LRT has had a significant impact on travel downtown. Transit modal split across the south downtown screen line has increased from 35 to 40 percent to 50 to 55 percent in the a.m. peak period. The study also examined the public's attitudes and perceptions of the transportation system as well as the reasons for mode choice. The majority of residents believed that both transit service and overall traffic congestion had improved with the introduction of LRT. Most travelers indicated that convenience is the critical factor in choosing between the automobile and transit. A significant portion of the population, however, identified travel time as the most important factor.

The purpose of this paper is to outline the effects that the implementation of a 12.5-km light rail transit (LRT) line and associated feeder-bus system has had on travel behavior in the rapidly growing city of Calgary, Alberta, Canada.

The line opened in May 1981 using a downtown transit mall (mixed bus and LRT) and seven suburban stations; 27 Siemens-Düwag U2-type cars are operated, usually in two- or three-car trains with 6-min peak-hour frequency. Feeder-bus routes and levels of service were substantially revised with the introduction of the LRT line.

The collection of data on travel behavior before and after the change in the transit system covered the period between April 1981 and May 1982. This period coincided with the leveling off of a vigorous decade of growth in Calgary (about 4 percent per annum), and the findings largely represent conditions that preceded any significant reduction in employment due to the economic downturn.

BACKGROUND

Figure 1 shows a plan of Calgary. A simplified representation of the geography of the city would show a concentrated commercial core with a crescent of residential areas spreading around its west side and a band of industrial land stretching down the east side. About one-third of the city's employment is in the central area, one-third in the east industrial area, and one-third spread throughout the city.

Although the downtown accounts for less than 20 percent of all vehicle trips in Calgary, the intensity of this travel is concentrated. In addition, crosstown traffic from the predominantly residential west side of town to east-side employment in industrial locations exacerbates downtown and inner-city congestion. Therefore, a number of the city's objectives emanate from a desire to manage traffic in the downtown and the inner city. The thrust of many of these objectives is to improve the physical environment of the downtown and the inner city, and they can be simply translated into one objective: to reduce unnecessary vehicular traffic in this area (1). However, although the objective can be simplified, the issue addressed is most complex, and the

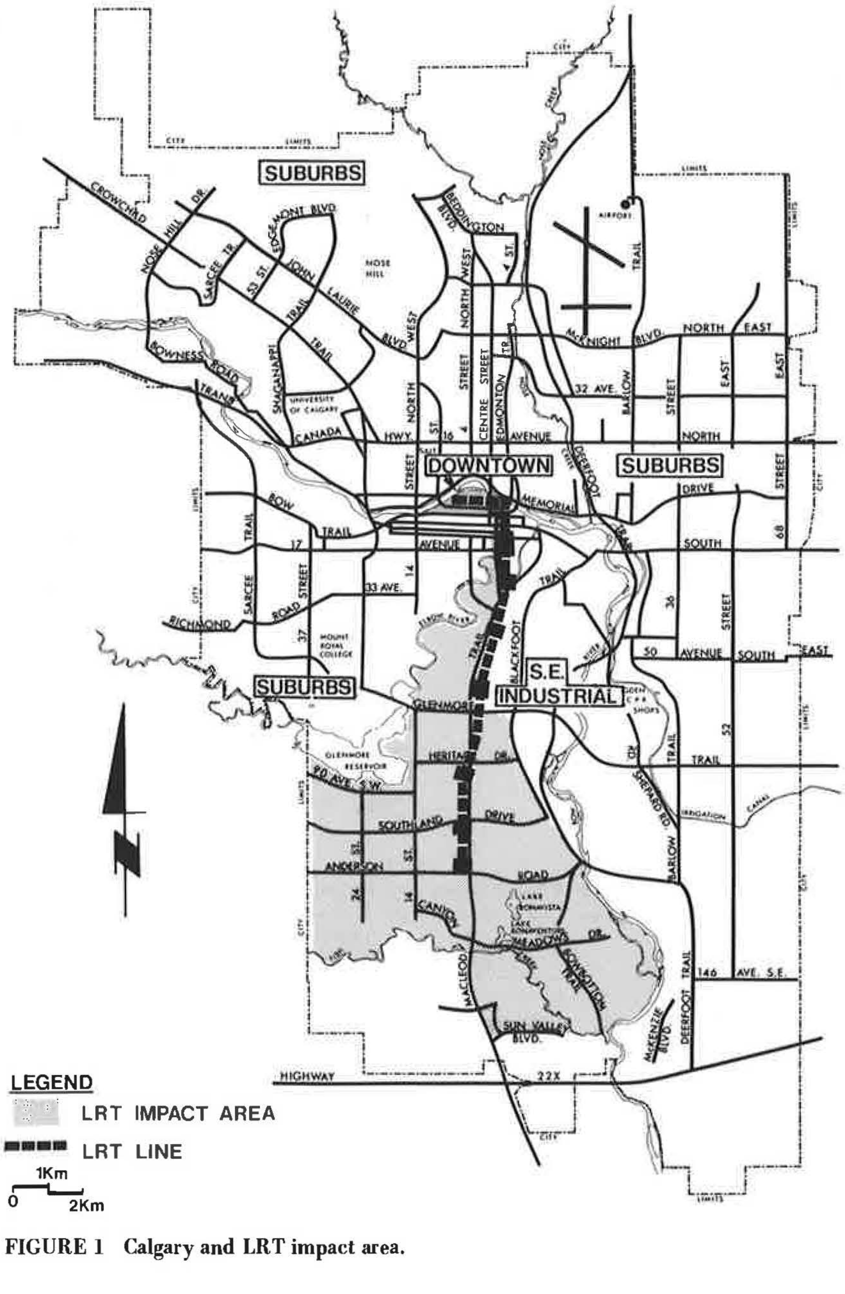

FIGURE 1 Calgary and LRT impact area.

strategies and policies that the city applies to it must be comprehensive and coordinated. These techniques include downtown parking and pedestrian schemes, roadway restraint, and suburban transit planning.

BUS SYSTEM BEFORE LRT

The major transit corridors leading to the downtown had their beginnings with the Blue Arrow express bus system, introduced in the early 1970s. The Blue Arrow system acted as its own feeder in the farthest suburbs and interconnected with crossing feeder routes as it approached downtown. Limited stops between the outer suburbs and the downtown gave it some of the characteristics of an express service; within the downtown, exclusive transit lanes were implemented to increase speed and schedule adherence. A series of free park-and-ride lots were developed with particular emphasis on proposed future rail corridors. Thus the Blue Arrow and its feeder-bus systems combined with park-and-ride facilities to form a prototype for the development of the LRT system that began service in 1981.

The improvements in the bus system have already had a significant impact on travel behavior. Figure 2 shows the impact on downtown-oriented travel during the p.m. peak hour. Total growth, represented by the circle sizes, has increased significantly. In the decade 1971-1981, the p.m. peak-hour work trip modal split to transit increased from 34 to about 50 percent. Citywide annual transit rides per capita changed from 60 to 93 in the same period.

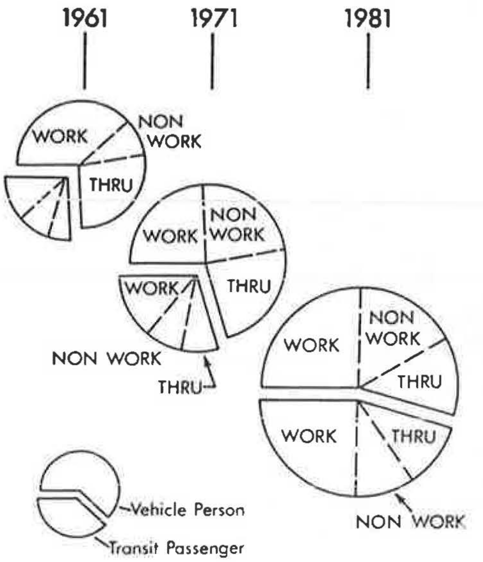

FIGURE 2 Composition of p.m. peak-hour downtown travel.

THE LRT SYSTEM

The patron catchment area for the Calgary LRT line encompasses approximately 95 km² with a population of 150,000 (approximately 1,600 persons/km²). The rail line runs adjacent to a major arterial roadway that serves abutting commercial land containing an employment population of 65,000.

The LRT alignment south of the downtown parallels an existing freight rail line for the majority of its length. The alignment was selected because of its location and ease of acquisition. It provides good access to the southeast industrial area and bisects the residential catchment area.

A total of 15 feeder routes and 8 connecting or crosstown routes were developed and approved to serve the south LRT catchment area. The complementary bus network was designed to serve the largest possible transit market. During the a.m. peak period, transit travel times to the downtown have been reduced approximately 20 percent throughout the suburbs. Total feeder-route operating hours were increased 72 percent, from 492 to 846 hr for weekday operation. This increase is the result of major improvements in transit service in new developing areas (2).

TRAFFIC IMPACT

Table 1 is a summary of transit use change after the implementation of LRT in the south corridor (3). These traffic counts were conducted across the south downtown screen line. The screen-line data indicate that there has been a significant increase in transit travel ranging from 59 percent during the a.m. peak period to 80 percent during the p.m. peak period. The major reason for this growth has been an increase in transit modal split from 36 to 48 percent during the a.m. peak period and from 23 to 39 percent during the p.m. peak period.

It should be noted that this transit ridership growth occurred over a period of time during which a number of fare increases took place. In January 1980 the transit fare was $0.50. By the time LRT was inaugurated in May 1981, the fare had risen to $0.65. The fare was further increased to $0.75 in 1982, which was when the post-LRT impact surveys were conducted.

TABLE 1 Traffic Volume at South Downtown Screen Line

	Two Way (7:00 a.m.-11:00 p.m.)		To Downtown (7:00-9:00 a.m.)		From Downtown (4:00-6:00 p.m.)	
Parameter	Volume	Percent	Volume	Percent	Volume	Percent
Before LRT						
Vehicle occupants	141,759	86	11,008	64	14,930	77
Bus passengers	23,461	14	6,080	36	4,599	23
Total	165,220		17,088		19,529	
After LRT						
Vehicle occupants	153,327	79	10,322	52	13,124	61
Bus passengers	12,172	6	2,240	11	1,838	9
LRT passengers	28,324	15	7,394	37	6,424	30
Total	193,823		19,956		21,386	
Change in transit use		73		59		80

Travel time studies were performed on the major north-south roads in the impact area. Generally the southern part of the corridor did not experience an increase in average speed during the peak periods (7:00 a.m. to 9:00 p.m., 3:00 to 6:00 p.m.). Increases in operating speeds were observed, however, between the downtown and a distance of approximately 2.4 km from the downtown. In this part of the corridor two major roadways, Macleod Trail and Elbow Drive, experienced increases in operating speed in the range of 1.6 to 9.6 km/hr. Contributing factors to the increased roadway speeds included reduction of transit buses in peak periods (between 40 and 80 percent fewer than before the implementation of LRT); widening of a bottleneck section of Macleod Trail (a primary artery); modest reduction in vehicle traffic, particularly in the inner city; and upgrading of traffic signal coordination.

INVESTIGATING TRAVEL BEHAVIOR

Survey Methodology

In the previous section the considerable impact that LRT has had on roadway traffic and transit volumes was identified. It is also important to understand the underlying changes in travel behavior and the reasons for this increase in transit use. This information would be very useful for planning future LRT lines.

Two surveys were used to evaluate the changes in travel behavior. A conventional on-board survey was conducted (4). The survey had a response rate of 50 percent and provided a reliable measure of LRT travel patterns during the a.m. peak period. It was also decided that a home interview survey was necessary (5). In the Calgary situation, this type of survey was the only feasible method of examining the travel patterns of the entire population, especially the automobile travelers. The home interview survey also provided an opportunity for an in-depth analysis of attitudes and perceptions about the roadway and transit systems and their reasons for choice of mode.

The remainder of this paper concerns the results of the home interview survey. The survey was conducted in March 1982, approximately 9 months after the implementation of LRT service. This delay was required in order to ensure that post-LRT travel patterns had stabilized. The survey sample consisted of approximately 5 percent of the households in the LRT corridor. The expanded survey results were compared with the census data to ensure that the survey had no inherent biases.

Existing Travel Patterns

Figure 3 shows the travel patterns in the study area after the introduction of LRT service. This overall perspective of travel patterns should always be remembered when the significance of various impacts is evaluated. These data refer only to trips that had an origin and destination within the south LRT corridor or downtown. The south LRT corridor is shown in Figure 1. It is on trips in this corridor that LRT had its greatest impact. External travel, trips originating outside the study area, or through trips were not included.

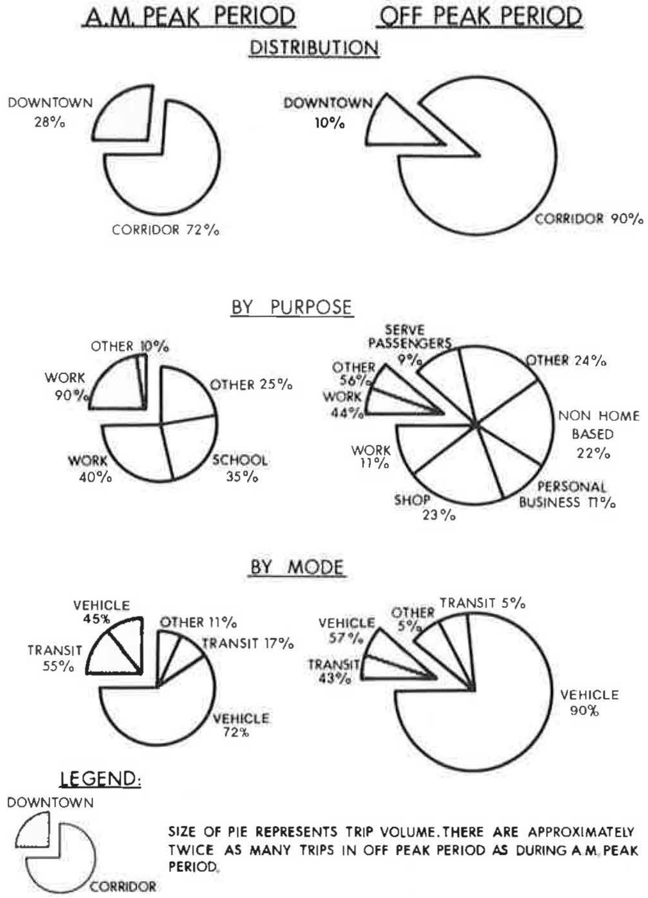

FIGURE 3 Travel in LRT impact area after LRT.

Travel characteristics are presented for the a.m. peak period (7:00 to 9:00) and the off-peak period. The off peak is defined as all travel outside the a.m. and p.m. peak periods (4:00-6:00 p.m.). P.m. peak-period travel has not been included in this presentation. There were approximately twice as many trips in the off peak as during the a.m. peak period.

During the a.m. peak, 28 percent of the trips were to the downtown. This travel consisted almost entirely of work trips (90 percent). Corridor travel accounted for 72 percent of the volume and contained mostly work and school trips.

During the off peak only 10 percent of the travel was to the downtown of which 44 percent was work trips. Corridor travel was much more predominant and had a much more varied distribution of trip purposes: work, 11 percent; shop, 23 percent; and personal business, 11 percent.

The highest transit modal splits were to the downtown. The a.m. peak modal split was 55 percent. Off-peak downtown travel also had a high modal split of 43 percent. The automobile was clearly the dominant mode for corridor travel and accounted for 72 percent of travel in the a.m. peak and 90 percent in the off peak.

Changes in Travel Patterns

The traffic count data indicate that there has been a considerable increase in transit modal split. In Table 2 the changes in modal split for various types of travel in the impact area are summarized.

LRT was designed to provide service primarily for downtown work trips. It was in this market that LRT has had its greatest impact. Downtown transit modal split during the a.m. peak period increased from 42 to 55 percent. This travel consisted almost entirely

TABLE 2 Changes in Transit Modal Split

	Before LRT (%)			After LRT (%)			
Type of Travel	Private Vehicle	Bus	Other	Private Vehicle	Bus	LRT	Other
Morning peak							
Downtown	57	42	1	45	7	48	0
Corridor	69	20	11	72	14	4	10
Off peak							
Downtown	67	31	2	57	4	38	1
Corridor	92	6	2	89	3	2	6

Note: Confidence interval = ±5 percent.

of work trips and accounted for a significant portion, 28 percent of all travel in the study area. It should also be noted that these changes in modal split are similar to those observed in the south downtown screen-line traffic counts.

A somewhat more surprising result was the significant increase in transit modal split, from 31 to 42 percent, for off-peak downtown travel. This increase in transit travel has occurred primarily with the work trip, which still accounted for 44 percent of the off-peak travel. The modal splits for other trip purposes such as shopping and personal business have not been influenced by LRT. It should be noted that downtown travel represented only 10 percent of all off-peak travel in the impact area.

LRT has had virtually no impact on corridor travel during the a.m. peak. There has been no measurable diversion to transit for any of the major trip purposes. The bus mode continues to remain more popular than LRT. Neither has LRT had any impact on off-peak corridor travel. Transit modal split remained at a very low level of 5 percent. Of the four types of travel considered, off-peak corridor travel had the highest volume.

Table 3 presents a more detailed analysis of the dynamics involved in this change in modal split.

TABLE 3 Diversion of Travel

Pre-LRT Mode	Post-LRT Mode	Percentage of All Travel	Post-LRT Modal Split (%)
Automobile	Automobile	42	
Bus	Automobile	3	
		45	45
Automobile	Bus	1	
Bus	Bus	6	
		7	7
Automobile	LRT	13	
Bus	LRT	35	
		48	48

Note: Data are for a.m. peak period downtown. Confidence interval = ±3 percent.

These results are for downtown a.m. peak-period travel, where LRT has had its greatest impact. The analysis examines the importance of each diversion from one mode to another in relation to all travel. Travel diverted from automobile to LRT represented 13 percent of all travel. At the same time there was a diversion from bus back to automobile of 3 percent. The volume of this diversion is significant because it represents 25 percent of the volume diverted from automobile to LRT. This diversion to automobile may be due to a perception of an improvement in traffic congestion after LRT was introduced.

The survey also investigated whether LRT had a significant impact on the other components of the travel process--trip generation and trip distribution. Travelers were asked, "Would this trip have been made before LRT?" The following results were obtained:

Response	Percentage of Travelers
Same trip	96
Same trip purpose, different location	2
No trip	2

LRT appears to have had a minimal impact on both trip generation and distribution.

Attitudes and Travel Behavior

Another important objective of the study is a detailed analysis of the population's attitudes and perceptions of roadway and transit systems. This information should provide a better understanding of travel behavior in relation to the introduction of LRT.

Each person was asked to identify which factors were most important in his or her choice to use automobile or transit. The results are presented in Table 4 and refer to all travel in the study area.

TABLE 4 Most Important Factor in Mode Choice

	Percentage of Respondents	
Factor	Automobile	Transit
Convenience	60	34
Total travel time	14	16
Out-of-pocket cost	-	12
Parking at destination	-	7
No response	10	20
Other	16	11

Note: Confidence interval = ±4 percent.

Convenience, or the flexibility to travel whenever one wants, was clearly the most important factor for the majority of automobile travelers (60 percent). Respondents were also asked to rate their degree of satisfaction with each of the factors on a scale of 1 to 5: 1, very unsatisfied; 3, neutral; 5, very satisfied. The degree of satisfaction with the convenience of automobile travel was ranked 5 and the convenience of transit travel was ranked 3 by automobile travelers. Convenience was also the factor most frequently mentioned by transit travelers, who indicated that they were very satisfied with the flexibility of automobile travel and satisfied with the flexibility offered by transit.

Total travel time was the second most important factor for automobile travelers. More important is the large spread between those who indicated convenience (60 percent) and those who indicated travel time (14 percent). These results should be considered in view of what kind of transit service is feasible. It is possible for transit travel times to be comparable with those of the automobile for downtown travel. It is very difficult to match the convenience of automobile with transit. No other factors were mentioned by a significant portion (5 percent) of the automobile travelers.

Three factors were mentioned by transit patrons: total travel time, 16 percent; out-of-pocket cost, 12 percent; and parking at destination, 7 percent. It appears that policies such as improving downtown travel time and controlling the supply of parking influence transit ridership.

The choice factors for an important segment of the population--those travelers who shifted from automobile to LRT--are as follows (confidence interval is ± 8 percent):

Factor	Percentage of Respondents
Convenience	29
Out-of-pocket cost	22
Total travel time	16
Parking at destination	11
Rush-hour driving	6
No response	15
Other	1

For downtown-oriented travel, convenience was still the most popular factor, indicated by 29 percent A considerable number of travelers also indicated factors such as out-of-pocket cost (22 percent), total time (16 percent), parking at destination (11 percent), and rush-hour driving (6 percent). The key feature of these results is that the perceived importance of the convenience factor is not always reflected in the actual travel behavior. Those who indicated that convenience was the most important reason in modal choice still switched to transit. The modal choice actually involves many factors. It appears that transit can be attractive when all other factors, especially out-of-pocket cost and travel time, are considered together.

Thus far the public's attitudes in relation to travel behavior have been examined. It is also important to determine the residents' general perception of the impact of LRT on the community. The public perception of what impact LRT has had on transportation in the corridor is summarized as follows (confidence interval is ± 2 percent):

	Percentage of Respondents	
Response	Traffic Congestion	Transit Service
Significant improvement	18	20
Moderate improvement	28	27
No effect	32	16
Worse	5	13
No opinion	17	24

Nearly half of the residents (46 percent) felt that traffic congestion had either improved or improved considerably. Similarly 47 percent felt that transit service had improved.

CONCLUSION

The Calgary LRT line is a substantial and tangible investment by the community in the management of its transportation system for the enhancement of the urban environment. The conversion of the prototype Blue Arrow service into a fixed rail transit line is a firm commitment to a continuing strong public transit program in Calgary.

The initial positive public reaction to the LRT has fulfilled the short-term expectations for the line. The striking change in behavior by commuters from the LRT catchment area is clear evidence of the influence that a major improvement in the level of transit service can have, even in a city where there is one automobile for every two citizens. The increase in downtown work trip transit modal split, from approximately 40 percent to the 50 to 55 percent reported in the home interview surveys, is confirmed by the downtown cordon crossing counts, which indicate increases in transit patronage of 59 percent in the a.m. peak period and 80 percent in the p.m. peak period.

Most residents believe that LRT has had a positive impact on both transit service and traffic congestion. The majority of travelers consider convenience to be the most important factor in their modal choice. A significant portion of the population, however, considers travel time to be the key factor.

LRT is performing its role in accomplishing Calgary's transportation objectives; the evidence is conclusive.

ACKNOWLEDGMENT

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Changes in the U.S. Rail Transit Car Manufacturing Industry

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ABSTRACT

The results of a study of the rail transit car building industry in the United States are presented. The study was undertaken in order to examine the economics of the industry, the factors that have affected it since 1965, and the current conditions, including trends that might provide insight as to its future. In the last 20 years, the industry has lost stability as a result of an influx of new capital, customers, suppliers, and technology and new methods of doing business. Management of transit authorities has changed as operating and maintenance staff from the street railway period have retired. Rail-car manufacturing has become much more risky, and the changes needed to distribute the risk fairly have been too slow in coming. As a result, the character of the domestic car manufacturing industry has changed markedly. Instead of integrated car builders who have final authority over design, fabrication, and assembly of transit cars, there are a number of final assembly plants building cars with substantial foreign content under the supervision of foreign car builders. Among the major elements that will guide the industry in the next few years are the small and uncertain market, the risk of innovation measured against the need for service-proven equipment, and the impact of supplier financing on foreign and domestic competition.

Rail transit cars are sophisticated vehicles that are considerably more complex than automobiles or freight cars. Rail cars consist of interrelated systems, each fitted carefully to the other. They are not built in the same way as an automobile. Instead of using a continuously moving assembly line, rail cars are built at a number of stations, largely by hand.

Car building is something of a misnomer. Cars are not built so much as they are assembled from purchased components and subsystems. For example, the major subsystems of a rail transit car are the car body or shell, the propulsion equipment (motors, controllers, and gears), and the trucks (truck frames, wheels, axles, bearings, and brakes). No car builder fabricates all of the major subsystems in its own shop. Traditionally, the car builder fabricates the body and buys the propulsion equipment and trucks. However, there have been a number of contracts in which the propulsion supplier was the prime contractor and subcontracted the car body.

There are four major tasks involved in the process of rail-car manufacture: design, fabrication, assembly, and systems integration. Design begins with the specification drawn up by the transit authority. The new car may be designed for compatibility with components and dimensions of older cars of the agency. The specification may not be sufficiently detailed to construct a car, so there may be a considerable amount of work to be done after the contract award. Through preliminary engineering and detailed design, the specification requirements are translated into shop drawings.

Fabrication involves forming and welding the car shell from steel shapes, building motors and electronic equipment, casting or welding the truck frames, and building other components. These are assembled, fitted into the car shell, and connected and the interior fittings and seats are installed. Final assembly usually refers to interior finish work and truck installation. Trucks can be assembled by the truck contractor or the car builder.

Systems integration is a continuous process, beginning in the design stage. It involves configuration management in which the proper fit and operation of subsystems and components are assured. Problems with integration may crop up any time during the assembly and fabrication process but often show up during testing. Once the car has been assembled, it must be proof tested and performance tested against the specification before it is shipped to the transit authority.

It is difficult to define precisely what makes a rail-car supplier a car builder. The amount of the car built by the supplier is not a good measure, because even a fully integrated car builder will subcontract 50 to 60 percent of the content of the car. Because designs can be licensed from other builders, the best definition should involve responsibility for the whole car. Whichever supplier has the responsibility for systems integration must be involved in all the components of the car. This is also the supplier who probably has contractual responsibility for the car and who stands behind the warranty. The car builder is therefore best defined as the supplier who signed the contract with the buyer and is responsible for systems integration.

The definition of the domestic industry is another issue. The country of incorporation is not a good measure of a domestic industry, because the rise of multinational corporations has led to wholly owned subsidiaries of parent firms incorporated in countries all over the world. The same is true of ownership. Foreign ownership of local companies, and vice versa, blurs the boundaries of the domestic industry.

The location of the material and labor input of a product defines its content but does not define the responsibility for the car. A rail car designed in this country and built with domestic components using U.S. labor has most of its impact on the local economy and clearly has U.S. content; nevertheless, if the systems integration and warranty responsibility come from another country, the car loses its domestic identity. For the purposes of this paper the domestic rail-car industry is defined as that activity occurring in the United States, and a car builder's location is defined by the country where the builder is headquartered and where systems integration takes place and final responsibility is accepted.

At this time ownership, control, design, and production of rail cars are not concentrated in any single U.S. corporation. It must be concluded that the United States has no completely domestic car builder, although it does have one foreign-owned integrated car builder (the Budd Company), an active supply industry, and several rail-car assemblers. This last segment of the industry has been supported by the Buy America legislation.

HISTORY

A brief history of the U.S. car builders active from 1965 to the present is presented. The approach taken was to examine every passenger car order during this period, selecting those that had the most effect on the car builder's fortunes, both good and bad. This is not intended to be a comprehensive summary of the orders or a complete history of each firm.

In 1966 the Budd Company won the competition for the Metroliner to be operated over the Pennsylvania Railroad's Northeast Corridor. Conceived by the U.S. Department of Transportation, the cars were to run at 160 mph, faster than the Japanese Shinkansen that had recently begun service. The Metroliners were considerably more complex than any previous self-propelled car. They have been described as very advanced prototypes and R&D projects rather than the production cars they were intended to be. The Metroliners were among the first cars to show how a rapid advance in technology could bring problems. Budd is reported to have lost $26 million debugging the cars after delivery.

The following year brought Budd two more orders that caused the company similar problems. The first order of cars for the Port Authority Transit Corporation (PATCO) Lindenwold Line were a significant attempt to advance the state of the art in rail transit, particularly with respect to automation. The Long Island Rail Road at the same time placed an order for its new generation of electric multiple-unit (EMU) commuter cars, the M-1s. A highly innovative new design contributed to problems with automatic train operation, brakes, air conditioning, and motors and alternators. Losses on this order, the other two listed previously, and a concurrent job for the Chicago Transit Authority (CTA) led to Budd's announcement to discontinue rail operations as a prime contractor in 1970. The company continued work as a subcontractor to General Electric (GE) on New York Metropolitan Transportation Authority (MTA) EMU commuter cars.

Budd was not the only car builder wrestling with the problems of sophisticated technology. There were several new orders in 1969, among them the long-awaited Bay Area Rapid Transit (BART) contract. The BART system and its cars were developed as a great leap forward in rail transit technology. Rohr Corporation, an aerospace firm beginning its diversification into urban transportation, underbid Pullman and St. Louis Car Company to win the contract. The cars, built using aerospace techniques, were of a totally new design. They suffered problems with motors, chopper control, automatic train control, and doors. Delays in the prototypes held up production, causing more losses to Rohr. The company wrote off $27 million on the $266.8 million contract.

In 1969-1970, St. Louis Car Company received two large orders from the Illinois Central Railroad and the New York City Transportation Authority (NYCTA) that caused similar problems and delays. The uneven market had left the company short of work and as a result the bids for these two orders were probably lower than the cost of production. The Illinois Central Highliner order first strained St. Louis Car's engineering capacity, then its production capacity. Draftsmen and production personnel who were not experienced in rail-car manufacture were hired in order to meet the tight delivery schedule, which ironically caused delays so that the schedule could not be met. The cars did not incorporate much in the way of new technology, but they were a new design that the company had never built before. Systems integration problems contributed to production and acceptance delays.

The R-44 cars for NYCTA were the first NYCTA cars since the 1930s to be built to a different basic design; they were not compatible with the rest of the fleet. For the R-44 contract, the transit authority specified higher performance, automatic train control, new trucks, propulsion control, and couplers. The cars were longer and heavier than earlier cars and could not be coupled with them into trains. Although St. Louis Car had built hundreds of cars for NYCTA, the newly designed equipment on the R-44 was revolutionary and troublesome; warranty work was extensive. The combination of these two problem orders is said to have forced St. Louis Car out of the business. An unrealistic bid price, too rapid expansion of production and engineering capacity, short delivery schedules, and new designs were contributing factors.

The late 1960s and early 1970s was a period when new competition entered the car-building industry. GE, a major supplier of propulsion equipment, made a corporate decision to take prime responsibility on cars using its subsystems. It first attempted to enter the industry by acquiring Budd but was discouraged by the antitrust laws. The company then bid on and won a contract for 144 M-2 EMU commuter cars for the New York MTA and Connecticut Department of Transportation, subcontracting car body construction to Budd and Canadian Vickers. These high-speed EMU commuter cars may be the most technologically complex in the United States. They were designed to run on either 650-V dc third rail or overhead pickup at 11,000 V ac, 25 Hz, or 12,000 V ac, 60 Hz, with a top speed of 100 mph, automatic train control, air conditioning, and automatic doors. The sophisticated technology and the new design made extensive debugging necessary.

GE followed by winning a contract in 1971 for the Southeastern Pennsylvania Transportation Authority (SEPTA) Silverliner IV EMU cars. Follow-on orders for SEPTA and similar cars for New Jersey Transit represented one of the largest production runs in the transit industry and were the most successful of GE's orders. During the next 7 years, 532 cars were built to essentially the same design, with small changes made between orders. Although the first cars had problems, the long production run contributed to the profitability of the order and the reliability of the last group of cars, the Jersey Arrow III.

In 1972 NYCTA advertised for bids for 745 cars, designated R-46. Pullman-Standard was the low bidder, eliminating GE, Rohr, and Westinghouse, teamed with St. Louis Car. The R-46 order, unfortunately for Pullman, could be considered a case study in everything that can go wrong with a transit car procurement. The specification called for a car similar to the R-44 that St. Louis Car had recently built. The contract was awarded for a fixed price without provision for escalation. During the design phase for the R-46, problems experienced with the R-44 caused NYCTA to request changes in the R-46 design. This delayed production into the 1973-1974 period of high inflation, so that Pullman's cost of production rose significantly higher than the original bid price. There were technical problems with the car as well. The truck frames on the R-46 developed cracks, which NYCTA claimed were covered under the warranty. Pullman was required to pay NYCTA $72 million in claims for this problem alone.

The size of the order strained Pullman's production staff. The work force was increased from 250 to 1,700, resulting in substantial learning-curve, quality control, and schedule problems. By the end of the program, Pullman had lost $45.78 million on the order.

The first contract for new light rail cars in 20 years was awarded in 1973 to Boeing-Vertol, another firm new to the industry. Boston and San Francisco made a joint award for 230 (later 275) cars to be built to an UMTA-sponsored standard light rail vehicle (SLRV) specification. None of the three old-line car builders chose to bid on this order: St. Louis Car was essentially out of the business, Budd was building only unpowered cars at the time, and Pullman was occupied with other work. The cars were complex and the design was new. Reliability and maintenance problems developed that had to be fixed under warranty. Inflation also ended Boeing's profits. The estimated loss on the 175-car Boston order was $40,000 per car.

Foreign competition became an increasingly important factor through the 1970s, as did the question of transit car standardization. As the Metropolitan Atlanta Rapid Transit Authority (MARTA) prepared to order its cars in 1975, there was hope throughout the car-building industry that one of the cars already in production would be suitable for this new rail system. Both Pullman and Rohr had hopes of selling modified versions of the R-46 and the Washington Metropolitan Area Transportation Authority (WMATA) car, respectively. MARTA officials and its consultants decided that these cars did not suit the system requirements and as a result Pullman dropped out of the bidding and Rohr, in a poor financial position from its BART and WMATA orders, withdrew from the market altogether on May 28, 1976.

GE officials spent a year discussing the specifications with MARTA and believed that they had a good understanding of the car design and contract terms. When the bids were opened, Franco-Belge unexpectedly won the contract, underbidding GE, the only U.S. bidder, by more than $10 million on a 100-car order. Later in 1976, following another bid lost to a foreign car builder, GE abandoned the car-manufacturing business, claiming that the sealed-bid low-price procurement favored inexperienced bidders who did not understand the risks involved in the industry.

Nineteen separate bids were received from 10 different bidders in response to the Greater Cleveland Regional Transit Authority's (GCRTA) advertisement for light rail cars, the first since the Boston-San Francisco order. The three remaining U.S. car builders--Budd, Pullman, and Boeing--all submitted bids but were underbid by Breda of Italy. Pullman, the lowest U.S. bidder, sued to halt federal funding but lost. Budd, teamed with the Urban Transportation Development Corporation (UTDC) in a consortium called Cleve-tran, was making its first bid on a self-propelled passenger car since the M-1 in 1967. The company had returned to the market in late 1972 with an order for 25 bilevel commuter cars for the Burlington Northern Railroad, making a decision to concentrate on cars without propulsion systems.

Following the GCRTA award, Congress passed the Surface Transportation Assistance Act of 1978, which included a Buy America clause. This may have had an effect on the competition for the next two orders, for Chicago and Baltimore-Miami, because only the bidders were U.S. companies.

When CTA ordered 300 cars in the 2600 series, Budd, Boeing, and Pullman were in competition once again, with important consequences for all three firms. Budd won a large order and a subsequent follow-on contract, which brought it back fully into the transit car manufacturing business. Boeing, however, had expected to win this order, having just completed a 200-car order for similar cars on which it had lost money. When bids were opened, Budd had underbid Boeing by $140,000 per car. The loss of the order convinced Boeing officials that there was little or no profit to be made in the industry. The CTA bid opening also showed Budd to have underbid Pullman by almost half. Pullman's losses on the R-46 and the National Railroad Passenger Corporation (Amtrak) Superliners, coupled with the failure to win its last two bids in Cleveland and Chicago, caused the company to withdraw completely from the passenger car market on March 21, 1978. Following Pullman's action, Budd remained the sole domestic car builder. Shortly thereafter its stock was acquired by Thyssen of West Germany, and it became a wholly owned subsidiary of that firm.

The domestic industry in the 1980s reflects the language of the Buy America provisions. Recent orders have tended toward use of domestically produced subsystems and final assembly of the cars in plants located near the city for which the cars have been bought.

FACTORS AFFECTING THE INDUSTRY

Analysis of the rail-car orders during the last 15 years and information from interviews with car builders and transit authorities point to a number of factors that affected the industry in the United States. All of them contributed to the one major problem: the lack of profitability of rail-car manufacturing.

Procurement Practices

Low-Bid Criteria for Award

Most rail-car procurements since 1965 have relied on a sealed-bid, fixed-price method. There are a number of problems with this policy. One is that a low-bid award does not take into account operating and maintenance costs over the life of the equipment purchases. Because the capital cost is the only factor governing the award, this may force a car builder to buy lower-quality subsystems and materials in order to win the contract. When the builder cannot put high-quality equipment into the car, performance and reliability are affected, which may lead to high warranty costs and reduced or eliminated profitability of the order. Also, when car builders do bid equipment of higher quality (and perhaps lower maintenance cost), the probability of winning the contract may be reduced.

The low-bid criteria may also discriminate against the experienced bidder. Car builders experienced with the specified equipment and the terms and conditions of a proposed order can assess the risks of the order more accurately than inexperienced firms. Prices reflect perceived risk, and in anticipating this risk, experienced car builders have tended to bid higher, making it less likely that they will win the order.

Foreign bidders, particularly those with little or no experience in the United States, may not fully understand the risks in the U.S. transit market. Foreign business practices differ; for example, court judgments in lawsuits are usually not as high. As a result, foreign bidders may not allow for sufficient bonding or liability insurance, thus lowering the cost of these items and allowing the firm to bid lower.

Escalation and Progress Payments

The method of financing rail-car purchases has also changed during the past 15 years. Until the early 1970s procurements were financed by the car builder using working capital and borrowed funds. The transit authority paid for the cars on acceptance at the end of the contract. The interest costs of whatever money was borrowed were spread across the car order as part of the unit price per car. If there was concern about price escalation for a particular contract, its effects were estimated and also added to the price of the car. The car builder assumed all responsibility for inflation, building protection into the bid price. By taking on the responsibility for inflation and interest fluctuations, the car builders were gambling that these costs would be predictable.

In the early 1970s the financial environment changed drastically. The costs of money and inflation rose much faster than had been anticipated. Figure 1 shows the trend of the prime rate since 1971 plotted quarterly, and Figure 2 shows two indexes of inflation commonly used in calculating escalation factors--the wholesale price index for metals and metal products, code 10, and the average hourly earnings for the Railroad Equipment Group of the Transportation Industry, standard industrial classification (SIC) 374. Both are compiled monthly by the Bureau of Labor Statistics, U.S. Department of Labor. Although wage rates increased at a fairly even pace during this period, there was a 29.4 percent increase in material costs in 1974, most likely caused by the behavior of fuel prices at that time. The prime rate also increased from 6.5 percent at the beginning of 1973 to a high of 11.75 percent in mid-1974.

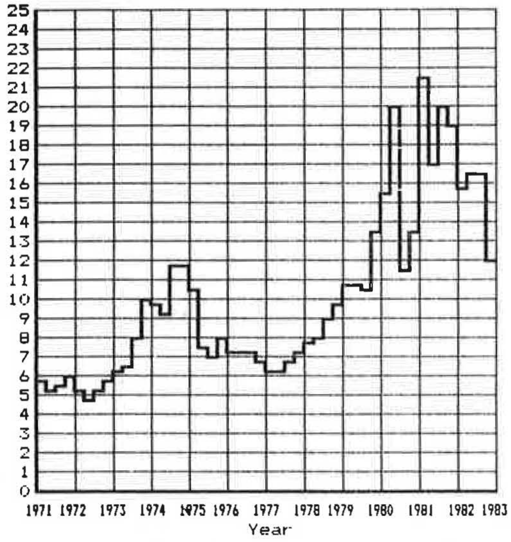

FIGURE 1 Prime rate plotted quarterly, 1971-1983.

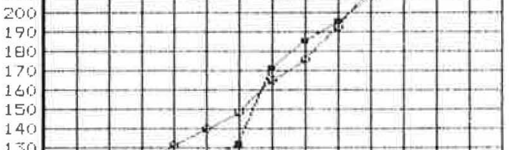

FIGURE 2 Rail-car cost escalation indexes, annual average.

The overall effect was that car builders incurred additional expenses that were not reimbursable. In some cases this occurred only a matter of months after the contract had been awarded. The costs of borrowing money, buying materials, and paying wages necessary to build the car were much higher than what had been reflected in the bid prices.

Pullman was one of the manufacturers caught without provision for inflation. The R-46 was bid for $275,381 per car in 1972. In 1976, while still in production, a modified version was offered to Atlanta for more than $400,000 per car. Boeing's light rail vehicle sold to Boston for approximately $300,000 in 1972 and was bid to Cleveland in 1977 for $870,000 while still in production. The instability of prices and interest rates forced two changes in the method of financing rail-car procurement. Escalation clauses and progress payments became much more prevalent in contracts. Both of these changes help spread the new risks more equitably between the buyer and seller.

In most escalation clauses, the transit authority promises to pay the car builder for increased costs in labor and materials; these increases are based on a published index rather than on the actual costs to the car builder. As a result, the procurement is not a cost-plus arrangement, which would put all the risks of inflation on the buyer. The two indexes most often used in U.S. contracts are those shown earlier in Figure 2. A typical breakdown is the one used in 1979 for the Baltimore-Miami rapid rail-car procurement. The cost of the car is considered to consist of 60 percent materials and 30 percent labor subject to escalation and 10 percent profit, which is not escalated. The Baltimore-Miami contract is one that puts a cap on the escalation clause. Increases in prices and wages over the length of the contract will be paid up to a certain limit but not above it. Baltimore capped escalation at 15 percent of the costs, whereas Miami (which had a longer delivery schedule) capped it at 20 percent.

Progress payments, if planned correctly, remove the necessity for borrowing money to finance car construction. At various points in the contract, the manufacturer is advanced the money needed to buy subsystems and materials, based on proven completion of a portion of the work. There is less agreement in the industry on progress payment schedules than there is for factoring escalation. The importance of progress payments is demonstrated by the R-46 order. Earlier payments by NYCTA allowed Pullman to provide nine more cars without increasing the total contract price.

Other Contract Terms and Conditions

Three types of contractual conditions have affected the industry's ability to make a profit. The first of these controversial practices is the clause called "Authority of the Engineer." In many cases the buyer's engineer or his delegated representatives have had unilateral power to interpret specifications, shut down production lines, or decide when the car builder will be paid for the work. This adds considerable risk to rail-car manufacture. NYCTA used this clause in the R-46 contract to stop Pullman's production and redesign the car. Pullman's expense for labor and materials continued while work, and subsequent payment, was delayed. The net effect was to add time and cost to production without recompense.

The second contractual clause relates to penalties and liquidated damages. According to manufacturers, liquidated damages can be assessed up to the full price of the contract, which they consider unreasonable (1,p.17). These large penalties have not been shown to improve performance in meeting reasonable delivery dates. A penalty to the full price of the contract would result in delivery of cars free to the transit authority, paid for by the manufacturer, which could easily put the firm out of business. Again, risks are added without recompense. Compounding the problem is the Authority of the Engineer clause. "One of the CTA's recent contracts says that it can suspend work any time its engineer see fit, and the CTA has the authority to determine whether construction delays are avoidable--a central decision when the builder must pay a penalty for late delivery of cars" (2). Reasonable penalties for late delivery are not the issue here. The problem has been the lack of an upper limit on penalties.

Guaranty, warranty, and reliability provisions have changed during the last 15 years. Warranties became too abstract, not defining the responsibilities of the buyer and the seller clearly and without ambiguity. Car builders complained that warranties were being used to cover maintenance activities, and transit authorities claimed that the manufacturers were refusing to do warranty work. Problems with new rail cars led to a trend to tighten warranties and make them more stringent. More subsystems were added under separate warranties and the length of coverage was extended. Warranty of reliability was added through fleet failure rate provisions. The increasing length and lack of definition brought more risks to the seller, because it increased the likelihood that more retrofit work would be required. The vague language of some warranties was subject to unilateral interpretation by the transit authority's engineer, again shifting the risks to the car builder without recompense. The net result was a loss of profitability on the order or a higher bid price to cover risks.

Car Design

Design Specifications

There are two basic types of specifications used to purchase rail transit rolling stock: design (hardware) and performance (functional). A design specification tells the suppliers exactly what to build, including material dimensions and in some cases make and model number. Performance specifications tell the supplier how the finished product must perform. Most transit-car specifications combine both these approaches. Design specifications are used in rail-car procurements in order to force compatibility with the purchaser's existing fleet or to ensure that new equipment meets physical and operational constraints on an existing system. Design specifications tend to discourage innovation. Although experience from other jobs may point to better engineering solutions, they may not be allowed. Tooling, manufacturing processes, and shop practices may be constrained by the specification so the supplier cannot use what he considers to be his most efficient techniques. Materials and subsystems may have been specified directly, so price or quality cannot be improved (or degraded) by substitution.

Diffused Responsibility

The buyer, the builder, subsystem suppliers, and consultants (if used) all have partial responsibility for the finished product. It can be difficult to assign liability for problems or failures.

Complex Technology

The long hiatus in rail transit research and development was partly to blame for the explosion of sophisticated technology that affected so many procurements. Technological advances in the 1960s and 1970s caused problems throughout the industry. The Budd Metroliners, PATCO cars and M-1s, Pullman R-46s, St. Louis Car R-44s, GE M-2s, Boeing light rail vehicles, and Rohr cars for BART and WMATA all had problems attributed to trying to introduce new technology too fast or to apply new technologies inappropriate to the operating environment.

A related problem was revolutionary design. In all of the orders just named, cars were specified that had never been built before. Even when subsystems are of proven design, increasing complexity leads to problems when systems are integrated. No one was prepared for these problems, and the prototype stage of development, which can be used to iron them out, was omitted, leaving development and production combined into one step. The result was entire production runs of cars in a hybrid state of development, causing poor reliability and increased maintenance costs.

Standardization

Standardization of rail transit cars has been a long-sought goal but an elusive one. Differences in track radii, tunnel clearances, speed and acceleration requirements, and maintenance practices at different transit agencies have made different car designs necessary. Lack of standardization, however, has contributed to several problems in the industry. One is the lack of economies of scale. In many cases new equipment must be designed for every car order, resulting in engineering, tooling, and start-up costs that must be folded into production costs, even for small production runs.

The lack of standardization has fragmented the marketplace. Instead of a large market for two or three designs, there are many small markets for dozens of designs. It is difficult for a supplier to justify investment in plant and labor for each small production run. There is less interchangeability when every part is different. Buyers face problems with price competition and availability of replacement parts.

Market Conditions

Size of Market

Compared with other transportation markets, the rail transit car market is small. As shown in Table 1, the total number of rail cars ordered is approximately 300 to 600 per year. The number in each order can be as small as the 14 light rail vehicles ordered by San Diego. The market may be too small to support a

TABLE 1 Number of New Vehicles Delivered Annually: 1971-1980 Average

Type of Vehicle	No. of Vehicles
Automobile, taxi, and motorcycle	11,439,000
Truck	3,074,000
Freight car	34,129
General aviation	13,859
Transit bus	3,770
Locomotive[a]	1,181
Intercity bus	738
Rail transit	264
Air carrier	237
Intercity and commuter rail car[a]	184

[a] Includes totals for Amtrak and Class I railroads.

domestic manufacturing industry that does not export. To some extent the industry's problems in the early 1970s were caused by too many large manufacturers competing for too small a market.

The small size contributes to the riskiness of the industry. A large amount of capital and skilled labor must be committed by the car builder in order to win business. This large commitment of resources is made in order to build only a few cars each year; at best only two or three orders are built simultaneously. Because factors beyond the car builder's control make it difficult to predict whether a profit can be made on a particular order, the firm must in effect bet its entire manufacturing facility every time it makes a bid.

Attracting capital to such a small industry is a problem that has been in existence since the 1930s. U.S. capital markets favor growing sectors of the economy out of proportion to their size. A small, declining industry, as this one has been, has the most difficulty issuing stocks and bonds or borrowing funds.

Uncertainty

The number of cars ordered varies widely from year to year. There is no funding commitment for a specific rail-car replacement rate from transit authorities or governments. The uneven market puts a strain on the bidding process. When several requests for proposals (RFPs) are released in just a few months and then none at all for a year, the car builder cannot put together a high-quality bid on all the work that may be available. Long periods with no work mean that the car builder may have to build, dismantle, and rebuild production staff and capacity repeatedly. This adds to nonrecurring costs of personnel recruitment and training when experienced craftsmen are lost.

Delivery Schedules

Delivery schedules are not geared to match the car builder's most economical rate of production. A large order may have to be built in a short period of time, causing a substantial learning curve. Without negotiation of the contract specifications, the car builder has no opportunity to change the delivery schedule, even if this might result in a lower price.

Competition

Intentional Underbidding

In many cases the low-bid selection process encouraged car builders to deliberately bid under cost in order to get an entrance into the market, using one order as a loss leader for the next. This is not a successful tactic in the long run. In the words of Arthur Hitsman of Boeing in 1979 (3): "There is really no opportunity to bid low on a transit car program and hope to make it up on the next order, because there is always going to be some new guy bidding the next order and he is going to be figuring that he will bid low this time and make it up on his next contract."

Entry of Aerospace and Foreign Firms

With the slowdown of traditional aerospace business and increased federal funding of rail equipment in the late 1960s, aircraft manufacturers were encouraged to enter the transit market. Foreign car builders apparently entered a void in the U.S. industry that had opened up because of other factors. The result of new entries into the business was to decrease the fraction of the market available to any one car builder. The market had been too small for the three traditional car builders; new entries made it more difficult for any firm to win enough enough orders to survive. To the extent that foreign markets are closed to U.S. manufacturers (4,p.27), overseas car builders have a sustaining market unavailable to U.S. firms.

Federal Involvement in the Rail Transit Industry

The creation of UMTA in 1964 (as part of the Department of Housing and Urban Development) with funding for capital improvements helped to revitalize a decaying transit industry. Seventy-five percent of the capital grants made between 1965 and 1970 went to rail systems. Of the rail grants, roughly half the amount was spent for rolling stock. The early legislation aided the rail transit industry to a much greater extent than it aided any other mode.

The two most significant pieces of legislation affecting the industry were the Urban Mass Transportation Assistance Act, as amended in 1970, and the Surface Transportation Assistance Act of 1978. The 1970 legislation was important for the level of funding it set for the UMTA program in future years. The 1978 act incorporated several important provisions discussed in the following and signaled increased congressional interest in the workings of UMTA and the mass transit industry.

Section 1 of the Urban Mass Transportation Assistance Act of 1970 called for (5,p.49) "a federal commitment for the expenditure of at least $10 billion over a 12-year period, to permit confident and continuing local planning and greater flexibility in program administration." This was a quantum leap in funding, allowing for an average of $980 million annually during the period compared with an average $113 million in grants from 1965 to 1970. This expansion of the program (shown in Figure 3) essentially created UMTA as it exists today. The commitment to funding allowed the agency to fund new urban rail systems in Baltimore, Atlanta, and Miami. The Washington, D.C., rail system was also begun at this time, funded by a separate appropriation. The commitment encouraged new rail starts both because of its magnitude and because of the 12-year program, which gave the time for planning and implementation needed for rail transit.

One other provision of the 1970 act became very important in the fortunes of the domestic rail-car manufacturers. This was Section 10, which influenced the entry of aerospace firms into the transit business (5,p.50):

> SECTION 10. The Secretary of Transportation shall in all ways (including the provision of technical assistance) encourage industries adversely affected by reductions in Federal Government spending on space, military, and other federal projects to compete for the contracts provided for under sections 3 and 6 of the Urban Mass Transportation Act of 1964, as amended by this Act.

Congressional concern about the health of key defense contractors led to this provision. The goal of increased competition was well intentioned, but the size of the market was not increased enough by the funding to allow the goal to be met.

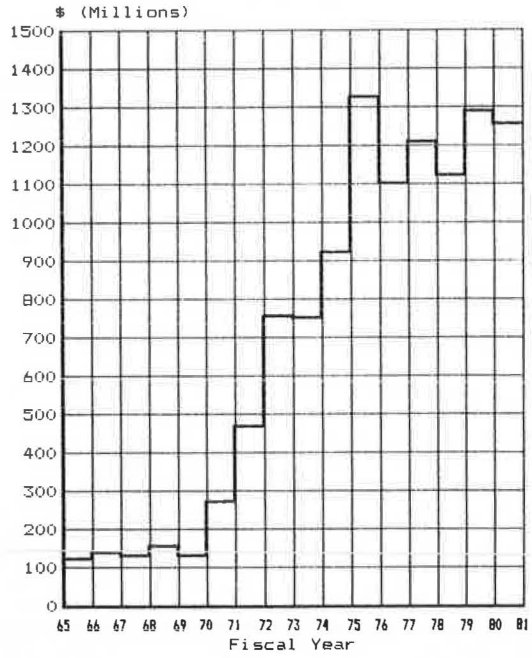

FIGURE 3 UMTA funding for capital improvements, adjusted for inflation ($1970).

The 1978 act incorporated another significant provision for the rail transit industry: Section 401, Buy America. This section had its antecedents in the Buy America Act of 1933, which stated that no federal money could be spent on direct purchases of foreign products. In 1978 Congress wrote a parallel to this act, creating a section that would apply to indirect purchases through federal grants. Until 1978 such purchases had never been covered by any type of Buy America legislation, and since 1978 there have been no other extensions into other federal programs. Section 401 states that (5,p.46) "only such manufactured articles, materials and supplies as have been manufactured in the United States substantially all from articles, materials and supplies mined, produced, or manufactured, as the case may be, in the United States will be used in such project(s)." UMTA has interpreted the phrase "substantially all" to mean that the value of the U.S. content of purchased equipment must be more than 50 percent.

Although the federal government is often blamed for the problems of the rail transit industry, it must be recognized that its influence, on the whole, has been to the industry's benefit through funding of capital improvements. Problems of poor procurement methods attached to public purchasing, although influenced by federal oversight, result from legislation at the state and local level forbidding the use of any method except competitive bidding. When the problem was recognized in 1978, the process was opened up and local governments were encouraged to pass legislation allowing negotiated procurement. This has since occurred in several states.

The large number of competing firms in relation to the size of the market in the early 1970s was a continuation of a problem that had existed for years previously. The addition of a few new companies led to enormous overcapacity for a limited market. Increased funding did not add enough orders to keep all the manufacturers in business, and some firms dropped out.

The replacement of excess domestic competitors by foreign firms was recognized as a problem by 1978, and Buy America legislation was passed to rectify the situation. By now there is less domestic industry to protect, and the increasing trend away from UMTA-funded procurements to other methods of financing has made this provision less effective.

TRENDS

Two forces have been shaping the rail transit car manufacturing industry in the last 2 years. Federal funding of transit programs was reduced so that initially all new rail starts in cities without rail transit were put on hold. Although with passage of the Surface Transportation Assistance Act of 1982 some new starts have proceeded, the future remains unclear. The other force is a reaction by transit authorities to the reliability problems and high cost of transit cars purchased during the last decade. The problems incurred by BART, WMATA, and MARTA have shown that there was something seriously wrong with the method of design and procurement of rolling stock. The shift to local funding has been the catalyst for changes in technical specifications, procurement methods, and financing.

Except in New York and Chicago, transit authorities are becoming less involved in designing cars. Performance specifications are becoming much more common. Houston is using a very general performance specification for its rapid rail procurement and in fact will design much of the system after the car has been chosen in order to allow many possible designs. This same philosophy is being pursued for light rail car procurements in Sacramento, San Jose, and Los Angeles-Long Beach.

Although older transit authorities do not have this liberty because of civil and system constraints of a system already in place, they are writing less detailed specifications. All of the LRT cars bought since the PCC car have used performance specifications that allowed a wide range of design.

A related change is the trend toward service-proven equipment. In some cases, particularly light rail purchases, this means buying a car "off the shelf" from a manufacturer who has built the car before. This was the way San Diego purchased cars for its new light rail line as well as the way in which Santa Clara County and Sacramento are purchasing theirs. Standardization of procurement methods, specifications, and car subsystems can facilitate this process, which should reduce nonrecurring costs to the car builder and bring production lines further along the learning curve.

New York's R-62 procurement is using a design specification that calls for (6,p.2) "equipment previously furnished and found satisfactory on the NYCTS . . . . The R-62 will be made reliable and maintainable by sound design based upon actual operating experience--and not based on some unsubstantiated language written into the technical specification."

The abandonment of the sealed bid in favor of methods allowing more negotiation of technical and contract specifications has helped speed the change in car design. Competitive bidding required a tight specification, because all the bidders had to be on an equal footing. Two-step procurements allow bidders to negotiate the specification requirements until they and the transit authority are satisfied with the result, at which point the price is considered.

San Diego made the first procurement in 20 years that was purely negotiated. State laws have prohibited public agencies in most states from price negotiation, requiring the selection of the lowest bidder. In 1982 both the New York and Georgia legislatures passed laws allowing full negotiation of contract terms and prices in the same manner by which private industry buys its goods, specifically to aid in rail transit purchases. In Atlanta the results of a bid opening for 30 cars to the authority's design with a sealed-bid procurement was a price 31 percent higher than the engineer's estimate. MARTA reissued the contract advertisement to four bidders for negotiation on escalation, price, contract terms and conditions, and technical requirements. When negotiations were concluded in September, Hitachi was the apparent low bidder with a price 84 percent of its original bid.

Insufficient federal funding has prompted a search for alternative methods of paying for rolling stock. New York City has become a leader in this search. Two new sources of funds have been spearheaded by the New York MTA: One is the safe harbor leasing provision written into the 1981 Economic Recovery Tax Act and the other is the concept of supplier financing. Both have been used extensively in other industries; the application to transit is new.

Safe harbor leasing allows transit authorities to sell the tax depreciation of that portion of new rolling stock not federally funded. A private party, after putting up 20 to 25 percent of the price of the vehicle, may depreciate the full cost in 5 years. The authority finances the other 75 to 80 percent through its own bonds. The private party pays the remainder back to the authority over the life of the vehicle and, because that party retains title, the authority leases the vehicle back at the same price. The private party gets the tax write-off, and the authority has full beneficial use of the vehicle at 80 percent of its total cost. This is, of course, an indirect federal subsidy of the capital cost of rolling stock, because the money saved by the authority comes out of the U.S. Treasury via tax write-offs. The New York MTA is the first transit authority in recent years to issue bonds backed by fare revenues. These bonds were used for the R-62 and R-68 purchases.

Purchases without federal funding also removed federal financing, which originally made progress payments more feasible. This makes the question of financing the procurement more important and an element of negotiation. In some cases a supplier can improve his competitive position by arranging financing at a rate below that available to the transit authority.

In the commercial aircraft industry, it has been standard practice for manufacturers to finance purchases of their equipment. When all the suppliers have access to the same interest rates and money markets, competition is fair. However, the interest rates available to a foreign supplier through an export bank may be lower than those available to domestic suppliers. This has caused Boeing some difficulty recently.

In 1982 during the negotiations for the second part of the R-62 order, the prime rate in the United States was 16.5 percent and the municipal bond rate was around 12 percent. Bombardier, through the Canadian Export Development Corporation, was able to arrange 9.7 percent financing, giving the firm a $130 million advantage over Budd and allowing Bombardier to win the order. Had Budd not withdrawn its complaint, a Department of Commerce ruling would have forced Bombardier to pay duties equivalent to the subsidy. In contrast, the financing offered by Hitachi for the recent contract award in Atlanta was rejected as more costly than that available to MARTA.

Supplier financing will most likely become a more common part of procurement negotiations where federal funding is not available, although the choice may be not to use it, as MARTA has done. Houston's recent call for bids requested suppliers to develop a package for financing 85 percent of the cost of the order.

RECOMMENDATIONS

There have been three significant problems in the industry in the past: sealed-bid, fixed-price procurement during high inflation; unreliable technology; and an erratic market. The transit industry has recognized all of these problems and has worked toward a solution of the first two. The market problem remains.

Procurement trends indicate where new problems may arise. Specification requirements that require proven equipment to be supplied will make it more difficult to introduce new technology or innovations or even new cars. The problems that came from attempting to innovate too quickly are well known and the industry is apprehensive about innovation. Nevertheless, as technology progresses, transit car designs should also be improved. Some cars now in production are based on early technology and do not incorporate some of the most successful innovations: low-alloy high-tensile (LAHT) steel (1930s) or chopper control (1960s), for example. The industry must still find a solution to the problem of gradually introducing new technology.

The trend toward supplier financing will have severe impacts on the competition between foreign and domestic car builders. When one car builder has access to financing at a favorable interest rate unavailable to its competitors, there is an advantage. This problem has occurred in other industries with no real solution to date.

The size and shape of the replacement market for rail transit cars is a major factor affecting the car-building industry in the United States. As shown in Figure 4, between 1983 and 1990 there will be approximately 1,000 cars that will require replacement or be needed for new rail starts that have not already been ordered. Between 1990 and 1995 only 900 cars will be required. The market from 1995 until well past the turn of the century is 500 to 600 cars per year, and there is little likelihood of any significant increase in orders beyond this figure.

The erratic market is a problem that has been cited by other studies but has never been confronted. Each transit authority determines when it will go out for bids to order cars. It also sets a delivery schedule for the car builder to meet. This produces periods with too many orders to be bid on efficiently and periods with too few orders to sustain production capacity.

In 1977, UMTA recognized that there were a large number of orders coming up and worked with the

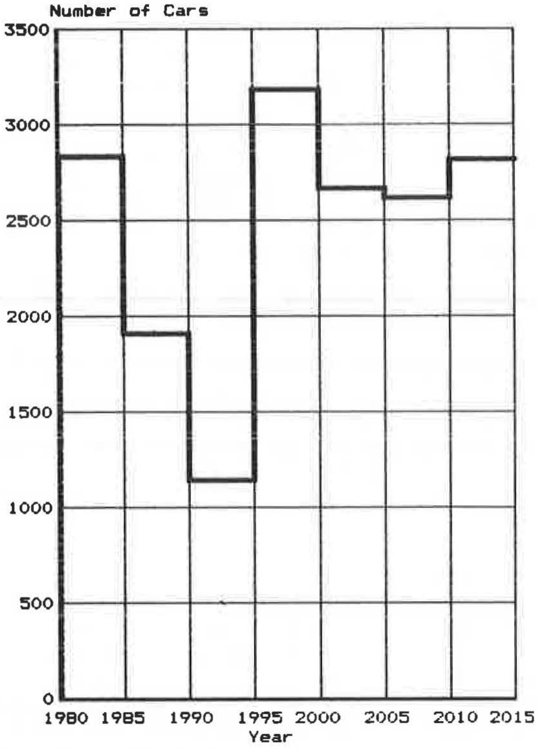

FIGURE 4 Future U.S. rail-car market, 5-year periods.

transit authorities to avoid issuing a large number of RFPs in the same year, but without much success. Neither UMTA nor the federal government has direct control over when a grant recipient will spend his funds. However, UMTA can influence car orders by sequencing grants. Although this has not been tried, it would be a powerful tool to help regularize the market. By holding back grants from the authorities when demand exceeds capacity or making more funds available when orders are scarce, UMTA might help stabilize the market. It would require a consensus from local authorities, Congress, and UMTA that a more regular market and stable supply industry were in their best interests and transcended other concerns.

The trend away from federally funded procurements (San Diego, New York, Houston) will further reduce UMTA's ability to influence the market. The industry could attempt to regularize the market voluntarily through such organizations as the American Public Transit Authority and the Railway Progress Institute. This type of self-regulation has been rare to date, although there are enough signs of cooperation on other matters to make the effort worthwhile.

Another source of stability would be a fixed, certain level of transit funding similar to the Highway Trust Fund that would allow long-range planning and budgeting by transit authorities. Assurance of funds for rail-car purchases over a decade would allow local authorities to spread orders out evenly instead of buying as many cars as possible while funding is available.

If this erratic market remains, it is up to the car builders to make whatever adjustments they can in order to continue in business. Two adjustments are indicated by size and shape of the current market. The first is to maintain a diversified product line. Only the car builders with the engineering and production staff and the capability to build all types of passenger cars will withstand the steep swings in car orders that are projected for each type of rail car. The light rail car builder faces 10 years of virtually no orders in the 1990s, and an average of 50 to 60 cars per year after that. In order to recoup an investment in plant and staff it will be necessary to build some other kind of rail equipment in the lean times. Continual work requires diversification.

The second adjustment is to gear production capacity to a typical order size of 100 cars. Investment in enough capacity to produce 700 cars a year is counterproductive when the market averages 500. U.S. car builders must learn how to turn out a small order of cars profitably. Order sizes will remain small (except for New York), and it will be necessary for a car builder to turn down orders where the method of procurement, design of the car, or terms and conditions will eliminate the chance of a profit. Bombardier decided not to bid the San Jose Santa Clara County Transit District light rail procurement even though it qualified because they said too many changes were requested in the design of the car.

Research, development, and introduction of new technology should be a cooperative effort. It has not been managed well in the rail transit industry, in many cases because the prototype demonstration stage of the cycle has been skipped. Demonstration is the most expensive part of the cycle. A prototype of concepts that have been tested in the lab must be made (essentially by hand), fitted onto existing equipment, and service tested.

Manufacturers have indicated a willingness to fund research through the laboratory stage. Authorities are willing to buy new designs once they have been proven in service. There is a gap in between that neither party believes it has the responsibility for nor the ability to afford. Bridging the gap may be a proper role of UMTA R&D funds, which it now carries out under Section 3 (a)(1)(C). Recently UMTA provided funds through this program for the test and evaluation of a new brake system for the WMATA fleet.

The best method of introducing new technology is to do it slowly and incrementally as a small portion of an overall proven system. Relying on a completely new design invites large risks. The need for high reliability in rail transit and the small market limit the amount of innovation that is feasible for each car order.

Rail-car manufacturing is not the only industry facing the problem of competing for credit against export financing. This problem has to be addressed at high levels of government. It is one that only the federal government can resolve because it also affects steel, aircraft, machine tools, and other industries. Protectionism is one solution--high tariffs on imports that raise the cost of imported goods to the advantage of domestic industry. From the standpoint of free and open markets, this is an unacceptable solution. Legislation that allows the Export-Import Bank or another arm of the federal banking system to match the credit rates offered by foreign suppliers is another possible solution. This would allow every manufacturer to offer more equal terms, reducing the importance of financing in the choice of a car supplier.

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Automated and Passenger-Based Transit Performance Measures

KELVIN BUNEMAN

ABSTRACT

Operational performance measures of a transit system are often best expressed in terms of the passenger. These include measures of productivity per passenger trip or per passenger mile, measures of crowding or seat capacity, and measures of on-time performance or schedule adherence. At the Bay Area Rapid Transit, detailed operational data are available daily as a by-product of automation, which saves considerable manual data collection. A computer program to use these data to produce operational performance measures is described. The program runs daily to allow schedulers to allocate vehicles accurately, which yields energy and maintenance savings, and for ongoing analysis of delays. Passenger-based delay measures are produced that have hitherto been unavailable.

Measurement of crowding or seat occupancy is relevant in two ways. First, during the peak periods, most transit systems are subject to a fleet size constraint. There are only so many buses or rail cars available, and some passengers have to stand. It is important to balance capacity among all routes to avoid an excess of standees on any particular route. Passenger demand varies within the peak period; for example, it may be highest between 7:30 and 8:00 a.m. but still heavy at 8:30 a.m. Schedulers must also balance capacity between the different times within the peak. Second, during the off-peak periods, it is important to operate no more vehicles than the minimum needed to guarantee most passengers a seat. This can be done in train systems by changing headways or train lengths. Headways may be mandated by externally imposed minimum service requirements, but train lengths are adjustable subject only to physical constraints such as the minimum indivisible train set length. An excess of vehicles will incur unnecessary energy and maintenance costs because of extra vehicle miles traveled. An undersupply of vehicles causes crowding, which may drive passengers away.

Measurement of on-time performance is generally done in terms of the number of late or missed bus runs or train runs. However, it is useful to produce statistical information on train delays as experienced from the passenger's point of view. Passenger-based on-time performance measurement puts in proper perspective the magnitude of system delays, differentiating, for example, between a 30-min peak-period delay versus a 30-min off-peak delay. It can assist a transit system in better allocating its resources toward various planned improvements and also provide a better measure of understanding of the actual impact of these improvements on passenger service.

The major distinction between the standard train on-time reporting of passenger service and passenger-based service measures is the weighting or importance given to a delay event. In train on-time reporting, as much value is given to an empty 3-car train delayed for 10 min as to a packed 10-car train delayed for the same 10 min. Obviously, the packed 10-car train carries a greater impact on passenger service than the empty 3-car train and should be so measured. Passenger-based delay measures reflect this proper weighting by basing calculations on passenger trips that are on time rather than trains that are on time.

A report prepared for UMTA in 1978 (1) addressed service availability at length, where service availability is defined as the impingement of failures on passenger-perceived service. The report is for automated guideway transit (AGT) systems, but the concepts discussed in the report are applicable to any transit system where there is substantial control over the vehicle and right-of-way, whether automated or not. In the report it is found that passenger-based service availability measures are most desirable but that these require more data than are collected by most operating systems.

In 1979 Heimann (2,pp.314-322) developed a passenger-based dependability measure. He modeled several hypothetical train delay incidents, showing train-to-train delay interactions and passenger-to-train delay interactions. He then computed delays for several cohorts of passengers traveling between several different stations for each of the train delay incidents. Though Heimann's work was based on the Massachusetts Bay Transportation Authority (MBTA) Red Line in Boston, a real system, he intended to exemplify a process rather than actually compute the daily dependability of the Red Line.

PRODUCTION OF PERFORMANCE MEASURES

Data Collection

In many transit systems, ride checks and point checks are necessary for measurement. These manually collected data must be coded for analysis, which requires a good deal of labor in the field as well as clerical effort at the central office. Budget limitations enforce limited checking and sampling. San Francisco's Bay Area Rapid Transit (BART) is fortunate to have both central computer train control and automated ticketing, which allow production of both train and passenger movement data. Central train control makes a record each time a train opens or closes its doors and of every train action.

BART pioneered the stored-fare magnetically encoded ticket system, which has since been adopted by the Washington (D.C.) Metropolitan Area Transit Authority (WMATA). A complete description is inappropriate here; the key point is that the proper fare is determined at the exit fare gate by reference to a table indexed by station of entry. Thus, origin information for each passenger is available at the exit station. Obviously, destination information--the fare gate's own location--is available and the time of exit can be recorded. This allows accurate production of passenger counts each day by origin and destination and time of day--a travel demand modeler's dream.

Computation of Performance Measures

The steps from raw data on passenger and train movement to the final performance measures are shown broadly in Figure 1. Structured systems analysis notation is used (3).

The passenger flow model (PFM) system within Figure 1 (so called because one part of the system includes a simulation model) is the focus of this paper. Elements of the data flows into it are defined as follows:

- Train action is one record identifying an event such as an open door or a closed door, including time of day, location, train identification, and train length.
- Exit counts by origin and destination are passenger exit counts for each of the 34^2 possible origin-destination (OD) pairs plus time of day.
- Detail timetable for each scheduled train run on each route gives scheduled door closing times for the first and all intermediate stops. It gives door opening times for the final stop. In addition, it gives expected final arrival times at other stations for passengers who will transfer. Like the public timetable, this timetable is offset 60 sec earlier than the central control internal train schedule. This allows trains to get up to 60 sec ahead of the internal schedule without penalty.

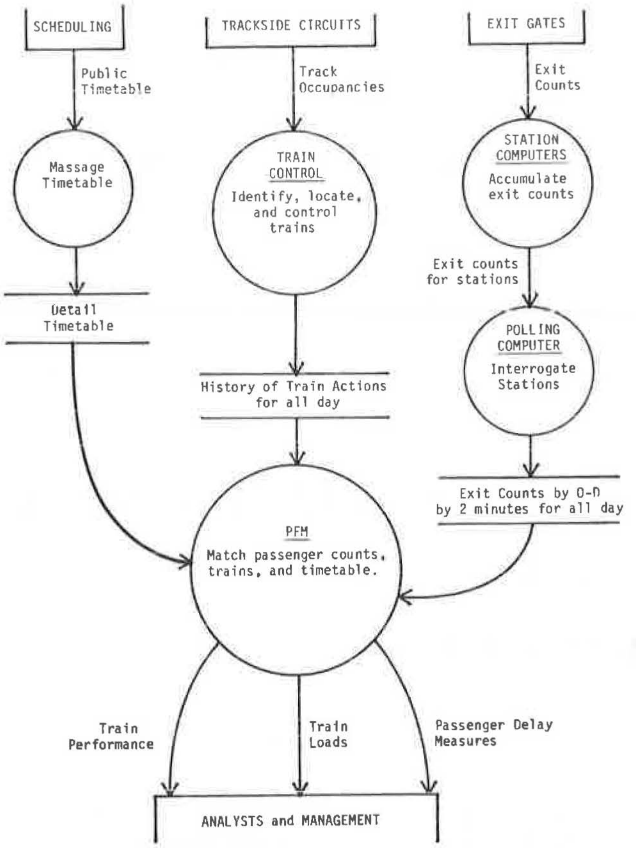


FIGURE 1 Data flow for performance monitoring.

The PFM system consists of computer programs written in FORTRAN. The following detailed descriptions of the programs are intended to accompany Figure 2.

Program 2.1: Automated Edit of Train Actions

Program 2.1 checks the train actions for consistency against an internal map showing stations and routes. It assembles train actions into train runs. For these purposes, a train run is a sequence of train actions from train reversal to train reversal (generally from one end of the line to the other end of the line). Each action in a train run is tagged with the starting and ending stations for that run.

Program 2.2: Matching Trains with Timetable and Generation of Train Performance Measures

For each train run, Program 2.2 finds the slot in the detail timetable that most closely precedes the train's actual departure time. It then checks every actual station stop along the run against the scheduled time for that stop. Because time is measured to 1-sec rather than 1-min accuracy, it is important to distinguish between when the door is opened (arrival) and when the door is closed (departure). The PFM system adopts the convention that the door closing time is the more important time for the first and all intermediate stops on a train run. The door opening time must be used at the final stop. By checking at each station, this program can annunciate each train delay by location, which allows accurate analysis of delays. Four types of delay event are possible. First, a train may be dispatched

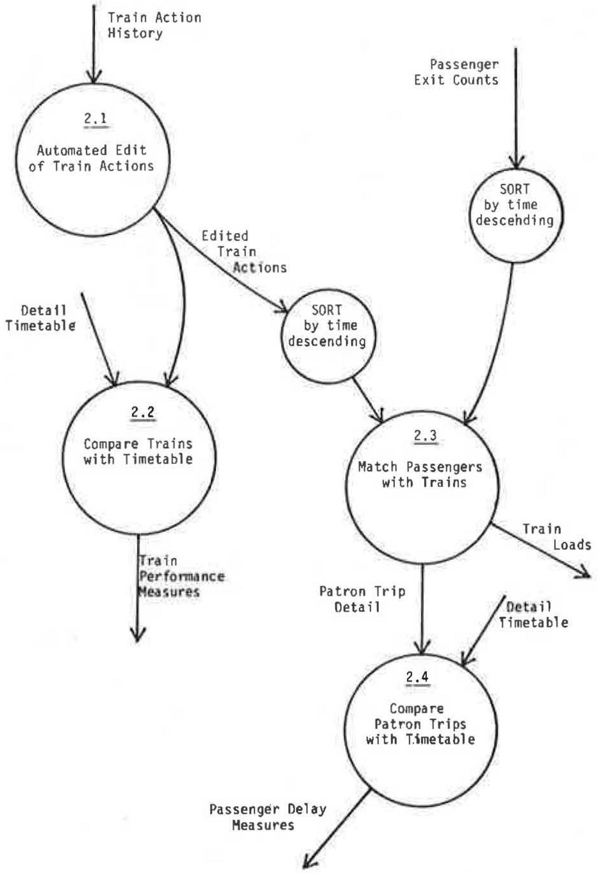


FIGURE 2 Data flow within PFM process.

late. Second, a train may be delayed en route between adjacent stations. Third, a train may be delayed at a station with its doors open--an excessive dwell time. Fourth, a delay may extend across several stations--a slowly moving train.

Program 2.2 can also generate standard train performance measures such as the number of train runs on time and end to end, the total number of successful train runs, and the number of cancelled or incomplete train runs. The program also has access to a table of distances between stations. Using these distances and the actual train actions and train lengths, it generates total revenue vehicle miles.

Program 2.3: Matching Actual Patrons with Actual Train Actions

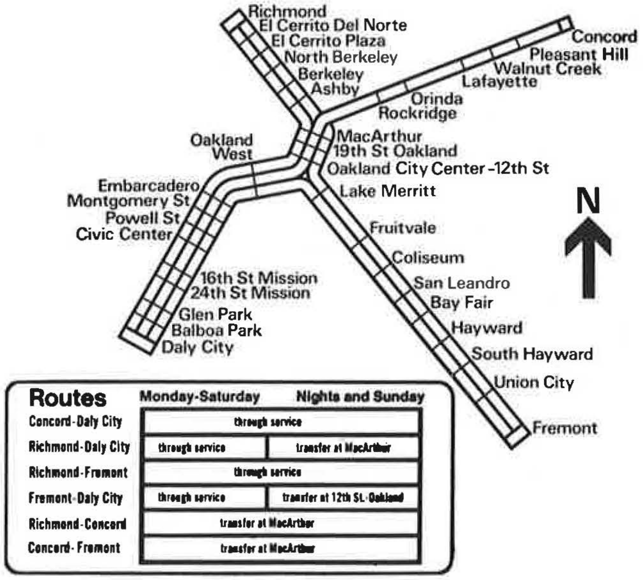
Program 2.3 is the most intriguing program in the PFM system. Train actions consist of all door openings and closings with time, station, route, and train identification. Patrons are recorded at their exit by time, exit station, and entry station. Because only patron exit data are available, this program is a time-reverse simulation, hence the nickname, BACKWARDS. Unlike stochastic simulations for experimental use, this is deterministic. The simulation may be best described by following one patron's trip backward from the exit:

1. Hold patron in exit station;
2. Load patron on the previous train that served his entry station; set patron arrival time to train door opening time;
3. Follow train back toward patron's entry station; if a transfer is needed, unload patron into transfer station; hold the patron at the transfer station until the previous train that served his entry station;
4. Set patron departure time to train door closing time and unload patron into entry station;
5. Hold patron in entry station until previous service between this station pair; and
6. Set previous departure time to time of previous train door closing; record patron trip (steps 5 and 6 allow recording of the headway to deduce patron waiting time).

Although the foregoing description is for only one patron, Program 2.3 actually works on all patrons and trains in parallel. It is driven by the train actions. Exit stations, transfer stations, entry stations, and trains are simple data structures containing counts of patrons and arrival and departure times. Note that there is no need to combine the three station data structures (exit, transfer, and entry) unless measures of platform crowding are needed. Timing is essential to the correct matching of patrons with trains. The patron exit counts are scanned every 2 min, which is less than the minimum scheduled headway. The time required for a patron to leave the train and ride the escalator to the lobby and fare gates must also be considered.

Program 2.3 uses a map showing stations, routes, and transfer requirements. The map tells which route or routes serve any given pair of stations. At BART, three suburban East Bay routes converge into one pair of tracks to serve the central city, San Francisco. The program knows that certain trips (OD pairs) are served by multiple routes. Typically shorter trips are served by multiple routes, whereas longer trips are served by only one route.

Passengers do not need to use their ticket to transfer from one train route to another. In some cases, they have a choice of transfer station. For example, passengers traveling from Fremont to Concord may transfer at any of the three downtown Oakland stations (see Figure 3). The current version of the program simply assumes that MacArthur Station is the preferred transfer station when there is a choice. This does not cause errors in patron travel



Routes	Monday-Saturday	Nights and Sunday
Concord-Daly City	through service	
Richmond-Daly City	through service	transfer at MacArthur
Richmond-Fremont	through service	
Fremont-Daly City	through service	transfer at 12th St.-Oakland
Richmond-Concord	transfer at MacArthur	
Concord-Fremont	transfer at MacArthur	

FIGURE 3 BART system map.

time measurement and affects train load measurement accuracy only between MacArthur Station and 12th Street Station. Other possible sources of error in this train load modeling include patrons who transfer even when direct service is available between their origin and destination, patrons who take excursion rides and enter and exit at the same station, and employees traveling on passes.

The train-load output of the program is sorted by location and time and reported for each of several locations. For each location, the report has one line per train, showing time, train identification, train length, number of passengers, and the ratio of passengers to seats. The accuracy of this report has been checked by walking through trains and counting passengers and found to be very high.

Program 2.4: Matching Passenger Trips with Timetable

Program 2.4 finds expected and actual wait time and expected and actual travel times for an entire day of patron trips. All patrons who made the same trip are grouped together into a patron move. Trips are the same if the origin, destination, and train run are the same. A patron move includes entry station, departure time, previous departure time, exit station, arrival time, train identification, and number of patrons involved (frequently just one or a few patrons). To avoid excessive searching, this program proceeds by departure time for all stations and routes in parallel. It maintains pointers into the timetable for each route and station.

The actual departure time and previous departure time define an interval within which the program finds all applicable departures on applicable routes. Three cases are possible: one scheduled departure (normal), no scheduled departure in interval (extra train or early train), or more than one scheduled departure in interval (cancelled or late train or trains). If only one scheduled departure is found between actual departures, there is some chance that a patron expected that departure and some chance that he arrived on the platform too late for that departure and expected the following departure. For example, with a 15-min scheduled headway, a train that started 5 min late appears to some patrons to be 10 min early. Two important assumptions about passenger expectations and passenger behavior are as follows:

1. What is the passenger's expectation of departure time? BART now publishes a detailed timetable, so for passengers who use the timetable the answer is clear. However, some passengers may simply expect a certain headway; they may just expect an average wait time equal to one-half the published headway. This headway expectation is less exacting than a timetable expectation. For transit lines with short route headways, the headway assumption is appropriate. For lines with long route headways such as commuter rail service, the timetable assumption is more appropriate. The patron on-time measures developed so far at BART use the tougher timetable assumption.
2. At what rate do patrons arrive on the platform to wait for their train? This question is relevant for trains that depart a few minutes early and for split-headway operation. Patrons who arrive just before a scheduled departure only to see taillights disappearing into a tunnel must wait a full headway. Although the first assumption implies that all patrons know the timetable, it is also assumed that they do not all arrive exactly at the time the train is scheduled to depart. Nor is it assumed that they all arrive uniformly over time. An estimate of how many patrons arrive promptly rather than uniformly over time must be made to assign delays. This information is not available automatically because only exit data with fine time resolution are available. This question has been investigated at least once before for rail service. In London, a 1970 study (4) suggested that for a 15-min headway, 42 percent of peak-period suburban rail patrons arrive promptly and 23 percent of off-peak patrons do so. The proportion of prompt arrivals tended to decrease with shorter headways. A 1970 study of British bus passengers (5) found similar results. In January 1983, an informal study at BART's suburban stations showed 11 percent prompt arrivals at the 7.5-min headway and 13 percent prompt at the 15-min headway. This is much lower than the British data, perhaps because BART did not then publish a timetable. Because BART now publishes a timetable, an arbitrary promptness criterion of 25 percent prompt arrivals was chosen for the patron on-time measure. This compromise value provides an adequate penalty for early trains.

A numerical example for one origin station follows: Suppose that trains are scheduled to depart at 8:00, 8:15, 8:30, ... Suppose that the 8:00 departure is on time and the next actual departure is at 8:25, and Program 2.3 indicates that 120 patrons rode the 8:25 train. The promptness criterion says that 25 percent of all patrons arriving between 8:00 and 8:15 arrived exactly at 8:15; the remainder arrived uniformly over time. In this example, Program 2.4 will compute the following:

1. Sixty passengers arrived uniformly at 4 per minute between 8:00 and 8:15, expecting to catch the 8:15 schedule;
2. Twenty passengers arrived promptly at 8:15, expecting to catch the 8:15 schedule;
3. Forty passengers arrived uniformly at 4 per minute between 8:15 and 8:25, expecting to catch the 8:30 schedule.

Then of the 120 patrons riding the 8:25 departure, 60 + 20 = 80 expected the 8:15 schedule and 40 expected the 8:30 schedule.

Having determined which schedule each passenger expects, it is easy to determine expected arrival time and compare it with actual arrival time. Figure 4 shows the average weekday distribution of passenger delays for several months at BART. This includes both waiting time and travel time. For transfer passengers, the entire train trip from initial wait through final arrival is measured.

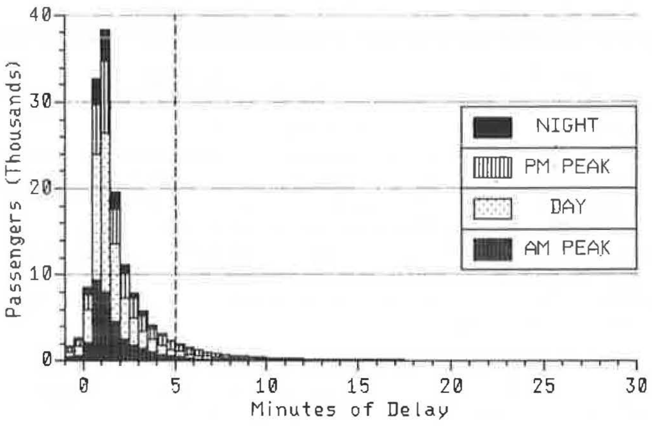


FIGURE 4 Histogram of passenger delays (May-October 1983).

Costs of Automated Performance Measurement

Approximately 3 man-years were required to develop the PFM software. This effort has been divided between independent software contractors and BART's own research engineers. The PFM system runs during the graveyard shift at the end of revenue train operations. It requires about half an hour to execute each night on BART's IBM 4341 and uses up to 1 megabyte of virtual memory. During the graveyard shift, however, there is little contention for the computer and a full megabyte of real memory is generally available. Operation and use of the PFM system requires less than 1 hr a day from data processing operations staff and an hour per day of a schedule analyst's time.

Automated performance measurement is considered a by-product, not the primary purpose, of the automatic fare collection (AFC) system, so it is inappropriate to include the costs of AFC as part of the costs of this measurement. The station computers and central polling computer cost about $750,000 in 1976 dollars and require an average of 0.4 full-time electronic technician to maintain. However, these computers provide other benefits by collecting data from other station equipment, such as ticket vending machines, for use by the treasury and police departments.

USE OF AUTOMATED PERFORMANCE MEASURES

The train-based delay event list generated by Program 2.2 is used during next-day analysis of train delays. It helps to bridge the gap between aggregate service quality measures, such as total train delays or total patron delays, and individual component failure measures. It helps distinguish between primary delays and secondary delays. Primary delays are those directly caused by a failure, whereas secondary delays are due to the train traffic congestion that follows a primary delay.

The passenger loads are averaged by train over 10 weeks, with separate moving averages for each day of the week. From these average passenger loads, measured at the five critical locations in the BART system, an optimal allocation of revenue vehicles is made. This allocation is to minimize crowding subject to several constraints such as minimum and maximum train lengths and the timetable (minimum headways).

Ongoing passenger load monitoring is necessary as demand patterns shift. Some changes are predictable, such as seasonal changes and changes during the week. Some demand changes are not so predictable, such as the ongoing overall increase in BART patronage or public response to changes in feeder-bus routes or station parking availability.

Approximately 12.5 full-time clerical positions would be required for passenger load monitoring if the automated system were not available. Whether loads are monitored manually or automatically, the monitoring is worthwhile. Operation of just 2 percent more vehicle miles than the load requires would cost about $584,000 per year just for energy and maintenance.

Passenger loads are also reported quarterly and used for long-range planning. As patronage grows and trains become more crowded, it is necessary to acquire more vehicles and reduce headways. Examination of passenger loads by time and by route can show the shape of the peak-period demand. A flatter, wider peak suggests that transportation systems management measures such as flextime are effective.

A project is under consideration to communicate detailed passenger load information to the passengers. This would inform passengers which trains are usually more crowded and which trains usually have remaining capacity. Surveys show that about one-third of BART's passengers could vary their working hours. These passengers might switch to less crowded trains if they were provided with suitable advisories.

Although automated measurement of passenger loads has been in use at BART for several years, the passenger-based delay measures are newly developed. The exact form of a measurement of passenger delays has not yet been decided. Two basic forms are possible:

1. Trip dependability, defined as follows:

D = (number of passenger trips on time times 100) divided by total trips,

where an on-time trip is a trip with delay less than some tolerable amount, such as 5 min. This measure would be expressed as a percentage; 99 percent would be very dependable service, whereas 50 percent would be very poor service.

2. Expected delay, defined as follows:

D = total passenger minutes of delay divided by total trips,

where a passenger minute of delay is one passenger delayed 1 min. This measure would be expressed in minutes; 0.1 min would be very dependable service, whereas 5 min would be very poor service. Unlike the trip-dependability measure, this is sensitive to the duration of delays.

Little is known about passenger disutilities with respect to length of delay for transit systems. For example, is a 10-min delay once a month better or worse than a 5-min delay twice a month? Leis (1) raises this type of question in greater detail.

Summary measures of on-time performance or delay, or even the distribution of delay such as that shown in Figure 4, are most useful if a link can be established between the aggregate measure and specific problems such as component failure. The causative relationship between component failure and total passenger delays can be broken down into four steps:

1. Equipment failure causes a slow or stopped train;
2. Time is required to diagnose the problem and restart or remove the train (primary train delay);
3. Secondary train delays occur because the primary train blocked the track and because the resultant high passenger loads cause station dwell delays; combined primary and secondary delays are a delay event;
4. Passenger delays occur both on board the delayed trains and while waiting downstream of the delay.

As Heimann (2) points out, much is known about step 1 and the relationship between steps 1 and 2. An automated vehicle and component repair tracking system is in use at BART. The link between steps 2 and 3 is currently established manually for each major delay event with computer assistance. This could be largely automated except that multiple primary delays occur and interfere with each other, making it difficult to distinguish delay events. The link between steps 3 and 4 has not yet been well established. Because passengers may experience the effects of more than one delay event in the course of a trip, this linkage should be further analyzed. Currently a computer report of passenger delays by train run is used to support the manual analysis of train delay events and to identify the likely cause of major passenger delays. The report breaks down delay time into an en-route component and a waiting-time (at platform) component. Results so far show that the waiting-time component of delay is generally larger than the en-route component.

Although this discussion has been largely oriented to measurement of the current state of an existing system, the passenger-based aggregate measure can be applied to future systems or to future configurations of existing systems. The real train actions can be replaced by simulated disturbed train actions produced by a train system simulator. The real passenger counts can be replaced by forecast passenger counts. Program 2.3 would be replaced by time-forward matching of trains and passengers.

CONCLUSIONS

With increasing automation in transit operations, the amount of operating data generated will increase. Automated OD ticketing and automated recording of vehicle movement make possible accurate passenger-based performance measurement. The PFM software could be configured to serve any guideway transit system that has data on all train movements and all patron exits by origin. Even automated zone-based or flat-fare ticketing systems, which record entries but not exits, can provide data to supplement manual counts and sampling.

Further research is needed to better understand the relationship between primary vehicle delays, secondary vehicle delays, and passenger delays. When these links are understood, it will be possible to allocate maintenance resources where they will best benefit the passenger. More research is also needed to investigate passenger expectations regarding wait time and timetable adherence and passenger annoyance due to delays of differing lengths.

ACKNOWLEDGMENT

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Monitoring the Quality of Service from the Passengers' Perspective

MATTHEW K. du PLESSIS

ABSTRACT

Management's concern with customer satisfaction and the common methods of gauging patrons' assessment of service are discussed. A method of performing surveys of trains and stations based on sampling techniques is then described. Performed on a periodic basis, the studies have an audit-type quality that helps alert management to potential problems and areas needing further investigation. The results of the studies are reviewed, and sample tables and graphs are presented. As a result of the data generated by the surveys, changes in train schedules were developed and further studies of the vehicle-cleaning process initiated. The increased reliability of the system is shown dramatically in a graph of published travel time variance.

Customer satisfaction is an important concern to managers in any organization but especially to those in a service industry such as public transportation. Being publicly owned, such transportation agencies find themselves subject to even closer scrutiny than private companies. For these and other reasons, senior managers of rapid transit agencies are anxious to have a tool for assessing the quality of service provided by their agencies. In this way they can be alerted to areas requiring management's attention and to trends that may need further investigation.

Two common methods of gauging patrons' assessment of service are

1. To summarize the number and types of letters and telephone calls received by the general manager and public affairs office or
2. To perform a passenger survey on a periodic basis.

The difficulties with these methods are that they incorporate a great deal of subjective judgment and varied interpretation and that they usually emphasize the negative exceptions in service.

In 1978 management of the Bay Area Rapid Transit (BART) decided that they wanted an assessment mechanism that would provide more uniform objective data, data that could not be obtained by a passenger survey. The result of this perceived need was the Passenger Services Sampling (PSS) Study conducted by Management Services at BART. The purpose of the PSS Study is to provide management with a perspective of the BART system as seen from the patrons' point of view. In a sense, the study gives management a periodic snapshot of the service provided by the BART system.

DESIGN AND DEVELOPMENT

The first step was to determine the variables or items to be used to evaluate service. A preliminary analysis was undertaken to define the passenger services that should be measured. As part of this analysis, the Management Trip Report that had previously been used and the Passenger Services Monthly Patron Complaint Report were reviewed. These reports provided a good first information source for compiling a listing of passenger service parameters that should be measured. These parameters were further refined in meetings with Marketing and Field Services managers until both departments were satisfied with the data that were to be collected. The items included in the study are listed as follows:

1. Station information
    a. Agent in or out of station agent booth
    b. Agent in uniform
    c. Supervisor present
    d. BART police present
    e. Brochures available
    f. Equipment operable (fare gates, ticket machines, elevators, escalators, etc.)
    g. Cleanliness (station, restroom, and elevator)
    h. Announcements heard over P.A. system
    i. Number of rule violations committed by patrons
2. Boarding information
    a. Waiting time
    b. Destination signs working
    c. Train exterior cleanliness
    d. Train operator watching doors
3. Trip information
    a. Trip time
    b. Car interior cleanliness
    c. Car loading
    d. BART police on car
    e. Rule violations committed by patrons
    f. Announcements heard on car

It was determined that the best way to collect the information required would be to employ a group of individuals full time for a given period of time and have them collect data using statistical work-sampling techniques. The study was designed so that it could be conducted by six temporary employees over a two-week period on two shifts. The only special qualification required of the samplers was the ability to learn quickly and follow fairly detailed instructions. One-half day of training was sufficient to prepare the samplers for regular data collection.

At first the data were gathered on forms designed for manual analysis. Naturally, the analysis of the data and preparation of tables and graphs were extremely time consuming when done manually. Over the years, the data collection form has been changed to a format suitable for direct keypunching of the data (see Figure 1) and a program written to analyze and compile the data. Recently, the computer capability to produce graphs has also been utilized.

The samplers surveyed both stations and trains. In the stations the samplers performed either an abbreviated check or a full check. The abbreviated station check included only a determination of station cleanliness based on standards provided by BART (see Figure 2) and a tallying of passenger rule violations occurring in the station. The full station check included the abbreviated check data and the following information:

1. Elevator call response time,
2. Elevator cleanliness,
3. Agent availability,
4. Presence of officers from BART Police Department (BPD),
5. Brochure availability,
6. Restroom cleanliness, and
7. Other miscellaneous data.

Of the 1,146 station checks made, 575 were full-station checks.

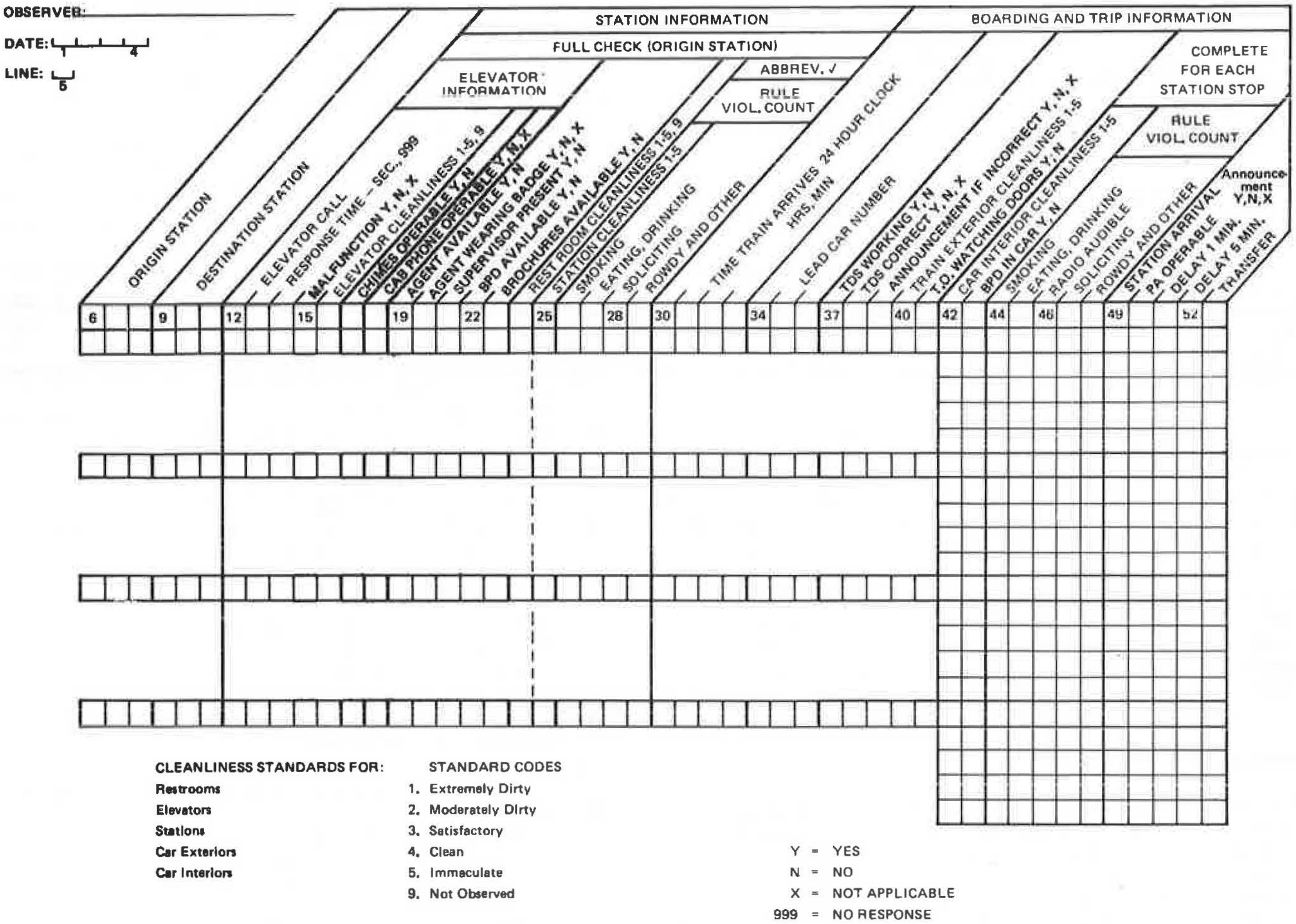
In sampling the trains, the temporary employees noted train arrival time, train destination sign (TDS) operation, vehicle cleanliness (both exterior and interior), announcements, and other information similar to the station sampling data. The samplers traveled back and forth on each section of the system in a leapfrog fashion. They followed the routine shown on the sampling forms. A trip can vary from one station to five stations. The samplers began their trips on the lead car and moved back one car at each station. When the samplers reached the scheduled destination station, they got off and performed the indicated station check, either abbreviated or full. They then rode the next train to their next scheduled destination station. A total of 4,130 station-to-station rides were made.

The samplers also maintained various logs as required, for example, inoperative public address speakers on the vehicles, unsafe or unusual occurrences, and off loads or delays.

RESULTS

The final report on the study includes more than 50 graphs and tables, but four examples will give the overall picture. The observations are summarized in two distinct categories--train sampling and station sampling. Because the charts are similar, only some examples from the train-sampling category will be considered.

In looking at weekday service conditions for the total system (see Figure 3), it can be seen that arrival (T.O.) announcements made by the train operators have increased over the last 4 or 5 years.



CLEANLINESS STANDARDS FOR:	STANDARD CODES
Restrooms	1. Extremely Dirty
Elevators	2. Moderately Dirty
Stations	3. Satisfactory
Car Exteriors	4. Clean
Car Interiors	5. Immaculate
	9. Not Observed

Y = YES
N = NO
X = NOT APPLICABLE
999 = NO RESPONSE

FIGURE 1 Passenger services sampling evaluation form.

The train operators were making arrival announcements 89 percent of the time in 1978 and 94 percent of the time in 1982. Transfer announcements, on the other hand, have dropped from 51 percent in 1978 to 45 percent in 1982. The exterior cleanliness of the trains has fluctuated over the years, decreasing overall. The interior cleanliness of the trains has declined each year. A study was done of the car cleaners last year by one of the other management engineers. Also, the exterior cleaning of the cars is being carefully monitored by the operations staff.

The dramatic decrease in smoking violations on trains between December 1978 and April 1980 can be attributed to two important events:

1. The transbay tube fire in January 1979 and
2. The passage by the state legislature of a $50 fine for smoking in the BART system.

The graph of the published travel time variance in Figure 4 shows the percent variance of actual travel times from published travel times. An obser-

5. IMMACULATE:	Clean station entrances, concourse level, and platform level. No apparent litter, cigarette butts, or overflowing trash cans.
4. CLEAN:	Light littering, cigarette butts, candy wrappers, etc., on floor. Clean otherwise.
3. SATISFACTORY:	Light littering as for a Number 4 rating, discarded newspapers apparent. Spill stains on floors, lightly-soiled ceilings or walls.
2. MODERATELY DIRTY:	Generally dirty appearance. Overflowing trash cans, littering as in Number 3, but more widespread. Spills, dirt and new staining apparent on floors.
1. EXTREMELY DIRTY:	Very dirty station. Trash and spills per Number 2. However, more garbage cans are overflowing, numerous spills, strewn garbage.

FIGURE 2 Station cleanliness standards.

	MAY 82	APR 80	MAR 78
T. O. ANNOUNCEMENTS			
ARRIVAL, % TIME MADE	94	91	89
TRANSFER, % TIME MADE	45	43	51
TRAIN PERFORMANCE			
EXTERIOR CLEANLINESS	2.8	3.6	3.0
INTERIOR CLEANLINESS	3.1	3.2	3.5
PATRON ORDINANCE VIOLATIONS PER CAR	.03	.07	.12
- SMOKING PER CAR	.001	.002	.010*

*DEC 78 DATA

FIGURE 3 Train sampling: weekday service.

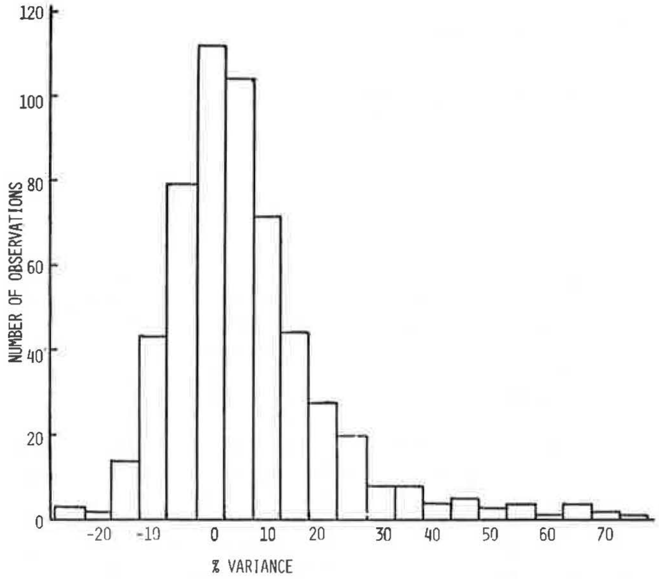


FIGURE 4 Train sampling: published travel time variance (Lines A, C, M, R; weekdays).

vation of 20 percent variance means that the trip listed as 10 min actually took 12 min or that it was listed as 60 min and actually took 72 min. This lack of differentiation between these two instances, which have different passenger impacts, led to the development of a separate set of graphs showing actual minutes of deviation from published travel times.

The summary graph of performance curves for published travel time (Figure 5) provides a clear picture of how service has improved at BART. In 1979 the patron faced a less than 10 percent probability that the actual travel time would not exceed the published travel time. In 1982 the probability was almost 90 percent that the actual travel time would not be more than the published travel time.

An important consideration for patrons, however, is getting a seat once on the train. Figure 6 shows the average car loading for weekdays on the C Line to Concord. A loading factor of 3 means that all seats are full; 5 represents a crush load with the car at or near maximum loading. As can be seen, in 1980 the homebound trains on the C Line (track 1) were very crowded between 3:00 and 5:00 p.m. Fortunately, conditions have improved since that time.

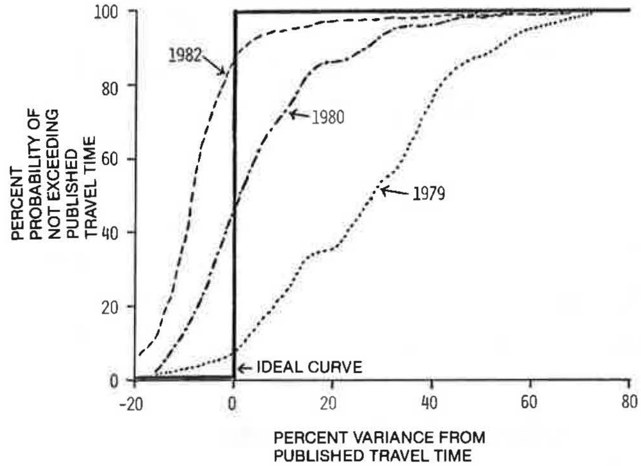


FIGURE 5 Published travel time performance curves.

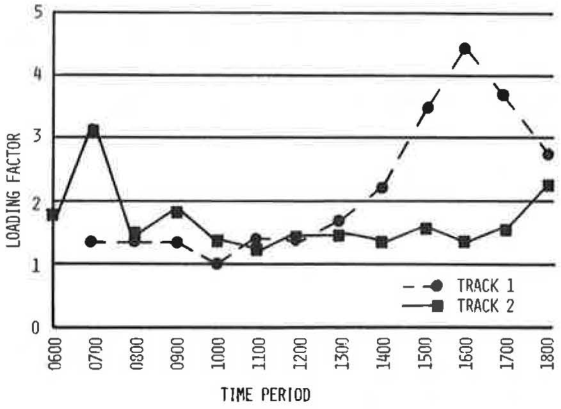


FIGURE 6 Average car loading for weekdays on C Line (1980 data).

These same types of graphs and tables can also be prepared for weekend service and can be broken down by line and even by station. The comparison graphs by years help indicate trends in any category.

BART is fortunate in that much of the travel time data and equipment availability data are being captured through other groups at BART in a more timely and accurate method. For that reason, these items were recently dropped from the PSS Study. The elimination of these indices has helped simplify the sampling procedure and has made the final report of the PSS Study a little easier to assimilate.

CONCLUSIONS AND IMPLICATIONS

As has already been indicated, the decline in the cleanliness of the vehicles, both the exterior and the interior, led to further study and analysis. Data on train announcements has also prompted management to investigate and update the procedures for train operators.

After the initial PSS Study, the train schedule was modified to address the loading problem revealed by the study. Also, the vehicle maintenance shops were supplied with a list of vehicles having inoperative public address speakers. The study also brought to light the problem of poor station signing for elevator location.

These PSS studies have given management some useful information on the impression made on patrons by BART's service. Performing the studies on a periodic basis gives the studies an audit type of character that highlights changes in service. As can be seen from the experience at BART, these sampling studies are effective tools for objectively measuring an agency's performance.

ACKNOWLEDGMENTS

Credit must be given to the other management engineers involved in the PSS studies: Charles Goldenberg, Margurite Fuller, John Post, Ron Edmondson, and Robin Cody. Charles Goldenberg was the original designer of the study and each engineer has made some enhancements to the procedures to simplify and improve the process. John Post was primarily responsible for the development of the computer program used to compile the data.

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The Impact of Metrorail on Trip Making by Nearby Residents: The Van Ness Case Study

ROBERT T. DUNPHY

ABSTRACT

In a before-and-after study of the impacts of extending Metrorail service into a dense residential community of 30,000 persons along upper Connecticut Avenue in Washington, D.C., it was found that there was substantial diversion of nonwork automobile trips to transit by those who are not in the work force and have a car in the household, a diversion of work trips to transit for both workers with a car in the household and those with no car, and no significant increase in the total amount of daily nonwork trip making, because transit increases were matched by reductions in automobile trips.

Much of the analysis of transit use has focused on the commuting trip. The Metrorail before-and-after study concentrated initially on determining the impact of the Metrorail system on commuting to downtown Washington and adjacent employment centers in Arlington County, Virginia. The extension of Metrorail's Red Line from a terminus at DuPont Circle, on the edge of downtown, into residential neighborhoods as far as 2 miles north on Connecticut Avenue provided a unique opportunity to study the effects of nearby rail service on travel from a residential neighborhood within walking distance, especially for nonwork trips.

STUDY AREA

The study area is shown in Figure 1. It is bounded generally by Rock Creek Park on the east and south, Massachusetts and Wisconsin avenues on the west, and Ellicott Street and Nebraska Avenue on the north. It includes the residential neighborhoods of Woodley Park, Cleveland Park, Tenleytown, North Cleveland Park, and Forest Hills. As shown in Table 1, it is primarily an area of multifamily housing, with many large older apartment complexes along Connecticut and Wisconsin. The automobile ownership is relatively low; a high percentage of households are without cars and few have more than one. The District of Columbia is the dominant work location; a relatively high percentage of commuters use transit. Between 1970 and 1980, there was a slight increase in the area's population, to 29,136, which is unusual for a highly urban community.

CHANGES IN TRANSPORTATION SERVICE

The principal radial arterial street in the corridor is Connecticut Avenue. The study area extended about 1 mile to the west to Wisconsin Avenue, although the majority of the population is relatively close to Connecticut Avenue. The three Metrorail stations that opened in December 1981 provided direct service to the previous terminal station 2 miles away, DuPont Circle. More than 90 percent of the survey respondents reported that they were located within walking distance of one of these new rail stations. Headways were the same as previous service on the Red Line--6 min during peak periods and 10 min during midday.

The opening of Metrorail service was accompanied by a major rerouting of the bus system to feed the rail stations and eliminate competing service. In the spring following the opening of the rail system, the number of local buses on Connecticut Avenue at Klingle Street, in the middle of the corridor, was reduced from an average of 21 to 14 buses per hour in the peak direction during the three morning peak hours. The reduction in express bus service (which did not stop in the corridor) was even more dramatic--from 22 to 8 per hour. Midday bus service had also been quite high before the extension of rail

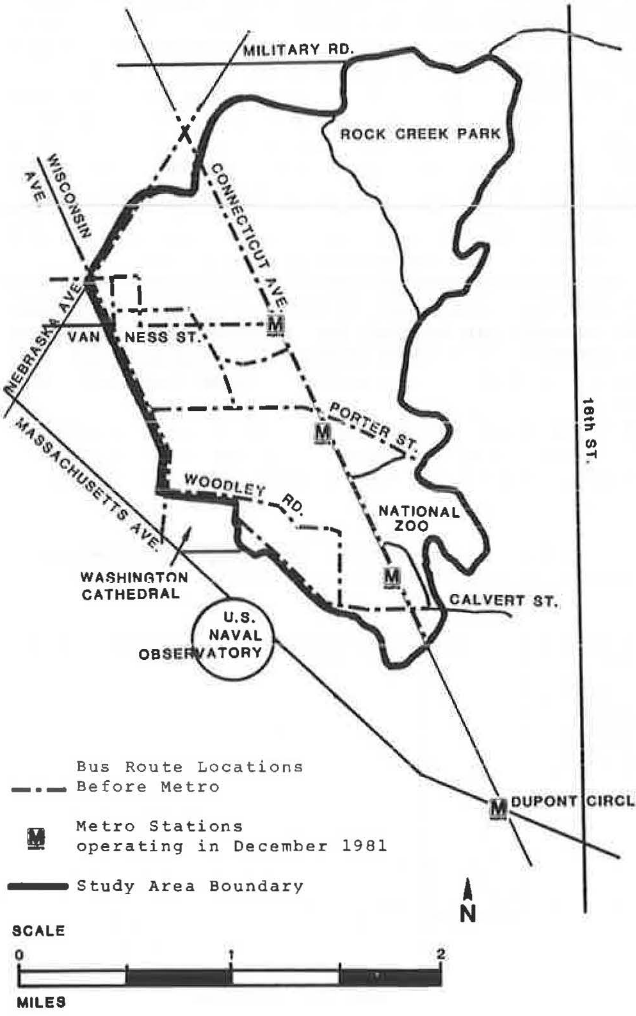

FIGURE 1 Map of study area.

TABLE 1 Characteristics of Van Ness Community, 1980

Parameter	No.	Percent
Housing		
Single family detached	2,308	15
Townhouse	1,132	8
Apartments (units)		
2-4	192	1
5+	11,350	76
Total	14,982	
Population		
1970	26,344	-
1980	29,136	-
Automobile ownership		
No car	-	32
One car	-	52
Multicar	-	15
Means of travel to work		
Drive alone	5,043	35
Carpool	1,970	13
Public transportation	5,779	39
Walk	1,035	7
Other	834	6
Total	14,661	
Family characteristics		
Live alone	-	58
Family	-	34
Other	-	8

Note: Data are from 1980 census.

service--11 buses per hour in each direction between 9:30 a.m. and 3:30 p.m.--an average of 1 bus almost every 5 min.

Bus ridership was high in this corridor before Metrorail service was extended. Counts of transit riders entering the regional employment core made by the Council of Governments (COG) found that Connecticut Avenue buses carried the second highest volume of any route during the morning peak except the Shirley Highway bus lanes. Moreover, the average occupancy of Connecticut Avenue buses immediately before the extension of the Metrorail system was the highest of any route entering the downtown. An average of 48 passengers per bus was carried for the period between 6:30 a.m. and 9:30 a.m. on both local and express buses.

Travel time comparisons before and after the Metrorail service extension are complicated by their variance according to the orientation of the trip. However, morning peak period running times from Van Ness to DuPont Circle averaged 21 min by bus before the extension of Metrorail as opposed to a station-to-station time of 6 min by rail, a 15-min saving. This saving may be reduced by longer walking times to destinations on Connecticut Avenue between Metrorail stations and time needed to get through the rail station.

STUDY DESIGN

The initial focus of this study was on nonwork travel, as described earlier. The data are part of a set of related surveys intended to measure several components of travel changes in the corridor. The study issues identified originally were as follows:

1. How does nonwork trip generation change?
2. How does nonwork transit use among non-car-owning households change?
3. How does rail transit affect nonwork transit trips and automobile use among persons in households with cars?

In order to analyze nonwork travel changes of community residents, before-and-after surveys were conducted by telephone.

A question about commuter trips was added during the questionnaire design when it was determined that proper reporting of nonwork trips required collecting all daily trips made by the respondent. This would make it possible to probe for midday trips by workers. The initial survey was conducted during the fall of 1981. The consultant, John R. Hamburg and Associates, used a systematic sample to select names from a reverse telephone directory. One individual was interviewed from each responding household. The interviews after service extension were conducted by the COG staff in the spring of 1982 following the Metrorail extension on December 5, 1981. A computer-assisted telephone interview technique was developed, which made it possible to obtain data on prior travel mode of residents reporting the use of Metrorail from one of the three new stations. The same individuals responding in the survey made before the service extension were used as the sample frame for the survey after the extension. This panel of the same individuals surveyed twice yielded a paired sample of 178 persons from households without cars and 434 persons from households with one or more cars. The further breakdown by worker status is as follows for the survey after service extension:

	Automobile Availability	
Worker Status	None	One or More
Employed	84	310
Not employed	94	124
	178	434

Because of the special interest in analyzing the impact of Metrorail on different market segments, most of the following analysis is reported separately for each cell.

COMMUTING CHANGES

It was not expected that the Metrorail extension would result in a significant change in the number of work trips per commuter, which are felt to be insensitive to transportation supply. In fact, as shown in the following tabulation, there was a slight, statistically insignificant decline in the number of home-based work trips per worker:

	Daily Home-Based Work Trips per Worker	
Car Ownership of Household	Before Metrorail Extension	After Metrorail Extension
One or more	1.56	1.49
None	1.54	1.43
All households	1.55	1.48

It is likely that there was a higher level of vacation days taken in the spring, when the second survey was conducted. Changes in relative transit use are described separately, depending on whether an automobile was available to the household.

Households with Cars

Use of transit by commuters in car-owning households, relatively high at 38 percent before the extension of Metrorail, increased by 9 percentage points after the opening of the new rail stations, as shown in Table 2. This increase was matched by an equivalent decline in the percentage of residents commuting by automobile. Although these workers report at least one vehicle in the household, there

TABLE 2 Means of Travel for Commuting by Van Ness Corridor Workers with Car in Household

	Percent of Commuters			
Means of Travel	Before Metrorail Extension	After Metrorail Extension	Change (%)	Percent Change
Transit	38.5	47.7	+9.2	+24
Automobile	53.2	43.6	-9.6	-18
Taxi	1.3	1.3	-	-
Other	7.0	7.4	+0.4	+0.5
Total			-	-4

may be commuters in one-car households who are dependent on transit because another person in the household needs the car, either for commuting or other purposes.

Following the introduction of rail transit to the corridor, transit use increased and automobile use declined, so transit became the dominant commuting mode. When considered as a percentage of the number of home-based work trips from car-owning households before the Metrorail extension, the 9+ percent shift in the market share between transit and automobile amounts to a 24 percent increase in the number of transit commuters and an 18 percent reduction in the number of automobile commuters. Some of this change occurred among those who may not have had regular access to a commuting vehicle. However, it appears that most of the shifts in commuting occurred among workers with an automobile available, for whom Metrorail provided a better alternative. No significant changes were observed in commuting by taxi or other (mostly walking) modes.

Households Without Cars

Persons from households without automobiles can truly be described as transit dependents. Although in general such households cannot afford an automobile, the income data suggest that this is not true of most of the survey area residents. Many of the 32 percent of households who do not have cars have apparently made that decision because of the excellent transit service combined with neighborhood parking limitations. In addition, some older residents may be unable to drive because of physical limitations.

An overwhelming share of workers from households without cars (73 percent) commuted by transit before the opening of the new Metrorail stations. As shown in Table 3, the transit share of commuting increased by more than 10 percentage points even within this transit-dependent category. Most of the increased transit use was diverted from the automobile category, which declined by 7 percentage points. Although these commuters do not have access to a car at home, it is possible for them to ride with others, either as a favor or by sharing costs. However, because these commuters cannot reciprocate by sharing driving, such arrangements can be difficult. A decline of more than 2 percent was reported in the share of other types of travel, most of which is walking. There was also a decline of 1 percent in the share of commuters without cars who use taxis to get to work. Although such small changes were not statistically significant for this size of survey, the data suggest that these modes are used to a disproportionate amount by persons without cars because they are not satisfied with the existing transit service.

TABLE 3 Means of Travel for Commuting by Van Ness Corridor Workers Without Car in Household

	Percent of Commuters			
Means of Travel	Before Metrorail Extension	After Metrorail Extension	Change (%)	Percent Change
Transit	73.4	83.9	+10.5	+14
Automobile	9.7	2.8	-6.9	-71
Taxi	3.9	2.8	-1.1	-28
Other	13.0	10.5	-2.5	-19
Total			-	-6

The introduction of the Metrorail extension to the Van Ness neighborhood resulted in an increase in the transit share among carless commuters comparable with that of workers with a car in the household. Because transit commuting among transit-dependent workers was already so high before the opening of the new stations, the number of transit trips in this category increased by only 14 percent. This increase was accompanied by a reduction of 71 percent in commuting as automobile passengers as well as smaller reductions in taxi travel and walk trips. Although the increase in transit use by commuters without cars may not have removed any automobiles from the streets, it has appeared to offer such individuals a higher level of mobility.

NONWORK TRAVEL

The potential effects of Metrorail on nonwork travel are twofold:

1. Increased transit use for existing trips and
2. New trips induced by the service improvement (unlike work-trip rates, which are assumed to be inelastic to transportation service).

Because the opening of the new Metrorail stations affected transit accessibility primarily at the home end, the analysis of nonwork travel impacts was conducted separately for home-based and non-home-based trips.

Home-Based Nonwork Trips

Most nonwork travel consists of round trips from home to a destination and back home. A non-home-based trip occurs as one leg of a tour from home to more than one destination before returning home. This analysis of home-based nonwork trips includes all of the round trips as well as the home-based ends of the tours.

The average number of daily home-based nonwork trips before and after the Metrorail extension is shown in Table 4, classified by labor force status and automobile availability. The trip rates before

TABLE 4 Daily Home-Based Nonwork Trip Rates by Residents of Van Ness Corridor

	Trips per Person		
Category	Before Metrorail Extension	After Metrorail Extension	Change
Workers			
Households with cars	1.06	1.09	+0.03
Households without cars	0.59	0.67	+0.08
Nonworkers			
Households with cars	1.94	1.94	-
Households without cars	1.18	1.20	+0.02

and after the service extension are generally close and none of the differences are statistically significant. The largest difference occurred in the category of workers without cars, where home-based nonwork trips increased by about one-tenth of a trip per day (14 percent). It appears that the service extension has not resulted in a substantial increase in total nonwork travel from homes within walking distance of the new stations.

A comparison of trip rates by type of traveler showed that persons who are not employed made significantly more home-based nonwork trips than did workers and that those with at least one car in the household made more nonwork trips than those without a car. The highest amount of daily home-based nonwork travel, almost two trips per day, occurred among those who had access to a car and were not working. The lowest rate occurred among the employed without cars, who made an average of only about two-thirds of a home-based nonwork trip per day. Combining the home-based nonwork trips from Table 4 with the number of home-based work trips reported earlier results in a daily total for home-based trips by workers that is higher than that for persons not employed. The highest trip rate for home-based trips was for workers with cars, who averaged about 2.5 trips per day. Workers in households without cars averaged slightly more than 2 home-based trips per day, whereas nonworkers in car-owning households averaged slightly less than 2 daily trips. The lowest daily trip rate occurred among nonworkers without cars, who made an average of slightly more than 1 home-based trip per day.

The number of total daily home-based nonwork trips made on transit by corridor residents is shown in Table 5 by labor force status and automobile availability. Transit use was found to have increased for those in households with cars and to have decreased for those in households without cars. However, the only category with a statistically significant change was that of nonworkers in households with cars, who more than doubled their daily transit trip making with an increase of 0.19 trip per day. This was also the only category with a reduction in the number of daily automobile trips for home-based nonwork purposes, which declined by 26 percentage points, a 15 percent reduction. This finding suggests that the opening of new Metrorail stations in the neighborhood has made it possible for persons not in the work force to divert nonwork automobile trips to transit. Changes in home-based nonwork travel by mode before and after the service extension are shown in Figure 2 for workers and in Figure 3 for nonworkers. The latter do not have the time limitations of workers, which preclude additional nonwork transit travel. Rail trips, although possibly faster than by the existing bus, are generally slower than a comparable trip by automobile, especially during off-peak hours. Because persons from households without cars are already frequent transit users, it is difficult to increase their transit trip making for home-based nonwork trips. Finally, a much sharper difference is found in the use of transit for home-based nonwork purposes between those in car-owning households and those without cars compared with transit use for commuting by those two types of households.

TABLE 5 Daily Home-Based Nonwork Transit Trip Rates by Residents of Van Ness Corridor

Category	Trips per Person Before Metrorail Extension	Trips per Person After Metrorail Extension	Change
Workers			
Households with cars	0.05	0.10	+0.05
Households without cars	0.34	0.37	-0.03
Nonworkers			
Households with cars	0.15	0.34	+0.19[a]
Households without cars	0.91	0.87	-0.04

[a] Statistically significant at 95 percent level of confidence.

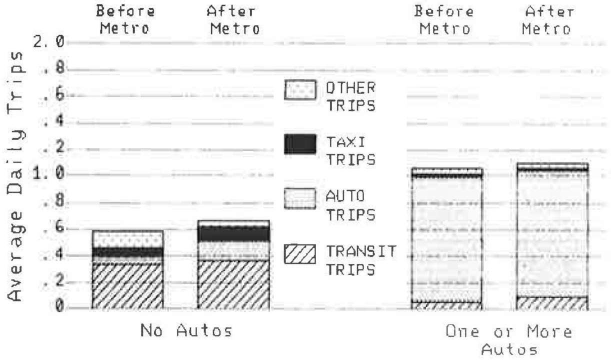

FIGURE 2 Home-based nonwork trips by workers.

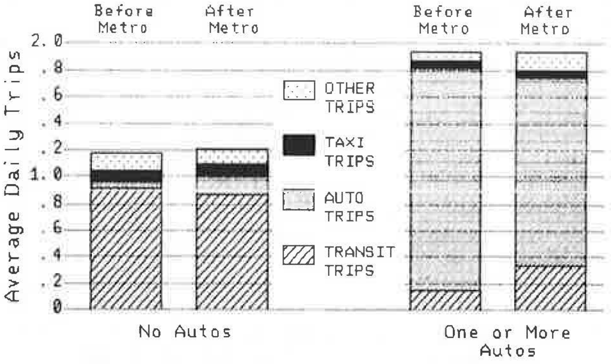

FIGURE 3 Home-based nonwork trips by nonworkers.

Non-Home-Based Trips

The opening of three new Metrorail stations in the study corridor can be shown to have increased transit service for home-based trips by residents. Its impact on non-home-based trips is not obvious. Downtown workers and others traveling to the central business district (CBD) had the advantage of Metrorail service for their intra-CBD trips even before the survey. The opening of the new stations therefore would serve only those non-home-based trips made along the Connecticut Avenue corridor. Comparisons of daily non-home-based trip rates for an average resident of the corridor are shown in Table 6 before and after the Metrorail service extension. Although the change in trip rates for non-home-based trips by workers was small, there was a large increase for nonworkers, both with and without cars. On further analysis of the data by mode, it is found that the increases are primarily in automobile trips for those with cars and in transit trips for those without cars. The increase in automobile travel by nonworkers with access to an automobile suggests that the increase is not related to the change in Metrorail service. It is more likely to be a sea-

TABLE 6 Daily Non-Home-Based Transit Trip Rates by Residents of Van Ness Corridor

	Trips per Person		
Category	Before Metrorail Extension	After Metrorail Extension	Change
Workers			
Households with cars	0.85	0.88	+0.03
Households without cars	0.57	0.47	-0.10
Nonworkers			
Households with cars	0.12	0.33	+0.21
Households without cars	0.13	0.34	+0.21

sonal factor, because both categories of nonworkers increased their daily travel by the same amount, even though one used primarily transit and one primarily automobile.

Changes in the transit share of non-home-based trips are shown in Table 7. The use of transit for these trips is greater than it is for home-based nonwork trips in each category except that of nonworkers with cars. This is probably because of the primarily downtown orientation of both workers and nonworkers. A non-home-based trip is therefore likely to occur within the downtown region, where Metrorail provides excellent service. Moreover, because more workers reported commuting by transit, they are more likely to use transit for midday trips. Although increases were observed in the transit share of non-home-based trips by workers, the small sample sizes and low trip rates make these changes statistically insignificant.

TABLE 7 Relative Transit Use for Non-Home-Based Trips by Residents of Van Ness Corridor

	Percent of Trips by Transit		
Category	Before Metrorail Extension	After Metrorail Extension	Change (%)
Workers			
Households with cars	21	24	+3
Households without cars	53	66	+13
Nonworkers			
Households with cars	0	6	+6
Households without cars	100	76	-24

It appears that there is no statistically significant effect of the extension of Metrorail on non-home-based trips made by corridor residents, probably because most trips were located outside the corridor.

CONCLUSIONS

In the analysis of changes in travel behavior before and after the extension of Metrorail's Red Line into the Van Ness Community the following results were found:

1. There was an almost equal increase of more than 9 percent in the transit share of home-based work trips for workers without automobiles as well as for those from car-owning households,
2. Transit use increased and automobile travel was reduced for home-based nonwork trips by those who have at least one car in the household, and
3. There was no significant change in the daily trip rates for either work or nonwork trips.

The increase in the transit share of commuting trips was not anticipated, because the mode split for home-based work trips was already so high before the rail extension. However, because of that high demand, the loading factors on buses were very high, frequently preventing a passenger from boarding the first bus. The additional capacity provided by Metrorail allowed an almost equal increase of 10 percentage points in transit use for both workers from car-owning households and those without an automobile. This is similar to an earlier conclusion in this study that transit use to the regional core increased by similar percentages for each income group, even though the base levels were much lower for high-income commuters.

The most significant relative changes in transit use by corridor residents occurred in home-based nonwork trips. Relative transit use more than doubled among those who were not employed and had at least one car in the household; there was a comparable reduction in automobile travel. Such individuals do not have the same time constraints as workers, whose nonwork travel must be fit into a schedule that is dominated by working and commuting. In this particular case, the use of an automobile in the city can be difficult during the day because of the problems with parking. It therefore appears that such individuals are willing to replace certain nonwork automobile trips with transit. Overall, they do not appear to be traveling more.

The finding of no significant change in daily travel by those without access to a car is contrary to theories about the value of transit speed for transit-dependent individuals. It has been suggested that greater transit speeds will induce more total travel for such travelers. However, in this case, the level of bus service on the main arterials serving the corridor, Connecticut and Wisconsin avenues, was quite high before the Metrorail extension. Between 9:30 a.m. and 3:30 p.m., there were 13 buses per hour scheduled in each direction on Connecticut Avenue, an average headway of less than 5 min. Because congestion during midday is relatively light, midday transit accessibility by bus was quite good before the rail extension. Moreover, walking distance to the nearest bus stop was generally much less than that to rail stops. Therefore, for many nonwork trips, Metrorail may not have provided a better alternative for transit dependents. The increase in transit use by nonworkers with a car in the household represents a choice between automobile and transit. Apparently these individuals relate the dependability of rail transit to that of the automobile. They know that they can count on Metrorail to return them from a destination without the uncertainty and route complexity of the bus system. In addition, they may be making longer trips, for which Metrorail provides a true time saving over the bus.

In summary, this analysis of travel patterns by residents of a high-density residential neighborhood close to downtown has found substantial gains in transit use, both for work and nonwork trips. For commuters the rail system has provided needed capacity over and above the prior bus system. For nonworkers used to the convenience of driving around town, Metrorail provides an alternative that is perceived to be much better than the bus. For transit dependents, however, the frequency of the bus service combined with their understanding of routes and schedules allows a level of mobility for nonwork trips that apparently has not been significantly improved by rail transit.

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The opinions presented in this paper are those of the Council of Governments Metrorail before-and-after study staff.

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A Radio-Frequency Deicing System for Third Rails

RICHARD KWOR

ABSTRACT

A radio-frequency (RF) deicing system for third rails has been proposed. It consists of an RF generator, transmission lines, a work coil, and a mechanical scraper, all mounted on a train. The system definition of such a setup is presented. Several coil configurations are studied. Experimental setups for static calorimeter tests, dynamic temperature rise tests, and deicing tests are described, and results are reported. With 50-kW 185-kHz RF generator power, successful deicing was accomplished up to a speed of 43.5 km/hr at an ambient temperature of -2.2°C using a ferrite-core coil. Finally, possible future improvements to the system are discussed.

During a winter storm, snow, ice, sleet, high winds, and low temperatures often cause rail transit systems to experience a variety of equipment and operational problems. One such problem is the icing of the third rail (the rail that supplies power to trains). This causes the power collector to lose electrical contact, which results in a disabled car or creates excessive arcing. A layer of ice forms and adheres to the third rail when there is precipitation near the freezing temperature of water (0°C). Sleet storms cause the worst icing problems, but snow on the third rail that has melted in the rising daytime temperature can readily freeze if the temperature then drops below the freezing point.

Third-rail heaters have been effective in minimizing these icing problems on many transit systems. However, these ohmic heaters in general consume an inordinate amount of energy. An energy-efficient approach is to melt a thin layer of ice at the interface between the rail and the ice. This will break the strong adhesive bond between the rail and the ice layer. Once this bond has been broken, the rest of the unmelted ice can be easily removed by a mechanical scraper. Blackburn and St. John estimate the required interface melt thickness to be about 2 μm (1). The most desired mechanism for this approach would be to couple energy directly to an ice layer approximately 2 μm thick next to the interface between the rail and the ice with little or no energy being directly coupled to either the layer of ice more than 2 μm from the interface or the rail underneath. Unfortunately, this calls for a dramatic change in the physical properties of ice at the interface.

Even though there is some evidence that the ice properties are different at the interface compared with the bulk, such drastic differences are not anticipated. Hence, the next best solution is to have the energy source at the interface but located in the rail. The ice layer in immediate contact with the rail surface will be melted by the heat energy transferred from the rail to the ice. It is possible to achieve this rather easily by radio-frequency (RF) induction heating.

The basic concept of RF induction heating is rather straightforward (2,3). Essentially, a high-frequency alternating current is passed through a work coil in the close neighborhood of a load. This induces a current in the load. Its magnitude depends on the permeability of the load and falls off from the surface to the center of the work load with a rate of decrease that is higher at higher frequencies. It is this induced current that causes the rapid heating of the load.

For rails made of high-permeability materials, RF induction deicing is efficient in several respects. First, the heat is generated within the top few micrometers from the rail surface, where it is needed, and hence little is wasted by being transferred to the ambient. Second, modern RF generators have respectable conversion efficiencies. Third, this deicing system is very responsive in that rail surface temperature changes occur rapidly. The deicing is much less effective for aluminum-clad composite rails because aluminum has a much lower permeability.

An RF deicing system for third rails without coverboards, such as those used in the Boston and Chicago transit properties, is discussed. Important system design criteria are provided and discussed. The experimental setups used to test the performance of the RF system are described. Three kinds of work coils are described along with their performance testing. Finally, preliminary deicing experiment results are reported and the feasibility of a practical RF third-rail deicing system is discussed.

SYSTEM DEFINITION

To test the concept of RF deicing of the third rail, an experimental deicing system was developed. It is shown schematically in Figure 1 and consists of an RF generator, an air-core stepdown transformer, an RF work coil, and a mechanical scraper (not shown in the figure). The generator supplies RF power to the coil, which couples part of the energy to the third rail through an air gap. Flexible water-cooled lines are used to connect the generator to the transformer primary. A rigid water- or glycol-cooled transmission line is used between the transformer and the work coil for higher efficiency.

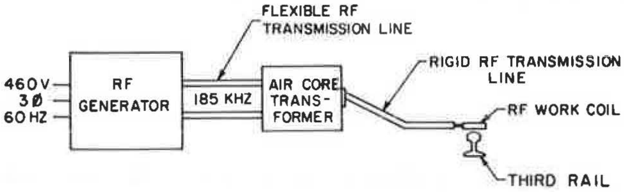

FIGURE 1 Basic components of RF deicing system.

Practical RF deicing systems would be mounted on a train. The initial goal was to develop a system with an operating speed of 24 km/hr or higher at -4°C on the uncovered third rail of the Boston transit property (the 85-lb/yd ASCE rail). A work coil lateral positioning tolerance of +5 cm and a coil-to-rail gap of 0.3 to 1.3 cm were chosen to include the effect of train vibration. To determine the system frequency and power level required for operation at 24 km/hr, a thermal analysis was conducted using a one-dimensional finite-element heat transfer model. From the results obtained, it was found that a total rail dissipation of 18 kW over a length of 30 cm was required to melt 1 μm of ice at the rail-ice interface. The operating frequency was chosen to be between 150 and 450 kHz. With this frequency range, the power absorbed in the rail is concentrated in the top several micrometers and very little energy is wasted in heating the bulk of the rail. In order to supply 18 kW to the third rail, a 50-kW RF generator was used. The power coupled to the rail depends on the work coil design, the coil-rail air gap, the lateral displacement, and the skew angle of the coil with respect to the rail. Experiments were performed to assess the deicing performance capability of various coil configurations and to measure performance parameters for each coil. Deicing experiments were then performed using all the coils. The experiments are described in the next section.

RF RAIL HEATING EXPERIMENTS

Three coil configurations were considered: the pie-wound coil, the wide reverse pie coil, and the ferrite-core coil. The first two are called air-core coils because the magnetic path through the coil is totally through air. They are 35.6 cm long, made of four turns of 1/4-in. copper tubing, and can be enclosed in fiberglass for weather protection (Figures 2 and 3). The ferrite-core coil is shown in Figure 4. It consists of a U-shaped manganese ferrite core and two four-turn coils wound on it. The specific core material was MN60 manufactured by Ceramic Magnetics, Inc., of Fairfield, New Jersey. Element testing was performed with these coils. The tests performed were the same for each coil and included the following:

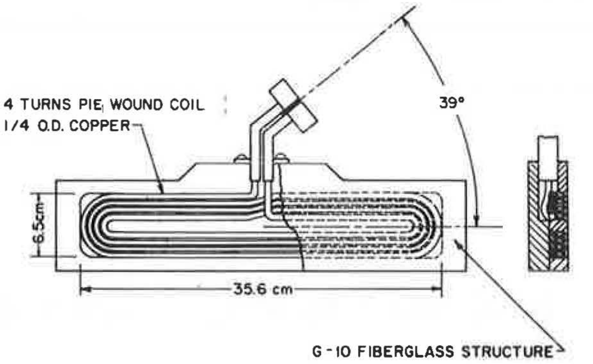

FIGURE 2 Pie-wound air-core coil.

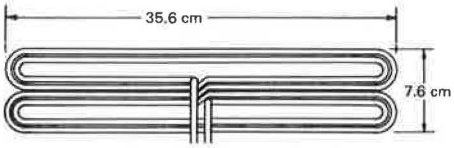

FIGURE 3 Reverse pie air-core coil.

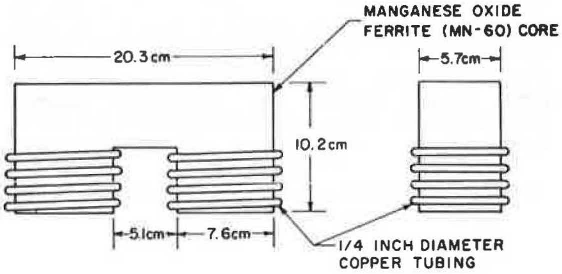

FIGURE 4 Ferrite-core coil.

1. Static calorimeter test,
2. Dynamic temperature rise tests [scanning infrared thermal imaging (Thermovision) and thermocouples], and
3. Deicing test.

The objective of the calorimeter test was to measure the net power supplied by the RF coil to the rail cap as a function of gap, skew angle, and coil lateral displacement. The test was performed using the setup shown in Figure 5. The calorimeter shown was fabricated from the cap of an 85-lb/yd ASCE rail and thus accurately simulated the actual rail. The

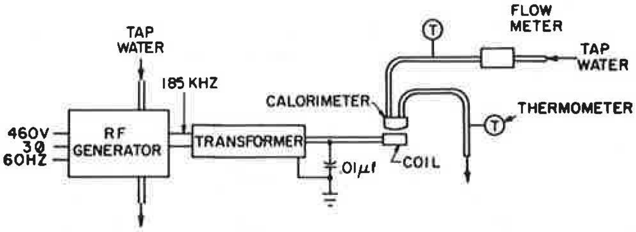

FIGURE 5 Calorimeter test setup.

water flow rate was measured using a flow meter. After the RF generator was turned on and the temperature of the calorimeter reached steady state, the temperature of the water before and after it flowed through the calorimeter was measured for various combinations of lateral displacement and skew angle (Figure 6). From these data the power absorbed by the calorimeter was calculated.

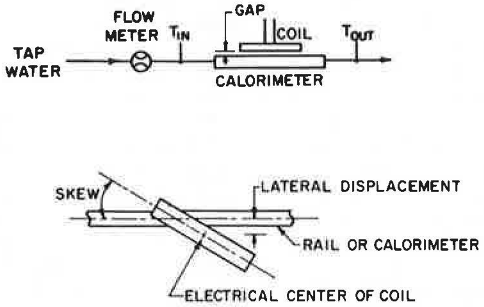

FIGURE 6 Definition of gap, skew angle, and lateral displacement.

For the most efficient deicing, the rail heating pattern must be uniform. The purpose of the surface heating profile test was to measure the surface temperature along the rail cap and to find out which coil configuration had the most uniform heating pattern. The test was conducted at room temperature with the RF work coil acting on the 85-lb/yd rail mounted on Vought Corporation's 5.8-m rotating drum. The coil-to-rail gap was set at 1.27 cm. An infrared thermal imaging system (Thermovision) and the test setup are shown in Figure 7. The view on the Thermovision monitors the heating pattern produced by the coil. To give the rail surface a high emissivity for these tests, a thin coat of flat black paint was sprayed on the rail cap. The thickness of this coating was about 8 μm, which analysis showed would cause a negligible effect on the measured temperatures. The different temperatures on the rail cap are represented by 10 colors on the Thermovision monitor. Thermocouple measurements were then used to confirm the Thermovision response results.

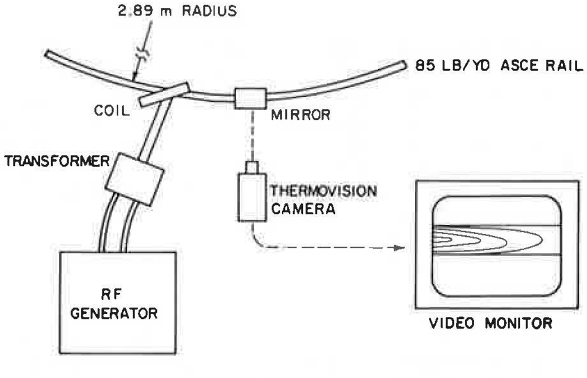

FIGURE 7 Thermovision test setup.

In the deicing test, the actual environmental conditions were simulated. The test setup is similar to that used in the surface profile tests (Figure 8). A mechanical scraper is attached about 15 cm behind the coil. The rail was first cooled to a temperature of about -7°C and then lightly sprayed with water while it was rotated until the desired ice thickness was obtained. The ice thus formed was generally glaze ice and covered both the top and the sides of the rail cap. The rail was then allowed to stabilize to a temperature of -3.3 to -4.4°C. After stabilization, the wheel was brought up to the test speed, the generator turned on, and the scraper actuated. The deicing operation was carried out for one-fourth revolution of the drum.

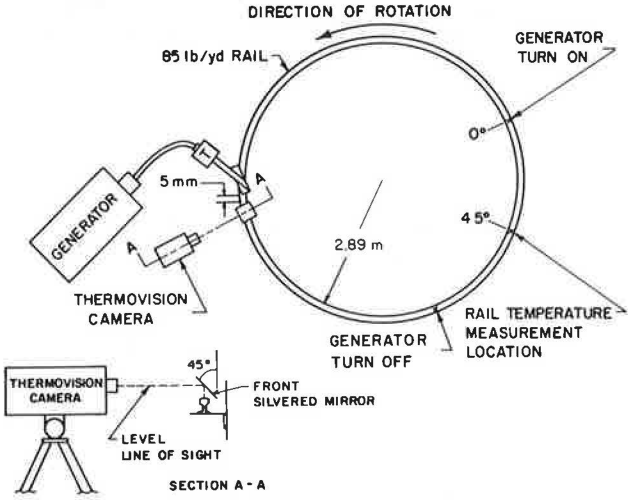

FIGURE 8 Surface heating profile experiment setup.

RESULTS AND DISCUSSION

The first coil tested with the RF system was the pie-wound air-core coil. Calorimeter test results are shown in Figure 9. As expected, the absorbed power decreases with lateral displacement. The 20-degree skew angle provides the maximum tolerance to lateral displacement. The design goal of 18 kW with up to 5-cm lateral displacement was not attained because 3.8-cm displacement was the maximum possible at 18 kW. The 20-degree skew angle was selected for the remaining tests because it provided the maximum tolerance to lateral displacement. Surface temperature profile results showed that the pie-wound coil produced nonuniform heating of the cap with highest temperature at the corners. The heating also extended around to the side of the cap where heating was not needed in the deicing operation. Deicing tests were performed for a rail temperature of about -4°C. The maximum deicing speed attainable was 8.85 km/hr for this coil.

The magnetic flux pattern for the reverse pie coil is quite different from that of the pie-wound coil. Such an arrangement would be expected to produce more uniform heating of the rail. The surface temperature rise results confirmed this. A much more

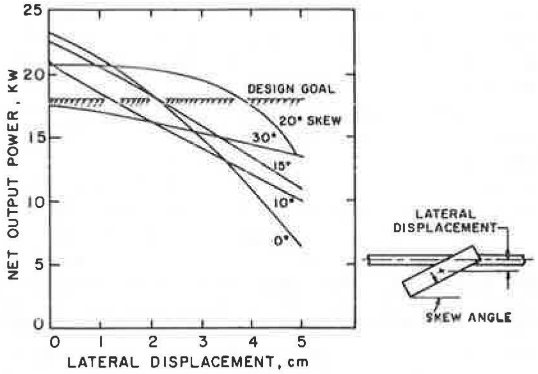

FIGURE 9 Calorimeter test results: pie-wound coil.

uniform distribution of energy to the rail cap than the pie coil was obtained. On the other hand, the calorimeter test results (Figure 10) showed that the reverse pie coil provided less lateral tolerance. A skew angle of 15 degrees is seen to provide the best compromise between power input and lateral displacement. Using the reverse pie coil, complete deicing was achieved up to 12.9 km/hr.

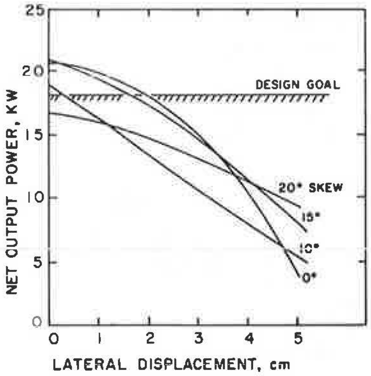

FIGURE 10 Calorimeter test results: reverse pie-wound coil.

The ferrite-core coil was designed to be used with little or no skew or lateral displacement. Calorimeter test results showed that the use of a ferrite core greatly increases the energy coupling to the rail. This was because the ferrite core provided a highly conductive path for the magnetic flux, reduced the leakage, and concentrated the flux into a smaller area in the rail cap. A maximum deicing speed of 43.5 km/hr was achieved for a rail temperature of about -2.2°C, which was the best deicing speed of all coils tested. However, in its current form, the ferrite-core coil suffers from substantial internal heating and produces the most nonuniform heating of the coils tested. This coil will require additional development. Laminating the core material can limit internal heating and an alternative core configuration will help to achieve a more uniform heating and thus increase the deicing speed.

CONCLUSION

Experimental results have shown that a practical third-rail deicing system using RF energy is feasible. However, many problems still need to be solved for development of a practical system. Based on this work, further research and development in the following areas is recommended:

1. Work-coil coupling efficiency and rail cap heating uniformity need to be increased. This can be accomplished by improving the design of the coil.
2. The provision for automatic matching of the load impedance to the RF generator is needed. This will ensure constant power to the rail while the train is moving.
3. The problem of RF generator cooling has not yet been addressed. A closed-circuit water-cooling system needs to be installed on the train and the coolant must not freeze in winter.
4. In the absence of ice and at a slow vehicle speed, efficient RF coupling results in rapid rail surface heating and oxidation. Some feedback control mechanism is thus needed for rail overheat protection.
5. The 200-kHz 50-kW RF generator used in the foregoing experiments has a vacuum tube oscillator. The generator is rather bulky and its ruggedness has not been tested. One possible solution is to replace it with a solid-state RF generator (50 kHz), which is smaller, lighter, and less costly. Another important feature of the solid-state generator is that its primary power can be 600 V dc, which can be tapped directly from the third rail. A thermal analysis will be needed to determine the effect of the lower frequency on the deicing efficiency.
6. The effects of the electromagnetic radiation from the RF generator must be studied. The possibility of electromagnetic interference with vehicle control and communication must be investigated. The biological effects of any possible radiation leakage should also be addressed.
7. Other engineering developments needed include a tracking mechanism for the RF work coil to follow the rail, a flexible transmission line between the transformer and the coil, and weather protection for the air-core transformer.

Even though the results reported in this paper were based on the uncovered third rails, the system can be modified for third rails having coverboards. The air-core coils described in this paper are small enough to fit between the third rail and the coverboard, but the mechanical scraper must be specially designed. The rest of the system would be housed inside a vehicle and thus does not require any extensive modification.

With all the foregoing developments incorporated, the RF deicing system may prove to be a good alternative solution for third-rail problems in adverse weather.

ACKNOWLEDGMENTS

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Morning Peak Hours in the Stuttgart Transit and Tariff Authority

WERNER BRÖG, ERHARD ERL, and WOLFGANG WÖRNER

ABSTRACT

The problem of traveling on public transportation during the morning peak hours is well known but has not been solved. This is because peak-hour traffic volume can only be reduced if the individuals who have the option of starting work at different times actually make use of this option. However, changing work and school schedules has an impact not only on the transport system but also on an individual's private life. The results of a study conducted by the Stuttgart Transit and Tariff Authority are described. The characteristics of public transit use in the morning peak hours are shown. The potential of transit users who have flexible schedules is indicated and a number of policies to deal with the problem are suggested. Furthermore, the potential number is determined of those who can react to the negative conditions of public transit in peak hours by switching to other modes of transportation.

The focus of specialist discussions geared at finding ways to reduce peak-hour travel is to extend the times when work and school begin (1) over a longer period of time. The effectiveness of policies that might accomplish such a change has repeatedly been proven theoretically but the problem has not been solved. This is because peak-hour traffic volume can only be reduced if the individuals who have the option of starting work at different times actually make use of this option. However, changing work and school schedules has an impact not only on the transport system but also on an individual's private life. Accustomed daily routines are interfered with and usual social contacts are hampered (2).

The Stuttgart Transit and Tariff Authority (VVS) commissioned a team of social scientists to conduct a study (3) in order to get information on the problem of peak-hour travel in a specific area and on the impact that different policies would have on the problem of peak-hour travel. VVS wanted special attention paid to the social situation of public transit passengers.

VVS serves an area of 3012 km^2 (about 1,145 miles^2) with a population of 2.14 million. In 1979, 655,000 passenger trips per weekday were made by buses, streetcars, and S-bahn (rail rapid transit) in the system (4). About 13 percent of these trips are peak-hour trips in the definition of this study (incoming traffic to the central zone of the service area between 6:00 and 8:00 a.m.). During the morning peak hours, public transit is used to the limit of its capacity.

The study of peak-hour traffic was done in two stages. From a regional travel survey (5) there was information on 67,700 persons and 51,900 public transit trips. These data were used for a descriptive evaluation of peak-hour travel. They also gave the base for in-depth interviews with a subsample of 316 households in which peak-hour passengers lived. The results of these interviews are presented in this paper.

FLEXIBILITY OF PEAK-HOUR PASSENGERS

The analysis is based on those trips recorded in the travel survey that are defined as peak-hour trips. For these trips, it must be determined whether and under what conditions flexibility in scheduling is possible.

To make temporal flexibility operational, a 30-min adjustment in the beginning time of trips is used in accordance with the literature on the subject (6). An interviewee is said to be flexible in scheduling his time if he can organize his daily routine so that the peak-hour trips can be made either 0.5 hr earlier or later.

For the situational analysis, all of the characteristics explored in the interview that pertain to the individual and the trip and that are of explanatory value in the given instance are used. Thus, it is necessary to divide the temporal variability into individual dimensions to which the characteristics determining the situation can be assigned (see Figure 1).

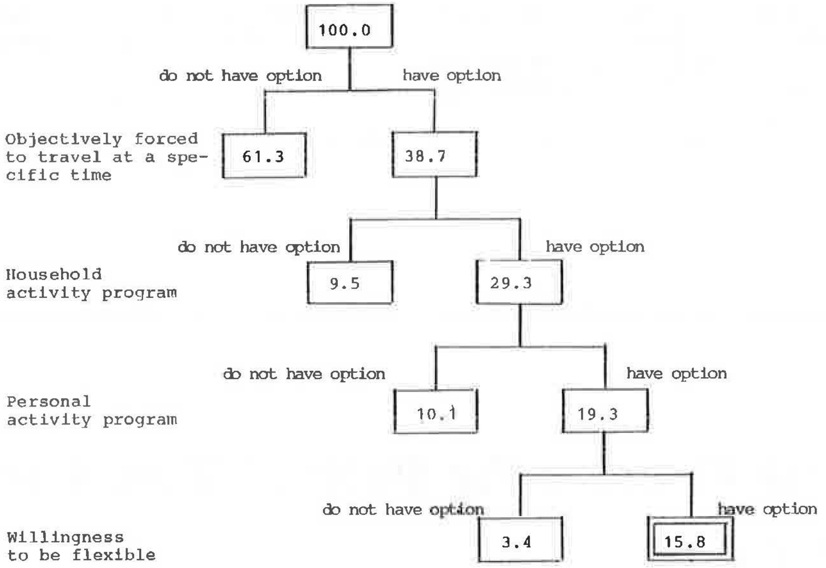

FIGURE 1 Option of traveling at another time: situational groups.

Objective Time Constraints

The objective necessity of traveling at a specific time depends on the extent to which given conditions, externally fixed appointments, and so on, limit a person's flexibility. This included, on the one hand, appointments at specific times at the destination of the trip made during the peak period (such as the beginning of work) and, on the other hand, the service offered by the public transit system. The most important objectively fixed times are the beginning of work and school. Constraints caused by departures of and connections between the VVS vehicles are negligible. Of all the dimensions, objective time constraints include the greatest proportion of those with no options. This shows how important new policies in this area could be.

Household Activity Program

In the second dimension, the influence of the household activity program in keeping the peak-hour passenger from making his trips during off-peak hours was investigated. Activities with other family members or household members can be of a similarly obligatory nature as externally fixed appointments (7, Chapter 3).

Restrictions occur when the activity program of the entire household would have to start earlier if the individual in question were to begin his peak-period trip earlier. The time schedule of the other household members does not always make this possible, however. In a few instances, time limits occur because multiperson trips (e.g., taking passengers to the public transit stop) are made that cannot be made either earlier or later.

Eating and preparing meals together during the morning, evening, and especially at midday is one of the most important fixed activities of the household. Joint leisure activities and other occupations in the house and outside the house are less important in limiting the flexibility of peak-hour passengers.

Personal Activity Program and Willingness to Be Flexible

Because the peak-hour trips made by the individuals studied were almost always the first trips of the day and because they were usually trips to work or school, that is, mandatory activities of a definite duration, making the same trip either earlier or later would affect the entire daily routine, from getting up in the morning to going to sleep at night. Changing this personal activity program, which is frequently subject to externally fixed times in personal, and especially in social and leisure, activities, is difficult for many of those traveling during the peak hours.

A superficial view of the problem leads one to conclude that "soft" constraints more or less predominate, such as getting up too early or leaving work too late. However, one should not forget that this is not merely unpleasant but also restrictive to the entire activity program as it exists: If a person starts work either earlier or later, this means that the hours that he keeps no longer fit the routine of his social environment. A person's willingness to be flexible in scheduling his time naturally also influences potential rescheduling.

An individual can only make his peak-period trip either earlier or later if he has the option of behaving differently open to him in all of the dimensions. This shows one the proportion of trips that are definitively determined by each dimension and also which group of persons has no reason not to make their peak-hour trips either earlier or later (Figure 1).

The restrictions to travel at certain times are the most important reasons why trips are made at specific times; three out of five persons are restricted because of this dimension. Because of their household and personal activity programs, another 10 percent of the peak-hour passengers are not free to make their trips at other times. Only every 30th peak-hour passenger travels at the time he does because he is subjectively unwilling to be flexible in scheduling his time. Of all passengers traveling during peak hours, approximately every sixth peak-period passenger (15.8 percent) has open the option of traveling at another time. This defines the upper limit of the current potential of persons flexible in scheduling their time if no steps are taken to change the status quo.

Situational Analysis

It is possible to show individual temporal flexibility under changed conditions by using this situational analysis of options. The model structure can be used to show the impact of eliminating fixed schedules on the potential number of persons flexible in scheduling their time. This can be done for each dimension. Thus, the situational group model is used to show the change in temporal flexibility that results when the restrictions usually existing in the various dimensions are eliminated. This so-called dynamized situation then shows how many of the relevant peak-hour passengers then enter the situational group with options and how many are still subject to restrictions in other dimensions.

The dynamization of the dimension of being forced to travel at a specific time shows the situation when the externally defined restrictions for beginning the peak-period trip, that is, the time when work begins or school begins or other appointments at the destination begin or the public transit schedules, are eliminated. The peak-period passengers who are not flexible because they are forced to travel at a specific time account for 61.3 percent of the total, the largest situational group. Thus, doing away with these external constraints would have an especially great impact on travel.

Surprisingly, however, the result of the dynamization is that the group with options only increases by 16.7 to 32.5 percent. Not even every third peak-period passenger who is forced to leave when he does in the morning because of externally fixed appointments can (or wants to be) flexible in scheduling his traveling time when the appointment begins at a different time. The majority of the two-thirds of the peak-period passengers in this situational group are inflexible in scheduling their time because of constraints in other dimensions.

When the restrictions to travel at specific times are eliminated, the restrictions caused by the personal activity program become more important than other dimensions in defining the options that a person has to travel at another time. One can assume that the additional temporal flexibility will not change the behavior of 13.2 percent of the peak passengers studied because their daily routines would then begin either too early or too late.

It is important to note that if the objective time-scheduling restrictions are eliminated, the peak-period passengers might still be subject to constraints, because some of the passengers are influenced by constraints not only in one dimension but also in other dimensions. When persons are no longer objectively compelled to travel at specific times, the situation for those with fixed work hours and flextime is similar for all the situational groups.

Thus, surprisingly enough, the greater freedom of those with flexible work hours is not reflected in their scheduling their hours more flexibly or their being willing to reorganize their daily routines. Even those on flextime are subject to a routine and their activity programs are quite regular. It has frequently been shown that when flextime is introduced, it is not used in a manner to effectively reduce peak-hour travel; most people tend to continue to start work at the same time as previously.

For purposes of comparison, the result in the other dimensions of doing away with the restrictions will be discussed. In contrast to the group of peak-period passengers forced to make their trips at specific times because of objective constraints, the other situational groups are naturally less important, because on the one hand they are more difficult to influence by putting different types of policies into effect and on the other hand they are considerably smaller. Thus, the impact that might be expected is limited from the start.

When constraints relating to the household activity program are eliminated, the group of persons with options is increased by only 1.2 percent. Most persons are subject to other constraints because of their personal activity programs.

The impact of policies aimed solely at the personal activity program is only a minimal increase (3.9 percent) in the size of the group with options. The majority of persons forced to travel at specific times are not willing to change their daily routine. Those with options are the target group whose traveling might be done at other times than during peak hours. Thus, it is worthwhile to look at this group more closely and to characterize the individuals according to sociodemography, attitudes, and behavior. Of those persons with the option of traveling at another time:

1. Two-thirds are male,
2. All are over 18 years of age,
3. Those who are employed are most flexible as regards time,
4. More than two-thirds work at places of employment that have flexible work hours,
5. An above-average number of persons in this group (three-fourths) have a car that is always or sometimes at their disposal,
6. Their displeasure caused by the overcrowding of the vehicles is somewhat greater than average,
7. More than 50 percent use commuter rail as their primary transit mode, and
8. The proportion with a pass for public transit is somewhat smaller than average.

A target group is thus defined that can be approached with information and motivational strategies. For this purpose, it is of great practical importance that a large number of these target persons use the S-bahn as their primary travel mode and can thus be directly approached there.

POLICIES TO REDUCE PEAK-HOUR PASSENGER CONCENTRATION

Based on the results of the situational analysis, measures can be deduced to increase flexibility in scheduling time, and the effectiveness of these measures can be studied. Steps can be taken to increase temporal flexibility in all of the dimensions responsible for determining travel situations. Thus, possible measures can be discussed based on these dimensions.

The reasons persons are objectively forced to travel at specific times are more or less governed by the times when work and school begin. For about 4 percent, the set travel time is determined by the VVS connections.

It is possible to alter these temporal restrictions by having work begin either earlier or later or by introducing flextime. Both of these steps have a number of advantages and disadvantages. Changing the fixed hours when work begins has a greater impact on reducing peak-hour travel than introducing flextime, according to available model calculations. However, a prerequisite for this change is a planning scheme tailored to the local situation; that is, the time when work begins in the participating employment sites must be coordinated to suit the location and the transit conditions.

A situational analysis of temporal flexibility shows clearly that if people are forced to begin work either earlier or later, only one-third of those affected would be subjectively or objectively flexible in scheduling their time. This means that changing the time when work begins would cause more or less severe scheduling conflicts for household and personal activities; it would also cause problems on another level because persons would be unwilling to reschedule their activities.

Thus, in order to reduce the number of objectively fixed time schedules for employed persons, flextime should be introduced; it is then possible for the individual peak-hour passenger to voluntarily travel either earlier or later. This makes it possible for the passenger to optionally reorganize his daily routine on an individual basis to adjust to the new conditions. In order to encourage a large enough number of individuals to make use of flextime in such a way that it will have an impact on the reduction of peak-hour travel, supportive measures that inform people of the advantages of traveling at other times and motivate them to use their flextime accordingly should be used.

There is additional potential to be gained by adding those whose flextime does not allow them to travel at another time for the time being. All in all, doing away with objective time constraints can increase the group of employed persons with the option of traveling at another time by 16.1 percent. This reflects an increase of 9.7 percent for all peak-period passengers.

Decreasing objective time constraints for persons traveling to school or training sites is mainly possible by changing the time when school or training hours start. Giving students more leeway to organize their daily routines is usually impossible. Situational analysis shows that a high proportion of school children and trainees are restricted by other dimensions when lessons start either 30 min earlier or later. Thus, rescheduling will cause problems for most of this group. The rescheduling should therefore be kept to a minimum and the effects of this rescheduling should be cushioned by supportive steps in the other dimensions.

The proportion of VVS passengers forced by VVS connections to travel when they do is very small; it is only 4.4 percent. Thus, taking steps (usually quite expensive) in this area would have only a minimal impact. Also, to the extent that flextime is introduced, restrictions in this dimension will be reduced, because persons will then have more leeway in deciding when to begin their trips to work.

The possible impact of eliminating restrictions caused by the household activity program is minimal when compared with the impact of changing the time when work and school begin. Furthermore, it is also difficult to influence household activities. It is only possible to take steps that would make it easier for households to reorganize their activity programs, that is, steps that would have only an indirect influence on the households.

The two single most important components of the restrictions on time scheduling in this dimension were identified as household activities in the morning and the family lunch at midday. In the first case, different solutions would have to be found in each household; at the most, the possibility of coordinating activities could be increased if flextime were introduced.

On the other hand, it is possible that friction because of household activities in the morning would increase even more if peak-hour travel were reduced and the times when work and school began were dispersed. It is not possible to suggest here any specific steps that might be taken.

However, the fixed times set for eating lunch together, which cause peak-period trips, could be eliminated (especially for school children) by making it possible for them to eat lunch at school or by introducing all-day schools. Furthermore, one can expect that as a result of shorter work hours and an increased number of schools that do not hold classes on Saturdays, there will be more time for household activity programs.

In some ways, people have more leeway in rescheduling their time when they are subject to personal rather than household restrictions. In the former case, only the peak-period passenger himself is affected by rescheduling; in the latter case, the whole household is affected.

In these dimensions, the most important reasons why people have time schedules that leave little leeway is that they think that rescheduling their time would force them to begin everything either too early or too late or that they could no longer punctually begin their leisure-time activities, such as running errands and shopping in the evening.

If shops were open longer, this would have little impact on whether peak-period passengers would travel at different times. It would be more effective to reduce subjective reasons for not beginning daily routines either earlier or later. In light of the high stability and routinization of the personal activity program, it would be helpful if the target persons became more conscious of the existing options open to them to reorganize their daily routines. The reorganization of the personal activity program would be simplified if externally fixed times and time limits were done away with such as the times when recreational facilities (e.g., sports arenas, restaurants, cultural establishments) open and close.

Given current conditions, the potential that can be attained by taking steps of this sort is naturally also limited. A large number of those who are not free to reschedule their daily routine due to their personal activity programs must be encouraged to willingly reschedule their routines before behavioral changes can be expected to occur.

Those persons inflexible in rescheduling their time due only to their personal unwillingness to be flexible currently account for 3.4 percent of the total. This group increases to the extent to which temporal restrictions are eliminated in other areas. This shows how important it is to take steps to convince people that they should change their behavior, irrespective of what other policies might be introduced.

Two aspects can be emphasized in approaching the foregoing group:

1. Give them information about the problem of peak-period travel, showing the extent of peak-period demand and the problems that this causes; this convinces the individual of the importance of his own personal contribution.
2. Show them how much more comfortable it would be for them to travel at other times and emphasize other advantages of their traveling either before or after the peak period.

Informing those persons with the option of traveling at another time of the advantages of traveling during off-peak hours can have a positive impact on their travel behavior.

The question of how the absolute peak demand of the VVS might be decreased will be supplemented by more far-reaching considerations at the end of this paper. The negative effect of the peak-hour demand on the public transit system is caused less by the absolute number of passengers during these times than by the highly variable demand during the day. Thus, the supply during the peak hours is also limited by the lesser demand during off-peak hours. Therefore, if it is possible to increase the number of passengers during the off-peak (later morning and evening) hours, when there are relatively few passengers, it will indirectly be easier to cope with the peak hours.

This emphasizes the importance of an integrated marketing concept. Peak-period passengers are thus not the only target group. For this reason, information strategies and public relations measures should also be aimed at potential VVS customers using public transit for occasional trips and leisure activity trips.

Policies to increase flexibility in scheduling time can be aimed at all of the dimensions that are responsible for determining the travel situation. In Figure 2, examples of the most important policies are summarized, and a highly simplified evaluation has been made based on the following criteria:

1. Size of the potential influence of the policy,
2. Type of impact (voluntary or mandatory),
3. Degree to which conditions can be influenced by introducing the new policy, and
4. Ability of the transit authority to put the policy into effect.

MODE CHANGE

Overloading can result in switching to other modes of transportation. In order to study the impact of this problem on public transit, passengers' options of switching to other modes were determined and the probability of a change in modal choice resulting from decreased comfort during the peak hours was estimated (8).

The analysis shows that every tenth passenger basically has the option of using an alternative mode of transportation (see Figure 3). However, to a particularly large extent, peak-hour passengers are forced to use public transit due to the travel time, that is, the speed of public transit in comparison with other modes of transportation.

If one surveys the results of the modal-split conditions for commuting and school travel, driving a car is a potential alternative mode that is mentioned relatively rarely. The bicycle and passenger in a car are modes mentioned considerably more frequently.

CONCLUSION

This study has proved that the problems resulting from peak-hour travel are complex and that there are few generally valid solutions to the problem. Although it is proper and helpful to point out the high costs incurred by the transit authority because of peak-hour travel, it must be noted that public transit is a form of transportation designed for the majority; thus, public transit is destined to cope with peak-hour volume. Furthermore, most peak-hour passengers are subject to constraints. Thus, it is frequently impossible or inconvenient for passengers to travel at those times that the public transit managers deem to be desirable.

One of the most important insights of the study is that individual activity programs are highly stable and routinized. Even if people were totally free to determine when they would start work and school, this would have only a limited impact on

DIMENSION	EXAMPLE OF POLICY	Approachable Potential	Voluntary in nature	Effectiveness of policies	Can be actualized by the VVS
Objectively forced to travel at a specific time	1) Changing fixed time when work begins, staggered work hours	+	-	+	-
	2) Introduction of flexi-time	+	+	0	-
	3) Changing time when school begins	+	-	+	-
	4) Improving VVS connections	-	+	+	+
Household activity program	1) Eliminating "mandatory" family lunches	0	+	0	-
	2) General Extension of time during which household activities can be participated in	0	+	-	-
Personal activity program	1) Extending closing hours for shops	-	+	+	-
	2) Pointing out existing reorganisational options	0	+	0	0
	3) Decreasing objective time barriers	0	+	0	0
Willingness to be flexible	1) Information on the problems caused by peak hour travel and demonstration of increased comfort which is possible	0/+ *)	+	0	+

*) In combination with other policies

+ =high
0 =medium
- =low

FIGURE 2 Policies to increase temporal flexibility and evaluation of effectiveness.

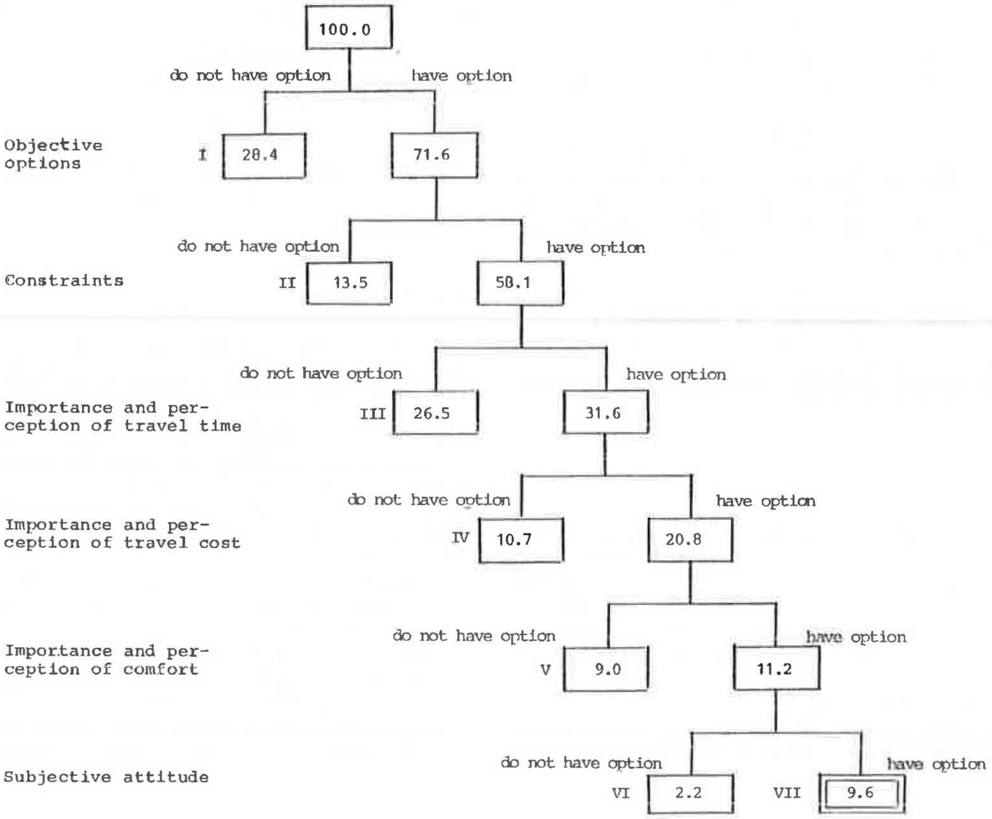

FIGURE 3 Option of changing mode of transport.

solving the problem of peak-hour travel. Furthermore, in the VVS, especially in the rapid rail transit system, the S-bahn is well frequented during the entire rush-hour period. Therefore, if the S-bahn were used somewhat earlier or later, this would simply transfer the problem from one train to the next. If the trips were postponed until after the current peak hours (about 8:00 a.m.), this would result in increased costs (especially for personnel), which could not be neutralized by cutting back on expenses elsewhere.

The capacity of the S-bahns in Stuttgart could also be increased by adding additional multiunit trains (trains with three units instead of two units). Although this involves investment costs, if the multiunit trains could make it possible to increase the capacity of the trains enough to cope with peak hours, in the long run this would probably be the most economical solution.

Decreasing the passenger load in transit vehicles by changing the times when schools start seems to be promising only when used in specific instances.

Two groups have been pinpointed who should be informed about the problems caused by peak-hour travel for the VVS and who should be encouraged to reconsider their travel behavior and possibly change their travel habits in a manner that would be positive for the public transit system. One of these groups is those passengers (10 percent) who have the basic option of not using public transit; the other group consists of those who could travel at another time.

Furthermore, businesses, public authorities, and administrations should be encouraged to introduce flextime in order to increase the proportion of passengers flexible to travel at other times. Success is possible, if at all, only over longer periods of time; much patience is needed.

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Development of Incentive Contracts for Transit Management

SUBHASH R. MUNDLE, JANET E. KRAUS, and GORDON J. FIELDING

ABSTRACT

Contract management is a widely used practice within the transit industry. Incentive contracts, however, are infrequently used to procure these services. The considerations in combining the two practices are discussed. The result is an incentive-fee arrangement with a private firm for the manageent of a local transit system. The basic concept being presented is that the management company's fee can be related to the performance of the transit organization. There are many beneficial features of this approach. First, it conveys to the contractor a sense of the transit agency's priorities for improvement. Second, it provides an incentive and rewards the management company financially for its success. And third, it can lead to an overall improvement in the productivity of the transit system. The process that a transit agency could follow in establishing an incentive program with an eligible contract management firm is presented. The options and key considerations that may arise during each step of the process are discussed. By following this guidance, the local agency should be able to synthesize these decisions and considerations systematically into a contract document for obtaining contract management services.

The development of an incentive contract appropriate to the local situation can be illustrated as a sequential process, shown in Figure 1. The first step is the decision to explore incentive-clause opportunities for existing or future contractual arrangements. Next, the local agency personnel should define what they wish to achieve through the incentive clauses. These objectives then lead the way to the detailed definition of the incentive clause. Key elements are the performance indicators against which fees will be determined, payment programs, and contract types. All of these decisions are brought together into the final bid or contract document.

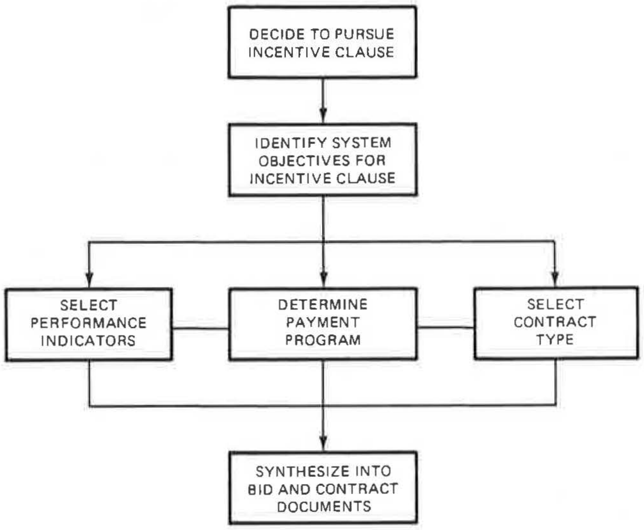


FIGURE 1 Framework for developing incentive contracts.

The process for developing an incentive contract for transit management is discussed. Each step is defined in a separate section. Throughout the discussion, the terms "incentive clause" and "incentive contract" are used interchangeably. The common concept being developed is a performance-related payment program around which a new contract is drafted.

DECIDE TO PURSUE INCENTIVE CLAUSE

The nature of incentive contracts and their previous applications are discussed. A review of these fundamental aspects of incentive contracts should enable the local transit agency to make the decision whether to pursue such an arrangement.

First, what is an incentive contract? Essentially, it is a legal agreement for services in which some or all of the fee or profit paid to the contractor is awarded according to performance against preestablished standards. In early applications, these standards reflected budgets and schedules for producing hardware such as ships and airplanes. The use described here would tie payment to the transit system's performance as measured by an indicator of efficiency or effectiveness.

The most commonly used contract for government services is the cost-plus-fixed-fee (CPFF) arrangement in which the contractor is awarded a set fee and reimbursed for costs incurred regardless of the outcome. The incentive contract concept refutes this. The fee is not paid automatically; rather, it must be earned by achieving contractually specified performance levels.

The fundamental principle of the incentive contract is that the profit motive is the driving force in business and that it can be tapped to achieve better performance results. It assumes that the contractor's motivation will vary with the presence or absence of incentive clauses through which additional profit can be made. Contract terms ensure that superior performance is rewarded with high profits, mediocre performance by average profits, and poor performance by low profits or even penalties.

Second, when might an incentive contract be applicable for transit management? There are many reasons why an organization might wish to convert from a fixed-fee to an incentive-fee contract for transit management. The two most prominent situations are when one area of the system is declining in performance and needs special attention or when overall performance of the contractor is undistinguished. In the former situation, a particular problem might be approaching crisis proportions (e.g., operator absenteeism or vehicle reliability) and public awareness of the problem is leading to heightened scrutiny. In this situation, the incentive fee would be appropriate to focus management's attention on resolving the problem. The incentive program might only be in effect until the decline in performance was arrested. In the latter scenario, the transit system may have a very general description of responsibilities for its contractor. Although the contractor may be complying with its terms, the performance may be average and the agency may expect more outstanding results, particularly where there is a competitive market for the contract. In this case, the incentive contract would establish more clearly defined requirements for the contractor in line with agency objectives for performance improvements.

Third, what is the experience in the transit industry? Incentive contracts have been used for a number of services and cut across many modes. Selected examples are discussed here for commuter rail services, small transit systems providing fixed-route or demand-responsive services, and airport ground transportation services:

1. Commuter rail: A common clause in several commuter rail agreements in Boston, Chicago, and Philadelphia relates to on-time performance; both bonuses and penalties have been prescribed for performance above or below the specified threshold. Other areas for incentives relate to consist size to assure an adequate number of cars and frequency of cleaning cars and stations.
2. Small transit systems: Service in local communities is often provided by a contractor according to a fixed-unit cost (e.g., rate per hour or mile of service). This rate can be adjusted upward or downward against performance thresholds in one or more areas. Incentive contract clauses at several small systems in California have focused on on-time performance, completed trips, working air conditioners, preventive maintenance intervals, missed trips, and passenger loads.
3. Airport ground transportation: One example of an incentive clause for this type of service focuses on the extent to which public operating assistance could be reduced by private operation of the bus routes to the Dallas-Fort Worth regional airport. The service is expected to turn a profit in several years, relieving the local communities of any responsibilities.

Productivity improvements were the major objective for incentive provisions in the examples just discussed, although a wide array of operating factors have been targets for incentive arrangements. The decision about which areas on which to focus usually was based on operational deficiencies that delineated the critical areas in need of improvement. This process of problem identification leading to incentive remedies results in clearly defined and realistic objectives. This is the next step in the process.

IDENTIFY SYSTEM OBJECTIVES FOR INCENTIVE CLAUSE

The key question to be answered at this point is, "What do we want to accomplish?" The organization should identify those critical areas of its operation where extra effort is needed on the part of management company personnel. If the agency believes that the extra effort would warrant potential increases in the management company's fees, it could choose the incentive-contract approach. A clause targeted to the priority area would be incorporated into the agreement for management services.

Virtually every transit system has established a set of goals and objectives, which provide the starting point in the development of incentive contracts. Priority goals and objectives suggest the areas where the incentive contract should concentrate and can assist in the subsequent identification of appropriate performance indicators by which to measure the achievement of these objectives.

As an example of how this process might evolve into the beginnings of an incentive contract, a goal of improving cost efficiency might be stipulated. This could be clarified further to the functional area where efficiency was lagging, such as the maintenance of revenue vehicles. This maintenance efficiency could be measured with a number of different performance indicators, including the maintenance cost per vehicle mile or vehicle miles per mechanical road call. This last item, the performance indicator, becomes the key measure to be employed in determining incentive payments. However, it is important to note that this selection of indicators should be preceded by the identification of incentive-contract objectives.

In opting for the incentive-clause remedy, the agency should be able to define the desired result that the contractor is expected to achieve. These objectives should be defined clearly and concisely. Similarly, the objective should be realistic. In order for the contractor to be motivated to expend the necessary extra efforts, the reward must be perceived as worthwhile and achievable.

SELECT PERFORMANCE INDICATORS

Three major elements make up the incentive arrangement: the performance indicator, payment mechanism, and contract type. Performance indicators are used by transit organizations to evaluate performance and to determine how the entire agency or particular functional area is performing relative to stated objectives. In the development of incentive contracts, performance indicators are used to gauge the contribution of a contract management firm to producing transit service efficiently and ensuring that service is supplied effectively. The extent to which financial rewards or penalties are imposed is measured through performance indicators.

Performance indicators are made up of statistics that reflect the three key factors in transit service delivery:

1. Input: To produce a specific level of transit service, the manager must tap the system's resources. These resources are the input statistics and include the labor hours, vehicles, fuel, and other resources required to produce service.
2. Output: the quantity of service produced is output. Examples of service output statistics include miles and hours of service. Output is the area where transit management has the greatest amount of control and authority. Hours and miles of service provided reflect the system's operating plan as well as the efficiency with which it schedules and operates its resources.
3. Consumption: The amount of service that the public uses reflects the effectiveness of the transit system. Examples of service consumption statistics include passengers and passenger miles. The consumption rate of transit services is affected by many variables and external factors, many of which are beyond the transit manager's control.

The interrelationship among these statistics serves to define different classifications of performance indicators. This can be illustrated if each type of statistic is considered as the side of a triangle, such as the one shown in Figure 2 (1). The intersecting points of the triangle are the statistics used to measure an objective. The relationship of any two statistics, for example, service input and service output, results in one of the classifications of performance indicators. For this process, the following three categories of performance indicators can be developed:

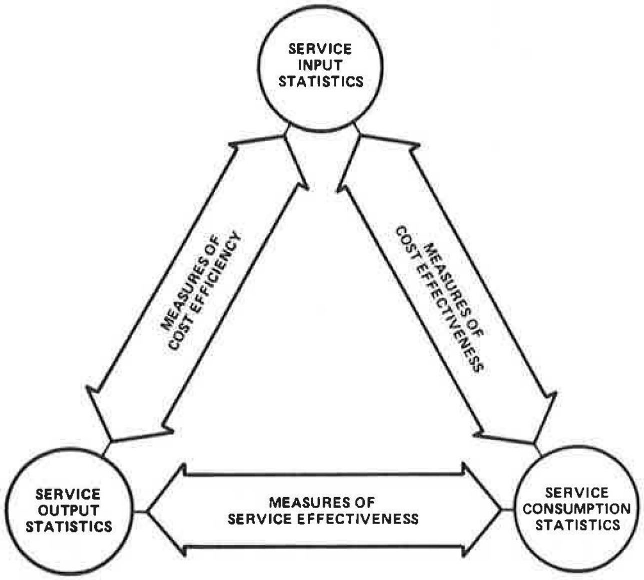


FIGURE 2 Relationship of statistics and indicators.

- Cost efficiency: how well labor, capital, and fuel (input) are used to produce service (output);
- Cost-effectiveness: the relationship of input costs of labor, capital, and fuel to the consumption of service by the public; and
- Service effectiveness: the relationship of the level of service provided to the amount of service utilized or consumed.

Although many indicators can be used to identify a transit system's strengths and weaknesses, some are more appropriate than others for incorporation in an incentive contract. Because the transit management company's performance against these indicators will determine the size of its fee or profit, it is important that several limiting factors be recognized. Five considerations in choosing among indicators include the extent to which

1. The manager will be responsible for performance and can be held accountable for results,
2. The manager will have the authority to make necessary changes to improve performance,
3. The manager has control over internal and external factors that influence results,
4. The performance indicator is easy to understand, and
5. The data to quantify performance are readily available.

The extent of accountability, authority, and control that a manager is given will vary from system to system. In general, as the preceding discussion has described, the manager is best able to determine service output levels. Service input levels also are controllable, though the manager must work within constraints such as labor contract provisions. Service consumption, however, can be affected drastically by many factors beyond a manager's purview, such as gasoline availability or the unemployment rate. Therefore, it is recommended that agencies select performance indicators that measure cost-efficiency--the relationship of input and output--and avoid effectiveness-related indicators for the purpose of an incentive clause, at least in the initial contract years.

DETERMINE PAYMENT PROGRAM

The next step in the process is to relate performance level to payment to the contractor. The amount of the incentive payment can be calculated in several ways. It can be the only amount the management company receives or it can be an amount in addition to a preestablished fee. Also, the payment program can incorporate penalties as well as rewards.

Five possible options for payment programs are described as follows:

1. Unit rate: The contractor receives a bonus point periodically. Sample applications would be a bonus of 2 cents per revenue mile for trips operating on time and a $1,000 monthly bonus for exceeding a particular performance threshold.
2. One-time bonus: A single reward is made for achieving a threshold performance level. Most likely this would occur at the end of the contract year after results have been evaluated. This approach places paramount importance on reaching one numerical goal. Also, it can be readily adapted to a bonus pool for all employees who might have contributed to the manager's success.
3. Incremental amount: A sliding scale is established to reflect the relative ease of achieving certain levels of improvement. This step-function relationship between payment and performance is illustrated in Figure 3 for the indicator average mileage interval between road calls. In this example, a contractor could increase the percentage of fee received from 2.5 to 10 percent if the performance is improved from 1,500 to 2,500 miles between mechanical road calls. Any improvement below this level would reduce the fee awarded accordingly.
4. Proportional amount: Contractors receive a specified percentage increase in fee matched to the percentage increase in performance. Many proportional payment options can be developed; Figure 4 shows four.
5. Fee pool: A total amount of funds would be set aside as the maximum available for incentive payments. A schedule for reviewing performance and awarding a portion of the pool would be established simultaneously. Funds would be awarded in whole or in part (or not at all) for exemplary performance during the contract period. These payments traditionally complement a base fee that is paid automatically as compensation for the company.

Each payment program option has advantages and disadvantages. Distinguishing characteristics are the relationship between payment and performance, funding limitations, and the ability to penalize as well as reward the contractor. It is important to note that both parties to the incentive contract (the transit agency and the management company) may hold differing perceptions of these advantages and disadvantages.

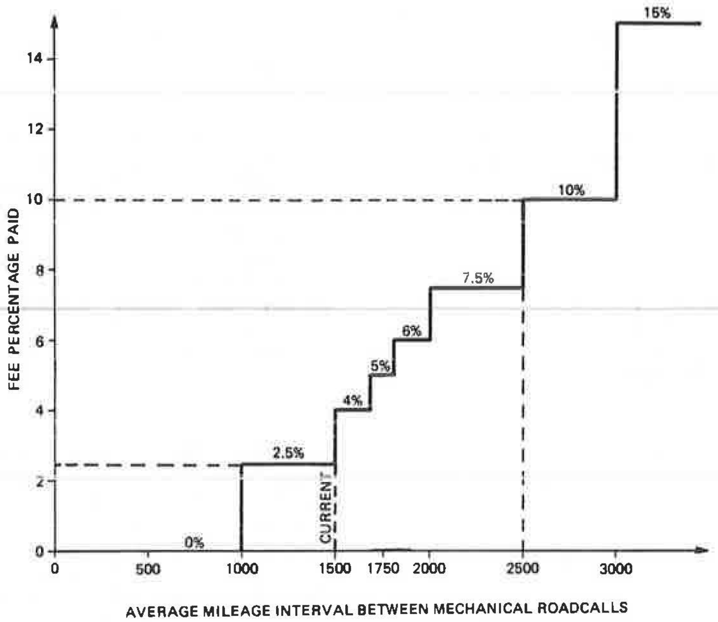
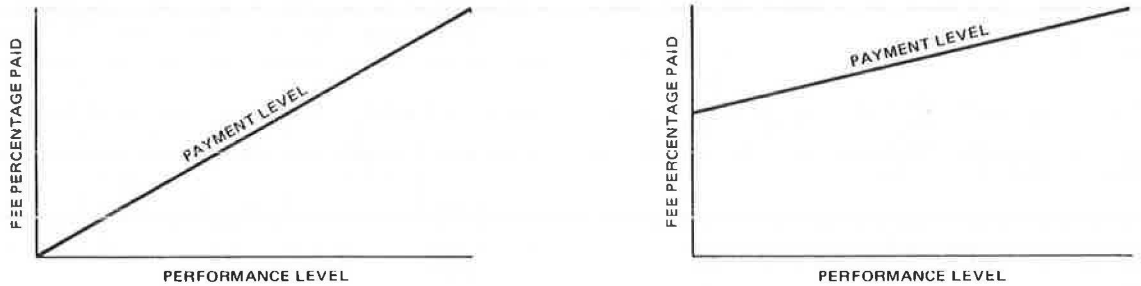


FIGURE 3 Incremental-payment method.

SELECT CONTRACT TYPE

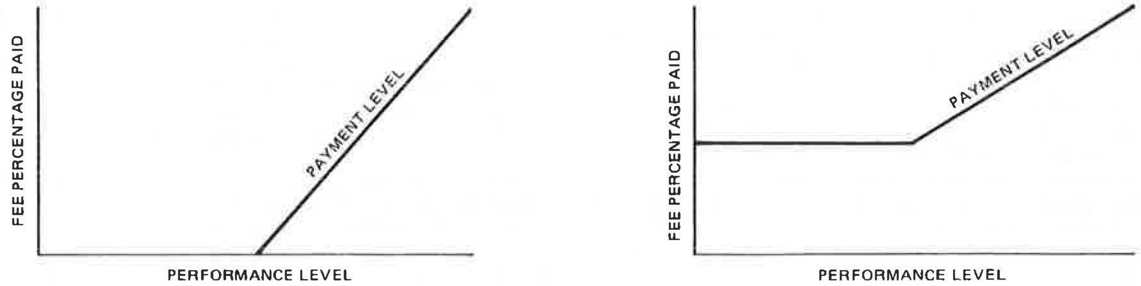
The indicator and payment program must be incorporated into a contract document. There are four general contract types commonly used by government agencies, two of which are used most often in the transit industry. They are the CPFF, mentioned earlier, and the firm fixed price (FFP). The former would provide the transit management company with a budget for operating the transit system on top of which a fixed fee would be earned by the company. The CPFF contract has the fewest incentives; costs are reimbursed and fees are paid regardless of performance results. The fixed-price contract is often derived on the basis of unit cost; the contractor is reimbursed so much per unit of service delivered, often measured by revenue mile or revenue hour. The company's profit is one element of this unit cost. If the company can trim costs and operate at less than the unit cost, these savings represent additional profit. However, if costs rise beyond the unit rate, the company is still obligated to operate at the contractual rate and thus incurs a loss.

Two other types of contracts involve incentive fees and award fees. The incentive fee in its traditional form is a bonus for savings. Any costs saved



TOTAL FEE BASED UPON PERFORMANCE LEVEL

BASE FEE PLUS INCENTIVE FEE BASED UPON PERFORMANCE LEVEL



TOTAL FEE BASED UPON SUPERIOR PERFORMANCE LEVEL

BASE FEE PLUS INCENTIVE FEE FOR SUPERIOR PERFORMANCE LEVEL

FIGURE 4 Proportional-fee payment methods.

under the target cost are shared by the contractor and procuring agency according to a predetermined sharing formula. This could be applicable to a sliding-scale fee arrangement tied to the extent of improvement in the priority area. The latter contract splits the fee into guaranteed and awarded amounts. A set percentage is paid automatically to the contractor to reimburse fixed costs and guarantee a return on investment. The balance is awarded as an incentive if a review panel determines that excellent performance has been achieved in specified areas. The review process is defined in the contract document.

The various contract types exist because there are a variety of procurement situations. One type of contract may be appropriate for developing new technology, whereas another is best suited for procuring office supplies. Key considerations are the amount of risk to be taken by both parties, the extent of uncertainties regarding costs and technical elements, and the amount of administrative oversight required. The CPFF contract, for example,

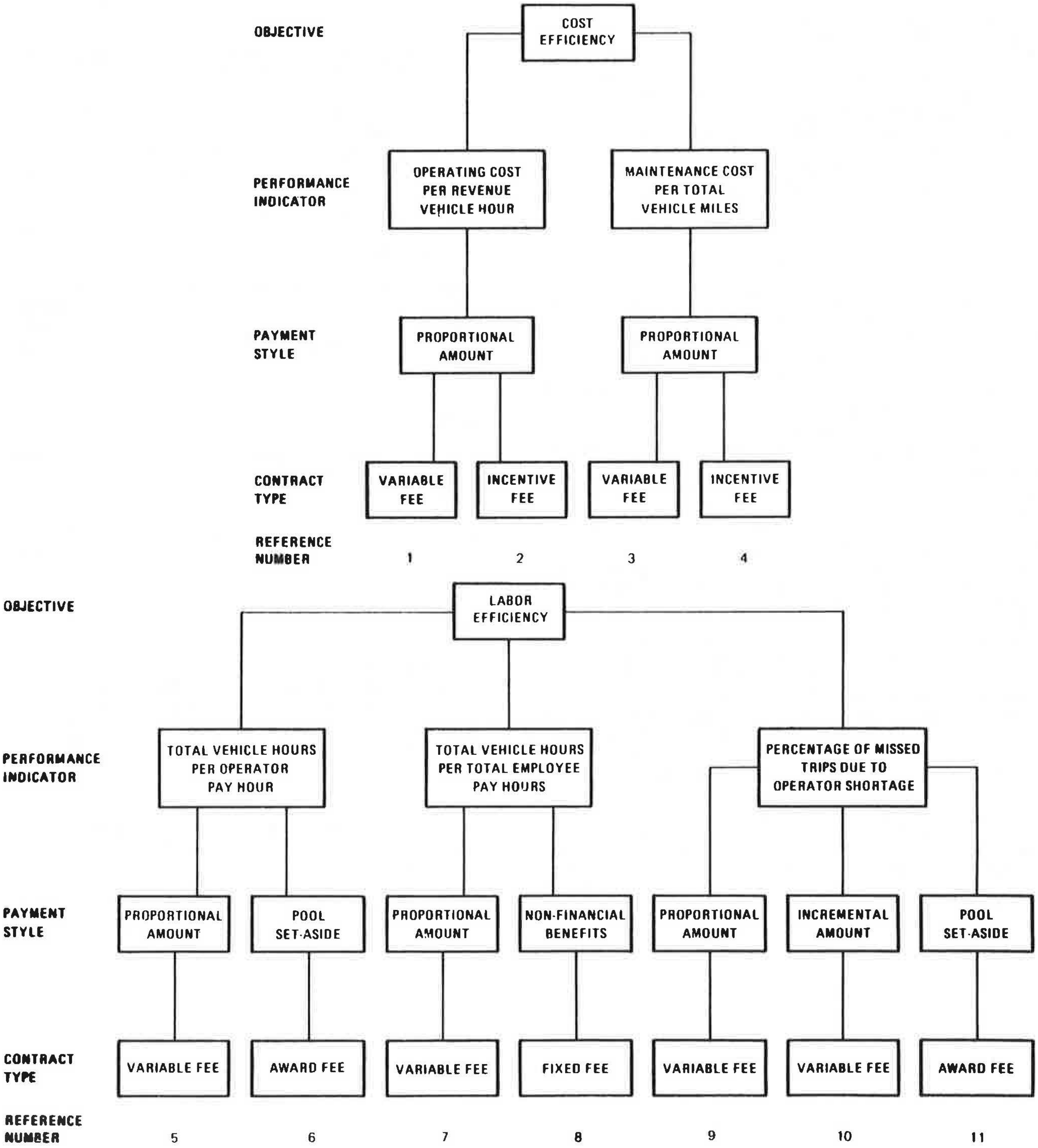


FIGURE 5 Synthesis of the incentive-contract program elements.

is appropriate when a specific level of effort is required but there are high technical and cost uncertainties. The award-fee (CPAF) contract is appropriate in similar circumstances but when there is a desire for improved performance in selected areas. These areas may, in fact, be measurable through qualitative rather than quantitative means. The incentive-fee contracts are appropriate if contractor initiative is essential for a successful outcome. These contracts would be used when some uncertainties existed yet confidence was high that performance could be achieved. Finally, the FFP contract is appropriate for situations with few unknowns; the basis for performance is known and technical and cost uncertainties are low.

An incentive-type contract is a useful device that should be employed in appropriate situations. Of itself, it possesses no inherent qualities that assure success. Rather, it is useful when a determination has been made that there is a specific need for better-than-minimum performance. The anticipated benefits ought to exceed the costs that could be paid out as additional profit or incurred internally for additional contract administration.

SYNTHESIZE INTO BID AND CONTRACT DOCUMENTS

The preceding activities lead to the final step wherein the incentive-contract document is made final. The synthesis of the incentive-contract program places the overall objective (e.g., labor efficiency) as paramount. Contract and payment types become secondary and support the definition of objective and appropriate performance indicator. In this approach, then, the objective and focus of the contract arrangement are defined first, a performance indicator is chosen second, and the contract type and payment style are selected last. The result, shown in Figure 5, is a diagram led by the efficiency objective. The next choice is among the improvement areas. In this illustration, the choice for the agency to focus on is either cost or labor efficiency. For each focus area, several performance indicators can be applied. For example, cost efficiency could be measured through the operating cost per vehicle hour and the maintenance cost per vehicle mile. Each indicator could be used with several different payment styles. Gradual changes in performance may be best reinforced through a proportional payment style (a linear relationship between payment and performance), although incremental amounts, a pool set aside, and other payment styles may be suitable in certain circumstances. A contract type corresponds to each payment style. The proportional amount would be arranged through a variable- or incentive-fee contract; the pool set-aside payment would require an award-fee contract. The upshot of this approach is the definition of each incentive-contract alternative by following a particular vertical line on the diagram. A total of 11 various contract alternatives are shown in this example.

At this point, the agency should have a clear understanding of its objectives and should have defined an incentive program that complements these objectives. Should the agency choose to proceed with an incentive contract, it would conduct several implementation tasks, including the following:

1. Identify baseline performance and expected levels of improvement;
2. Establish administrative procedures for data collection and contract monitoring;
3. Finalize payment clauses for the contract to define criteria, amount, and schedule; and
4. Solicit bids and negotiate and execute the contract.

In preparing for an incentive program, the agency is offered the following cautions:

1. Consider only those performance areas over which the management team has control,
2. Set standards that are achievable,
3. Use indicators that are easy to understand and require minimal data collection, and
4. Assure that the incentive program does not result in a shift in attention away from overall system management.

In summary, the successful incentive program is one in which the benefits to the system in improved productivity and responsiveness exceed the additional expenses for management company fees and administrative costs.

ACKNOWLEDGMENT

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Application of a Model To Optimize Simultaneous Bus Garage Location and Vehicle Assignment

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ABSTRACT

A demonstration is presented of a new methodology that simultaneously locates and sizes bus garages and reassigns vehicles to trips with respect to the garage locations being considered. The advantage of this methodology over existing methodologies is that existing vehicle assignments are not used. The existing vehicle assignments were originally constructed with the existing garage locations in mind. Therefore, the use of existing vehicle assignments does not permit a realistic evaluation of the cost of locating at a new site. The methodology presented and demonstrated accounts for the interdependence of garage location and vehicle assignments and it gives the analyst a realistic estimate of the costs of locating at a new site. The methodology is demonstrated with a Southeastern Michigan Transportation Authority (SEMTA) case study. The northeastern third of the the SEMTA transit network is used in the demonstration, and sites in this area are evaluated. At each iteration the methodology reassigns vehicles to trips and these reassignments are illustrated with computer plots.

In previous papers concern was expressed over the deficiencies in the existing methods to locate bus garages (1-6). Specifically, the assignment of vehicles to trips is considered fixed regardless of the garage location being evaluated. Generally, the evaluation of potential locations is conducted by estimating the deadheading cost between the site and existing pull-out and pull-in points (the points where route assignments begin and end). However, once a new bus garage is built, the scheduling department will normally redesign vehicle assignments so that deadheading between the new garage and assignments is minimized. Therefore, the existing assignment does not provide the analyst with an accurate estimate of what the deadheading costs will be if a garage were opened at a new site.

When current methodologies use existing vehicle assignments (blocks), the evaluation generally determines that the existing garage locations or nearby locations are good sites for garages. The reason for this is that when the scheduler designs vehicle assignments, he attempts to minimize deadheading from existing sites. Therefore, if the scheduler is doing a good job, existing locations will always appear to be good locations for garages. This trait has perplexed transit operators who wish to locate a new garage away from an old site but find that existing sites are well located with respect to existing vehicle assignments (7-9).

The solution to the problem that existing vehicle assignments dictate the location of new garages is to regroup trips into vehicle assignments as different combinations of new and existing garage locations are being considered. In this way the assignments are scheduled with respect to the locational characteristics of the new and existing sites considered, and the assignments are not biased by the location of an existing garage.

The purpose of this paper is to present an application of a mathematical program that simultaneously locates garages and reassigns vehicles to trips. The significance of this methodology lies in its ability to more realistically represent the transit system. In the methodology presented here it is recognized that the location of garages and the assignment of vehicles to trips are really interdependent activities. Further, failure to consider their interdependence has been shown to significantly bias the cost analysis of prospective garage sites (2,5). In this paper only a brief description of the mathematics underlying the model is presented. For the interested reader, the mathematics are thoroughly documented elsewhere (2).

METHODOLOGY

The smallest component of the methodology is the vehicle assignment (a block). A block starts with a bus pulling out from a garage and starting a trip on a route. Once the bus reaches the end of the trip, it can either pull back into the garage or hook to another trip. If the bus hooks to another trip, it has the option of pulling into the garage or hooking to another trip on the completion of the second trip. The path the bus takes from its pull-out through its hook and its pull-in is a block.

A vehicle scheduler will attempt to design blocks so that all scheduled trips are assigned a vehicle and deadheading costs between the garage and pull-out and pull-in points and those of hooks (layover and travel costs) are minimized.

In this methodology the assignment of trips to blocks and blocks to garage sites is done with a linear program the objective of which is to minimize the sum of the deadhead costs and facility costs in the combination of garages considered. The deadheading costs are the sum of pull-out travel costs, hook travel and layover costs, and pull-in travel costs. Further, a special auxiliary variable is included in the mathematical program to ensure that the bus that pulls out of one garage is returned to the same garage.

Facility costs of the sites consist of a fixed charge for opening a site and a construction and garage operation cost that increases linearly with the number of buses assigned to the garage. Garage sites are switched off and on to permit the evaluation of different combinations of sites. To switch a site off, its capacity is bounded to zero, and to switch a site on, its capacity is bounded by the maximum number of vehicles that can be assigned to the site. As garages are switched on, the appropriate fixed charge is added to the result of the objective function. Sites are switched off and on through a branch and bounding process until the optimal combination is found. [For a complete discussion of the model, see the report by Maze et al. (2).]

The decision rules used in the branch and bounding process start with all sites in an undecided set, $\{k_2\}$, where members have not been fixed open or closed [the decision rules are taken from a paper by Khumawala (10)]. Then, through the delta decision rules, sites in $\{K_2\}$ are tested for candidacy to a set where all members are fixed open (set $\{K_1\}$). In the garage problem this entails testing existing garages to determine whether they remain in the optimal option. Next, the omega decision rule determines which of the members remaining in $\{K_2\}$ can be made members of a set where all members are fixed closed (set $\{K_0\}$). In the garage problem, this entails testing candidate sites to determine which can be eliminated. After sites have been tested with both rules, the sites that still remain in $\{K_2\}$ can be evaluated by enumerating all combinations of members of $\{K_2\}$ plus all members of $\{K_1\}$. The two decision rules are as follows:

1. If the least possible increase in total variable costs (the sum of deadhead, variable garage operating, and variable garage construction costs) due to not opening a facility is greater than the fixed charge, the facility should remain open (delta decision rule). The least total variable cost decrease of opening a site can be estimated by solving a linear program including all sites ($L[\{K_1 \cup K_2\}]$; $\{K_1\}$ may be empty at this point) and then solving a linear program without the facility in question ($L[\{K_1 \cup K_2\} - j]$).
2. If the largest possible decrease in total variable cost due to opening a facility is less than its fixed charge, the site should remain closed (omega rule). The greatest total variable cost decrease can be estimated by solving a linear program with only those facilities that have been fixed open through the delta rule ($L[\{K_1\}]$) and then adding one site and solving that linear program ($L[\{K_1\} + j]$).

In both of the foregoing rules, $L[]$ is the linear program including the set of sites inside the brackets, $\{K_0\}$ is the set of sites fixed closed, $\{K_1\}$ is the set of sites fixed open, and $\{K_2\}$ is the set of sites that have not yet been fixed open or closed.

CASE STUDY

This hypothetical case study is presented to demonstrate the application of the model. The northeast third of the transit network of the suburban Detroit operator [Southeastern Michigan Transportation Authority (SEMTA)] is used in the demonstration. The chosen portion of the network includes routes that are currently serviced from SEMTA's Macomb garage. Included are nine routes with a combined total of 447 trips.

System Characterization

The portion of the SEMTA system considered consists of all fixed routes that fall roughly between Lake St. Clair on the east, downtown Detroit on the south, and Van Dyke Road on the west. These boundaries cover a triangular area including the east side and eastern suburbs of the Detroit metropolitan area. This region does not completely enclose the paths of all routes. There are minor exceptions; for example, there is a crosstown route considered that follows 9 Mile Road. The two termini of this route are the box (Figure 1) indicating a route pull-in and pull-out point about a mile north of the 8 Mile Road and Jefferson Avenue and the box on the west side just northwest of the 8 Mile Road and US-10 (Lodge Freeway).

Route Description

All the routes considered except the one crosstown route mentioned earlier are radial commuter-oriented routes. Many of these have a broad variety of travel patterns. For example, the bus route that operates on Van Dyke Road has five different patterns. Although all five patterns have common portions of travel (they all travel along Van Dyke Road between 8 Mile Road and 15 Mile Road), some trips on the route have a southern terminus downtown and others have a southern terminus near Jefferson Avenue and 8 Mile Road. Hence, although only nine routes are considered, the coverage of the east side is greater than what might be imagined because of the fragmented nature of the route patterns.

Although some of the routes are located along the western boundary of the triangular region considered, the most densely covered portion is the eastern portion of the east side, in the Gratiot-Jefferson corridor. For example, the Gratiot Avenue route (Route 560) has more than 100 inbound and outbound trips daily. Other routes that lie in the same area include Kercheval-Mack (Routes 610 and 615), Jefferson (Routes 630 and 635), and Harper Avenue (Route 580), which have 86, 61, and 15 trips daily, respectively.

The clustering of service in the Gratiot-Jefferson corridor is also reflected by the position of the pull-in and pull-out points shown in Figure 1. The pull-out and pull-in points are clustered along the corridor. There is a total of 25 such points in Figure 1. There is only one in the central business district (CBD) of Detroit, although there are actually several places where routes begin or end in the CBD. Most of these points are at best a few blocks away from one another, but because of the scale of the map, they are represented by one box.

Site Identification

Within the study area there exists one SEMTA garage. This is the Macomb garage (site C in Figure 1) and it is located on 15 Mile Road just to the east of Gratiot Avenue. The Macomb garage is considered to have a capacity of 100 buses.

Three other sites are considered potential locations for garages. The identification of the candidate sites is based on the following criteria:

1. The candidate site should be close (e.g., 1 mile or less) to a major arterial or freeway, and
2. The site should not be occupied by a structure that is currently in use and the adjacent area should be of a similar land use (e.g., industrial, warehouse, or light commercial).

Three candidate sites are selected based on these criteria and based on knowledge of the transit network. The model could be expanded to include more sites and an even larger network, but in this study the data are coded by hand for batch entry to the mathematical programming package. Because the model requires two deadheading cost estimates for each trip (one for the pull-out and one for the pull-in) and one deadhead cost estimate for each potential hookmate for each trip from each garage, the coding becomes a rather lengthy task if the number of either trips or potential garage locations is large. For example, in the case study there are 4 garage sites, 447 trips, and 3 potential hookmates for each trip. This results in about 9,000 cost parameters to be coded for entry into the mathematical program. The model can easily be expanded to include more sites and trips if future users wish to apply it to

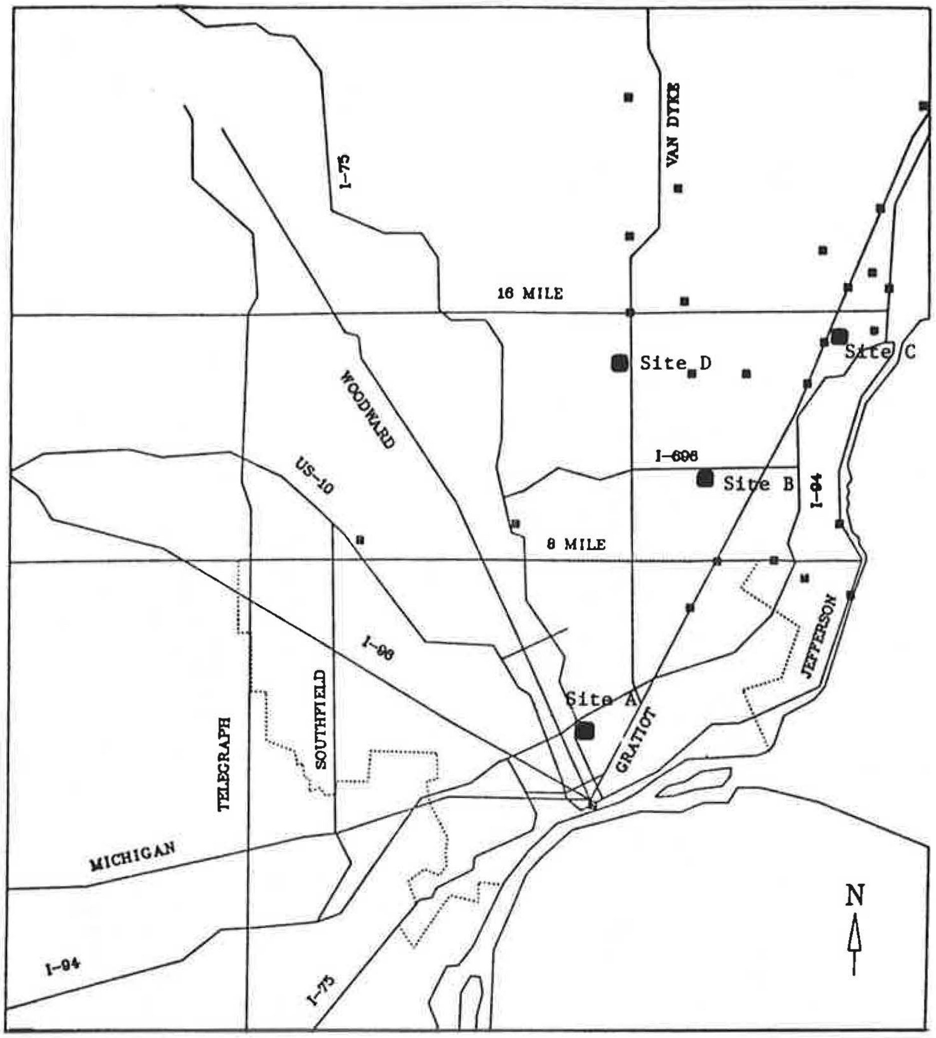

FIGURE 1 Detroit area base map.

larger-scale systems. On consideration of the hand coding involved in the case study and on trading off this effort with the loss in realism in proving a small-scale example, a decision was reached to examine only four sites. It is suggested that future users wishing to consider large systems create an automatic coding system for data input.

Site A in Figure 1 is in an area that was cleared for urban renewal and is still largely vacant. Besides a few warehouses, the central maintenance facility for the Detroit Department of Transportation (the transit operator for the the city of Detroit), and a small public housing development, the area is largely vacant land. The site has good access to I-75 and is close to I-94, Gratiot Avenue, and downtown Detroit. Site B, located adjacent to I-696, is in an area of predominantly light industry and there exists ample vacant land. Site D is located near the intersection of 14 Mile Road and Van Dyke. There is nearly a quarter section of vacant land that abuts a factory.

Admittedly some of these sites may be unavailable for use as garage locations, and if this study were being conducted for an actual transit operator, investigations would need to be conducted to determine ownership, zoning, political feasibility, and other characteristics of the site. Because the sites are identified only for the purposes of demonstrating the model, this is unnecessary. Once the sites to be considered have been identified, the next step is to estimate the cost parameters based on these sites and based on the portion of the transit network considered.

Model Parameter Generation

The model parameters that need to be generated can be divided into three types: garage operating costs, both variable and fixed; garage construction costs, both variable and fixed; and deadhead costs, which include travel time and distance costs of pull-outs, pull-ins, and hooks and the time cost of layovers. The methodology used to estimate each of these costs is described in the following subsections.

Garage Operating and Construction Costs

Garage operating and construction cost functions were estimated as part of a previous UMTA University Research and Training Grant (2). Both costs are annualized and the functions are shown in the following. The cost functions are modeled after those derived by actual engineering cost studies of bus garages, and the functions are estimated using SEMTA cost information (11,12). In the derivation of the cost functions, a 10 percent spare factor is assumed. The annual construction cost function is based on a 25-year design life and a discount rate of 9 percent.

Total annual garage operating cost = $192,412 + $10,340 (number of buses assigned to a garage).

Total annual garage construction cost = $68,933 + $3,190 (number of buses assigned to a garage).

Deadhead Costs

Deadhead costs include the costs of travel from the garage to pull-out points, travel between hookmates, travel from pull-in points to the garage, and the driver's time during layovers. To estimate the deadhead costs for the Detroit case study, the Urban Transportation Planning System (UTPS) computerized highway network of the metropolitan area is used (13). The network contains average speed of travel and the length of highway links. The mileage cost (the cost to operate a bus per mile) and the time cost (the driver's wage per minute) are applied to the Detroit metropolitan area's UTPS highway network. The UTPS module UROAD is used to determine the minimum-cost paths and to accumulate the costs from every centroid to every other centroid.

Centroids can be moved or created so that they are located approximately at every pull-out and pull-in point and at every garage location. In this way the costs of traveling to every pull-out point and from every pull-in point to all garage sites and between all potential hookmates can be estimated. The advantage of this methodology is that transportation costs are estimated with a simulation that closely approximates the actual costs between every pair of points of interest within the system. The distance and time costs are derived from the computerized highway network by using actual SEMTA travel costs of 30 cents per mile and average driver wages, including all benefits, of 22 cents per minute. The deadhead cost estimates are annualized for all possible pull-outs and pull-ins and for the three best hookmates for each trip.

Now that all cost parameters have been estimated and the system has been characterized, the model can be applied to the system, which is described next.

Model Application

The first step is to develop a list of sites to be evaluated. The algorithm enters the delta rule phase and existing sites are tested to determine whether they can either be fixed open (see $\{K_1\}$) or remain undecided (set $\{K_2\}$). Next the algorithm enters the omega rule phase and all sites remaining in $\{K_2\}$ are tested to either become fixed closed (set $\{K_0\}$) or remain in set $\{K_2\}$. Sites remaining in $\{K_2\}$ enter a branch and bound phase and the result is an optimal solution.

Delta Decision Rule

The first step in the delta rule is to run a linear program with all garage capacities upper bounded at their maximums. The second step is to set the upper bound of the capacity of one garage equal to zero, rerun the linear program, and calculate the difference in the total variable cost from the first to the second run. If the variable costs increase by a sum greater than the removed site's fixed charge, the site is fixed open. The third step is to iterate back to step two until the list of sites is exhausted.

The running of the problem with all upper bounds set equal to the site's maximum capacity is the only time the problem is to be run with a raw set of data. From that point onward, the basis of the previous run is revised. The initial solution is as follows:

Site	Existing Capacity (no. of buses)	No. of Active Buses Assigned
A	0	14
B	0	1
C (Macomb)	100	72
D	0	4

Total variable cost = $2,040,783,

Total cost = $2,948,297.

To help interpret the result, Figures 2-5 are used. Figure 2 indicates the relative locations of the four sites. The size of the box indicating each site is proportional to the number of buses assigned to each site. As can be seen, the largest box is located at site C and it is proportional to the 72 buses assigned to that site.

To interpret Figures 3, 4, and 5, it must be remembered that at each iteration the model not only assigns buses to the garages considered at that iteration but also optimally assigns buses to trips. Figure 3 shows the pull-out assignments from each of the sites considered. To understand how to interpret Figure 3, note the location of site A, the southern site, closest to downtown Detroit, and the wide isosceles triangle pointing downward from site A and terminating in downtown Detroit. The box at the tip of the triangle indicates a trip terminus point, as do all the other similar boxes. The base of the triangle is proportional in length to the number of buses that are assigned to pull out from site A for trips starting in downtown Detroit. As can be seen in Figure 3, there are a large number of pull-outs from site C (the site of the Macomb garage). The proportion of activity originating from site C corresponds to the relatively large quantity of buses assigned to this site.

Figure 4 shows the quantity of flow of buses between trip termini. More specifically, the triangles shown are proportional to the hooking activity between trip termini. Note in Figure 4 that the majority of the hooking activity is between the trip terminus along Gratiot Avenue and to the east (see Figure 1 for the location of Gratiot Avenue). The majority of the hooking activity corresponds to the location of the majority of the routes.

Figure 5 defines the pull-in activity. This figure is read in the same fashion as the other figures showing flows of buses.

In the first run of the model, only one bus is assigned to site B because this garage is relatively close, in terms of travel cost, to site C. Therefore, if a bus is to be assigned to site B, there must be a deadhead cost savings, as compared with site C, equal to or greater than the cost of constructing a new space at site B. To demonstrate the trade-offs between the facility costs and the deadhead costs, the optimization model is rerun with the facility costs at site C increased so that they are equal to the facility costs at a new site (variable garage operating costs plus variable garage construction costs). Site B is assigned 12 buses instead of only one, whereas the number of buses assigned to the existing garage at site C is decreased from 72 to 42.

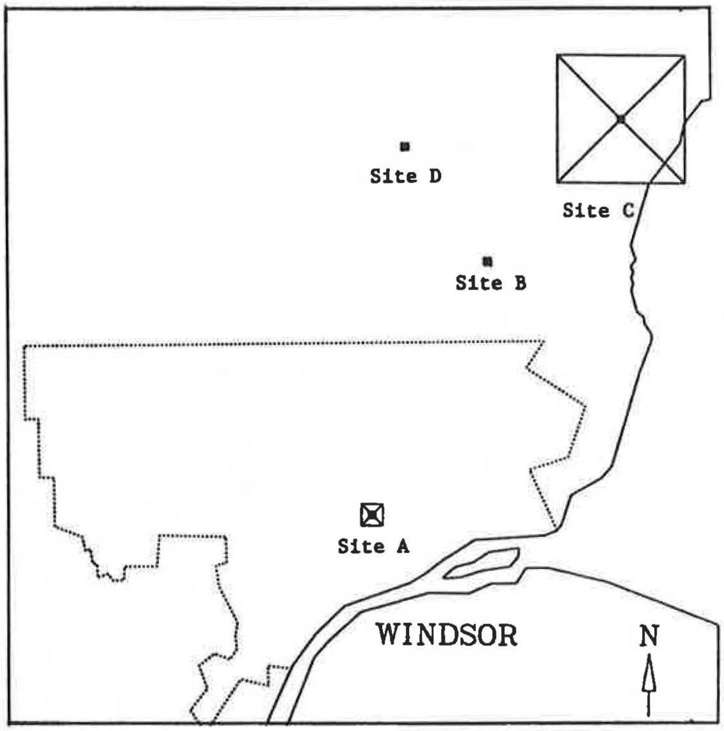

FIGURE 2 Relative number of buses assigned to sites.

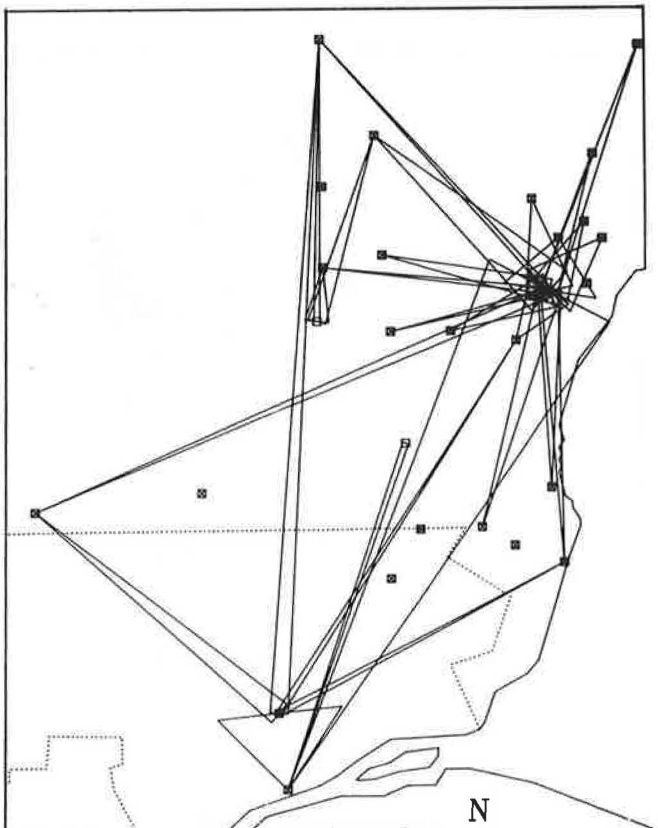

FIGURE 3 Pull-outs with all garages included.

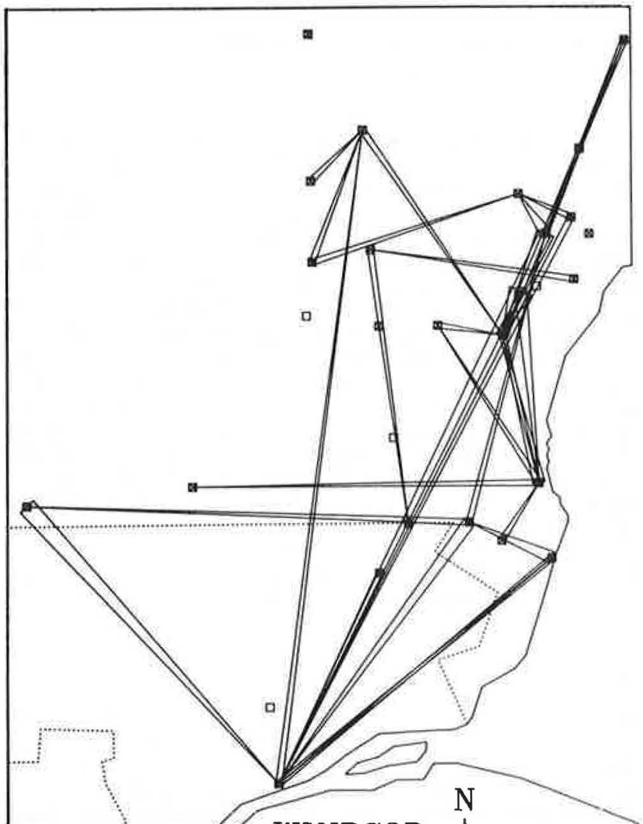

FIGURE 4 Hooks between routes with all garages included.

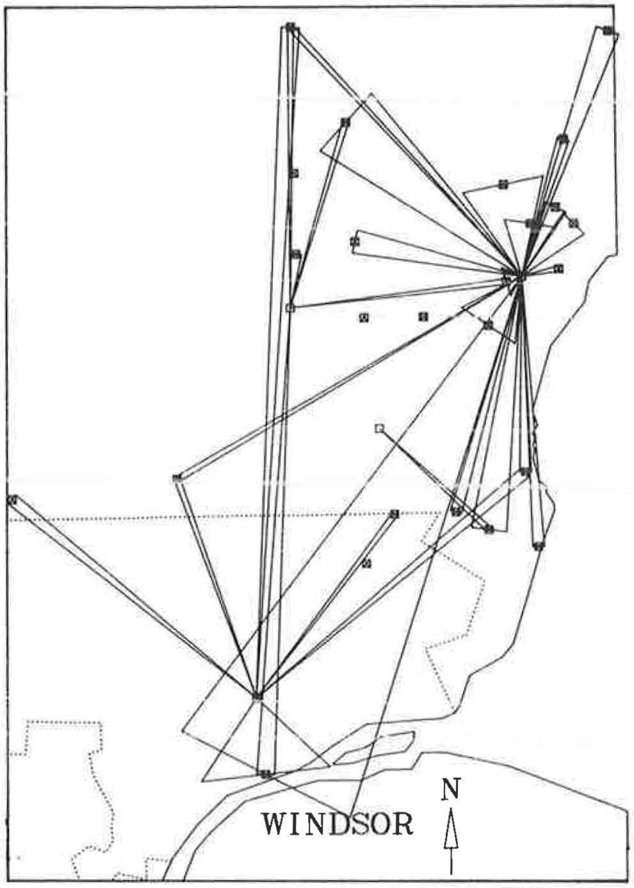

FIGURE 5 Pull-ins with all garages included.

The next step in the delta decision rule would be to switch off the existing site and determine whether it should be fixed opened (made a member of $\{K_1\}$). To prove that the existing garage at site C should remain open, another linear program is run with all sites except site C switched on. The linear program with only sites A, B, and D results in assignments of 38, 27, and 25 buses, respectively. The sum of the facility variable costs and deadhead costs in the solution is $2,338,750. The difference between the cost of the combination with sites A, B, and D switched on and the cost with all sites switched on is $297,967. Because this is greater than the fixed charge of $192,412 (because the garage is already built there is no construction cost fixed charge), the delta value is greater than zero and site C will be the optimal solution.

The next step in the process is to eliminate candidate sites from consideration. Candidate sites are eliminated through the omega rule in the following.

Omega Rule

The first step in the omega decision rule is to run a linear program with only members of $\{K_1\}$ switched. Then one member of the undecided set $\{K_2\}$ is switched on at a time. The results of the omega rule are shown in Table 1. Because all candidate sites have omega values less than zero, all are placed in $\{K_0\}$. The optimal solution is to keep the garage at site C and eliminate the other sites from further consideration. The flow of pull-outs, hooks, and pull-ins is shown in Figures 6, 7, and 8, respectively.

TABLE 1 Omega Rule Results

Omega Value	Active Bus Assignments			
$\Omega_A = -176,641$	$N_A = 16$	$N_B = 0$	$N_C = 74$	$N_D = 0$
$\Omega_B = -257,058$	$N_A = 0$	$N_B = 4$	$N_C = 86$	$N_D = 0$
$\Omega_D = -247,191$	$N_A = 0$	$N_B = 0$	$N_C = 84$	$N_D = 6$

CONCLUSIONS

In this paper an optimization model is demonstrated that simultaneously considers garage location and the assignment of vehicles to trips. The methodology was demonstrated by applying it to the transit network of the Detroit area's suburban operator. Approximately a third of the operator's network is used in the example. However, there is no reason that the model could not be expanded to consider the entire network or even a larger network. Expanding the model is simply a matter of coding more data.

The model works by opening and closing garages at prospective locations, evaluating the cost of transit operation with each combination, and iterating until a minimum-cost combination of garages is found. At each iteration plots are produced showing the flow of vehicles assigned to trips, between trips, and back to the garages. These plots provide an interesting interpretation of the model's assignments.

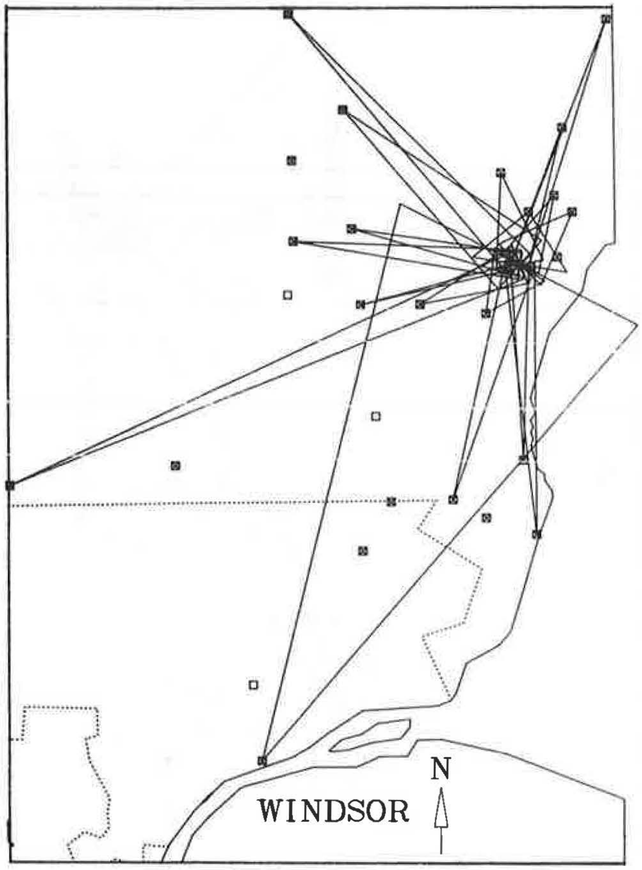

FIGURE 6 Pull-outs with only garage C included.

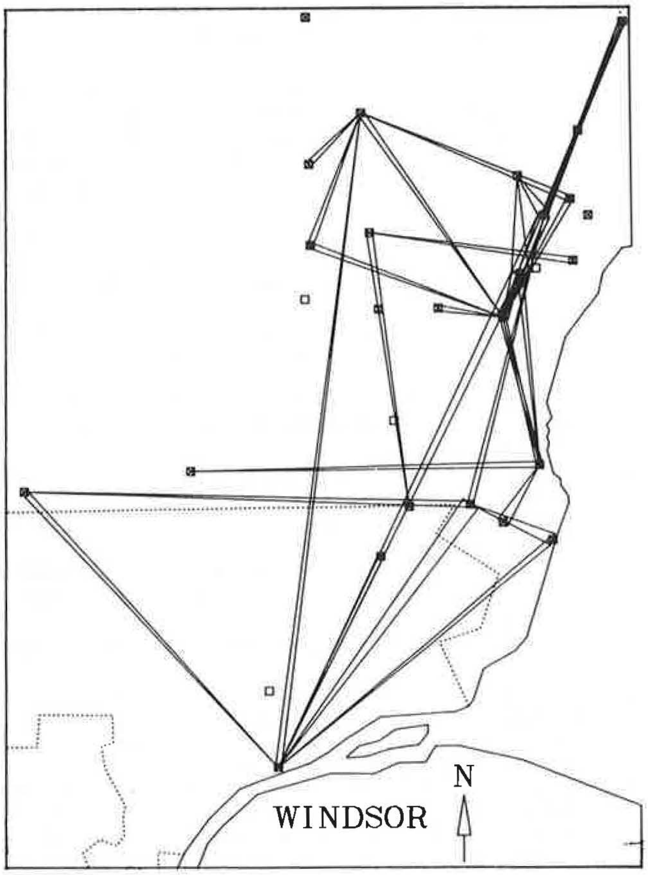

FIGURE 7 Hooks between routes with only garage C included.

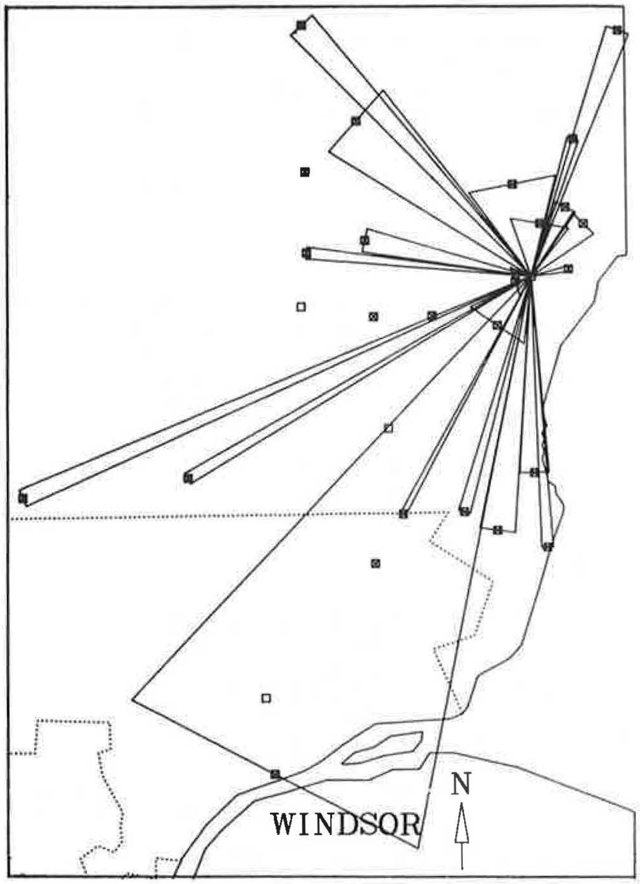

FIGURE 8 Pull-ins with only garage C included.

The importance of the model's development and application lies in its ability to realistically represent the interrelation between vehicle assignments and garage location. Other available methodologies assume that the vehicle assignments are fixed regardless of the location being evaluated. This assumption is unrealistic. In actual situations, when new garages are located, vehicles are reassigned with respect to the locational properties of the new garage. Hence, evaluating a new garage with existing vehicle assignments does not result in an accurate estimate of what it would cost to locate a garage at a candidate site. Further, existing vehicle assignments are biased toward existing garage sites. By recognizing the interrelationship between vehicle assignments and garage locations, the methodology results in realistic cost estimates of locating at a particular site and it does not suffer from the bias built into existing vehicle assignments.

The model provides a more realistic system to analyze the bus garage problem, but there are still many problems that remain to be solved. Two of the prominent problems are as follows:

1. Although vehicle assignments have been disaggregated down to the trip level, little has been done to ensure desirable driver assignments. There are reasons to believe that during run cutting good vehicle assignment will result in better driver assignments. When dealing with the bus garage problem, others have considered driver assignments by first packaging groups of blocks on the same route or route segment into desirable driver assignments (14). Then the route or route segments are allocated to garages using a mathematical program. Because this second approach does not consider the vehicle and driver assignment simultaneously, it has some of the same flaws as the method in this paper. To the best of the authors' knowledge, no feasible solution exists to the problem of simultaneous assignment of buses and drivers. Therefore, probably the best that can be done at this time is to iterate between a multifacility vehicle assignment model and a driver assignment model when new garage locations are investigated.

2. Currently, all mathematical programming techniques used to locate and size bus garages require technical knowledge that is not commonly available at transit agencies or through consulting firms. To date, the authors know of only one example where a transit agency commissioned a garage location study that included the use of mathematical programming (15). Therefore, it is unlikely that any mathematical programming techniques, in their current forms, will ever be commonly used. On the other hand, many transit agencies use complicated mathematical programs on a daily basis. RUCUS and other scheduling and run-cutting packages are commonly used and include complicated mathematical programs. What makes these packages operable by most transit agencies is that they have been automated to the point where the user does not need to understand mathematical programming. Until garage location and sizing methods become more automatic, it is unlikely that analytical methods will receive widespread use.

In conclusion, there is still much work that needs to be done in the development of bus garage planning methods. Besides resolving the two problems mentioned previously, these methods should probably become part of the long-range transportation planning process. Typically, transportation plans are only concerned with provision of service with little regard for operational problems. On the other hand, operational planning for garages tends to occur only when there is pressure to build one new facility with little regard for long-range changes in service. These two activities need to be drawn together.

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First-Year Impact of Reduced Transit Fares on Southern California Rapid Transit District

SUSAN PHIFER

ABSTRACT

In 1980 voters in Los Angeles County passed a referendum designed to support public transit development through a dedicated sales tax. One feature of this referendum, the reduced-fare program, substantially lowered the bus fares at the Southern California Rapid Transit District (SCRTD) and provided a subsidy to maintain adequate service levels. The lower fares precipitated a surge in patronage on SCRTD lines. This growth in system boardings made it necessary to accelerate monitoring of the bus lines and to increase service levels in many cases. The attempts made by SCRTD to deal with the patronage growth and the impacts on patronage, service levels, and operating productivity are described.

Voter approval of the Transit Development Program referendum in 1980 ushered in a new era for public transportation in Los Angeles County. Through this referendum, the voters mandated the development of a regional rail rapid transit system. The referendum, known as Proposition A, is one of the largest dedicated taxes for public transportation ever voted by a county electorate in the United States. An opportunity has thus been presented to accomplish major transportation improvements in Los Angeles County.

The Los Angeles County Transportation Commission (LACTC) placed Proposition A on the ballot at the November 4, 1980, general election. The measure was approved by 54.2 percent of the county voters. After a legal challenge, the measure was validated by the California Supreme Court on April 30, 1982. The new Transit Development Program started on July 1, 1982.

Proposition A provided funding for three specific programs: lower bus fares (reduced-fare program), local transit improvements, and construction of a rail rapid transit system. Proposition A increased the sales tax in Los Angeles County by 0.5 percent and raised almost $300 million in the first year. This revenue was combined with state and federal funds, fares, and other revenues to provide a comprehensive public transit program in Los Angeles County.

Every incorporated city in Los Angeles County will receive a direct allocation of sales tax revenues for local transit improvements. Each year, 25 percent of the sales tax revenue will be set aside in a special fund and then divided among the 82 cities and the county unincorporated areas, according to the population of each jurisdiction. Each city (or the county in the case of unincorporated areas) will decide how to provide better local public transportation services for their community. They may spend the funds themselves or contract with other service providers, such as the Southern California Rapid Transit District (SCRTD). This 25 percent allocation of the sales tax funds to cities is permanent.

For the first 3 years--July 1, 1982, through June 30, 1985--the first claim on the balance of the funds is for fare reductions. The district's base fare was reduced from 85 to 50 cents with concurrent reductions in the balance of the district's fare structure. Funds are provided for the additional service necessary to relieve overcrowding from increased ridership induced by the lower fare. Funds will also be allocated to the municipal bus operators as necessary, to keep their base fare at the 50-cent level. During the first 3 years, funds not required for the fare-reduction program are available for rapid transit development programs.

The fare-reduction program of Proposition A ends in July 1985. At that time funds will be reallocated as follows: 25 percent for the cities, a minimum of 35 percent for transit guideway development (Metro Rail and light rail projects), and the balance of 40 percent for discretionary public transit improvements as defined by LACTC. These programs could include fare-relief subsidy, maintenance of bus service, or acceleration of rail rapid transit construction.

One feature of the Transit Development Program is the focus of this paper: the first-year impact of the Proposition A reduced-fare program on SCRTD. The reduced-fare program caused significant changes in ridership and service levels. Initially, ridership surged, then continued at a slower growth rate throughout the first year. Growth in ridership affected the service levels required to maintain adequate capacity. In the first half of the paper the attempt made by SCRTD to deal effectively with the surge in ridership is described. The actual impacts of the reduced-fare program on patronage, service level, pass sales, and operating productivity are documented in the second half of the paper.

PREPARING FOR IMPLEMENTATION OF THE REDUCED-FARE PROGRAM

Actions by the Board of Directors

Subsequent to the April 30 validation of Proposition A by the California State Supreme Court, the policy bodies of SCRTD and LACTC approved a master agreement, also called the Memorandum of Understanding (MOU). Intended to prevent system productivity from worsening, the MOU outlined actions and constraints under which the district was to implement the Proposition A reduced-fare program. The MOU, revised in February 1983, will remain in effect through the end of the mandated reduced-fare program, June 30, 1985. Key features of the MOU include the following:

1. The district will lower its fare structure to designated levels on July 1, 1983,
2. The district will provide enhanced service on existing lines to accommodate the increased ridership demand resulting from the lowered fare structure,
3. The district will redeploy its services

wherever possible so that capacity is shifted to meet additional demand,

4. The district will maintain its productivity as measured by designated standards and not allow conditions to become worse on lines where excessive crowding exists,
5. The district will prepare brief statistical reports at regular intervals covering specified performance indicators, and
6. LACTC will reimburse the district for these actions up to a set dollar limit per month for up to a set limit of vehicle service hours per year.

The SCRTD Board of Directors affirmed the master agreement by approving the revision of the district's fare structure. As required, the base fare was lowered from 85 to 50 cents, a 41 percent decrease. There were corresponding reductions in all fare categories. Student and college or vocational school fares experienced the greatest reductions: cash fares were reduced more than 70 percent and their respective pass prices were reduced more than 80 percent. In Table 1 the bus fares before and after Proposition A are presented.

TABLE 1 Bus Fares Before and After Proposition A

Type of Fare	Price ($) Before July 1	Price ($) After July 1
Cash		
Regular	0.85	0.50
Senior citizens and handicapped	0.40	0.20
Students (under 19)	0.65	0.20
College and vocational	0.85	0.20
Pass		
Regular	34.00	20.00
Senior citizen and handicapped	7.50	4.00
Student (under 19)	22.00	4.00
College and vocational	26.00	4.00

To prepare for the expected patronage increases due to reduced fares, the Board of Directors authorized the general manager to proceed with necessary personnel hiring, bus preparation, and additional data collection.

Actions by District Staff

The district developed internal guidelines for making service additions (1). In order to stay within the previously mentioned constraints of the master agreement and comply with its spirit and objectives, exceeding of the standards in any of the following five respects was deemed sufficient justification to recommend additional service:

1. A 140 percent loading standard exceeded on four consecutive trips each day,
2. Pass-ups caused by crowding reported at the same location or along the same route segment for at least three consecutive days (or on weekends) (pass-ups cannot be eliminated by schedule adjustment),
3. An average maximum load (AML) for the 3-hr peak period of more than 55 passengers (the maximum load is the highest load occurring on a single trip and is generally a little higher than the load measured at the peak point),
4. A 100 percent loading standard exceeded for local services during the off-peak period and on Saturdays and Sundays (three consecutive trips must exceed the standard each day), and
5. A 100 percent loading standard exceeded on express lines for three consecutive trips each day.

Although these guidelines did not state what level of crowding was acceptable, they were intended to identify and alleviate the most overcrowded services.

The district's preparatory activities were coordinated by the Interdepartmental Proposition A Implementation Task Force, which had representation from each of the affected departments. The district obtained additional bus operators, as customary, by converting part-time drivers to full-time status and by hiring additional part-timers. By performing a costly overhaul and upgrading of the retired fleet, the district obtained the necessary additional equipment. All SCRTD departments made expeditious preparations for the implementation of the fare-reduction program based on an expected surge in ridership.

MONITORING OVERCROWDED CONDITIONS

The district's major concern regarding the reduced-fare program was that the initial patronage increase might be very large and might more than fill available capacity on many lines. Some excess capacity existed before July 1 due to steady patronage declines during FY 1982. However, it was believed that capacity would quickly be exhausted on many lines. Accurately predicting the size and location of the expected patronage overloads was not possible, especially because the fare decrease was so significant. The primary goal of the district in responding to this uncertainty was to make plans that would allow overloading problems to be quickly identified and corrected, thus avoiding prolonged hardship to patrons.

Initially, the most severe crowding problems were expected to occur during the peak periods when capacity was least. Bus line patronage is not generally tracked at the peak period independently. Therefore, to track peak patronage growth and assess remaining capacity, a system was developed to follow 72 bus lines. These 72 lines included 80 percent of the service and represented a spectrum of service types. To track peak-period patronage on these lines, peak-period data from before the reduced-fare program were gathered, creating a base line. A method was established to estimate total peak-period ridership on a line from the number of passengers on board at the peak stop. Past experience has shown that the ratio of total passengers to passengers on board at the peak stop is not affected by a change in ridership level. This ratio is especially stable when the time period under consideration has a consistent pattern of ridership, such as the a.m. or p.m. peak period. The base-line data for each of the 72 lines determined the ratio. SCRTD then collected subsequent patronage data at a line's peak stop and estimated the total ridership for the period using the ratio. This estimation method allowed a savings in manpower and made it possible to monitor the 72 lines more frequently after the July 1 fare reduction.

Patronage data on individual lines can vary as much as 10 percent on a typical day, but summing the peak-period patronage for the 72 lines gave a more reliable estimate of the growth in peak-period ridership. In addition, the individual line estimates were used to determine possible overloading problems as defined in the internal guidelines discussed previously. Where overloading was indicated, the line would be rechecked to assess the regularity of the occurrence.

By early planning, SCRTD hoped to identify and address the worst overcrowding problems promptly.

TABLE 2 Average Daily Boardings Since July 1, 1982

Date	Weekday			Saturday			Sunday		
	Avg Daily Last Boardings (000s)	Percent Change Last Month	Percent Change Daily per Year	Avg Last Boardings (000s)	Percent Change Daily per Month	Percent Change Last Year	Avg Last Boardings (000s)	Percent Change Month	Percent Change Year
1982									
July	1,116	3.5	–4.7	673	1.8	–3.7	475	9.3	–2.0
August	1,220	9.3	4.8	736	9.5	8.9	576	21.2	21.1
September	1,256	3.0	3.8	718	–2.6	5.5	538	–6.6	18.5
October	1,374	9.4	12.5	700	–2.5	1.8	544	1.2	22.5
November	1,360	–1.1	13.2	706	0.9	6.1	498	–8.5	13.7
December	1,351	–0.7	17.8	724	2.6	9.3	503	1.0	12.0
1983									
January	1,391	3.0	23.8	667	–8.0	9.0	493	–2.1	16.0
February	1,402	0.8	24.9	702	5.3	0.2	495	0.5	7.0
March	1,422	1.5	25.5	739	5.3	1.4	521	5.3	22.3
April	1,442	1.4	30.2	756	2.3	16.9	525	0.8	23.7
May	1,471	2.0	33.4	773	2.2	19.9	536	2.1	27.7
June	1,476	0.3	36.9	755	–2.3	14.2	587	9.5	35

Because of the size and diversity of the SCRTD bus system, not all capacity problems could be anticipated. For these, SCRTD relied on complaints. Complaints came from several sources, including the public, bus operators, dispatchers, and road supervisors. All complaints were evaluated, usually by point check, and then service was augmented if necessary. In September when school resumed and student patronage surged, the use of complaints to detect crowding was necessary.

FIRST-YEAR IMPACTS OF THE REDUCED-FARE PROGRAM

Patronage Growth

In the initial 2 months of the fare-reduction program there was a 12 percent surge in average weekday patronage. However, few demand capacity problems were experienced. Spare capacity existed in the system as a result of steady patronage losses over the previous two fiscal years, so initial increases could be absorbed.

Checks of ridership in the initial weeks suggested that the majority of the patronage increase was taking place during the midday period and on weekends; the smallest increase was in activity oriented to the central business district (CBD) during the peak periods. This explained how a 0.7 percent increase in service level was able to accommodate a 12 percent growth in patronage during the first 2 months of the program.

Table 2 shows average daily boardings for the calendar months from July 1982, the start of the reduced-fare program, through June 1983. As can be seen, the weekday boardings have steadily increased each month except for the November and December seasonal patronage loss, which nevertheless represented a ridership level more than 13 percent higher than that of the 1981 holiday season. Saturday and Sunday ridership levels, though more erratic month to month, have also experienced an overall gain since July. Weekend patronage levels have been consistently higher than those of the previous year, displaying larger increases on Sundays than on Saturdays.

Figure 1 gives the quarterly growth in patronage on weekdays, Saturdays, and Sundays for FY 1983. During this period, two pronounced increases in patronage occurred. One happened in July with the advent of reduced fares and one in September concurrent with the opening of the schools. The latter is a seasonal shift that was significantly inflated by the lower student fare. As is evident, patronage continued steady growth through FY 1983. Original predictions, drawn from past experiences with fare reductions, had stated that system patronage would probably level off during the second quarter (October to December 1982). This pattern of continuing growth was unexpected.

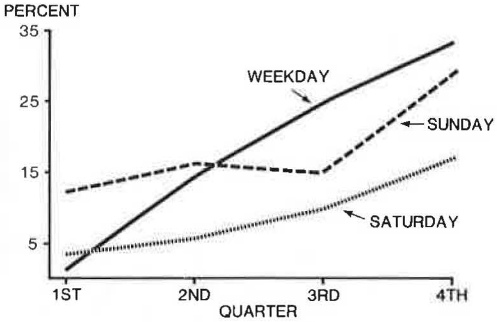

FIGURE 1 Change in daily patronage, FY 1983.

Service Hours and Equipment

As the patronage increase strained the capacity of many lines, service was augmented. In Table 3 the annualized system revenue vehicle hours in effect for six representative months from April 1982 to April 1983 are reported. The drop in service hours that occurs between April and June 1982 reflects the

TABLE 3 Change in Revenue Vehicle Hours

Date	Annualized Revenue Hours[a]	Percent Change
1982		
April	6,650,353	–
June	6,599,144	–0.77
September	6,673,098	+1.12
December	6,767,312	+1.41
1983		
January	6,860,569	+1.38
February	6,874,360	+0.20
April	6,928,705	+0.79

[a] For months coinciding with significant changes in the bus system.

seasonal service decrease caused by the recessing of school. Revenue vehicle service hours increased again in September and continued steady growth thereafter. The district made a concerted effort during this period to abide by the master agreement when service was augmented. As a result, although patronage increased more than 27 percent by February 1983, revenue service hours had increased only 2.7 percent. However, as FY 1983 approached its end, the annualized revenue service hours being operated by the district had surpassed, by an estimated 60,000 to 80,000 hr, the 6,883,000-hr cap agreed on in the MOU.

Another aspect of increasing service is the additional bus requirements. Figures 2, 3, and 4 show the number of additional buses added per month

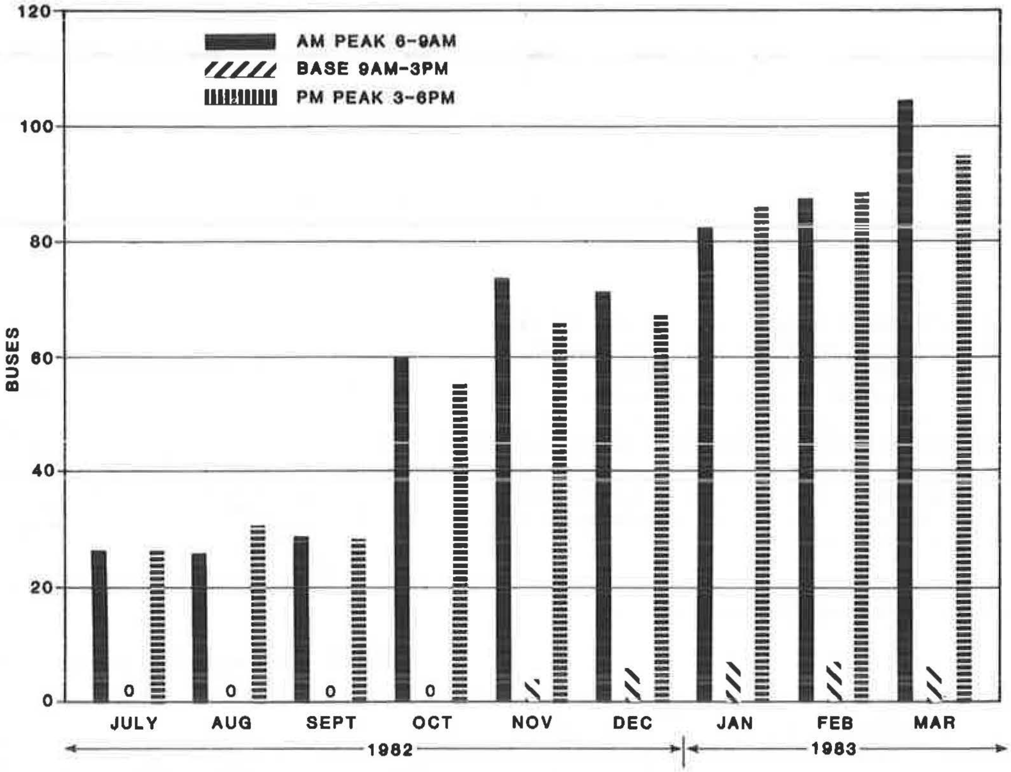

FIGURE 2 Cumulative monthly bus additions for weekdays.

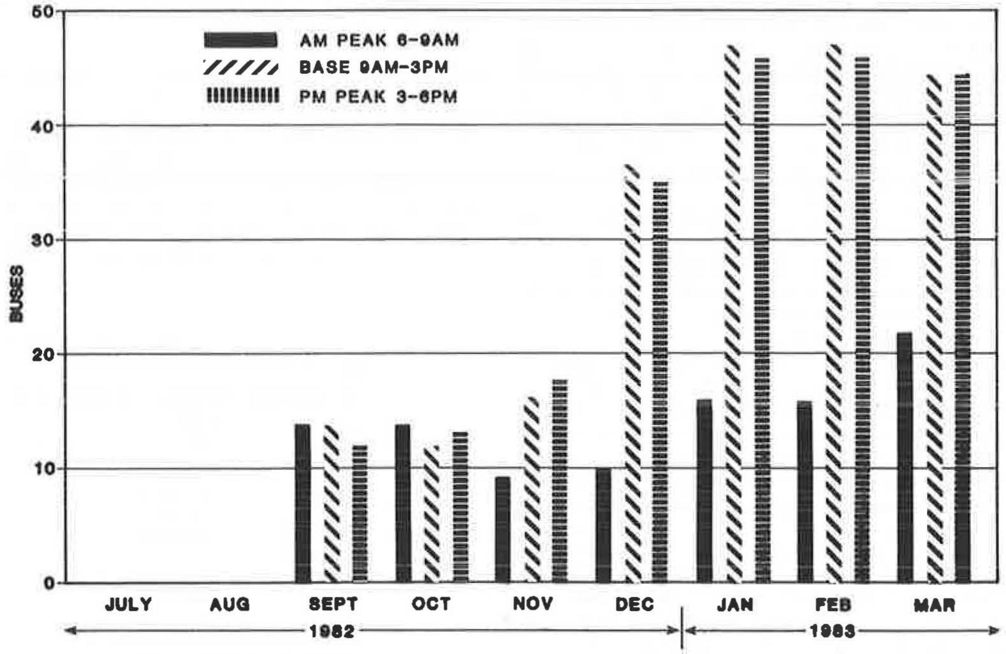

FIGURE 3 Cumulative monthly bus additions for Saturdays.

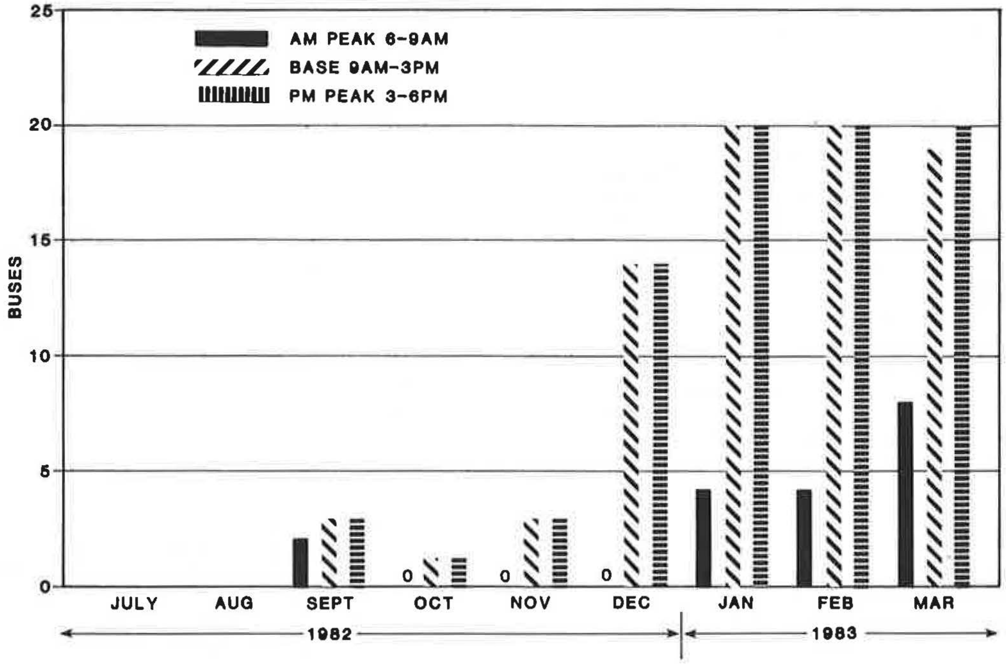

FIGURE 4 Cumulative monthly bus additions for Sundays.

from July 1982 to March 1983. As can be seen in Figure 2, weekday bus additions hovered around 30 buses from July through September and then rose sharply to around 60 buses in October. Weekday equipment requirements increased in the a.m. and p.m. peak periods, whereas weekends required additional equipment during the midday and p.m. peak periods. Since October, bus patronage has continued a less dramatic but steady rise, and bus additions have grown consistent with this demand.

Pass Sales

Pass sales have escalated in volume as expected; however, the various categories of bus passes exhibited dissimilar patterns of growth. Figure 5 shows growth in sales by type of pass purchased. Although pass sales for all types are higher since the bus fares were reduced, the student and college and vocational pass categories demonstrated the most dramatic rise; student pass sales escalated to surpass both those of senior citizen and regular passes. The disproportionate growth in student pass sales is attributable to the 80 percent reduction in the student pass price on July 1 versus a 41 percent reduction in the regular pass price. For this reason, some Los Angeles County school systems are considering cutting costs by reducing or terminating their school bus contracts with private carriers and purchasing student passes from SCRTD (1). Even with

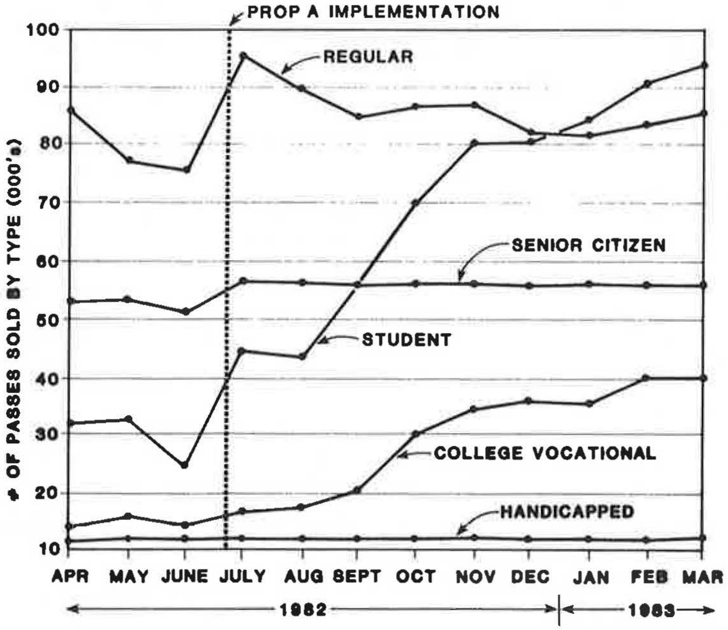

FIGURE 5 Pass sales by type per month.

staggered school hours and efficient scheduling, providing school bus service exerts a heavy load on the district, because students travel in patterns requiring extra bus assignments and excessive nonrevenue miles.

When average pass use per day by type of pass is examined, another result of the reduced fares can readily be seen. In Table 4 bus pass sales are compared with the average pass use per day by type of pass for the months of February 1982 and February 1983. It is interesting to note that actual sales of regular passes rose 2 percent and their average use increased 5 percent from February 1982 to February 1983, whereas the percentage of average daily boardings by regular pass fell 2.8 percent. Concurrently, the sale of student passes rose 162 percent and their average pass use fell 21 percent, whereas the percentage of average daily boardings by student pass gained 6.3 percent. Student pass sales surpassed the sale of regular passes for the first time in SCRTD history in January 1983.

TABLE 4 Comparison of Pass Sales and Average Pass Use per Day by Pass Type

	February 1982		February 1983		Percent Change	
Pass Type	No. Sold	Avg Pass Use per Day	No. Sold	Avg Pass Use per Day	No. Sold	Avg Pass Use per Day
Regular	82,198	3.49	83,766	3.65	+2	+5
Senior citizen and handicapped	64,084	2.23	67,351	2.52	+5	+13
College and vocational	14,237	2.82	40,373	2.56	184	-9
Student	34,781	2.98	91,296	2.36	162	-21

Operating Productivity

The district makes an ongoing effort to maintain and increase the productivity of its bus operations. Productive bus operations are marked by good utilization of bus capacity and a high proportion of operating time spent in revenue service. In the case of SCRTD, the need to offer service to a wide service area such as Los Angeles County limits the efficiency that can be obtained. However, the rise in patronage caused by the lower fares has favorably affected productivity by increasing bus utilization in the midday period when excess capacity is available on most lines.

Bus service productivity is measured by a variety of indicators. Some common measures are passengers carried per hour or per mile of service, nonrevenue bus hours as a percentage of total bus hours, and rate of return from passenger fares (farebox operating ratio). Table 5 shows these performance measures for intervals from April 1982 through April 1983. All productivity measures in Table 5 experienced improvement concurrent with the patronage growth except, as expected, the last one, farebox recovery.

Some of the added efficiency demonstrated in Table 5 occurred due to the increases in off-peak patronage. The remainder resulted from productive scheduling measures that contained peak vehicle requirements in spite of the significant patronage increase. Between June and December 1982, a 21 percent increase in total monthly boardings occurred. Approximately 15 percent of this increase occurred during the peak periods, supplemented by a 3.5 percent increase in peak buses.

The rate of growth of the district's operating costs declined between FYs 1982 and 1983. Farebox revenue fell dramatically in July, and, interestingly enough, it has maintained a fairly uniform level since then, in spite of the continuing growth in patronage. The even farebox revenue levels combined with significant patronage growth during the weekday base and weekend time periods tend to indicate a notable increase in discretionary bus travel and not solely the attraction of new patrons. Pass sales data would indicate that regular pass buyers are making these discretionary trips. However, the true proportion of discretionary trips contained in the increase is as yet unsubstantiated.

TABLE 5 Operating Productivity Measures

Date	Passengers per Revenue Hour	Passengers per Revenue Mile	Nonrevenue Hours per Total Hours (%)	Farebox Operating Ratio (%)
1982				
April	53.0	4.0	7.39	42
June[a]	52.1	3.9	6.75	38
		Fare Reduction		
September	59.9	4.5	6.92	24
December	63.4	4.7	6.91	23
1983				
January	65.1	4.8	6.60	23
February	66.0	4.9	6.67	24
April	66.1	4.9	6.45	24

Note: Performance measures are for months coinciding with significant changes in the bus system.

[a] School recess.

CONCLUSION

Perceiving the need to improve their public transportation, the voters of Los Angeles County mandated development of rail and light rail transit systems by approving the Transit Development Program referendum in 1980. The sales tax referendum also called for reduced bus fares during the first 3 years and compensated the affected bus companies by providing a subsidy derived from the sales tax. This local funding allowed the district to avoid major service cutbacks that had been planned to begin in July 1983. The Transportation Development Program was a real boon to the district, because it demonstrated local support for a rail system and obviated the need to cut bus service in FY 1983.

However, the reduced bus fare imposed by the program severely underpriced the cost of a bus ride for all riders. The extremely low cost of the student pass has led to tremendous growth in student patronage. The resultant need to add service for this relatively low revenue-producing segment of the transit market has been especially costly for the district in terms of bus requirements, high nonrevenue service hours, and lowered operating ratio. In addition, the district's patrons who have been misled by the low subsidized fares will be distressed when the mandated subsidy ends in July 1985 and fares return to a more reasonable level.

Patronage levels had been expected to stabilize within the first 6 months of the reduced-fare program. However, this has not occurred, and patronage is continuing to rise. The district is working with LACTC to restrain the growth of service hours as much as possible, because the district could potentially exceed the maximum hours agreed on for FY 1984 (1). It is necessary to contain the service hours of the bus system at this time, because in FY 1985 the guaranteed subsidy for bus transit will end. Unguarded growth now would assure major service withdrawals in 1985 and the loss of the goodwill of district patrons.

ACKNOWLEDGMENT

Special thanks to Don Dravis for preparing the manuscript and to Susan Chapman for composing the charts.

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Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Using the 1980 Census to Evaluate the Equity of Transit Service in Northern New Jersey

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ABSTRACT

A computer-based method is developed to evaluate the compliance of New Jersey Transit with Title VI of the 1964 Civil Rights Act regarding a fair and adequate distribution of transit service to all persons. The method involves a combining of transit-service and census data so minority areas and the level of service to these areas can be identified. One county (Union County) was selected as a test case to examine the four main problems encountered. The first involved geographical matching of transit routes and census tracts. Second, transit service had to be measured and apportioned to the tracts. Third, minority classifications were defined and assigned to the tracts. Finally, a means was necessary to present the results in an easily interpreted format.

At the request of New Jersey Transit (NJ Transit), the newly formed state organization responsible for owning and operating most of the public transportation services in New Jersey, a procedure was developed at Princeton University for evaluating the equity of transit service to the various minority groups residing in northern New Jersey's urbanized areas. This was prompted by NJ Transit's need to report to UMTA the compliance or noncompliance with Title VI of the 1964 Civil Rights Act regarding a fair and adequate distribution of federally assisted transit service among all persons.

The two main data requirements for this study were the transit operations and the census information. The route locations and frequencies for approximately 150 bus routes, 9 commuter rail lines, and 1 subway (Newark) were provided by NJ Transit. Also provided were similar data for privately owned, state-subsidized bus services. The census data concerning the various minority groups were obtained from the 1980 census at the tract level. The study region in northern New Jersey contained 1,280 tracts in the following 10 counties: Bergen, Essex, Hudson, Middlesex, Monmouth, Morris, Ocean, Passaic, Sommerset, and Union (see Figure 1).

Union County was used as a test case to focus on the four main problems that had to be resolved in order to permit a rational, rapid, and objective display of the facts. The first problem concerned the geographical matching of transit routes and census tracts. Second, transit service had to be measured and apportioned to each tract. The third problem involved defining the minority classifications and assigning those properties to the tracts. Finally, a method was needed to present the results so that all pertinent information could be displayed for easy interpretation and assessment by UMTA's evaluators.

GEOGRAPHIC MATCHING OF ROUTES AND TRACTS

The transit routes were provided by NJ Transit as a series of bold lines traced over streets on Hagstrom maps. A digitizer was used to code these routes for computer storage as a series of line plots with X-Y coordinates. [Digitizing routes involves tracing the route on a sensitive table with a special pen that automatically records the location of a point (node) when it is depressed.] From the X-Y coordinates of the nodes, routes were pieced together as a series, or chain, of links (see Figure 2).

The tract boundaries were available in a digitized form from the Princeton University Computer Center. This file, as with the route file, consisted of a set of X-Y coordinates, but these coordinates were in latitude and longitude (Figure 3). Therefore, a method to combine the two data sets into a

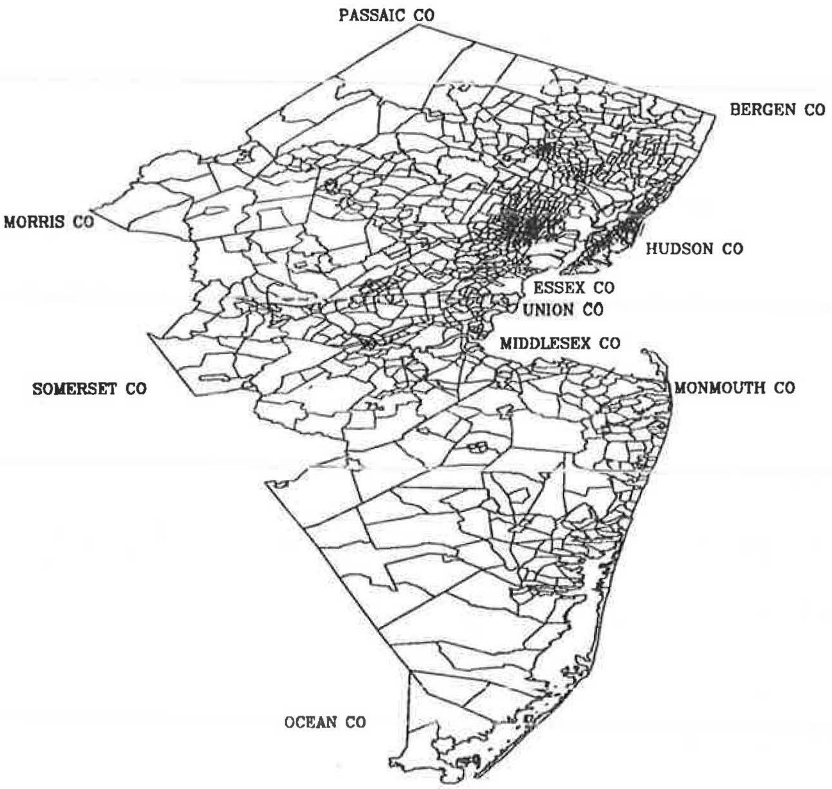

FIGURE 1 Study region: 1980 census tracts, northern New Jersey.

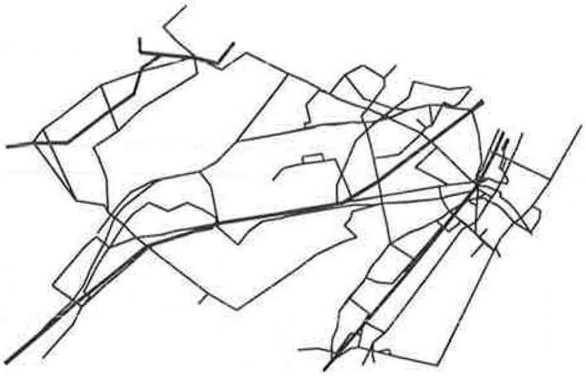

FIGURE 2 Union County transit routes.

common, geographically accurate set of coordinates was required (i.e., the two maps had to be fitted to the same scale and orientation).

The problem at first appeared to involve a simple rotation and translation of one data set to fit the other. So the first attempt was to transform the tract data and produce a transparent map to overlay on the Hagstrom. From these two maps, the routes were defined by digitizing the points of intersection between the route and tract boundaries as the routes traversed the tract map (see Figure 4).

This immediately led to two problems. First, routes often follow tract boundaries (because many boundaries are main roads), which creates difficulties assigning routes to a tract. The second and more serious problem occurs when random errors are introduced into the digitizing and transformation processes, which results in an assignment to the wrong tract of a route that is on or close to a border.

The only way to ensure that a route follows a boundary exactly is to assign the route nodes and boundary points the same X-Y coordinate. This is an extremely slow process and could not have been completed by the project deadline. Therefore it was decided to adopt a process developed by Walter G. Anderson of the Princeton University Interactive Computer Graphics Laboratory (ICGL) in which a band or service region is constructed around the route. This process--called the ribbon approach--is discussed in the next section.

One last improvement that permitted faster input of the routes was to digitize them without regard to tract boundaries. Because both the route and tract coordinate files are stored, it appeared logical and faster to let the computer calculate the points of intersection between the routes and the tracts.

ASSIGNING SERVICE TO TRACTS

Once the routes were stored in the computer as a set of points located within the census-tract map, the two data sets (demographic and transit service) had to be related for each route in each tract. The goal was to obtain a measure of service that was simple and meaningful.

The simplest relationship between the tracts and the routes was the distance each route extended through any given tract. This was easy to calculate but presented some modeling problems. Bus routes tend to fall along tract boundaries, but because of the random errors incurred in digitizing the points, the computer assigned everything to one tract or another. Obviously, a route running close to a boundary is actually serving the neighboring tract as well as the tract through which it travels. The

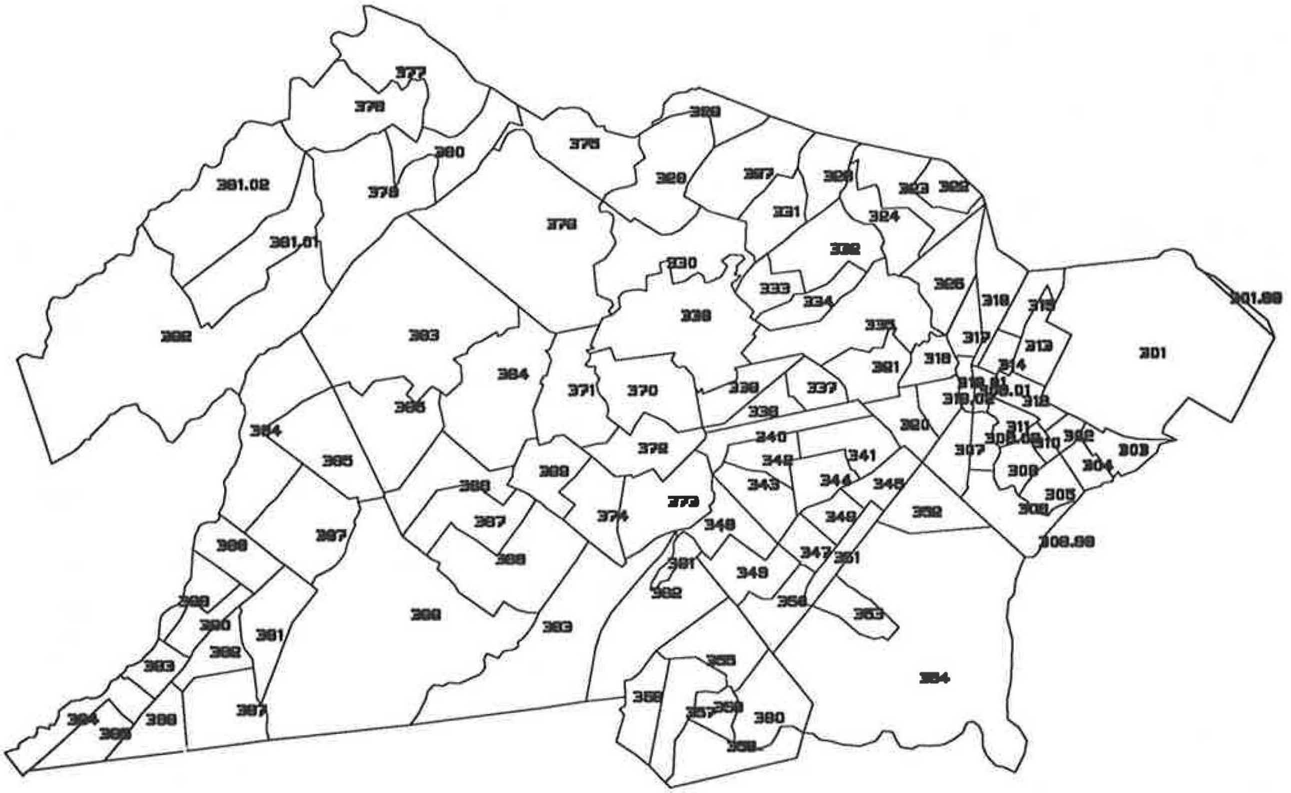

FIGURE 3 Union County 1980 census tracts.

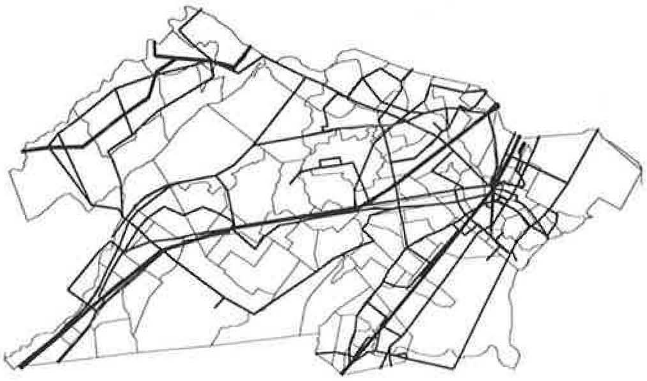

FIGURE 4 Union County tracts and routes.

route-miles measure did not make allowances for this situation. Another failure of this system was that differences in types of bus and rail service could not be considered in a realistic day. In order to distinguish between a local and an interstate bus, one would probably use a regression coefficient reflecting the probability that a person will board an interstate or intrastate bus. To find this coefficient would entail much time and data manipulation and the result would not be a clear or understandable representation of the measure of service.

After consideration of several other methods, the final decision was to pursue what is now referred to as the ribbon approach. The procedure is straightforward and logical in its methodology.

The theory centered around those boarding public transit. The person most likely to board a particular bus is someone standing in a location where the cost of the walk to the route is less than the value of the net benefit to be gained from the service at the end of that walk. A method was developed where it was possible to construct a ribbon of any width around a chain of links (a bus route) (Figure 5). This enabled a decision about what actually constitutes service to be made in a realistic and meaningful way. The final choice, made in consultation with NJ Transit, was to allow a 0.25-mile distance or service area on either side of the local bus routes and a 0.50-mile service area on either side of the interstate routes. Railroad stations were given circular service areas of a 0.50-mile radius because the stations are the only points where passengers can

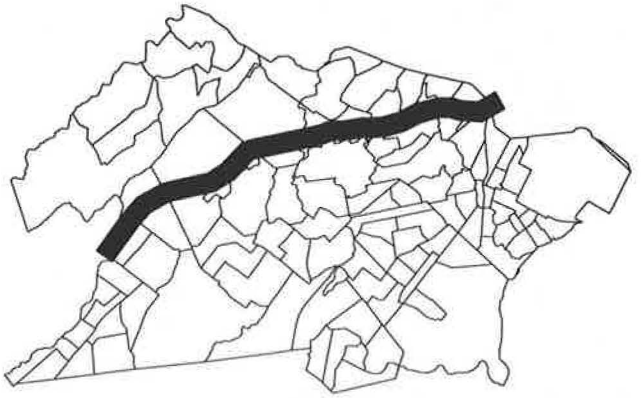

FIGURE 5 One-fourth-mile service ribbon: NJ Transit bus route 150.

board. These distances represent reasonable walking distances for their respective services.

The second step was to measure actual service to the tracts. The region lying in a route's service area (i.e., the route ribbon or station circle) was found and apportioned to each tract. The area computations were accomplished by drawing straight parallel lines close together inside the ribbon or circle (Figure 6). The area inside any tract is found by computing the length of each line in that tract and multiplying the total by a constant for the line spacing.

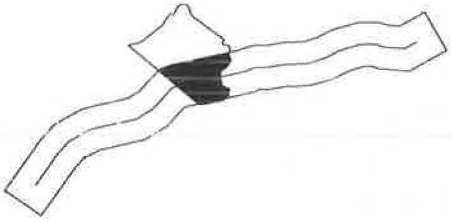

FIGURE 6 Intersection between Union County Census Tract 378 and 0.50-mile service area around NJ Transit bus route 150.

The shaded or ribbon area for each route in each tract is then divided by the total area of that tract, giving a percentage of the area in any particular tract served by a given route. This is shown as follows:

$$\text{Percentage of } \mathrm{TRACT}_i \text{ served by } \mathrm{ROUTE}_j = \mathrm{RIBBON\ AREA}_i^j/\mathrm{TOTAL\ AREA}_i.$$

Each of these percentages was then multiplied by Q_i^j, which was the frequency of ROUTE through TRACT on a typical workday. For the train stations, Q_i^j was the number of scheduled trains at each individual station. This allows the frequency to be set to zero for closed-door bus service to some tracts and to remain at its normal value through tracts that are fully served. The percentage of area served represents the probability that a bus route will be available to a person in TRACT_i, and the frequency represents the number of buses in a typical day. This service level is for each individual route for each tract; therefore, total service to a tract is the sum over all the routes for that tract.

This measure of service is in reality a measure of service to the geographical section of land represented by the tract. Thus it represents the service an individual in that tract will encounter. The numbers are compared with the census data by (a) assuming uniform distribution of the population within a tract and (b) comparing the service level with a measure of the probability that a certain person standing in TRACT_i will be of a particular background (e.g., the probability that the person standing in TRACT_i is black equals the percentage of the population of TRACT_i that is black).

There are many advantages to using the ribbon approach for calculating service to an area, the most important of which is the simple reasoning behind the weighting of the service. However, it also allows flexibility in setting frequencies, changing the width of the ribbon of service, and relating the service measures to different segments of the population data base.

BLOCKING TRACTS BY MINORITY CLASSIFICATIONS

Once the level of transit service has been determined for each tract, it becomes important to find the classifications and number of minorities who are receiving the service. The selection of the minority groups included in the study came after consultation with NJ Transit and UMTA representatives. Minority data were obtained from the 1980 census Summary Tape File 3A (1). It was decided by NJ Transit, UMTA, and Princeton that the following seven minority classifications were appropriate for the purposes of this study (the census files from which the data were extracted are given in parentheses): carless households (97, 123), black (12), elderly (65 and over) (54), income level (family) (73), minority (total) (12, 14), Spanish (12, 14), and transit handicapped (54).

Each tract was assigned a percentage of the minority for six of the seven categories, the exception being income, which was assigned as the median level for the tract. It was necessary to determine regional means and medians from county-level data because small values are often suppressed at the tract level. The tracts were grouped by different shadings to permit viewing of high minority concentrations in the region or county. The gradations for the shadings were selected with reference to the magnitude of the regional mean (see Figures 7 and 8).

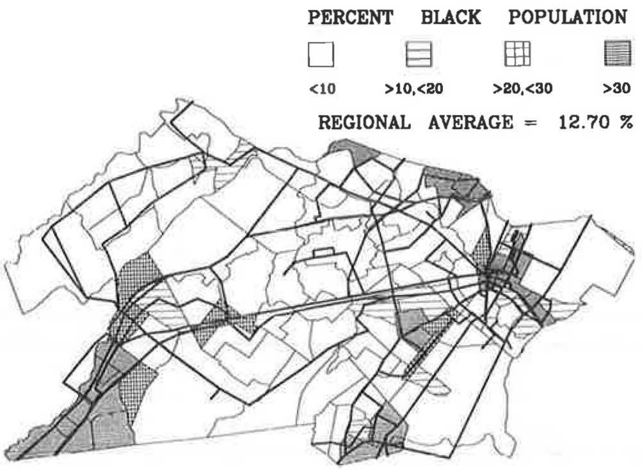

FIGURE 7 Percentage of black population.

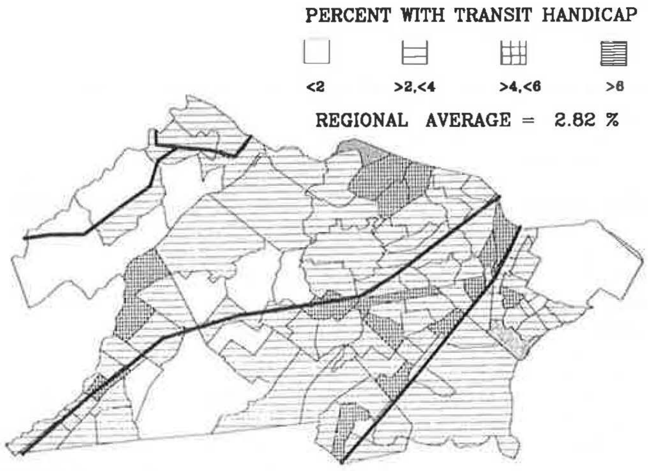

FIGURE 8 Percentage with transit handicap (shaded tracts).

Means provide a good measure unless the data contain "wild shots" (extreme values). It was therefore decided to use medians also, which give a more robust measurement. To do this, all tract values were ranked and a regional median and two hinges (i.e., quartiles) were established. These quartiles, taken from regionwide values, permitted comparison of minority concentrations not only within one county but also between counties (see Figure 9). This method proved to be misleading because of areas of high minority concentration. For example, the regional median for blacks is 1.9 percent (65 blacks per tract) compared with a mean of 12.7 percent (the difference being attributed to several areas with more than 90 percent black population). Therefore, Figure 9 identifies tracts with 2 percent black population as above the median and thus high-minority areas.

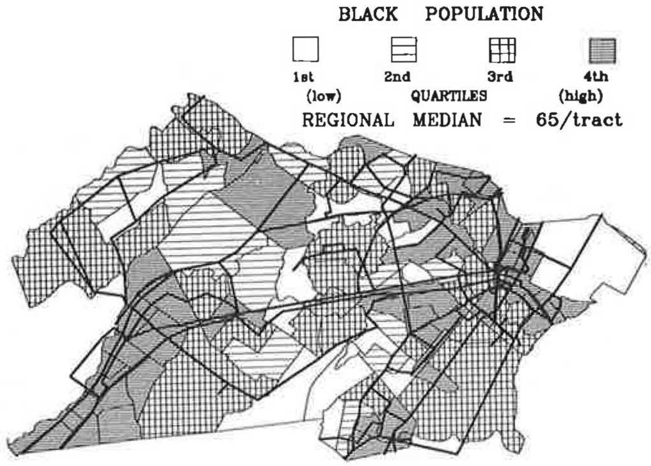

FIGURE 9 Black population (quartiles).

By multiplying the percentage of tract area by the frequency served (as described in the previous section), a measure of amount of service to that tract is obtained. Summing over all tracts provides totals for minor civil division or county. The major assumption made in these calculations is that each tract is homogeneous and of uniform density, which means that variations in population densities within tracts are not considered. However, it provides a reasonable approximation.

EFFECTIVE PRESENTATION OF RESULTS

Once the service levels were calculated and the minority groups identified, it was necessary to provide clear and concise representations of the combined data. Several different formats that allowed simultaneous scanning of both transit service and demographic data for a county or the entire region were tried. These formats centered around combinations of shadings, skyscraper plots, and variable bandwidths.

The two plots most appropriate for displaying census data were shaded tracts and skyscrapers. The tracts were shaded based on even gradations using means as reported in the previous section (see Figure 7). The skyscraper plots are vertical bars drawn at tract centroids proportional in height to the data item being displayed (see Figure 10). The advantage of the skyscrapers over shading is that shading implies sharp differences between tracts when in some cases they may only be 1 or 2 percent apart. The skyscraper or bar plots reflect the actual percentage for each tract.

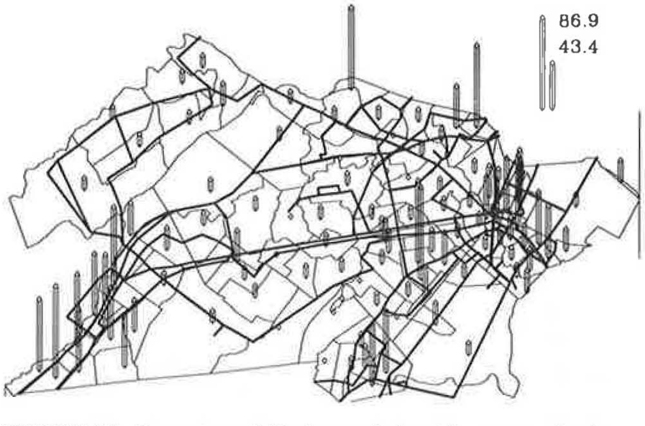

FIGURE 10 Percentage of black population (skyscraper plots).

In attempting to display transit service, both frequency and coverage have to be considered for each tract. Frequency can be shown as bandwidths where the thickness is proportional to the number of buses traveling on that link (see Figure 11). Coverage can be easily visualized by shading the service regions (ribbons) around each route and noting the unserved (unshaded) areas (Figure 12). By multiplying frequency by percentage of tract served, a number reflecting service within a tract can be

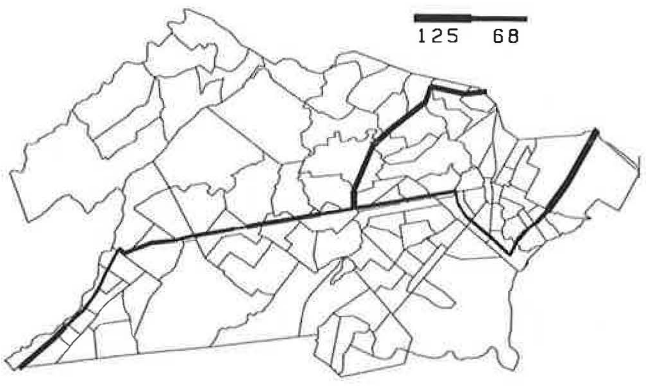

FIGURE 11 Transit frequency in buses per day.

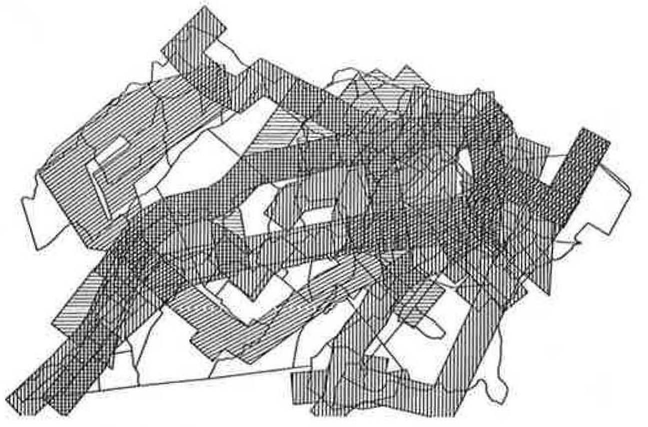

FIGURE 12 Transit coverage.

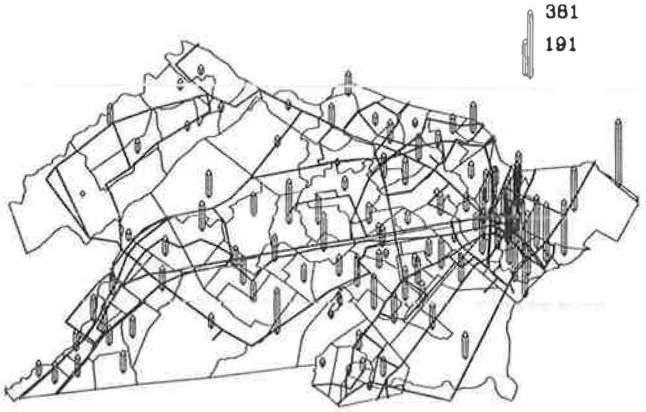

FIGURE 13 Bus service in Union County.

obtained and displayed using skyscrapers (Figure 13). This value represents the number of times per day the average tract resident can board a bus or a train.

The relationship between the census data and the level-of-service measure is the key step in attempting to define the equity of service. In Figure 14 the values for percentage of minority and local bus service are given to provide a clear, graphical representation of transit service to minorities in Union County. A similar diagram is presented in Figure 15 for carless households and rail service.

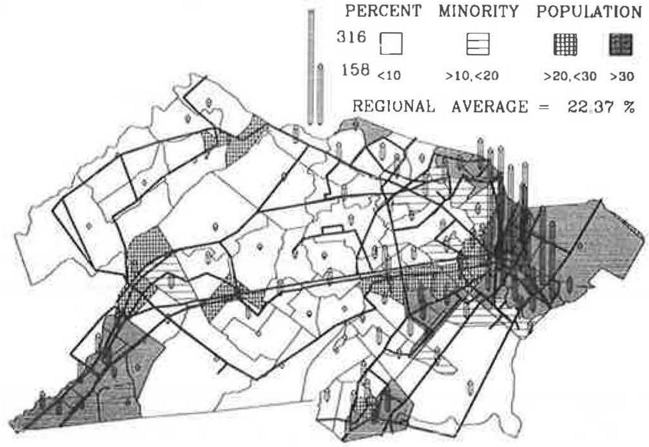

FIGURE 14 Bus service and minority population.

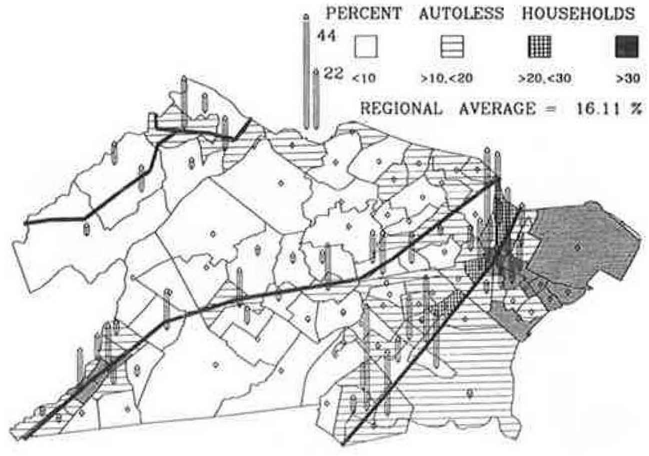

FIGURE 15 Rail service and carless households.

CONCLUSION

This research was undertaken by Princeton University with the intent of exploring quick and economical methods for relating census data and transit service. The application of this comparison, as presented in this paper, was to provide a measure of the equity of service to minority groups for reporting Title VI requirements. A series of criteria and measures were selected that presented the information in a realistic and beneficial manner.

It became obvious during the course of this project, however, that many of the techniques used could be expanded into other areas of transit planning and analysis. In determining equity of service, it was also possible to identify unserved areas and compare intrastate and interstate bus and rail service levels. Expanding on this process can lead the planner to methods for determining new transit needs in view of changing land use patterns or prediction of ridership potentials along proposed routes. Thus, it is believed by the authors that this method for assigning transit service based on demographic data is not restricted to the determination of equity of service but can be applied to a wide range of future research.

The question that remains for UMTA and others to answer is whether transit service (in this example in Union County) is equitable. If one measures the number of opportunities per day per capita to board a transit vehicle (the measure of service to each tract) and multiplies that by the number of persons in each minority group in each tract, a composite number can be generated for the county.

After this had been done, the following number of daily opportunities were found in Union County for minority, white, and total population for local and interstate bus service:

		Transit Service Frequency Per Capita	
Category	Total No. of Opportunities	Local	Interstate
Minority	127,818	68.2	43.5
White	376,276	46.3	34.7
Total	504,094	51.8	36.9

If populations in each tract are homogeneous and evenly distributed and if the availability of a bus (or train) over an average weekday is a fair measure of transit service, the conclusion drawn is that service is better (more frequent and closer) in those tracts with a higher percentage of minority population. But this is known because low-income households live more densely and have fewer cars. Therefore, this is where bus customers are more likely to be.

ACKNOWLEDGMENT

The authors would like to express their appreciation to the people who donated expertise and direction to this study. Walter G. Anderson of the Princeton University Interactive Computer Graphics Laboratory provided the algorithms for creating the ribbons, calculating the intersections, filling the tracts and service regions, and retrieving the census-tract coordinates, all of which were crucial elements in this study. Jeffrey Zupan and the staff at NJ Transit contributed key suggestions for service levels and formats along with timely delivery of data.

Also, Bernard P. Markowicz kept this study moving with insightful advice on some difficult problems. A polygon version of the 1980 Census Tract Boundary Coordinate File, leased by Geographic Data Technology, Inc., was made available through the Princeton University Computer Center courtesy Judith Rowe, Shirley Robbins, and Doug Mills, who also made available Summary Tape File 3A through the Princeton-Rutgers Census Data Project. Finally, Alain Kornhauser, director of the Princeton University Transportation Program, provided the overall direction of this effort.

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Publication of this paper sponsored by Committee on Public Transportation Planning and Development.

Abridgment

Design of a Nighttime Transit System for Salt Lake County, Utah

RAYMOND C. MILLER

ABSTRACT

Salt Lake County, Utah, has experienced tremendous population growth along with an increased demand for transit services since 1970. The Utah Transit Authority (UTA), a publicly funded organization, was conceived in 1970 and is responsible for providing public transportation to Salt Lake County. UTA has continuously modified services to accommodate the growth and changing travel patterns throughout its history. However, transit service after 7:00 p.m. had not been changed since its implementation more than 10 years ago. Analysis of the nighttime transit service in this region revealed that this service was not functioning effectively. Three conceptual systems were developed, and the system that best met the goals is described. The new system was implemented on November 22, 1982.

Currently, transit systems throughout the United States are undergoing serious financial problems (1). The transit company basically has two alternatives to balance the budget. One is to increase revenue by increasing either ridership or fares. The other is to decrease costs or service.

The Utah Transit Authority (UTA) operates approximately 27,000 revenue miles per weekday, 5.6 percent of which are operated after 7:00 p.m. Therefore, approximately 1,500 revenue miles of service make up the night system, which is defined as all trips departing from the central business district (CBD) after 7:00 p.m.

Historically, UTA's night service has been one of the least efficient in the system. The service terminated at 9:30 p.m., which is when the last trips departed from the CBD. The service was implemented during the early 1970s when the UTA system was originally conceived. Since that time, the region as well as the travel demands of the population have continued to grow.

The primary goal of this research was the development of a nighttime transit system that offers the public a better service. The first objective in accomplishing this goal was to accurately identify the characteristics of the existing service. The second objective was to determine regional characteristics such as activity centers, population densities, and trip origins and destinations. The third objective was to reduce operating costs and maintain or increase the existing ridership level. The fourth objective was to extend the hours of service.

The primary goal and set of objectives lead to the hypothesis that decreasing transit coverage during the evening and night period and extending the hours of service will improve the economic efficiency of transit service after 7:00 p.m.

OPERATING CHARACTERISTICS OF PRIOR SYSTEM

The night transit system was made up of 26 routes operating 134 one-way trips, most of which originated in downtown Salt Lake City. With the exception of one route that serviced Ogden from Salt Lake City, all of the routes operated within Salt Lake County. The service provided extensive coverage or accessibility, especially to the east side of Salt Lake Valley. The system was implemented in the early 1970s, at which time a large percentage of the population resided in the east portion of the valley. Since the early 1970s, a large amount of commercial and residential development has occurred in the southwest portion of the valley, yet little service existed within this area. Comparing the night system to the total transit service for Salt Lake County indicates the poor performance. For instance, system averages indicate that passengers per mile is 1.9, passengers per hour is 35.1, and passengers per trip is 21.7 (2). The night system averages were 0.93, 18.4, and 10.9, respectively.

In order to measure the efficiency of a route, the performance indicators of passengers per mile, passengers per trip, and passengers per hour were weighted equally. Using this method of analysis, an index was developed for the purpose of comparing the different routes of the night system. The method of equally weighting the categories was to divide the indicators of each route by the respective total and then add the three categories; the highest score indicated the most efficient route.

Efficiency index formula for route i = (passengers/hour for route i divided by the sum of passengers/hour for all routes) + (passengers/mile for route i divided by the sum of passengers/mile for all routes) + (passengers/trip for route i divided by the sum of all passengers/trip for all routes).

The night system cost approximately $800,000 per year to operate. The costs are made up of a number of components. In an effort to accurately determine the costs of the night system, it was theoretically separated from all other transit services (3).

The cost components of the night system include miles of operation, which includes revenue and nonrevenue miles, and hours of operation, which is the total time paid to bus operators.

The system operated a total of 105.48 bus driver hours. This component is separated from other costs because it is a significant portion of operating costs. Historically, operator wages account for a significant portion of total operating costs. The labor rate per hour for a bus operator is $9.28, which includes fringe benefits such as vacation time, sick leave, and insurance. On a daily basis, the bus operator labor costs $978.58.

The cost per mile less operator labor costs includes such elements as fuel, tires, maintenance labor and services, and repair parts. The average cost per mile is $0.9068. Total miles of operation per night was equal to 1,821.9, which includes 1,661.9 revenue miles and 160 nonrevenue miles. The total cost of operating the night system per day was $2,554.32.

Revenue, on the other hand, is calculated simply by multiplying the total average number of passengers per day by the average revenue per passenger. The average number of passengers per day was 1,473. This number is an average of the 12 latest calendar months.

The average revenue per passenger was determined to be $0.30. The base fare structure for service at this time of day is $0.40. However, discounts for pass users, senior citizens, children, the handicapped, and transfer users bring the average paid fare to $0.30. Therefore, the average farebox revenue per day amounted to $441.90.

Measuring the economic efficiency involves determining the percentage of the operating costs covered by farebox revenue. In the case of the prior night service, 16.5 percent of the costs were covered by revenue. This is much lower than the system average of 22 percent.

SYSTEM DEVELOPMENT

The major goals in the development of a new system were

- To reduce the operating costs,
- To improve economic efficiency ratio of revenue to cost,
- To serve major activity centers,
- To extend the hours of service, and
- To minimize the impact of current transit users.

Three alternative system designs were developed. The costs, vehicle requirements, advantages, and disadvantages of the alternative systems were then compared so that the most effective system could be selected internally by UTA staff members.

The alternative selected is made up of 13 routes. The hours of service are 7:00 to 11:30 p.m., including 100 one-way trips.

This system was designed to operate in major corridors to increase travel speed and eliminate the negative impact of bus operation on neighborhoods at a late hour. The route structure offers increased frequency instead of maximum coverage in an effort to improve the ridership of each route as well as system ridership.

The major advantages of this system are as follows:

1. Most major activity centers are accessible by transit,
2. Neighborhood impacts are reduced,
3. Routes run later in the evening than the current service provides,
4. Costs are decreased, and
5. There are minimal operator and vehicle requirements.

The major disadvantage is that there is less coverage than with the prior system.

Figure 1 shows the route structure of the new system, which is currently in operation. In the new system the miles of operation were reduced from 1,661 to 1,454. The hours of operation per day were reduced from 114 to 96.

A formula was developed to forecast ridership of the new system utilizing past average daily ridership as the data base. The logic behind this quick-estimation technique is to determine the change in ridership resulting from system design changes and the extension of the hours of service. The estimation of the impact due to the extended hours of service was obtained by taking a percentage of the total internal automobile travel for a metropolitan area the size of Salt Lake (4).

The formula is as follows and the estimated result has proved to be accurate:

$$\{[IVT_1 + W_1\ (PT)]/[IVT_2 + W_2\ (PT)]\} \cdot MF = \text{ridership change factor},$$

where

IVT_1 = in-vehicle travel time of old system;
IVT_2 = in-vehicle travel time of new system;
W_1 = access time under old system;
W_2 = access time under new system;
PT = an accepted factor of 2.5, which represents the human tendency to exaggerate time spent walking to and waiting at a bus stop; and
MF = the percentage of increase in internal urban travel due to the extended hours of service.

CONCLUSION

The first 5 months of operation of the new service proved to be quite successful. Total miles of opera-

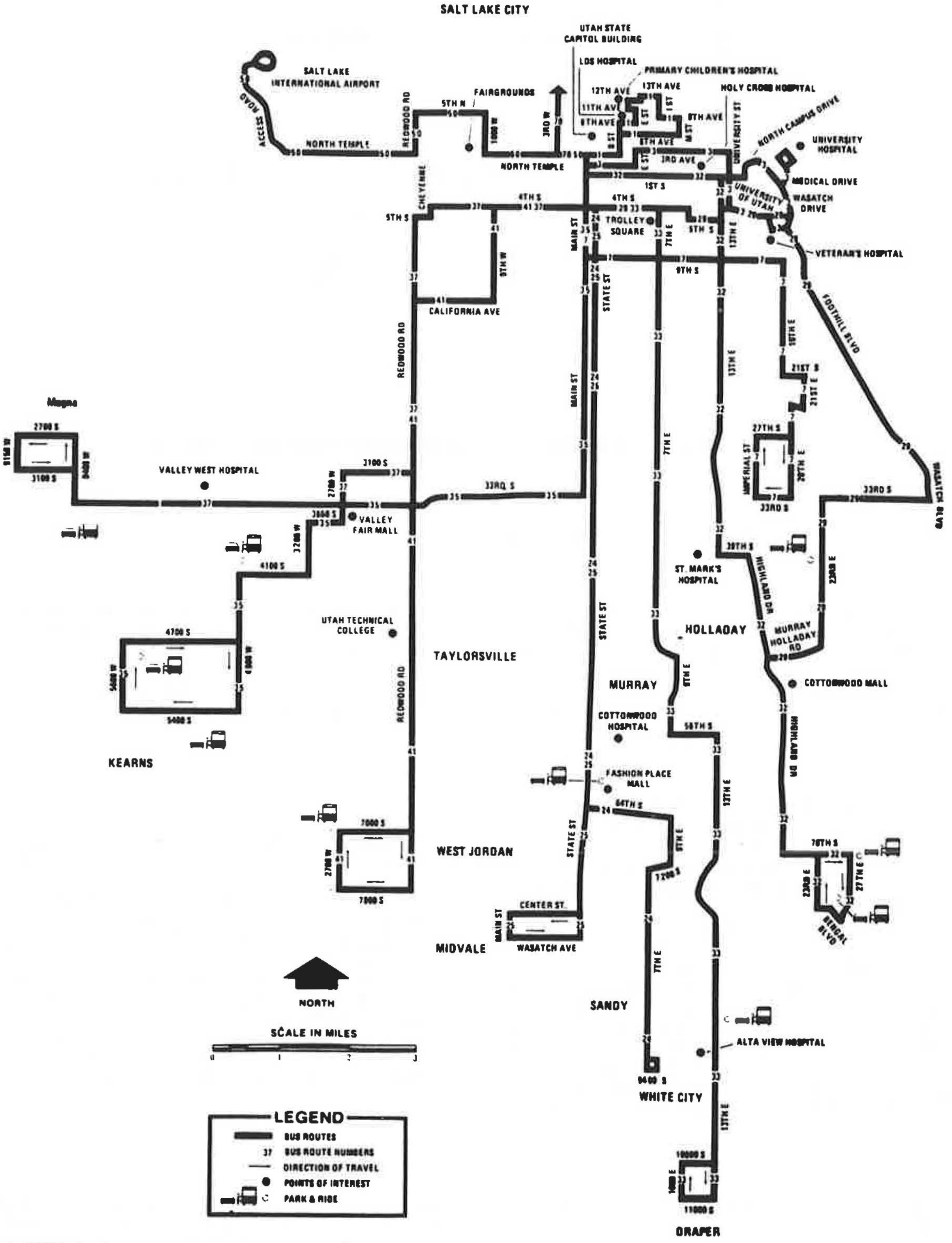

FIGURE 1 System route structure.

tion were reduced by 12.5 percent and hours of operation were reduced by 15.8 percent. The combination of increased ridership and decreased costs has led to a more efficient service.

The new service operates 100 trips per night, which includes 1,454.7 service miles. The ridership level per night has increased to 1,615, the highest level on record (Figure 2). The ratio of passengers per mile is currently 1.1 and is expected to remain at this level.

This research and the resulting service alterations have been based on the hypothesis that decreasing transit coverage during the evening and night period and extending the hours of service will improve the economic efficiency of transit services after 7:00 p.m. Comparing the economic efficiency of

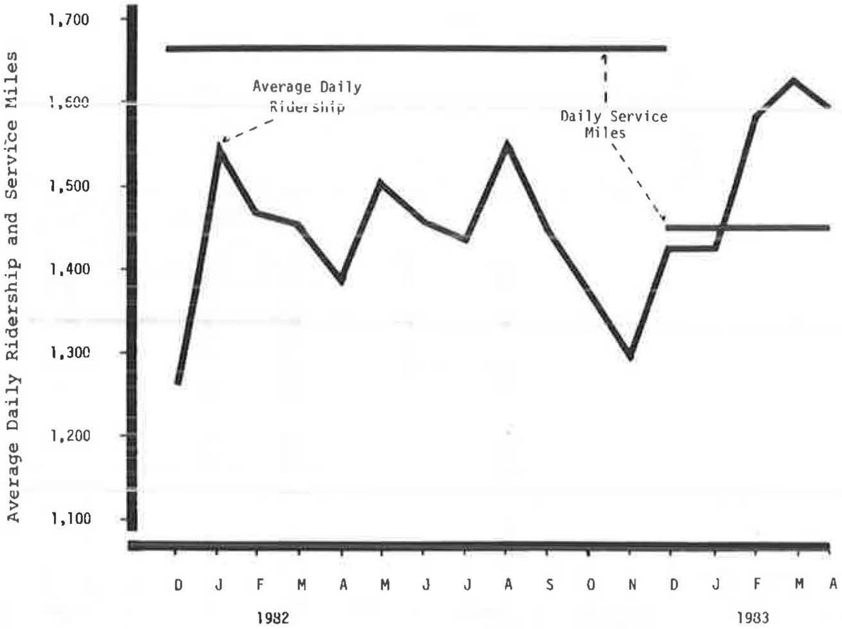

FIGURE 2 Nighttime service ridership history.

the past system with that of the new system for the same time period and the following formula, the revenue cost ratio improved from 16.5 to 20.6 percent:

$$\text{Economic efficiency measure} = (R/P) \times P/[M\ (C/M) + LR\ (H)],$$

where

R/P = average revenue per passenger,
P = average daily ridership for 5-month period,
M = total miles operated per day,
C/M = cost per mile (less operator wage),
LR = labor rate per hour (includes benefits), and
H = total hours of operation.

The community of Salt Lake County has been the biggest beneficiary of the recently implemented night service. The social benefits of later service have not been measured, but late workers can now get to and from work, residents can use the bus for late night social events and evening classes, and shoppers can use the bus later. The community has also benefited from the reduced cost of providing this service.

ACKNOWLEDGMENT

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The 1983 New Jersey Transit Rail Strike: A Systematic Emergency Response

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ABSTRACT

Many recent experiences with transportation system disruptions have affected the transit system distribution networks of urban core areas. The United Transportation Union strike of New Jersey Transit (NJ Transit) Rail Operations, Inc., during March 1983 represented a unique situation. In this case, a statewide public transportation system, geared for the provision of long-distance line-haul access to a large urban center, implemented an emergency contingency plan to provide an alternative to this line-haul service. NJ Transit's contingency planning and implementation processes are described. The processes and results are compared with those of other large public transportation systems that have recently experienced service disruptions. A number of conclusions are drawn based on NJ Transit's performance in responding to the strike and the comparison with experiences of other transit agencies. The findings illustrate the importance of (a) predicting the necessity of having a plan and having the lead time to develop one and (b) establishing and maintaining close working relationships with other agencies whose cooperation is vital to successful plan implementation.

On January 1, 1983, the New Jersey Transit (NJ Transit) Corporation officially took over the operation of its nine rail lines, which until that time had been operated by the Consolidated Rail Corporation (Conrail). This occurred in response to a congressional mandate issued the previous year that directed Conrail to divest itself of all passenger service operations in the Northeast Corridor.

In April 1982, NJ Transit indicated that it would assume the operation of its rail lines. Because it was the first of the affected agencies to do so, this marked the first time that a state agency, created to administer and provide public transportation, would operate a commuter railroad. [Eventually, New York Metropolitan Transportation Authority (MTA), Maryland MTA, and the Southeastern Pennsylvania Transportation Authority (SEPTA) did likewise.]

NJ Transit is New Jersey's statewide public transportation agency. It is different from most other large public transportation authorities in both size and mission. It oversees a statewide public transportation network, providing a wide range of services, including local-urban bus, suburban-to-urban commuter bus, and commuter rail. Each service category is composed of additional subgroups of distinct service performance. The average daily performance of each of the three major service segments is summarized as follows (data are from the NJ Transit Department of Planning, June 1983):

Service	No. of Daily Passenger Trips	Avg Trip Length (miles)
Rail	138,000	20.9
Local bus	276,000	4.3
Commuter bus	84,000	11.0
Total	498,000	

Every day 500,000 trips are made along NJ Transit's extensive bus and railroad networks. Its nine railroad lines, which provide intensive long-distance service between points in northern New Jersey and New York City, account for 69,000 of those riders, including 58,000 during the 6:00 to 9:00 a.m. morning peak period. The ridership distribution by line is shown in Figure 1. Figure 2 and Table 1 show NJ Transit and Port Authority TransHudson (PATH) rapid transit peak-period ridership.

A key goal of NJ Transit when it made the decision to assume operation of its rail lines was to achieve significant operating efficiencies by negotiating changes in antiquated and inefficient work rules with the operating unions. When NJ Transit let these intentions be known, it received clear signals from labor indicating that such a strategy would be challenged and could result in a system shutdown. At that point (September 1982), it was decided that a contingency plan for providing alternative service for railroad passengers would be developed.

Recent experiences in several large cities that have suffered prolonged transportation system disruptions point out the importance of creating and using contingency plans to minimize the negative impacts. Otherwise, the resulting "congestion in core areas can become unmanageable to the point of endangering public safety and adversely affecting the economic health of core area businesses" (1). The availability of contingency plans that outline crisis response actions and delegate roles and responsibilities to various actors can be useful to maintain order and to help commuters cope with the situation. Therefore, several operators and responsible government agencies have developed plans designed to help the public cope with transportation disruptions and the means with which to implement them. The purpose of this paper is to examine NJ Transit's contingency planning process and the eventual implementation of that plan. Results from recent research of transportation contingency planning efforts are used to provide important characteristics of planning and implementation. These characteristics are used as bases of comparison for NJ Transit's experience. They are also used to distinguish some characteristics of contingency plan preparation and implementation that are unique to transit agencies similar to NJ Transit.

CHARACTERISTICS OF CONTINGENCY PLANNING

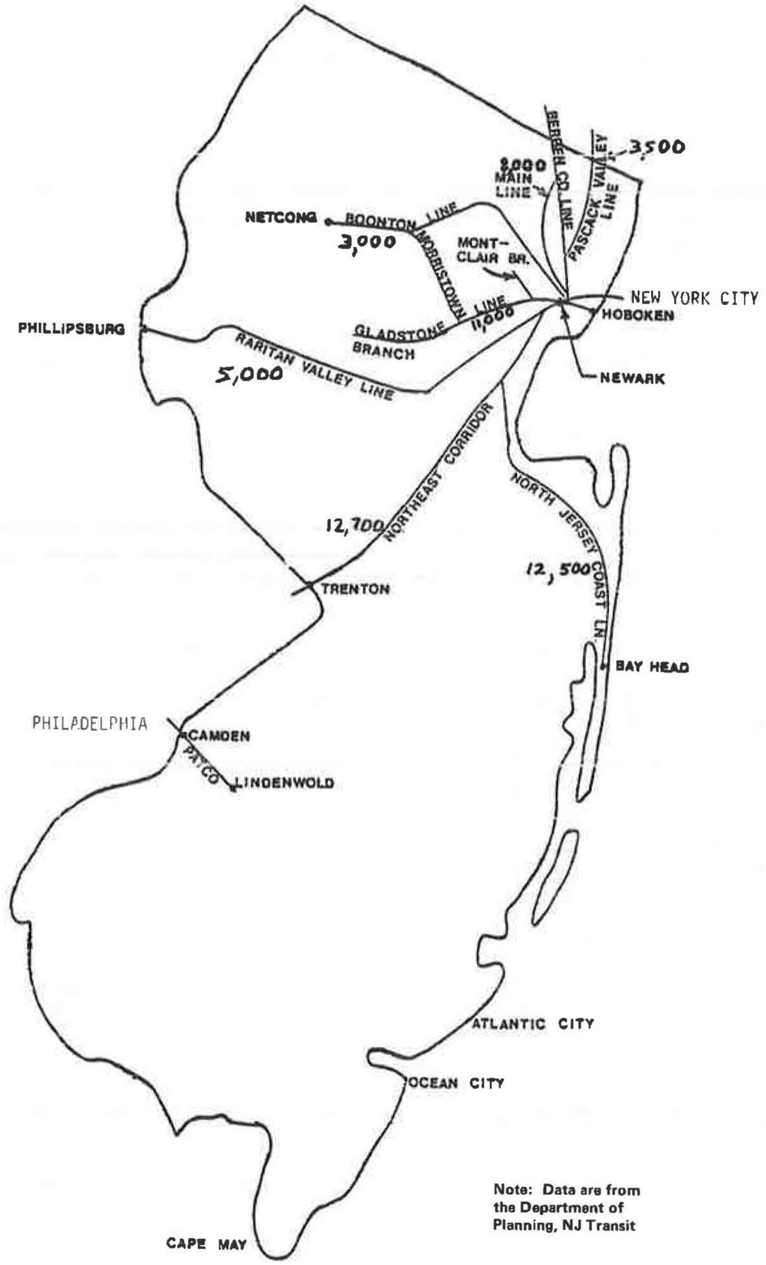
A significant amount of literature has been published regarding governmental and community preparations for transportation supply disruptions (in addition to work on organized response to natural disasters). This research has resulted in the identification of potentially important characteristics for contingency planning efforts. Meyer and Belobaba identified four issues that must be dealt with uniformly when crisis-response plans are developed (2):

1. Clear identification of priorities for governmental response,
2. Interorganizational coordination,
3. Delineation of specific tasks and responsibilities, and
4. Relation of the likely forms of behavior of disaster and crisis victims to the measures incorporated into a contingency plan.

Of course, contingency planning and implementation processes differ depending on the nature of the crisis. Different types of emergencies will elicit varying responses from the general public. For example, the amount of advance warning and the degree of consensus among government authorities will vary by type of emergency (e.g., a natural disaster, an energy shortfall, or a transit shutdown). However, accurate anticipation of public reaction and strong, direct action are critical elements of contingency plans in any situation. The finer points of public policy should always yield to the necessity of a clear governmental presence, which is perceived as helping to maintain reasonable public order (3).

Although some correlations exist between contingency planning for transportation disruptions and other types of crisis planning, each process has characteristics that differ from those of the others. After researching several transit system disruptions, Meyer and Belobaba concluded that for transportation contingency planning, there are three such attributes (2):

1. Planning efforts tend to become politicized. Measures are selected for political reasons, actors' roles depend on responsibilities given to them, and



Note: Data are from the Department of Planning, NJ Transit

FIGURE 1 Average peak-period ridership, New Jersey passenger railroads.

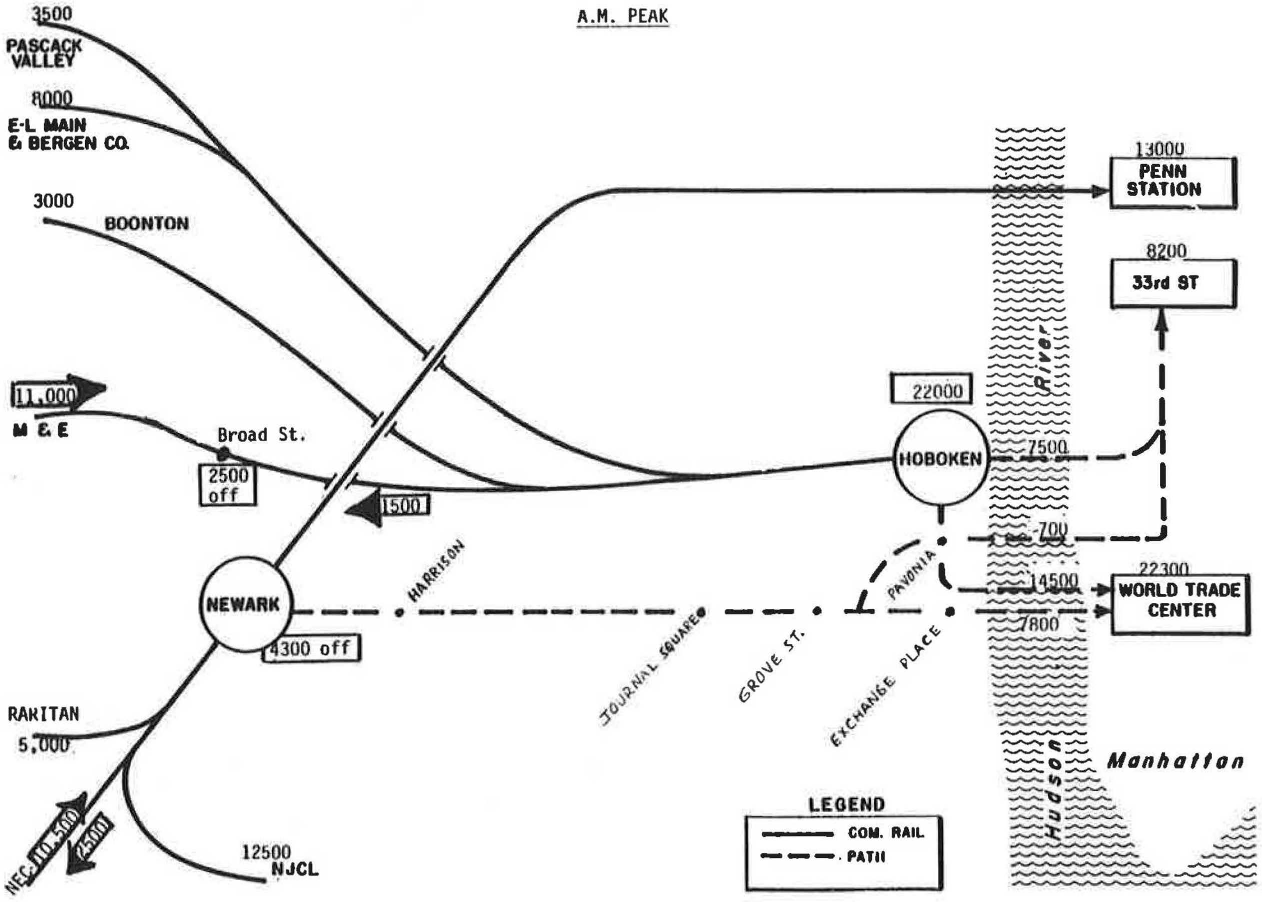


FIGURE 2 NJ Transit rail passenger movements.

TABLE 1 NJ Transit Peak-Period Rail Ridership

Location	No. of Riders	Location	No. of Riders
Inbound			
New Jersey Division		New Jersey Division	
From		To	
Northeast Corridor	10,500	New York Penn Station	13,000
North Jersey Coast Line	12,500	PATH	
Raritan Valley Line	5,000	33rd Street	700
Subtotal	28,000	World Trade Center	7,800
		Newark	4,300
		Points before Newark	2,200
		Subtotal	28,000
Hoboken Division		Hoboken Division	
From		To	
Morristown and Essex Line	11,000	PATH	
Main and Bergen Line	8,000	33rd Street	7,500
Pascack Valley Line	3,500	World Trade Center	14,500
Boonton Line	3,000	Newark Broad Street	2,500
		Points before Newark and Hoboken	1,000
Subtotal	25,500	Subtotal	25,500
Total	53,500		53,500
Outbound			
Northeast Corridor	2,500		
Morristown and Essex Line	1,500		
Other	500		
Total	4,500		

plans often become a source of leverage for influential interest groups. Emphasis is given to crisis management and program implementation.

2. Effective response to a crisis situation requires a management structure with clear lines of authority and communication.

3. Crisis situations offer unique opportunities to implement actions that under normal circumstances would not be adopted or would take a long time for approval. A need for quick governmental action often dissipates routine implementation obstacles. (For example, during the 1966 New York City transit strike, Fifth Avenue and Madison Avenue were converted into one-way streets to improve traffic flow. The proposal had previously met stiff opposition but was kept in place after the strike.)

The characteristics of contingency plan implementation are also important. Implementation "must not be conceived as a process that takes place after, and independent of, the design of policy. Means and ends can be brought into somewhat closer correspondence only by making each partially dependent on the other" (4). In other words, policy makers should pay as much attention to the machinery necessary for executing a program as they do to that for launching one. Lloyd and Meyer identified a set of characteristics for project implementation, many of which can be applied to contingency plan implementation (4):

1. Successful implementation requires a group of individuals who are committed to orchestrating the innumerable events necessary to overcome implementation obstacles.
2. Responsible agencies must maintain a flexible approach toward implementation and be willing to make adjustments.
3. Developing and maintaining a constituency that can support the plan from development through implementation is vital to success.
4. Consistent communication and feedback designed to gauge the response of constituents and modify strategy accordingly are necessary.
5. A marriage between the goals of the professional advocates of the plan and the objectives of those wielding political power is an important ingredient for success.

PREPARATION OF RESPONSE TO NJ TRANSIT STRIKE

Shortly after the NJ Transit Board of Directors voted to assume operation of its railroad from Conrail, a small task force was established to develop a rail strike contingency plan (5). The task force included staff from NJ Transit corporate headquarters, the NJ Transit bus operations subsidiary (NJT Bus), and the newly formed rail operating subsidiary (NJT Rail). In addition the task force included representatives from the New Jersey Turnpike Authority, the Port Authority of New York and New Jersey (PANYNJ), New York MTA, the New Jersey Highway Authority, and the New Jersey Department of Transportation (NJDOT).

From the outset, the task force had two goals. First, rail management was directed to provide for the orderly shutdown of the railroad. This called for the manning of towers and bridges for freight movements, protection of rail equipment, ticket agency audits, and the closing of stations, yards, and other facilities.

Simultaneously, NJT Bus began to develop plans for substitute bus service. After close work with staff from the Port Authority Bus Terminal (PABT) and the PATH rail system, a preliminary plan was agreed on by September. Essentially, the plan was to deploy substitute buses along many of the affected rail corridors.

The Plan

The plan consisted of three elements designed to meet the varying needs within each rail corridor. Priority would be given to the peak-hour travel needs of commuters bound for Manhattan, Newark, and Jersey City. This would require busing for approximately 40,500 riders through a combination of regular routes and satellite park-and-ride bus service. [This assumed that 25 percent of normal rail passengers would carpool or buspool and that riders normally boarding at Newark could continue to board PATH trains bound for lower Manhattan or National Railroad Passenger Corporation (Amtrak) trains for midtown Manhattan there.] The plan was as follows:

1. Rail riders would be accommodated, to the extent possible, on regular routes operated by NJT Bus and the state's private interstate carriers.
2. In those instances when there was no regular route service available within the proximity of a rail line or the number of rail riders far exceeded the available capacity of regular routes, a satellite parking system would be established. Rail riders would be shuttled to major gateways to New York City (such as the PATH stations at Hoboken, Jersey City, and Newark).
3. Single-occupancy vehicle restrictions would be established. Rail riders would be encouraged to ride in carpools, vanpools, and buspools in order to minimize the impacts of additional traffic volume on the state's already congested highway network.

Plan Development

The plan raised a number of questions regarding the operation of regular route and satellite services:

1. How many additional NJT Bus vehicles and drivers would be available for substitute bus service?
2. Would private carriers be able or willing to provide service where NJ Transit could not?
3. Could an adequate number of available parking facilities for satellite bus service be identified?
4. Could the major bus terminals absorb the new demand generated by the rail strike?
5. What would be the projections of displaced rail passengers by corridor?
6. Would municipal governments and police departments be willing to cooperate?

Regular Route Service

NJ Transit's ability to meet the needs of rail commuters depended on the availability of certain resources. First, the initial delivery of 700 new commuter buses, expected during the latter part of 1982, was delayed by a strike at the factory. The number of buses that were available by the beginning of 1983 was to determine the ability of NJT Bus and private carriers to augment regular route service.

Second, the number of available drivers involved the potential use of retired drivers to supplement the regular work force. Issues of compensation needed to be determined for these workers.

Third, a list of all available entry points to Manhattan had to be determined. Initially, consideration was given to the area's major bus terminals, including the Port Authority Bus Terminal (Manhattan), Penn Station (Newark), and Journal Square (Jersey City). The Staten Island Ferry (Staten Island) was added to avoid overloading Journal Square. These urban terminals were to serve as the destination for satellite lot and regular route bus services, facilitating transfer to PATH and New York City Transit Authority (NYCTA) subways to connect with major work destinations.

Fourth, the degree of cooperation that could be expected from the private carriers was unknown, as was their capacity to expand service. Several carriers, however, did indicate willingness to provide extra regular route and contract service.

It was decided that the decision of how many additional buses to place in regular service was to be decentralized. The private carriers were asked to schedule additional service on their routes as demand warranted and were to bear full responsibility for the financial consequences. The number of additional NJ Transit buses and drivers to be added was to depend on the numbers of rail riders displaced within NJ Transit bus route corridors and the availability of extra drivers and buses.

Satellite Park-and-Ride Service

The initial determination of additional bus capacity available for regular route service underscored the need for providing shuttle bus service from major park-and-ride locations in the various rail corridors. Five major rail corridors served by seven rail lines were targeted for satellite park-and-ride lot development. It was estimated that 13,000 riders could be accommodated through expanding regular route service to the urban terminals. Thus, approximately 27,000 riders would have to be served through satellite park-and-ride service.

Initially, utilization of existing park-and-ride lots at major railroad stations was considered. However, the possibility of picketing by striking railroad workers forced the task force to seek other locations.

The process of locating candidate parking areas began with setting goals for total spaces for each rail corridor. Ideally, each lot was to accommodate a minimum of 500 cars and support a 10-bus operation. An inventory of major shopping centers and industrial and public facility parking lots was compiled by contacting local Chambers of Commerce, retail associations, county planning departments, and state and local economic development organizations. In addition, leading commercial and industrial realtors and corporations were contacted to obtain leads on underutilized or vacant parking areas.

Because there was no funding available for the leasing of parking space, the number of available locations was quite limited. The search produced 17 locations having a combined total of 15,400 parking spaces. Letters of agreement were individually tailored to the specific needs of NJ Transit and the site owner. Each agreement contained clauses governing the hours and duration of operation, insurance coverage, and the installation of communications equipment and trailers.

Finally, eight parking facilities with a capacity of 11,000 spaces were secured for use during the strike. In addition, five rail station parking lots were used, despite the threat of picketing, to supplement these facilities when the demand warranted additional capacity.

Chartering Private Carrier Service

NJ Transit's ability to provide service for these special park-and-ride locations was constrained by the number of additional drivers and vehicles that were to be available. NJ Transit eventually committed itself to providing an additional 109 vehicles for regular route and satellite bus services. However, the projected vehicle requirements for the satellite system alone totalled 324.

Eventually, 13 private bus carriers agreed to provide service from satellite facilities located in their service areas. Buses had to be chartered on a per-bus basis, and payment had to be guaranteed, whether or not the bus was actually needed on any given shift. This lack of scheduling flexibility made the chartered service one of the more costly elements of the contingency plan. In return, riders were to be guaranteed high-quality, frequent bus service in lieu of their trains.

Terminal Capacity

Questions regarding the adequacy of terminal capacity necessitated a high degree of cooperation between NJ Transit and the Port Authority of New York and New Jersey to

1. Expand the capacity at PABT in midtown Manhattan and
2. Reschedule PATH trains to meet increased demand at Newark Penn Station and Journal Square.

The plan called for 47 percent of the added buses to use Newark Penn Station as a gateway to New York City. Thirty-nine percent of the buses were to go directly to PABT; the remaining 14 percent were to go to Journal Square in Jersey City.

The decision to maximize use of Newark Penn Station was the result of several factors. First, it could accommodate riders to Newark, Jersey City, Hoboken, and midtown and downtown Manhattan. Second, this terminal could be approached by arterial and limited-access highways from several directions. Finally, the availability of PATH and many NJ Transit bus routes made this location an excellent transfer point.

It was determined that PABT could accommodate 198 extra buses. Many of the major satellite locations, including the Meadowlands Sports Complex, were to send buses there. The use of Staten Island represented an approach to reducing the overcrowding of PATH station terminals such as Journal Square by commuters destined for lower Manhattan. The biggest obstacle anticipated for this gateway was one of perception.

New Jersey commuters were unfamiliar with the time involved in traveling to lower Manhattan via the Staten Island Ferry. They perceived this as being a much longer trip as opposed to traveling via PATH. Commuters had a negative attitude toward this point of entry because at least two modal switches would be required to complete a trip (car to bus, bus to ferry, and ferry to subway). As a result of light patronage, buses originally intended to terminate at the Staten Island Ferry were rerouted to the Journal Square PATH station.

Implementation

On February 26, 1983, the United Transportation Union (UTU) announced that they would strike the NJ Transit rail system effective the following Tuesday, March 1. (NJ Transit had assumed operation of the rail system on January 1, and labor negotiations took place over the ensuing 7 weeks.) On that day, all commuter rail service was idle, forcing 69,000 commuters to find alternative means of transportation. The strike lasted 34 days; rail service was resumed on April 4, 1983.

Strike Preparation

During the weekend before the strike, the strike task force contacted each of the private bus carriers, satellite lot owners, and other transportation authorities to reestablish the commitments made during December. Originally, the strike contingency plan was completed and details were released to the public on December 21, 1982, with the expectation that a shutdown would occur when NJ Transit began self-operation of rail service on January 1, 1983.

The verification of letters of commitment received from the lessors of the satellite parking lots did not present a problem. Dates and contract specifications were changed to meet the needs of the owners and NJ Transit. More than 500 private and NJ Transit buses were made available for the strike contingency effort by the evening before the strike. Directors of other transportation authorities were contacted to provide sufficient lead time to prepare for the strike.

An emergency press conference was held on Sunday, February 28, 1983, to inform public officials and the media of the impending shutdown of rail service. Communicating the details of the rail strike contingency plan to the public was a critical element of the implementation process. Printed material designed to inform elected officials, news media, unions, and commuters about the substitute bus service was issued on Monday. Substitute bus service brochures describing the available bus service with respect to frequency, cost, and destinations by rail corridor were distributed on trains and at rail stations and provided to the news media. Toll-free telephone information centers were added to handle the increased number of calls expected on Monday.

In addition to communicating the details of the substitute bus services, NJ Transit informed the public of the unresolved labor issues that led to the strike. In addition, progress made in negotiating these labor agreements was continuously updated.

Manpower needs to support the substitute bus operations required the performance of strike duty by NJ Transit management staff. On the Monday before the strike, employees were assigned to serve as ticket sellers, bus starters, and other functions to supplement experienced bus operations personnel.

Bus Terminal Activities

The anticipated problems of bus and passenger overcrowding at the major urban center terminals were negligible during the strike. In New York City, PABT was able to adequately handle the increased bus arrivals and departures during the commuter peak periods. Additional NJ Transit personnel were assigned to facilitate the loading and departure of evening rush-hour buses.

The terminals in Jersey City and Newark did not experience overcrowding on bus loading platforms, but congestion from additional passengers and automobile traffic resulted in bus delays and passenger confusion on the first day of the strike. In Newark, the joint action of local police and traffic personnel working with NJ Transit bus operations staff eliminated the traffic flow problems affecting commuter use of the terminal.

The biggest single problem encountered at the urban terminals involved disseminating commuter information. Uncertainty in locating bus departure platforms within the terminals during the evening rush hour presented the greatest source of inconvenience to commuters. NJ Transit management personnel were assigned to direct commuters to buses, and temporary signs were posted to direct passengers both outside and within the terminal buildings.

Satellite Lot Operation

Although accommodation of substitute buses was handled without any serious disruption of normal operations, the satellite lots presented several problems requiring adjustments in operating policy on the first day. After the second day, buses providing substitute service to lower Manhattan via Staten Island were rerouted to Journal Square, Jersey City. This change entailed the issuance of additional tickets for Jersey City and the redeployment of NJ Transit support personnel to handle the additional demand to this location. By the second day, these adjustments had been implemented.

The lack of additional capacity for ticket sales at the urban terminals necessitated the institution of a pay-as-you-leave policy on the evening buses. Commuters boarded the buses at the urban terminal and either presented a ticket or paid cash at the outbound destination. At satellite locations served by charter bus services, sufficient staff were deployed to collect cash and record the ticket sales. By the end of the first week of the strike, the availability of tickets at the satellite lots (and on a limited basis at the urban terminals) eliminated the need for pay-as-you-leave ticket collection.

Evening ticket sales were made available to commuters at the larger satellite lots. This convenience freed commuters from long morning ticket lines when they were rushing to get to work.

Contributions of Other Transportation Agencies

A number of agencies responsible for operation of transportation facilities played a role in the implementation of the contingency plan. The cooperation of these agencies was particularly critical toward ensuring minimal traffic delays for the substitute bus service.

Although a decision was made not to implement additional bus priority lanes, both the New Jersey Turnpike Authority and New Jersey Highway Authority provided a daily monitoring of vehicles by type and occupancy to determine whether emergency bus priority measures were warranted. These two authorities also dedicated staff to handle the increased traffic at satellite and regular bus park-and-ride lots operated on their property.

PANYNJ provided monitoring staff and additional personnel to handle the increased commuter information demands at PABT. The PATH rail system proved extremely cooperative by rearranging its service schedules to reflect the increased needs at NJ Transit's Newark Penn Station and Journal Square bus terminals. NYCTA provided additional subway trains to support anticipated increases in bus passengers making connections with the subway. Cooperation from these and other agencies allowed NJ Transit to quickly respond to unanticipated commuter problems that arose during the strike.

Contingency Plan Performance

Eighty percent of all rail commuters were forced to alter their daily work and commuter schedules as a result of the strike. Still, the vast majority

TABLE 2 Alternative Mode Use During Rail Strike

		Percentage of Ridership by Mode						
Rail Line	No. of Riders	Special Park and Ride	Regular-Route Bus	Automobile	Bus with PATH	Automobile with PATH	Amtrak	Other
Morris and Essex	8,926	55.61	9.20	7.56	11.11	13.68	0.38	2.46
Boonton	3,707	13.46	29.20	24.41	17.10	8.17	-	7.66
Main and Bergen	9,127	11.93	39.49	18.31	9.97	20.11	-	0.19
Pascack Valley	4,247	4.13	61.66	15.34	3.91	14.73	-	0.24
Montclair	586	9.60	25.96	12.76	10.00	10.04	-	31.63
Northeast Corridor	11,189	21.00	23.92	12.39	4.48	5.46	32.62	0.13
North Jersey Coast	12,117	32.00	24.99	15.43	8.93	13.27	5.36	0.02
Raritan Valley	5,195	18.98	36.07	20.62	9.30	14.04	0.99	-
Total	55,094	25.40	28.78	15.07	8.76	12.69	7.96	1.33

Note: Data are from NJ Transit Rail Passenger Survey. Total number of users by mode was as follows: special park and ride, 13,996; regular-route bus, 15,955; automobile, 8,304; bus with PATH, 4,827; automobile with PATH, 6,992; Amtrak, 4,385; other, 735. Data are for a.m. peak period eastbound only.

continued to use transit as the preferred mode of travel. Seven in 10 found alternative mass transit travel, whereas 30 percent either carpooled or drove alone. Within each rail corridor, the modal split varied directly with the type and quality of alternative transit service available. The automobile use rate varied from a low of 21 percent on the Morris and Essex line to a high of 38 percent along the Main-Bergen line, reflecting the superiority of special express bus park-and-ride service in the former corridor (6). In general as the availability of special bus park-and-ride service or alternative rail services declined, automobile use increased. The percentage of riders using each alternative mode during the strike is given in Table 2.

CONCLUSIONS

The efforts made by NJ Transit to anticipate and control the effects of the railroad strike were significant in helping to mitigate its negative impacts. The preparation and implementation of the contingency plan were highly successful for a number of reasons. First, the months of advance warning of the impending walkout gave NJ Transit ample time to formulate a workable contingency plan and to reach an adequate state of preparedness. Although UTU gave only 3 days' notice of their walkout, the plan was functioning smoothly within 2 days of its implementation.

Second, there was a clear sense of priorities regarding the type of strike response necessary, which was directly translated into a plan of action: the provision of a long-distance line-haul travel alternative for the 53,000 (peak-period) New York-bound commuters. Thus, much of the focus for NJ Transit's contingency plan was already set.

Third, favorable public opinion, political good will, and a high level of motivation among the NJ Transit staff all contributed to making the plan workable. Commuters and the general public supported efforts by management to reduce operating costs to prevent the continuation of the cycle of large fare increases that had been necessary during the previous 2 years. It was widely perceived that there was much room for achieving efficiencies through the renegotiation of the labor contracts. The governor was highly supportive of NJ Transit's efforts to renegotiate the labor contracts, as was much of the state legislature. Among the hundreds of nonunion NJ Transit employees who worked overtime to perform strike-related tasks there was a sense of mission and purpose. Diligent efforts to convey these factors through the media by NJ Transit staff were instrumental in maintaining a high level of support among the general public.

Fourth, and perhaps most important, was the role that NJ Transit played. For although it was the transportation agency that was struck by a large segment of its own work force, NJ Transit was the predominant actor throughout the entire plan development and implementation process. This represents a significant departure from the experience of many other metropolitan areas that have coped with transit service disruptions. In cases such as the 1980 transit system shutdowns in New York and Boston, contingency plan preparation and coordination were the responsibilities of commissions or task forces appointed and directed by municipal governments. It appears that this distinction in roles has some significant implications for the connection between policy making and implementation in a crisis environment.

The close proximity of professional staff and personnel resources represented significant advantages for NJ Transit in its role as developer and coordinator of all facets of the contingency plan. Meetings to discuss various aspects of the plan could be assembled on short notice. Similarly, the ability to make operational adjustments after the plan had been put into effect was equally fast.

Prior Experience

New York City's Emergency Control Board (ECB) was an administrative body created by the major's office to coordinate responses to municipal crises such as the transit strike. The ECB did a reasonably good job of setting policy for and coordinating several agencies responsible for contingency plan implementation. Nevertheless, it was a time-consuming process to translate policy into action and to communicate adjustments in implementation to so many actors.

In preparation for an impending transit shutdown in 1980, the city of Boston formed a transit emergency task force similar in scope to New York's ECB to guide its contingency planning effort. However, Boston's contingency planning experience was characterized as a highly politicized ad hoc multiagency effort with no established framework that identified specific roles. The lack of cooperation and coordination among the several municipalities that would have been affected contributed greatly to the noncohesive effort that characterized this experience. Boston never had to implement its plan. However, several of the analysts responsible for developing it felt that had it been put into effect, implementing agencies and several municipalities would have taken unilateral actions that might have created a very confusing situation (2).

A comparison of these experiences with those of NJ Transit illustrates the importance of some of the previously identified characteristics necessary for a successful contingency planning effort. Among the most important are establishing and maintaining a strong lead agency or commission and clear lines of authority and establishing and maintaining a high level of interorganization coordination and cooperation.

NJ Transit's experience has also shown that minimizing politicization of contingency plan development and implementation is highly desirable. (Admittedly, this will be difficult to achieve in many environments.) Furthermore, by minimizing the gap between responsibility for the policy setting and planning functions and implementation, it is more likely that goals outlined within the plan will be achieved.

Operational Conclusions

Among the more noteworthy successes regarding plan implementation was the successful utilization of private bus carriers as an alternative to rail service. Although this strategy was somewhat expensive, their willingness to cooperate and ability to rapidly form a workable transit network proved crucial to the success of the contingency plan.

The overwhelming preference of commuters for the most direct service possible (i.e., the fewest or most convenient connections) became readily apparent after the plan had been implemented. As shown by the rejection of service to the Staten Island Ferry, commuters tend to prefer routes that are perceived to be most direct, even if it means a longer trip. This tendency toward convenience was also displayed by commuters' preference for satellite parking in outlying areas as opposed to taking advantage of special park-and-ride facilities that were deployed close to Manhattan. This was most apparent at the interim park-and-ride facility created at the Meadowlands Sports Complex, which is conveniently situated on the New Jersey Turnpike less than 5 miles from Manhattan. Utilization of this facility was far below original estimates.

Once it became apparent that the replacement bus services would achieve the goals set out in the contingency plan, there were many questions concerning the necessity of supporting the railroad. However, a number of factors indicate that the special bus system represented at best a temporary solution.

The public was supportive of the substitute bus service for three reasons: provision of express trips, artificially low fares, and the desire to see rail labor costs controlled. The first two reasons--routing and fare levels--were quite costly (the rail cost per passenger is 20 percent less than the peak-period chartered service) and were implemented to help the rail riders cope with the crisis.

The third reason--willingness to be temporarily inconvenienced for a just cause--was not an inexhaustible resource. People were highly inconvenienced (80 percent had to leave home earlier, return home later, or both) and 30 percent were not served by substitute transit at all (6). The rail system is often superior in terms of service quality (comfort, reliability, accessibility), and it has more capacity to absorb projected growth in ridership.

Finally, the physical infrastructure of the region is not adequate to support an all-bus commuter system. The major bus terminals serving NJ Transit--PABT, Newark Penn Station, and Journal Square--are incapable of absorbing the necessary increases in bus traffic. Thus, it must be concluded that this system could not have been a suitable replacement for rail service on a permanent basis.

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A Methodology for Transit Station Impact Analysis

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ABSTRACT

A methodology is developed for the identification and evaluation of the impact of transit terminals on their environment. A catalog of transit station studies is presented that enables the user to initiate the evaluation process with the identification of critical impacts using a cross- and self-interactive matrix procedure. The impact that the station has on its environment as influenced by local land use patterns is examined by using the cross-interactive matrix. The self-interactive matrix establishes the station design elements and identifies the most sensitive station design components. Where important impacts exist, strategies for preventing problems or managing the issues involved are developed in terms of altering the station design variables or site location or promoting changes in neighboring land use so as to provide an acceptable environment.

The public's acceptance of new urban and intercity transportation systems is greatly influenced by the negative or positive environmental impacts created by terminals. The transit station itself is a major physical force within a community and can serve to enhance a neighborhood by bringing to it vitality and activity or to diminish the quality of life by adding congestion, noise, and blight.

Although the community as a whole usually benefits from a major transportation project, the gains are often not realized at locations surrounding the station because of disruptions of the social and environmental structure. In many cases residents of the neighborhood surrounding the transit station feel that they must bear all the negative impacts whereas the community receives all the benefits. Such conflicts must be resolved and solutions should demonstrate a balance between neighborhood and community values.

The purpose of this paper is to present a methodology for the evaluation of environmental impacts created by transit stations. The methodology recognizes the vast and diverse literature in the realm of transportation impacts and organizes this in a fashion that is useful to the practitioner. A catalog of transit station impact studies that enables the user to learn the nature of specific impacts created by transit terminals is used. The interactions of the various elements of the site plan are described to assist the planner in determining the causes of negative social and environmental impacts that must be dealt with in the design process. A hypothetical example is presented to demonstrate how the process is carried out.

IMPACT ASSESSMENTS

The first step in the impact assessment procedure is to identify the potential impacts of a transit station. These impacts are then incorporated into the alternatives analysis for the terminal design under study. Because an impact assessment must identify specific effects before the alternatives analysis, it is important that a disaggregated range of transit station impacts be used so that a detailed impact classification system is produced.

Impact Classification System

The impact classification system described in this paper is fully documented in a recent report, Catalog of Transit Station Impact Case Studies (1). The catalog is a reference as well as a state-of-the-art review of the impact of public transportation terminals on land use and community development. Published documents are described and a general overview of each is furnished with a capsulized sampling of the findings.

For classification purposes, a list of impact keywords (Table 1) is given. These impact keywords provide the user with an entry point into a reference catalog and a quick check of any descriptor in the catalog's overall classification framework. When a keyword is selected, the user is directed to the correct catalog topic area. If the user's keywords do not appear in the table, the list can be used to suggest similar or related descriptors.

The topic index in Table 2 provides the framework for the indexing in the catalog. Each topic area is a collection of descriptor keywords from Table 1 that are interrelated. Some impact descriptors are specific and are listed as individual topics, whereas others are quite general and are associated with other impacts that can be grouped under a single topic. Each major topic is listed in Table 2 with the descriptors associated with the topic and the number of references provided on the topic area.

Use of the Catalog

The following example illustrates how a typical impact is referenced in the catalog. Consider the case of a user who desires information on the development potential of sites adjacent to a public transportation terminal. The impact descriptor in this case is development potential, the associated keyword from Table 1 is development opportunity (joint development), and the topic index in Table 2 states that there are 17 references in the joint development section.

A sample reference, shown in Figure 1, furnishes the report title and the source for that reference. A listing of the full address of the supplier of the reference is presented in the catalog appendix. The next item in the catalog listing is a general annotation of the entire reference, followed by a description of the methods used to collect or determine the information. Finally, the major findings are described as they apply to this topic.

ILLUSTRATIVE EXAMPLE

Descriptive Scenario of Station Site and Terminal

Consider a transportation terminal that serves as a terminal and transfer point for commuter buses with

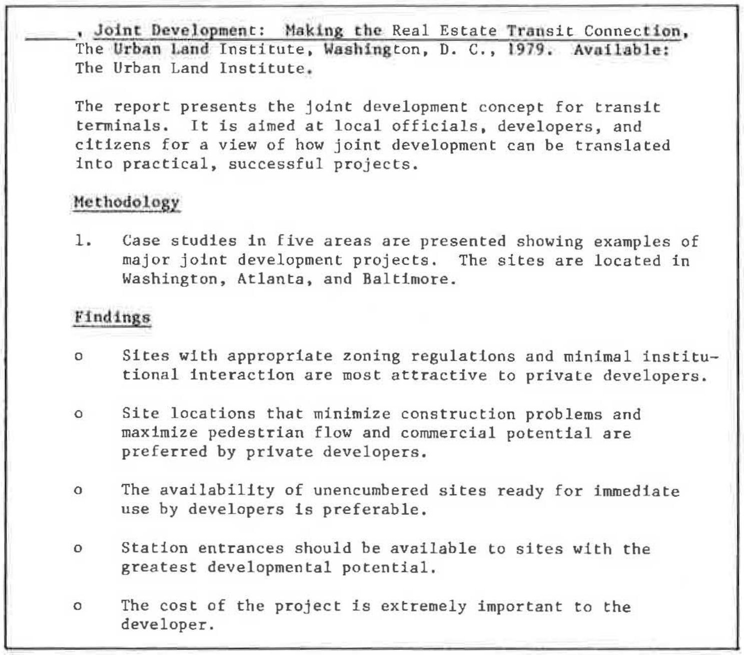
TABLE 1 Index of Keywords

Accessibility
Accidents (see Safety)
Aesthetics
Air Pollution
Assessments (see Property Values)
Attitudes (see Citizen Participation)
Capital Cost (see Economic Impacts)
Citizen Participation
Commercial Development
Community Cost (see Social Impacts)
Congestion
Construction Impacts
Crime
Development Opportunity (see Joint Development)
Disadvantaged Mobility
Displacement Cost see Construction Impacts)
Drainage (see Erosion)
Dust (see Air Pollution)
Economic Impacts
Educational Institutions (see Institutional Land Use)
Employment
Energy
Environmental Impacts
Erosion
Fares (see User Costs)
Financial Impacts
Goal Assessment
Housing (see Residential Land Use)
Image (see Citizen Participation)
Infrastructure
Institutional Land Use
Joint Development
Landscaping (see Aesthetics)
Level of Service
Life-style (see Social Impact)
Lighting (see Aesthetics)
Location Theory (see Terminal Location Data)
Modal Coordination
Neighborhood Character
Noise Pollution
Operating Cost
Open Space (see Institutional Land Use)
Opinions (see Citizen Participation)
Orientation (see Aesthetics)
Parking
Parks (see Institutional Land Use)
Passenger Volumes
Pedestrian
Population
Property Values
Psychological Effects
Public Policy (see Infrastructure)
Recreation (see Institutional Land Use)
Relocation (see Construction Impacts)
Residential Land Use
Retail Sales (see Economic Impacts)
Revenues (see Property Values)
Safety
Shopping (see Commercial Development)
Social Impacts
Speculation
Subsidy (see Economic Impacts)
Taxes (see Property Values)
Terminal Location Data
Traffic/Terminal Area (see Congestion)
Travel Impacts
Trip Length (see Travel Impacts)
Trip Reliability/Comfort/Convenience (see Level of Service)
User Characteristics
User Cost
Value Capture
Vehicle Volumes (see Passenger Volumes)
Water Pollution (see Erosion)
Wildlife and Vegetation Impacts
Zoning

TABLE 2 Topic Index

Accessibility (7)*
Aesthetics (7) landscaping, lighting, visual barriers, orientation, psychological effects.
Air Pollution (7) dust
Citizen Participation (6) attitudes, goals, images, opinions
Commercial Development (11) retail sales, shopping
Congestion (6) traffic around station
Construction Impacts (10) displacement cost, relocation, R-O-W
Crime (3)
Disadvantaged Mobility (3)
Economic Impacts (20) budgets, capital costs, capital programs, financial subsidies
Employment (7) jobs
Energy (8) power demands
Environmental Impacts (16)
Erosion (4) drainage, hydrology, water pollution
Infrastructure (17) public policy
Institutional Land Use (6) education, public service, parks, recreational
Joint Development (17) development opportunity
Level of Service (7) trip reliability and comfort and convenience
Modal Coordination (4)
Neighborhood Character (5) cohesion/stability
Noise Pollution (5)
Operating Cost (8) maintenance, operating costs comparison
Parking (6)
Passenger Volumes (8) user volumes, vehicle volumes
Pedestrian (5)
Population (3)
Property Values (16) assessments, mortgages, rent, revenues, taxes
Residential Land Use (12) housing
Safety (4) accidents
Social Impacts (14) community cost, neighborhood cost, life-style
Speculation (4)
Terminal Location (11) location theory
Travel Time (8) travel length
User Characteristics (7)
User Cost (6) fares, freight
Value Capture (4)
Wildlife/Vegetation Impacts (2) balance of nature
Zoning (4)

* ( ) indicates the number of references included in the topic.



______, Joint Development: Making the Real Estate Transit Connection, The Urban Land Institute, Washington, D. C., 1979. Available: The Urban Land Institute.

The report presents the joint development concept for transit terminals. It is aimed at local officials, developers, and citizens for a view of how joint development can be translated into practical, successful projects.

Methodology

1. Case studies in five areas are presented showing examples of major joint development projects. The sites are located in Washington, Atlanta, and Baltimore.

Findings

- Sites with appropriate zoning regulations and minimal institutional interaction are most attractive to private developers.
- Site locations that minimize construction problems and maximize pedestrian flow and commercial potential are preferred by private developers.
- The availability of unencumbered sites ready for immediate use by developers is preferable.
- Station entrances should be available to sites with the greatest developmental potential.
- The cost of the project is extremely important to the developer.

FIGURE 1 Typical catalog listing.

exclusive bus-lane privileges into the center city. The station is located at the fringe of a large metropolitan area of 500,000 population on a primary arterial adjacent to an Interstate freeway interchange. Because of its location at the fringe of the urbanized area, it does not serve local transit feeder lines and has no defined local service area.

The characteristics that provide a general description of the preliminary station design are as follows:

- Predominant mode: bus;
- Station type: surface;
- Transit line status: terminus; off-street siting;
- Station size: 2,000 passengers/day, peak demand;
- Pedestrian accessibility: poor;
- Automobile and bus accessibility: excellent;
- Parking capacity: 500 spaces; and
- Storage and maintenance facilities on site: none.

The neighborhood land uses immediately adjacent to the site are shown in Figure 2. A large plaza-type shopping center is located within 0.25 mile of the transportation terminal site. Garden apartments are within 0.50 mile of the site opposite the interchange. The vacant land to the rear of the terminal is zoned for commercial and light industry and adjoins medium-density garden apartment residential and single-family residential housing developments within a mile of the site. A gravel operation now exists at the eastern periphery of the vacant parcel. Access to the parcel from the arterial highway is available from a strip of land 300 ft wide immediately adjacent to the terminal site.

Terminal and Land Use Interaction Matrix

The matrix showing interactions between the station design characteristics and the existing neighborhood land uses is shown in Figure 3. The specific impact interactions indicated are derived from responses to the following question: Is there a perceived enhancing (positive, +), inhibitive (negative, -), or independent (zero, blank) relationship between the design characteristic and the land use? After this impact matrix table is completed, attention is focused on those cells that exhibit an inhibitive (negative) relationship. The interacting pairs of elements thus identify conflicts or issues that need to be addressed in the impact assessment.

A review of the cells in Figure 3 reveals that the proposed terminal is compatible with existing high-density housing, all existing transportation facilities, and retail facilities and would not preclude development of existing vacant property. However, the terminal location or design may have a negative impact on single-family residential development, educational facilities, and the gravel pit operation.

The next step in the analysis focuses on determining the specific causes for the anticipated problems. This is accomplished by now asking why this pair of elements is negative or what impact descriptors listed in Table 2 create the negative relationship. The key question can be addressed by professional planners, city officials, or citizen groups. For this example, the perceived negative station and land use impacts as identified from the cells in Figure 3 and the impact keywords (Table 1) are collected in Table 3. At this point, the planner can use the Catalog of Transit Station Impact Case Studies (1) to determine the significance of each impact and to determine what, if any, strategies are available for attenuating these undesirable effects.

Table 3 thus shows the keywords for referencing the catalog that are desired for each of the cells in Figure 3. For example, the interaction between single-family residential development and the bus mode produces the following keywords: air pollution, noise, property values, and aesthetics. A review of all the impact descriptors in Table 3 indicates that the overriding negative impact of this terminal is safety in the local neighborhood. The keyword "safety" is listed 21 times. Following safety, accessibility, congestion, noise pollution, and parking are most frequently listed. Accordingly, if the proposed station is to meet with local acceptance, the cited impacts should be resolved.

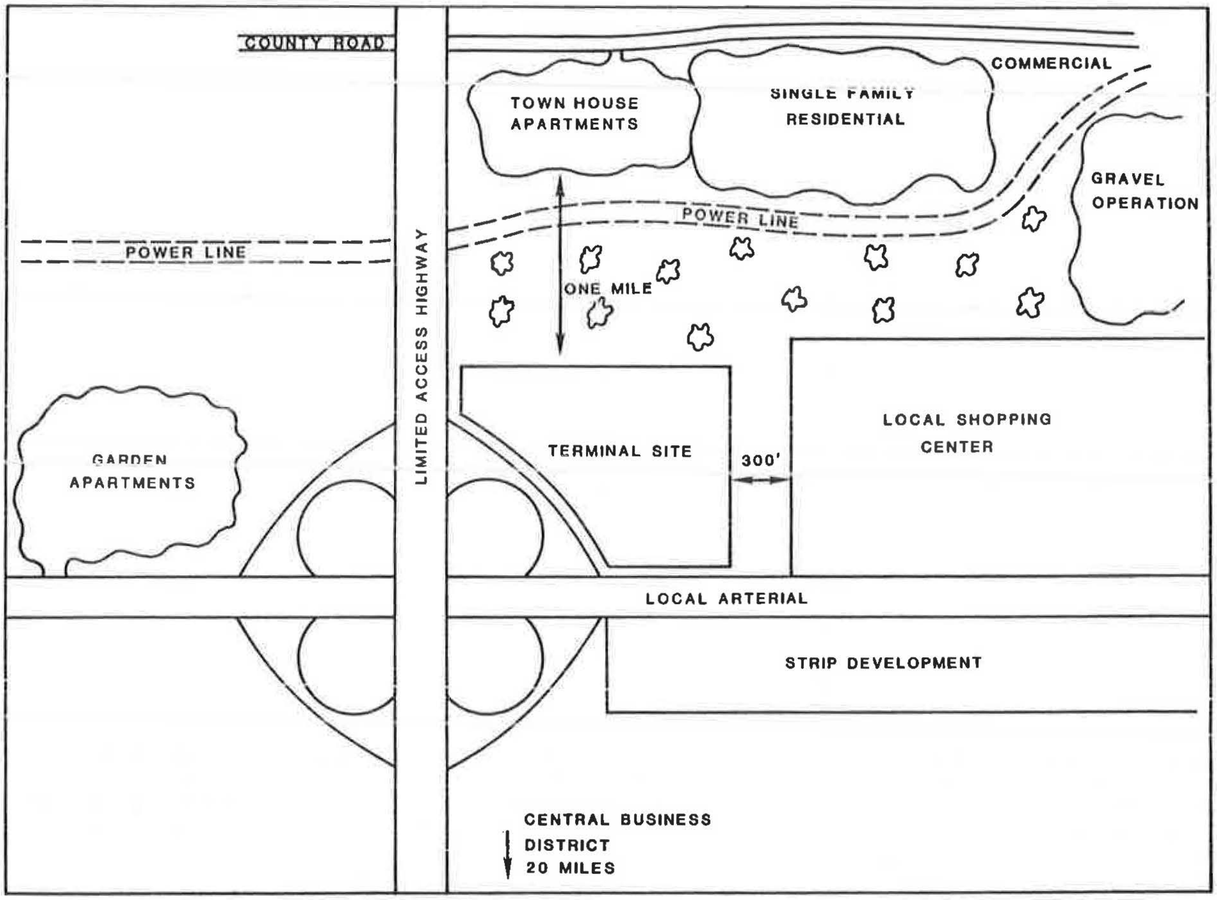


FIGURE 2 Transit station site example.

EXISTING NEIGHBORHOOD LAND USES

STATION DESIGN CHARACTERISTICS	1 Residential			4 Transportation and Utilities				5 Trade						6 Services						7 Cultural	8 Resource Production	9 Undeveloped Area	
	111 Single Family	112 Garden Apts./Townhouses	113 High Rise	42 Motor Vehicle	45 Highway/Street ROW	46 Automobile Parking	48 Utilities	52 Retail-Building Material	53 Retail - General Merchandise	54 Retail - Food	56 Retail - Apparel	57 Retail - Furniture, Home Furnishings, Equipment	58 Retail - Eating & Drinking	61 Services - Finances, Insurance	62 Personal Services	63 Business Services	64 Repair Services	65 Professional Services	68 Educational Services (Elementary School)	73 Amusement (Movies, Game Room)	85 Mining (Gravel Extraction)	91 Undeveloped Land	92 Noncommercial Forest
Predominant Mode: Bus	—			+	+	+	+			—			+	+	+	+			—	+	—	+	—
Station Type: Surface	—			+	—	+	+						+							+	—	+	—
Transit Line: Terminus/Off Site	—	+	+	+	+	+	+						+							+	—	+	—
Station Size: 2,000 Passengers/Day	—					—			+				+		+	+			—	+			
Predestrian Accessibility: Poor		—	—		—				—	—	—		—	—	—	—			—	—			
Automobile Access: Excellent	+			+	+	+	+		+	+			+	+				+	—	+		+	
Parking Capacity: 500 Spaces	+	+	+	+	+	+	+				+		+		+	+		+	—	+		+	
Storage & Maintenance: None	+	+	+	+																			
Joint Development Potential	—	—	+	+	+	+	+		+		+		—	—	+	+		+	—	+	—	+	—

INSTRUCTIONS: The matrix is completed by addressing the following question: "Is there a perceived enhancing (+), inhibitive (—), or independent (blank) impact relationship between the station design characteristics and the neighboring land uses?"

FIGURE 3 Terminal and land use interaction matrix.

TABLE 3 Summary of Potential Station and Land Use Issues

Station Design Characteristics	Existing Land Use	Impact Keyword
Predominant Mode: Bus	Single-Family Residential	Air pollution; noise; property values; aesthetics
	Educational Services (Elementary)	Noise; safety
	Mining (Gravel Ext.)	Air pollution; noise; aesthetics
	Noncommercial Forest	Wildlife/vegetation; zoning
Station Type: Surface	Single-Family Residential	Aesthetics; property values; noise
	Mining (Gravel Ext.)	Air pollution; aesthetics
	Noncommercial Forest	Aesthetics
Transit Line Status	Single-Family Residential	Aesthetics; air pollution; citizen participation; crime; noise; property values; safety; zoning
	Mining (Gravel Ext.)	Air pollution; aesthetics; noise
	Noncommercial Forest	Wildlife/vegetation; zoning
Station Size: 2000 Passengers/Day	Single-Family Residential	Congestion; noise; neighborhood character; crime; safety
	Automobile Parking	Accessibility; congestion; neighborhood character
	Educational Services (Elementary School)	Safety
Pedestrian Access: Poor	Garden Apts./Townhouses	Accessibility; congestion; modal coordination; parking; safety; travel time
	High-Rise Apartments	Accessibility; congestion; modal coordination; safety; disadvantaged mobility
	Motor Vehicle	Accessibility; parking; congestion; safety; modal coordination
	Highway/Street ROW	Accessibility; safety; congestion; joint development; pedestrian needs
	Retail - General Merchandise	Accessibility; commercial development; parking; safety
	Retail - Food	Accessibility; parking; safety
	Retail - Apparel	Accessibility; parking; commercial development; safety
	Retail - Eating & Drinking	Accessibility; parking; safety; user characteristics; commercial development
	Services - Finances	Accessibility; safety; parking; commercial development
	Personal Services	Accessibility; parking; safety; commercial development
	Business Services	Accessibility; parking; safety; commercial development
	Educational Services (Elementary School)	Accessibility; safety
Auto Accessibility: Excellent	Educational Services (Elementary School)	Safety
Parking Capacity: 500 Vehicles	Educational Services (Elementary School	Safety
Joint Development Potential:	Single-Family Residential	Commercial development, congestion; crime; parking; property values; safety; zoning
	Garden Apts./Townhouses	Commercial development; crime; parking; noise; air pollution; safety
	Educational Services (Elementary School)	Safety; congestion; noise
	Mining (Gravel Ext.)	Air pollution; noise; aesthetics
	Noncommercial Forest	Wildlife/vegetation; neighborhood character

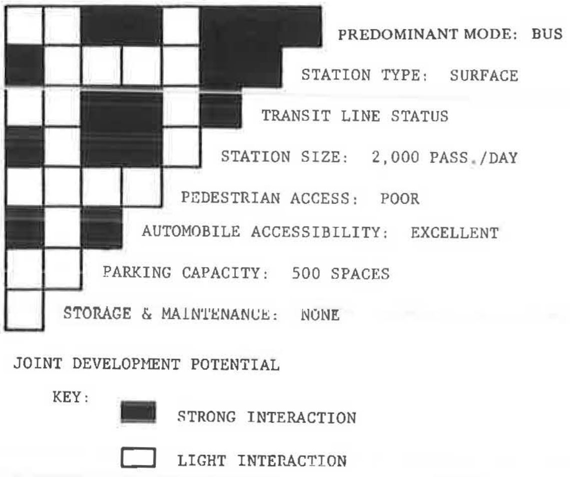


FIGURE 4 Terminal design interaction matrix.

Terminal Design Interaction Matrix

After the specific impacts have been established and remedies suggested via the catalog, it is necessary to determine where changes directed at lessening a single impact may in fact induce other impacts. This problem is addressed by developing a terminal design interaction matrix as shown in Figure 4. This matrix identifies interactions among the design elements and must be prepared using thorough professional analysis techniques. For example, the matrix shown in Figure 4 indicates that if the design element is a line-haul bus mode, the noteworthy interactions include considerations in station type, transit line status, station size, automobile accessibility, and parking capacity.

The summary of station design characteristics in Figure 5 uses those design elements with strong interactions identified in Figure 4 and explores why there is a strong interaction using the keyword impact descriptors. For example, in Figure 4 a strong interaction is indicated between the bus mode and the design of a ground-level terminal. The keyword list in the catalog indicates that this results from a community's concern about aesthetics, air pollution, congestion, noise pollution, and safety. As Figure 5 indicates by the predominance of strong interaction, the major impact to be considered when this terminal is being designed is forecasting the passenger volumes. Secondary impacts shown by Figure 5 are accessibility, parking, and congestion.

Station Design Development

The synthesis of the results shown in the terminal and land use interaction matrix and the terminal

	PREDOMINANT MODE: BUS					STATION TYPE: SURFACE			OFF-SITE TERMINAL			STATION SIZE			AUTOMOBILE ACCESSIBILITY	
IMPACT DESCRIPTORS	Surface	Station Size	Off-Site Terminal	Automobile Accessibility	Parking Capacity	Off-Site Terminal	Station Size	Joint Development	Station Size	Automobile Accessibility	Parking Capacity	Automobile Accessibility	Parking Capacity	Joint Development	Parking Capacity	Joint Development
Accessibility		●	●			●			●		●			●		
Aesthetics	●	●				●	●	●				●				
Air Pollution	●			●	●					●						
Citizen Participation																
Commercial Development																●
Congestion	●				●	●							●			●
Construction															●	
Crime		●			●			●								
Disadvantaged Mobility																
Economic Impacts								●						●		
Employment														●		
Energy																
Environmental Impacts																
Erosion					●		●									
Industrial Land Use																
Infrastructure																●
Institutional Land Use																
Joint Development							●									
Level of Service																
Modal Coordination						●										
Neighborhood Character																
Noise Pollution	●			●						●						
Operating Costs																
Parking			●	●				●	●	●						●
Passenger Volumes		●			●		●	●	●	●	●	●	●	●	●	●
Pedestrian Needs								●				●				
Population																
Property Value														●		
Residential Land Use																
Safety	●		●	●						●	●					
Social Impacts																
Speculation								●								●
Terminal Location								●						●		●
Travel Time										●						
User Characteristics															●	●
Value Capture																
Wildlife/Vegetation Impacts																
Zoning								●								

FIGURE 5 Summary of critical station design characteristics.

design interaction matrix provides a listing of the critical environmental and design factors. Once these factors have been identified, the catalog can be used to provide a starting point for tailoring the design to meet the local contingencies. In the previous example, results of the terminal and land use interaction matrix (Table 2) indicated that the sensitive environmental problems are safety, accessibility, congestion, noise pollution, and parking. These issues can be incorporated into the alternative design evaluation process and should be carefully considered during the selection of alternatives.

The terminal design interaction matrix (Figure 4) has identified via Figure 5 the most critical design factor, the volume of passengers using the facility, followed by parking accessibility and congestion. This information should alert the design team that a careful review of all the procedures used to estimate demand is warranted, as well as a review of all those station design elements that affect accessibility, parking, and reduction of congestion.

The final station design should show an attempt to provide a safe environment, possibly using grade separation for automobiles, pedestrians, and buses. Various types of designs to reduce noise pollution should be considered, and the final design should provide ample parking and maximum access and egress.

CONCLUSIONS

The focus of this paper is on increasing the professional's understanding of the complex terminal and land use interface issues. The problem components identified and defined are structured in a manner that can be expanded and adapted to varying circumstances, and the research strategy enables the generation of alternatives from which a suitable plan of action can be developed.

By use of the two matrices, relationships among the station design and location variables and neighborhood land use types are identified in terms of impact descriptors. Where important impacts exist, strategies for preventing or managing the issues involved can be developed in terms of either altering the station design variables and site location or promoting changes in neighboring land use so as to provide an acceptable environment.

The uniqueness of this methodology lies in its ability to provide a flexible technique that is responsive to particular location needs, alternatives, and constraints. This method is believed to be a substantial improvement over the use of predictive models for assessing the impact of transit stations on neighboring land uses.

ACKNOWLEDGMENT

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Abridgment

Designing for Passenger Information Needs in Subway Systems

ROBERT BECK

ABSTRACT

What methods subway riders use to maintain their bearings in relation to the city above, how successful those methods are, and what qualities of the subway environment assist or confound the rider's way-finding endeavors were investigated in this study. Three design issues emerged that had an effect on the rider's ability to find his way: architectural differentiation of subway stations; signage location, message content, and redundancy; and perceptual access, or the ability of subway riders to see through or out of a station to known landmarks for the purpose of orientation.

Information that facilitates efficient movement through transit facilities, whether provided by station architecture or by signs, is a crucial design factor affecting such issues as passenger security, convenience, and the desire to use transit. The information aspect of station design can also have a major impact on capital and operating costs.

Yet the information needs of passengers in transit facilities may be incorrectly perceived by designers because of differences from other environments.

Research has shown that when finding their way through a city, people will define their location in relation to the city's various physical features. Among these may be landmarks such as tall buildings, major intersections where many vehicular and pedestrian routes converge, or neighborhoods having distinctive identifying qualities (1). However, the subway rider is cut off from such surface features and must seek other sources of locational information. In this study it was attempted to determine what methods subway riders use to maintain their bearings in relation to the city above, how successful those methods are, and what qualities of the subway environment assist or confound the rider's way-finding endeavors.

ROLE OF ARCHITECTURAL DESIGN

The location, configuration, and architectural design of stations are significant determinants of transit use because they are the access points or front door of the transit system. Clean, comfortable, attractive, and safe station facilities are naturally important, but the movement and orientation of passengers is a key design factor that may not receive adequate consideration.

It is unlikely that riders will be able to enjoy using a transit system and appreciate its architectural features if they cannot easily navigate through it. "A pedestrian who is confused by incoherent space is not receptive to supplementary aesthetic visual inputs. When the main concern is orientation, aesthetic input is relegated to a lower level of receptivity" (2). Further, "poor visual design statements are particularly undesirable in transportation terminal environments, where pedestrians are likely to be anxious to meet train or plane schedules, and thus are more easily confused and disoriented" (2).

Insufficient consideration of way-finding needs not only can make the transit rider uncomfortable, it can even be dangerous (3):

> The transit designer should facilitate the rapid, purposive movement of people through the station. Whenever the user must pause because he is confused, uncertain, or frustrated, he is a potential target for a criminal incident. The passenger needs control and predictability in the transit station. He should know, or be able to find out rapidly, what to do to accomplish each activity. If not, passengers will be confused, frustrated, and angry.

With a single large illuminated sign costing several thousand dollars and the need for a great many of these signs, system signing can be a costly burden to a transit agency. Further, as station architecture fails in its ability to provide directional information, more signage will be needed in order to compensate for that failure. When there is inadequate passenger information, added personnel may become necessary to fill the gap.

A basic function of public transportation is to provide rapid transit. Time spent lost, wandering around, and confused defeats this function.

STUDY OBJECTIVES

Through unobtrusive observation and behavior mapping of novice riders of the subway systems of the Metropolitan Atlanta Rapid Transit Authority (MARTA), the New York City Transit Authority (NYCTA), and the Washington Metropolitan Area Transit Authority (WMATA), definition of the qualities of the subway environment that are beneficial to the passenger's way-finding and orientation tasks was sought. Emphasis was placed on examining the potential of station architecture to inform and direct, as well as on studying the effectiveness of conventional signage and other information devices.

DESIGN ISSUES

During the course of the study, three design issues emerged that had an effect on the way-finding behavior of subway riders. Each of these issues arose out of the actual physical design, features, and layout of a subway station. However, it was often the rider's perception of the physical reality, accurate or not, that influenced way finding. These three issues were as follows:

1. Architectural differentiation: lack of an architectural statement consistently indicating the different and often opposite destinations served by passageways, stairs, platforms, and other choice points;
2. Desirable characteristics of signs:
    a. Directional association: the placement of directional information so that it is easily and obviously associated with the pathway choice that the user must make,
    b. Message content: the need for directional information to be in a form and terms that are easily understood and useful,
    c. Redundancy: the need for the same information to be presented several times along a route; and
3. Perceptual access: the ability of subway station users to see through or out of the station to known landmarks or points on the movement pathway for the purpose of judging their location, direction, and distance from their intended destination.

Architectural Differentiation

Many of the difficulties experienced by subjects in the study could be traced to the lack of an asymmetrical architectural statement distinguishing between directional choices. Symmetry of a building's plan has generally been considered advantageous to way finding by facilitating the cognitive representation of a setting (4). However, having an overall cognitive representation of a station is not enough for successful navigation of a subway system. It is also necessary to be able to distinguish between the directional function of the station's individual parts. The rider's goal is to locate the specific part of the station served by the train that will deliver him to his ultimate destination.

The basic problem caused by the symmetrical mirror-image design of most subway stations is that it fails to acknowledge and alert the rider to the different and usually opposite directional nature of a station's two longitudinal halves. The manner in which this upsets the rider's ability to orient himself may be related to whether those riders are repeat users of the specific station, or system in general, or if they are complete novices.

In the case of the former, the nature of the problem may be easier to define. If a consistent system of asymmetrical or other architectural cues exists in a subway system, it will alert riders to the need for a pathway choice and perhaps provide a basis for making that choice.

The effect that symmetry has on the true novice is less obvious. Because such riders are experiencing a system for the first time, they would have no recollection of system features or cues to draw on. Asymmetry in this case would simply alert riders that there are differences between destinations of different pathways. NYCTA and MARTA riders entering subway stations that are symmetrically laid out appear not to realize that stairways on opposite sides of the stations serve different directions, let alone which directions they serve, until they confront a sign or make an error. Station asymmetry or other forms of architectural differentiation could emphasize the axis dividing stairs and platforms serving different destinations.

Desirable Characteristics of Signs

When station architecture fails in its ability to convey directional information, greater responsibility is placed on the signage system or other information aids that must compensate for the architectural failure. However, in many instances throughout the study, subjects sought assistance from signage and found no help or, worse, were misdirected due to the sign's location, its message, or the failure to provide further reinforcement through redundancy.

Directional Association

In some instances, a sign's effective meaning is a product not only of what its message says but also of where it is located. Several WMATA riders transferred to the wrong train platform by incorrectly assuming that the information on a sign referred to the escalator near which it was located whereas it actually was meant to direct riders to a distant escalator.

Message Content

Another obvious deficiency of signage is that its message may not be understood or be useful. Much of the signage encountered during the course of this study did not take into account the user's occasional tendency to not use all of the information presented in multiple-message signs (5).

The WMATA escalator sign also exemplified the importance of anticipating this transit user trait. The sign displayed route information followed by directional instructions in the same type face and letter size. The riders noted only the route information and disregarded the directional information, and so they proceeded up the wrong escalator.

Redundancy

It has been noted that because of the limitations of short-term memory and the ease with which recently acquired information can be forgotten, a certain amount of redundancy of information is necessary. This is especially true in anxiety-producing transportation environments (6). This need for redundancy was evident in all three systems because riders sought information to reassure themselves almost continuously during their trips.

The desire for such redundancy may be due to the sheer number of choice points compacted into even an average subway station. The simple trip from concourse to platform may involve knowing which stair to use, which platform side to wait by, which train to board on that side, and so on. The dynamic and crowded nature of the station along with the need to save time only make the situation more complicated.

Perceptual Access

The value of perceptual access is that it allows users to orient themselves within a structure in relation to the outside environment and its known landmarks. A useful quality for buildings in general, perceptual access can be especially important for the user of a subway system. With both the stations and line segments effectively hidden from surface view, visual access to the outside from within may well be the only way to get an idea of how the system relates to the city above. However, use of perceptual access for the purpose of subway system navigation must be tempered with care that the relationship between the rider's current station location and the observed landmark are functionally accurate in terms of the train network.

MARTA riders entering a newly opened station through which they could see the downtown Atlanta skyline directly ahead had no trouble in choosing the correct train platform. Riders entering from a direction not providing a view of the skyline were far less successful in making their platform choice correctly.

RECOMMENDED TRANSIT STATION DESIGN FEATURES

Based on the study results, the following is a list of design recommendations for subway stations that would facilitate passenger way finding.

Station Architecture

1. Stations should be designed to architecturally differentiate and distinguish the areas of a station serving different directions. Although actual structural features may be difficult to work into the functional design, much can be done through the use of architectural finishes, most obviously the color coding of inbound and outbound platforms. Whatever the method of differentiation, it should be consistently applied along a line or entire system in order to offer riders a recognizable, consistent, and dependable cue.
2. Where possible, train platforms and trackways should be visible from the concourse level in order to alert riders to the station's multiroute and multidestination nature as well as to provide an understanding of total station organization.
3. Stations should be structurally opened up wherever possible in order to provide perceptual access to outside landmarks. If intended as a navigation aid, the view to the landmark should relate functionally to the direction of trains from the station to the landmark.

Signage

1. Signs should be placed where they are clearly associated with their displayed destination information.
2. Signage information should be designed to discourage partial reading and resultant misinterpretation. This may involve a hierarchy of typefaces or letter sizes or both and an ordering of verbal information that will make the sign's message obviously incomplete unless the whole message is read.
3. Route and path information should be reinforced and restated both architecturally and by signs at every choice point along that route or path.

4. In systems serving cities with many known landmarks, verbal directional information can be reinforced and complemented by images of those landmarks, providing a link to the city above.

ACKNOWLEDGMENT

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Assessment of a High-Reliability Ticket Vendor Developed by PATCO

JACK E. CADIGAN and HOWARD B. WINKLER

ABSTRACT

A description and evaluation are given of a high-reliability ticket vendor (HRTV) developed by the Port Authority Transit Corporation (PATCO) of Pennsylvania and New Jersey. The ticket vendors are part of the automatic fare collection system used by PATCO in its rail operations. The HRTV evaluation has shown it to be superior in reliability and comparable in maintainability compared with other ticket vendors.

The objective of this paper is to describe and evaluate a ticket vendor recently developed by the Port Authority Transit Corporation (PATCO) of Pennsylvania and New Jersey to enable managers of transportation properties to assess the applicability of PATCO's vendor to their fare collection needs.

PATCO is a relatively small transit system that provides rail service between downtown Philadelphia and suburban Lindenwold, New Jersey, a distance of 14 miles with a total of 13 stations from end to end, for about 40,000 passengers per weekday and about 11 million passengers per year. The system, which began operation in 1969, is characterized by automatic train operation in which each train has a crew of one person and by automatic fare collection (AFC) in which the stations are unattended for long periods during each day. Ticket sales are made directly to the patrons by vending machines monitored by closed-circuit television (CCTV) cameras; the turnstiles, which subtract rides from the tendered magnetically encoded tickets and capture exhausted tickets, are also monitored by CCTV. PATCO's experience has demonstrated that AFC is workable, but it was found that the station equipment had high failure rates, which resulted in patron inconvenience and high maintenance costs. Following acquisition of new turnstile gates and some modifications, the gates now provide excellent service. Over the years there have been several programs to upgrade reliability of ticket vendors, but these programs have not achieved their design goals.

In 1977 a decision was made to initiate an in-house design of a high-reliability ticket vendor (HRTV). This effort was supported by an UMTA research and development grant financed by Section 6 funds. A prototype HRTV was developed and installed at the Lindenwold station on May 9, 1982. A first look at the operation and performance of this new vendor is provided in this paper.

HRTV DESCRIPTION

PATCO's HRTV, shown in Figure 1, is an exact-value ticket-dispensing vending machine (no change given) that can issue as many as three tickets of different values. It has been designed to accept large fares for issue of a single ticket and can accommodate any

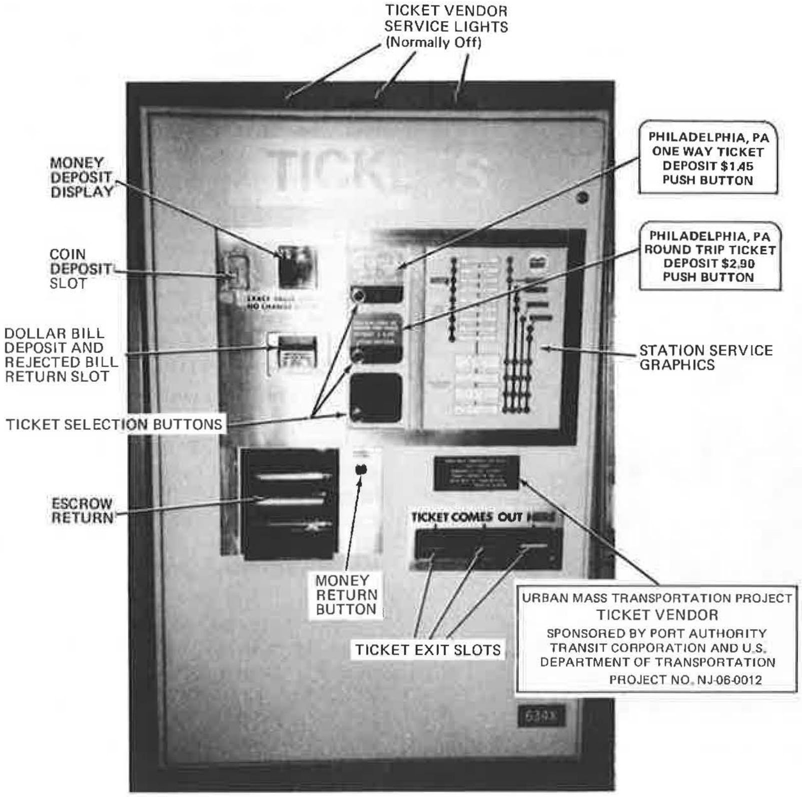

FIGURE 1 High-reliability ticket vendor (HRTV): operational configuration.

combination of nickels, dimes, quarters, Susan B. Anthony dollar coins, and one-dollar bills that add up to the exact fare. (Fifty-cent pieces can also be accepted, but current policy prohibits acceptance of this coin.)

HRTV design goals included (a) high reliability; (b) easy maintenance; (c) low equipment operations and maintenance costs; (d) greater use of electronic solid-state techniques and minimization of mechanical operations; (e) allowance for continued use of existing magnetically encoded tickets; (f) vending of recycled tickets, which may be slightly deformed and irregularly stacked; (g) use of presorted stacks of different ticket values; (h) design of subsystems to adjust to known problems of worn coins and bills and coin jams; (i) automatic issuance of tickets; (j) operation based on exact change (addition of a change maker, if desirable, is a minor retrofit); (k) operation in an outdoor environment; (l) no bill stacking; (m) no money counting in equipment; (n) acceptance of high-value escrow; (o) prevention and defeat of fraud; and (p) vandalproofing.

Vendor design has utilized the availability of CCTV surveillance. If a stack is jammed or out of tickets, one of three lights located on top of the cabinet is turned on when the internal logic detects the fault; if one of the other vendor subsystems fails, all three lights and a beeper are turned on. Figure 2 shows the vendor in a removed-from-service mode. Appropriate maintenance action is requested by the person monitoring the CCTV. The CCTV is also used to monitor the external physical security of the vendor. Internal security is maintained via separate locked coin and bill vaults and electromechanical counters that allow for determination of cash deposited and tickets sold.

A ticket can be vended only if the exact amount of money is deposited. At any point during the transaction before the ticket selection button is pressed and after the correct amount of money has been deposited, the MONEY RETURN button can be pushed and all the money being held in escrow will be returned. Light-emitting diodes (LEDs) display the sum of money deposited following insertion of each coin and bill. Figure 3 is a flowchart that presents the HRTV operation.

On the top left in Figure 3, the process of ticket purchase begins with START followed by DEPOSIT MONEY (words in capital letters refer to steps on the flowchart). The HRTV accepts dollar bills, Susan B. Anthony (SBA) dollar coins, quarters, dimes, and nickels. The HRTV currently dispenses tickets valued at $1.45 and $2.90, and any combination of bills and coins that add up to these values can be deposited in any order; it is possible to use two one-dollar bills for the higher-priced ticket. When a bill is deposited, the vendor assesses whether it is valid (VALID BILL?). If the bill is inserted into the bill slot with the incorrect orientation or has a value greater than one dollar or is badly worn or counterfeit, the bill will be rejected (REJECT BILL). Rejection takes place at the bill deposit slot, shown in Figure 1. If the bill is accepted, it goes into escrow within the vendor, and the amount deposited is displayed. Vendor logic determines whether each coin deposited is valid (VALID COIN?). If a one-cent coin or a slug is deposited, the VALID COIN? NO state exists and all coins and bills deposited will return from escrow. If a VALID COIN? YES state exists, the coin goes to escrow and the amount deposited is displayed. The next step in the sequence is TICKET BUTTON IS PUSHED.

If it is determined by the vendor logic that the

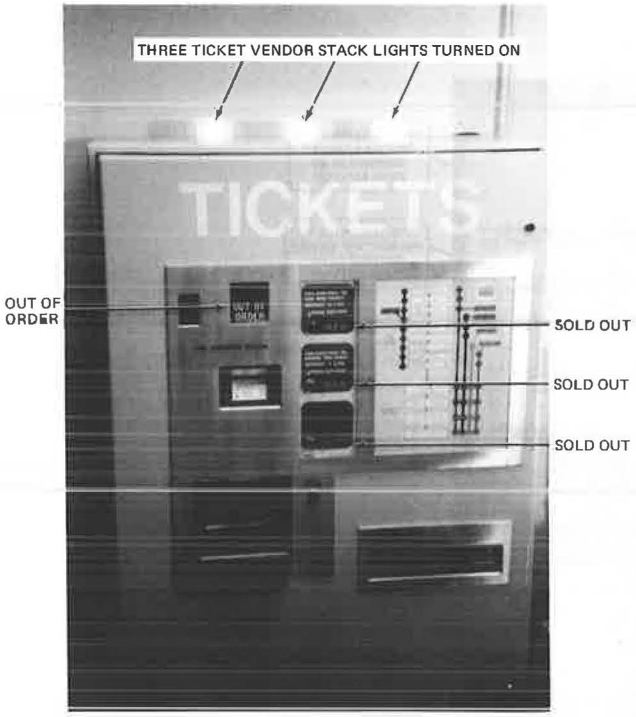

FIGURE 2 HRTV: removed-from-service configuration.

correct fare has not been paid, either an underpayment or an overpayment has been made. If there has been an underpayment, the next step is START OVER? If the patron decides not to start over, he determines the amount to be added and deposits the money, and the initial phase of DEPOSIT MONEY is repeated. If the patron decides to start over, he pushes the MONEY RETURN button, immediately after which the money is returned from escrow and the display returns to zero. The patron must then repeat the process, beginning with DEPOSIT MONEY. If there has not been an underpayment, an overpayment has been made, and the patron must push MONEY RETURN and follow the sequence shown in Figure 3, which will lead to a return of all money and require the patron to start over with the phase DEPOSIT MONEY.

If the correct fare has been deposited, the CORRECT FARE? YES branch is followed, and the START TICKET TRANSPORT process begins. A sensor determines whether the ticket advance has actuated the exit microswitch. If the response is no, the stack is taken out of service, and the stack lights are turned on. The patron must use another stack, push MONEY RETURN, and repeat the process at DEPOSIT MONEY.

The purpose of the exit microswitch is to ensure that if the ticket is not dispensed, the patron can get his money back. If the ticket advance has actuated the exit microswitch, the next step is for the vendor to vault escrow and capture the money. Another sensor determines whether the vault mechanism

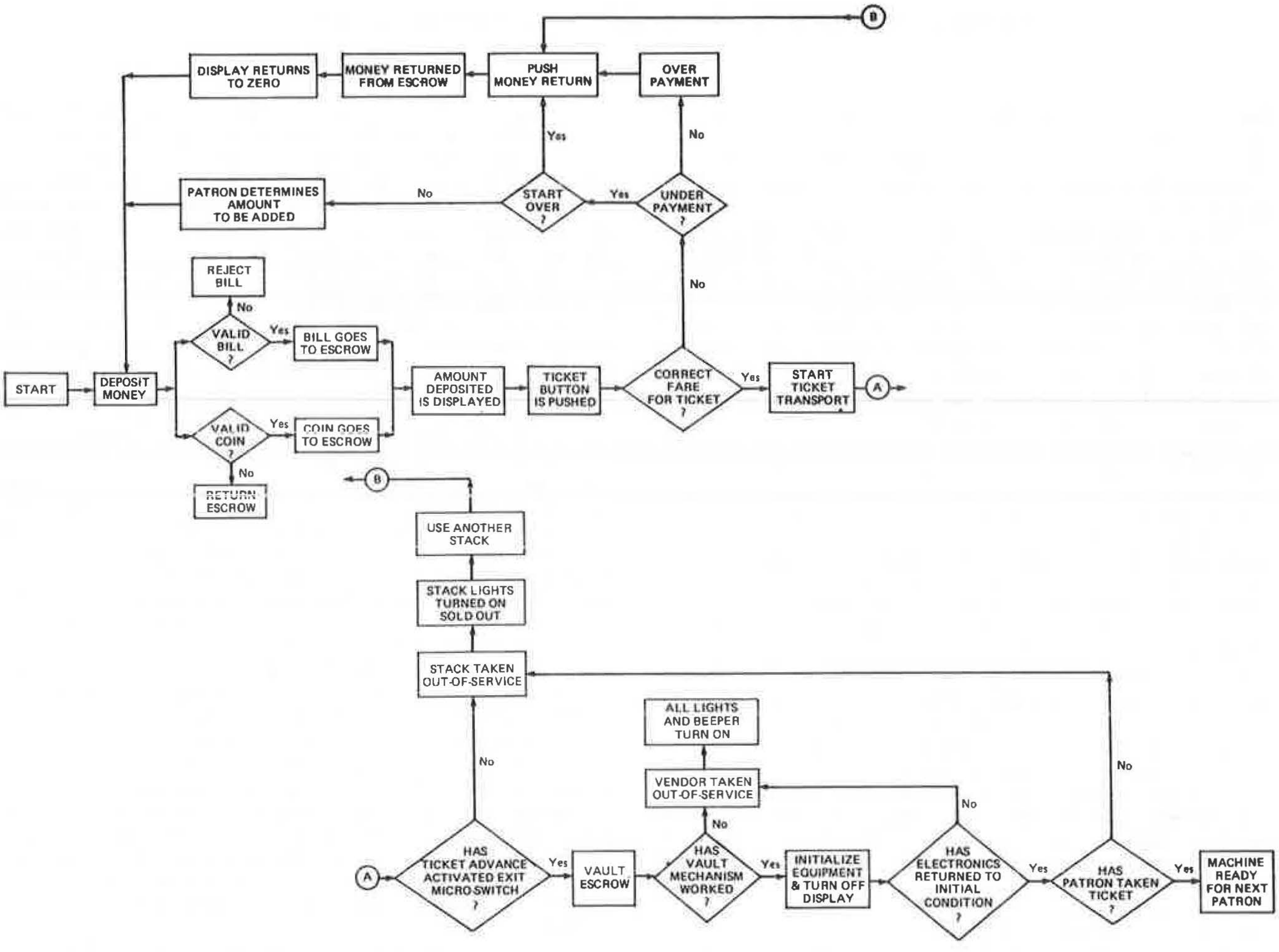

FIGURE 3 HRTV operations flowchart.

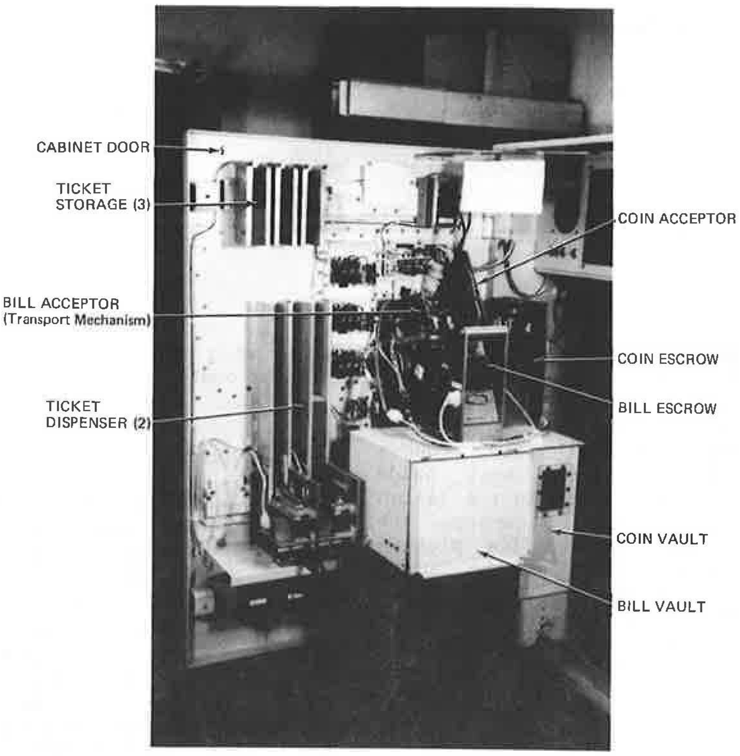

FIGURE 4 HRTV subsystems attached to door.

has worked. If not, the vendor is taken out of service and all lights and a beeper turn on. If the vault mechanism has worked, the vendor initializes the equipment and turns off the display. The vendor then performs a self-test to determine whether the electronics has returned to the initial condition. If not, the vendor is taken out of service, and if yes, it is next determined whether the patron has taken a ticket. If the answer is no, the stack is taken out of service and if yes, the machine is ready for the next patron.

There are 11 major HRTV subsystems, which include bill acceptor, bill escrow, bill vault, coin acceptor, coin escrow, coin vault, two ticket dispensers, command/control logic, nine transaction/ticket counters, power supply, and cabinet. Figure 4 shows the subsystems attached to the door, and Figure 5 shows the subsystems attached to the frame. The Rowe model BA-5 is the dollar-bill acceptor; the bills, if accepted, fall onto a belt in the bill escrow subsystem designed by PATCO. If a ticket is issued, the belt moves so as to deposit the bills in the vault, and if the MONEY RETURN button is pushed, the belt moves so as to deposit the bills in the till where they can be retrieved by the patron. The coin acceptor and coin escrow subsystems were also designed by PATCO. If a coin is accepted, it is held in escrow until the decision is made to make a ticket selection, at which time the container holding the coins pivots to allow the coins to fall into the vault; if a slug or one-cent coin is deposited or the MONEY RETURN button is pushed, all the coins (and bills) will be returned through the till. The most innovative feature of the HRTV is PATCO's design of the vendor picker unit, which on command pushes a ticket from the stack into the exit throat of the vendor where it can be extracted by the patron. In previous designs of power vendor units, the picker--a unit with small raised surfaces that pushes against the ticket--is fixed relative to the direction of the picker-arm stroke. It is necessary in this type of design that the relative dimensions between the picker surface and the ticket be held within a relatively small tolerance to ensure that only one ticket will be issued. The use of three

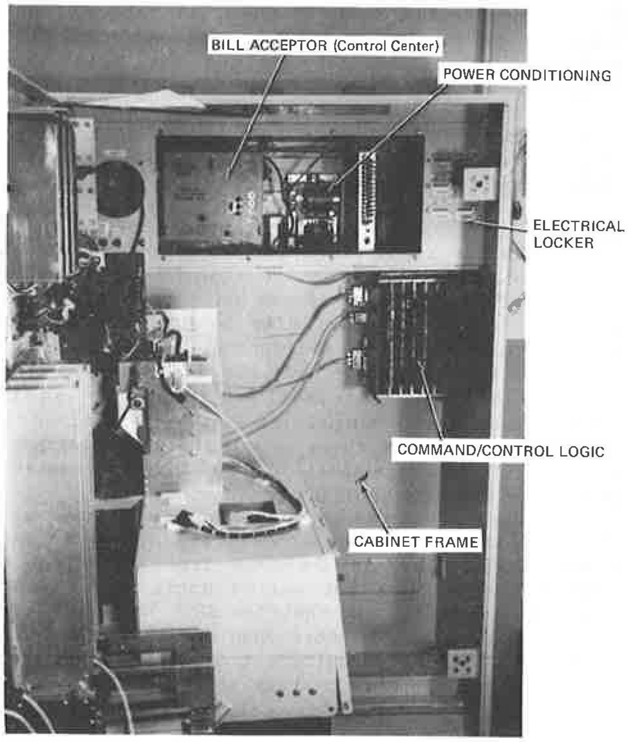

FIGURE 5 HRTV subsystems attached to frame.

TABLE 1 Vendor Reliability and Repair Performance

Equipment No.	Failures	Trials	Failure Rate	MCBF[a]	σ(MCBF)	MTTR[b]	σ(MTTR)
634 A	48	35,626	0.001347	742.21	784.15	0.3265	0.1816
X	7	19,074	0.000367	2,724.86	1,874.74	0.3375	0.1867
C	104	39,544	0.002630	380.23	318.25	0.3333	0.1208
D	55	33,186	0.001657	603.38	602.21	0.3018	0.1094
E	93	39,408	0.002630	423.74	379.37	0.3375	0.1867

[a] Mean cycles between failures.

[b] Mean time to repair (in hours).

gimballed joints in the HRTV allows for some relative motion between the picker surface and picker arm, and this greatly increases the acceptable tolerances in ticket shape and quality of stacking, which in turn improves reliability and reduces maintenance problems. Complementary metal oxide surface (CMOS) logic was used by PATCO in the design of the HRTV's command/control (C/C) subsystem. The C/C subsystem is distributed among five plug-in boards. An important design feature of the boards has been to locate in-line test points that normally read zero voltage along the outside edge; to trouble-shoot the vendor, the leads of a voltmeter are run along the test points in search of the fault, a nonzero reading.

HRTV PERFORMANCE

Reliability and maintainability data were collected during a 5-month test period from June 9 through November 11, 1982, for the HRTV as well as for the four Advanced Data System ticket vendors located at the Lindenwold station. The HRTV reliability performance over this period was estimated as 2,724.86 mean cycles between failures (MCBF), whereas the composite performance for the other four vendors was determined to be 492.55 MCBF. The performance as measured by MCBF and the mean time to repair (MTTR) during the 5-month test is shown in Table 1. [The composite performance for eight IBM and nine Cubic Western vendors operated by the Bay Area Rapid Transit was found to be 140.80 MCBF (1).] Significance testing of the MCBF for the HRTV and the four other vendors at Lindenwold indicated that there was only a 0.1 percent probability that the observed results could be due to chance.

It was determined that the mean time to repair the HRTV is 0.3375 hr and that this time is comparable with the repair time for the other vendors at Lindenwold. Repair time is the time to trouble-shoot and replace vendor subsystems on site; it was not possible to include shop time because the HRTV is unique. Based on this evaluation, it appears that the field service repair time has not been improved. The HRTV has the same level of complexity as the other vendors and turnstiles being maintained by PATCO personnel, so there should be no requirement for additional personnel or equipment resources other than a short training program.

Data were collected over a 3-day period to assess the service time of the vendors at Lindenwold station; service time is the time from initiation of currency deposit by the patron until a ticket is dispensed. It was found that the HRTV is much slower than the other four vendors when about nine deposits or less are made to acquire a ticket. If nine deposits are made, the service time of the HRTV is comparable with that of the other vendors, and for a greater number of deposits the HRTV is faster.

CONCLUSIONS

PATCO set out to design and manufacture a ticket vendor with improved reliability to meet the performance needs of operation within unattended stations and maintainability to reduce the costs associated with vendor operation. Based on this test and evaluation, it has been demonstrated that the reliability is significantly superior to that of the other vendors in the test group as well as superior to that of the vendors reported in the literature. Based on the test results, it was determined that the maintainability should be comparable with that of the other PATCO vendors and that no additional resources beyond those that exist at PATCO should be needed for performance of maintenance.

Consideration should be given to (a) assessment of expected reduction in reliability of a mass-produced X-vendor in comparison with the prototype X-vendor, (b) addition of a money changer, (c) redesign to allow for large-scale production, (d) purchase of a sufficient number of vendors and spare parts to provide all-automatic ticket vending at one or more stations, and (e) development of an acquisition cost data base to permit scaling of vendor acquisition for orders of different sizes. The vendors would be used in a demonstration to acquire a vendor reliability and maintainability data base, an operating-cost data base, a passenger utilization data base, and service-time data to permit definition of the number of vendors and money changers needed to accommodate various rates of patron traffic.

ACKNOWLEDGMENT

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