CONFERENCE PROCEEDINGS 8

SEVENTH NATIONAL CONFERENCE ON LIGHT RAIL TRANSIT VOLUME 1

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

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SEVENTH NATIONAL CONFERENCE ON LIGHT RAIL TRANSIT
VOLUME 1

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Foreword

The 1995 National Conference on Light Rail Transit (LRT) is the seventh such meeting. At the first conference, held in Philadelphia in June 1975, the technical session focused on introducing—or reintroducing—the concept of LRT in North America.

Now, 20 years later, there are 20 North American LRT systems in operation (including 11 urban areas that have initiated LRT systems since the first conference), eight areas with new starts or extensions under construction, and numerous others in various stages of planning and engineering.

The six prior national conferences have paralleled the development and reintroduction of LRT in North America. The technical information contained in the Proceedings of these conferences provides the planner, designer, decision maker, and operator with a rich bounty of experiences and ingredients necessary to a successful transit development project. The evolution of LRT experience is shown by the focus of the previous conferences:

- 1975—Reintroduction to LRT (Philadelphia, TRB *Special Report 161*),
- 1978—Planning and technology (Boston, TRB *Special Report 182*),
- 1982—Planning, design, and implementation (San Diego, TRB *Special Report 195*),
- 1985—System design for cost-effectiveness (Pittsburgh, TRB *State-of-the-Art Report 2*),
- 1988—New system successes at affordable prices (San Jose, TRB *Special Report 221*), and
- 1992—Planning, design, and operating experience (Calgary, *Transportation Research Record 1361*).

The seventh national conference emphasizes the lessons resulting from the maturing of North American LRT systems. Thus, the Conference Planning Committee decided that the conference title should be "Building on Success—Learning from Experience."

The conference also features the Transportation Research Board (TRB) and the American Public Transit Association (APTA) as cosponsors. This partnership is a formal recognition of the mutual and supportive respect for each other's aims and purposes in a cooperative conference venture.

Finally, there is the conference itself and the wealth of technical material offered in it. There are 18 sessions and several technical tours of Baltimore's LRT system. The Transit Cooperative Research Program, which was introduced by the Intermodal Surface Transportation Efficiency Act of 1991, is featured with two sessions. Other subjects cover the state of the art in light rail vehicles, intermodal connections, implications of the Americans with Disabilities Act, urban design considerations, safety and security planning, and operations and maintenance issues.

The objective of these conferences is to add to the growing body of knowledge and real-world experiences with modern LRT applications in order to continuously improve the systems being planned and those already in operation. Success can be fleeting, and we need to learn from past experience in order to do a better job of providing cost-effective public transportation services. The information, data, and research contained in these proceedings are meant to serve this need.

Thomas F. Larwin, Chairman, Conference Planning Committee
General Manager, San Diego Metropolitan Transit Development Board

PART 1
POLICY AND PLANNING FOR LIGHT RAIL TRANSIT SYSTEMS

Operating System Status

Status of North American Light Rail Transit Systems: 1995 Update

John W. Schumann and Suzanne R. Tidrick, *LTK Engineering Services*

Progress in light rail transit (LRT) in North America since the last National Light Rail Conference in 1992 is summarized. Existing system rehabilitation and new project planning, design, construction, and start-up activities are discussed. To depict the effects of recent changes in the North American LRT situation, the text and tables update information presented at earlier LRT conferences. Highlights of progress since 1992 include three more new-start LRT systems opened in Baltimore, St. Louis, and Denver; completion of the Los Angeles Green Line in mid-1995; and final design or construction of new starts in Dallas and downtown Chicago as well as on extensions in Portland, Baltimore, San Jose, Los Angeles, San Diego, Sacramento, and Cleveland. Other LRT systems continue to make improvements and renewals. Planning and preliminary design continue in several more places. With older systems largely renewed and a continuing string of new starts and extensions, LRT continues to be the affordable rail mode for an increasing number of cities. Current LRT projects encompass areas in which LRT is a natural step up from an all-bus system, as well as places that have discarded proposals for more technically novel or costlier guideways.

Twenty years and 90 mi separate the current meeting from the Transportation Research Board's (TRB's) first national light rail conference, in Philadelphia in 1975. Light rail and streetcar systems survived then in only eight U.S. cities, Toronto, and Mexico City. Aided by federal funds, Boston and San Francisco ordered replacements for aging car fleets, and several cities were comparing light rail transit (LRT) new starts with other technologies in alternatives analyses.

Much progress has been made in two decades. Older systems have been renovated, and new LRT systems are operating in 13 North American urban areas: nine in the United States and two each in Canada and Mexico.

As the latest in a series of TRB papers on this topic dating to 1977, this version updates the 1992 edition. Tables 1–6 provide information on the alignment characteristics, revenue vehicles, and operations of 22 physically distinct LRT systems in 20 U.S. and Canadian cities. Information is current as of the end of 1994.

Differences Among Light Rail, Streetcars, and Minimetros

A recurring topic among transit professionals and enthusiasts is the debate over just what LRT is or is not. Because light rail can be located so flexibly and encompasses a spectrum of applications, this debate probably will continue. TRB's Committee on Light Rail Transit uses this definition:

> Light rail transit is a metropolitan electric railway system characterized by its ability to operate single cars or

TABLE 1 Line Lengths, Car Fleets, and Productivity Indicators

	Parameters			Statistics		
City/System	One-Way Line km(mi)	No. of Cars	Rides/ Weekday	Cars/ km(mi)	Rides/ km(mi)	Rides/ Car
LRT-Group I:						
Baltimore, Central Corridor(d)	35.4(22.0)	35	20000	1.0(1.6)	565(909)	571
Calgary, C-Train(a)	29.3(18.2)	85	114500	2.9(4.7)	3908(6291)	1347
Cleveland, Shaker Rapid(b)	21.1(13.1)	48	9900	2.3(3.7)	469(756)	206
Denver, MAC(d)	8.5(5.3)	11	15000	1.3(2.1)	1765(2830)	1364
Edmonton, LRT(a)	12.3(7.6)	37	36000	3.0(4.9)	2927(4737)	973
Los Angeles, Long Beach (a)	35.4(22.0)	54	42000	1.5(2.5)	1186(1909)	778
Newark, City Subway(b)	6.9(4.3)	24	16800	3.5(5.6)	2435(3907)	700
Phila. Media-Sharon Hill(b)	19.2(11.9)	29	8200	1.5(2.4)	427(689)	283
Portland, MAX(a)	24.3(15.1)	26	24500	1.1(1.7)	1008(1541)	942
Sacramento, RT Metro(a)	29.5(18.3)	36	24300	1.2(2.0)	824(1328)	675
St. Louis, MetroLink(d)	29.0(18.0)	31	40000	1.1(1.7)	1379(2222)	1290
San Diego Trolley(a)(e)	55.4(34.4)	71	45000	1.3(2.1)	812(1308)	634
San Jose, Guadalupe(a)	32.2(20.0)	50	20000	1.6(2.5)	621(1000)	400
Subtotals/Averages	338.5(210.2)	537	416200	1.6(2.6)	1230(1980)	775
LRT-Group II:						
Boston, Green Line(b)	40.1(24.9)	220	213000	5.5(8.8)	5312(8554)	968
Boston, Mattapan-Ashmont(b)	4.3(2.7)	12	7000	2.8(4.4)	1628(2593)	583
Buffalo, MetroRail(a)	10.3(6.4)	27	28000	2.6(4.2)	2718(4375)	1037
Ft. Worth, Tandy	1.6(1.0)	8	5900	5.0(8.0)	3688(5900)	738
New Orleans, St Chas/Riverfront(b)	14.0(8.7)	41	26000	3.1(5.0)	1857(2989)	634
Philadelphia, Subway-Surface(b)	35.9(22.3)	112	77500	3.1(5.0)	2159(3475)	692
Pittsburgh, South Hills(b)	31.2(19.4)	71	29000	2.3(3.7)	929(1495)	408
San Francisco, Muni Metro(c)	39.1(24.4)	128	134300	3.3(5.2)	3435(5504)	1049
Toronto, Streetcars	75.5(46.9)	267	307100	3.5(5.7)	4068(6548)	1150
Subtotals/Averages	252.0(156.7)	886	827800	3.5(5.7)	3285(5283)	934
Totals/Averages	590.5(366.9)	1423	1244000	2.4(3.9)	2107(3391)	874

(a) New start opened since 1977; (b) Major reconstruction/rehabilitation since 1977; (c) Upgraded from streetcar to LRT standards since 1977; (d) New start opened since 1992; (e) LRV fleet shown (71 cars) excludes 34 new SD100 cars on site but not in service, as well as 18 more SD100s due in 1995.

short trains along exclusive rights of way at ground level, on aerial structures, in subways or, occasionally, in streets, and to board and discharge passengers at track or car-floor level.

This wording is intended to describe the technology that has emerged on new systems completed during the past quarter century while not categorically excluding streetcar systems that may be upgraded in whole or in part to LRT standards (i.e., reservation of some or all trackways from other traffic). At the same time, the definition specifically separates LRT from systems that are not propelled by electricity and those guideways—whether automated or manually operated—for which full grade separation is mandatory, namely,

- Automated systems that cannot interact with street traffic (at least, not yet); and
- Systems taking electric power from a third rail, which is not compatible with at-grade street operation whether in mixed traffic or reserved lanes.

Although their opinion is not universally shared, the authors believe the TRB definition, strictly interpreted, excludes certain systems that otherwise have some LRT characteristics:

- Philadelphia's grade-separated, third-rail Norristown High Speed Line, which nonetheless runs mostly single cars and collects fares on board;
- Vancouver's Skytrain, a "mini-metro" whose automated controls and linear induction motors preclude at-grade operation over crossings or in streets; and
- Chicago's Skokie Swift, with its modified subway-elevated cars, and South Shore Line, which has changed over time from country interurban to heavy-duty commuter railroad.

Even without these lines, there are now enough LRT systems on this continent to illustrate a broad range of facility, vehicle, and service applications.

Like the cities that they serve, LRT systems are never really finished. Facilities and vehicles must be renewed and replaced periodically as they reach the ends of their useful lives. For newer systems, and some older ones too, extensions and new lines are being built or planned to tap additional markets. Progress since 1992 is summarized here by city, starting with new starts opened

TABLE 2 Key Descriptive Statistics

City/System	Portion of R/W Reserved	Average Stop Spacing	Double Track	Through Service Routes	Number of Cars: 4-Axle(a)	Number of Cars: 6-Axle(b)	System Average Speed
	(%)	km(mi)	(%)	(No.)	(No.)	(No.)	km(mi)/hr
LRT-Group I:							
Baltimore, Central Corridor	100%	0.7(1.1)	61%	1	0	35	35(22)
Calgary, C-Train	100%	0.9(0.6)	100%	3	0	85	29(18)
Cleveland, Shaker Rapid	100%	0.8(0.5)	100%	2	0	48	30(18)
Denver, MAC	100%	0.8(0.5)	94%	1	0	11	23(14)
Edmonton, LRT	100%	1.3(0.8)	100%	1	0	37	30(19)
Los Angeles, Long Beach	100%	1.6(1.0)	100%	1	0	54	34(21)
Newark, City Subway	100%	0.6(0.4)	100%	1	24	0	28(18)
Phila, Media-Sharon Hill	87%	0.4(0.2)	71%	2	29	0	26(16)
Portland, MAX	99%	0.9(0.6)	89%	1	4(c)	26	30(19)
Sacramento, RT Metro	84%	1.0(0.7)	68%	1	0	36	34(21)
St. Louis, MetroLink	100%	1.5(1.0)	97%	1	0	31	43(27)
San Diego Trolley (d)	100%	1.6(1.0)	99%	2	0	71	30(20)
San Jose, Guadalupe	100%	1.1(0.7)	95%	2	6(c)	50	32(20)
Subtotals/Averages	98%	1.0(0.6)	90%	19	63	484	---
LRT-Group II:							
Boston, Green Line	89%	0.5(0.3)	100%	4	0	220	22(13)
Boston, Mattapan-Ashmont	100%	0.5(0.3)	100%	1	12	0	20(12)
Buffalo, MetroRail	100%	0.7(0.5)	100%	1	27	0	20(12)
Fort Worth, Tandy	100%	0.3(0.2)	100%	1	8	0	17(11)
New Orleans, St Chas/Riverfront	90%	0.2(0.1)	100%	2	41	0	15(9)
Philadelphia, Subway-Surface	17%	0.2(0.1)	100%	5	112	0	18(11)
Pittsburgh, South Hills	82%	0.5(0.3)	88%	4	16	55	26(16)
San Francisco, Muni Metro	45%	0.2(0.1)	100%	5	0	128	18(11)
Toronto, Streetcars	10%	0.1(0.1)	100%	10	215	52	15(9)
Subtotals/Averages	48%	0.2(0.1)	97%	33	431	455	---
Totals	77%	0.4(0.2)	93%	52	494	939	---

(a) Non-articulated, rigid body; (b) Articulated; (c) Vintage trolley cars for downtown loop, not included in totals; (d) See footnote (e) on Table 1.

since then and notes on existing systems in the United States, Canada, and Mexico.

New Starts Since Previous Update (1992–1994)

Three more new starts have opened just since 1992: in Baltimore, St. Louis, and Denver. In each city, the first LRT line is designated as the *central corridor*.

Baltimore

Maryland's Mass Transit Administration added LRT to its multimodal system in the Baltimore region when the northern half of its central corridor line was opened in May 1992. Just over a year later, the southern half entered revenue service, completing a 35-km (22-mi) starter line between Timonium and Glen Burnie. Former railroad lines, including a section of the abandoned Baltimore-Annapolis interurban, are connected through downtown Baltimore using tracks in reserved lanes on Howard Street.

Baltimore's cars are 29 m (95 ft) long and 2.9 m (9.5 ft) wide and are the first in North America with alternating current (AC) propulsion. Since opening, weekday patronage has grown to 20,000.

Three extensions to the basic line were contemplated in the original planning: north to Hunt Valley, at the edge of downtown to an Amtrak connection at Penn Station, and off the south line to Baltimore-Washington International Airport. These will increase the system to nearly 47 km (29 mi). It was decided to have these built under a single design-build contract, which was bid in 1994 and awarded to Whiting-Turner for completion in 1997.

St. Louis

At the end of July 1993, Bi-State Development Agency began service on *MetroLink*, an LRT line linking East St. Louis, Illinois, and downtown St. Louis, Missouri, with a chain of activity centers to the northwest: hospitals, the University of Missouri at St. Louis, Forest Park, Busch Stadium, and other leisure attractions. Completed to its full 29-km (18-mi) length in June 1994, the line now reaches Lambert Airport, the regional hub for commercial flight. Bi-State created an enhanced transit system by connecting many activity centers and carefully coordinating LRT with suburban

TABLE 3 Right-of-Way Locations

	km(mi) of Line						
City/System	Subway/ Tunnel	Exclusive R/W	Private R/W	Street or Highway Median	Reserved St. Lanes or Mall	Mixed Traffic	Total
		(a)	(b)	(c)	(d)	(e)	
LRT-Group I:							
Baltimore, Central Corridor	---	---	32.2(20.0)	---	3.2(2.0)	---	35.4(22.0)
Calgary, C-Train	1.9(1.2)	1.3(0.8)	13.2(8.2)	10.5(6.5)	2.4(1.5)	---	29.3(18.2)
Cleveland, Shaker Rapid	---	11.3(7.0)	---	9.8(6.1)	---	---	21.1(13.1)
Denver, MAC	---	---	5.6(3.5)	---	2.9(1.8)	---	8.5(5.3)
Edmonton, LRT (f)	4.7(2.9)	---	7.6(4.7)	---	---	---	12.3(7.6)
Los Angeles, Long Beach	0.8(0.5)	---	29.8(18.5)	3.2(2.0)	1.6(1.0)	---	35.4(22.0)
Newark, City Subway	2.1(1.3)	4.8(3.0)	---	---	---	---	6.9(4.3)
Phila, Media-Sharon Hill	---	---	16.3(10.1)	---	0.3(0.2)	2.6(1.6)	19.2(11.9)
Portland, MAX	---	8.7(5.4)	3.7(2.3)	8.4(5.2)	3.4(2.1)	0.1(0.1)	24.3(15.1)
Sacramento, RT Metro	---	9.5(5.9)	12.4(7.7)	1.0(0.6)	1.8(1.1)	4.8(3.0)	29.5(18.3)
St. Louis, MetroLink	1.3(0.8)	16.0(9.9)	11.7(7.3)	---	---	---	29.0(18.0)
San Diego Trolley	---	---	51.8(32.2)	1.6(1.0)	2.0(1.2)	---	55.4(34.4)
San Jose, Guadalupe	---	15.8(9.8)	1.8(1.1)	13.5(8.4)	1.1(0.7)	---	32.2(20.0)
Subtotals	10.8(6.7)	67.4(41.8)	186.1(115.6)	48.0(29.8)	18.7(11.6)	7.5(4.7)	338.5(210.2)
LRT-Group II:							
Boston, Green Line	7.2(4.5)	17.1(10.6)	---	11.4(7.1)	---	4.4(2.7)	40.1(24.9)
Boston, Mattapan-Ashmont	---	4.3(2.7)	---	---	---	---	4.3(2.7)
Buffalo, MetroRail	8.4(5.2)	---	---	---	1.9(1.2)	---	10.3(6.4)
Fort Worth, Tandy	0.6(0.4)	---	1.0(0.6)	---	---	---	1.6(1.0)
New Orleans, St. Chas/Riverfront	---	---	3.5(2.2)	9.0(5.6)	0.2(0.1)	1.3(0.8)	14.0(8.7)
Philadelphia, Subway-Surface	4.0(2.5)	---	---	1.9(1.2)	---	30.0(18.6)	35.9(22.3)
Pittsburgh, South Hills	3.4(2.1)	---	22.2(13.8)	---	---	5.6(3.5)	31.2(19.4)
San Francisco, Muni Metro	10.2(6.4)	---	1.2(0.8)	6.3(3.9)	---	21.4(13.3)	39.1(24.4)
Toronto, Streetcars	1.0(0.6)	---	2.6(1.6)	4.0(2.5)	---	67.9(42.2)	75.5(46.9)
Subtotals	34.8(21.7)	21.4(13.3)	30.5(19.0)	32.6(20.3)	2.1(1.3)	130.6(81.1)	252.0(156.7)
Totals: km(mi)	45.6(28.4)	88.8(55.1)	216.6(134.6)	80.6(50.1)	20.8(12.9)	138.1(85.8)	590.5.(366.9)
% Total	8%	15%	37%	14%	3%	23%	100%

(a) Aerial or surface with no grade crossings; (b) Surface, LRT private R/W with grade crossings; (c) Surface, reserved medians of highways and streets with grade crossings; (d) Surface, reserved lanes (other than medians) and LRT/pedestrian malls: (e) Street lanes shared by LRT and other traffic; "streetcar" operations; (f) Saskatchewan River bridge included under Subway.

buses. In late 1994, weekday LRT patrons numbered about 40,000.

Like almost every other city with a new-start LRT line, St. Louis has extensive plans for expansion. Encouraged hy the success of the starter line, voters in St. Clair County, by a 2:1 margin, have already approved a half-cent sales tax increase to provide the local share for a 40-km (25-mi) easterly extension from East St. Louis to Belleville and Scott Air Force Base. With private right of way, 13 stations, and average stop spacing of 3.1 km (1.9 mi), it should be one of the faster new LRT lines.

Denver

The newest start hegan revenue service in October 1994, when the Regional Transportation District (RTD) opened the 8.5-km (5.3-mi) *Metro Area Connection* (MAC). Using local funds to break a 20-year pattern of "analysis paralysis," RTD achieved several objectives:

- Provided enhanced transit to downtown Denver and adjacent neighborhoods;
- Set technology and design criteria for budget-conscious extensions;
- Completed two typically expensive elements of system construction: downtown trackage in streets and the maintenance shop for a regional network; and
- Removed several hundred daily bus runs from streets approaching downtown.

At 15,000, initial weekday ridership exceeded the forecast by 1,000, and RTD quickly ordered six more light rail vehicles (LRVs). Engineering is already in progress for a 14-km (8.7-mi) southwest extension to Englewood and Littleton. In addition, the region has embarked on major investment studies (MIS) in three more corridors: southeast along I-25, west to Lakewood, and east to the new airport.

Existing Systems in the United States

Boston

Serving the heart of the Boston metropolitan area, the Green Line network carries more people per weekday

TABLE 4 Stations, Double Tracking, Electrification, and Signaling

City/System	Passenger Stations & Car Stops	Double Track km(mi)	Traction Power	Substations		Type of Overhead	Signals	
				No.	Rating		Block	Traffic
	No.	(a)	(VDC)		(mW)	(b)	(c)	(c)
LRT-Group I:								
Baltimore, Central Corridor	25	21.7(13.5)	750	14	1	Catenary	91%	9%
Calgary, C-Train	31	29.3(18.2)	600	17	≤2	Both	92%	8%
Cleveland, Shaker Rapid	28	21.1(13.1)	600	6	(d)	Catenary	84%	46%
Denver, MAC	11	8.0(5.0)	750	7	1	Both	60%	40%
Edmonton, LRT	10	12.3(7.6)	600	8	2	Catenary	100%	---
Los Angeles, Long Beach	22	35.4(22.0)	750	21	(i)	Both	86%	14%
Newark, City Subway	11	6.9(4.3)	600	4	0.75	Trolley	100%	---
Phila. Media-Sharon Hill	50	13.7(8.5)	635	4	(h)	Trolley	50%	25%
Portland, MAX	26	21.6(13.4)	750	14	0.75	Both	52%	48%
Sacramento, RT Metro	29	20.1(12.5)	750	14	1	Both	77%	23%
St. Louis, MetroLink	18	28.0(17.4)	750	12	1.5	Catenary	100%	---
San Diego Trolley	36	54.7(34.0)	600	21	1	Both	94%	6%
San Jose, Guadalupe	30	30.9(19.2)	750	15	1.5	Both	58%	42%
Subtotals	327	303.7(188.7)	---	---	---	---	---	---
LRT-Group II:								
Boston, Green Line(f)	84	40.1(24.9)	600	11	3-6	Trolley	61%	39%
Boston, Mattapan-Ashmont(g)	8	4.3(2.7)	600	1	6	Trolley	100%	---
Buffalo, MetroRail	14	10.3(6.4)	650	5	2	Catenary	81%	19%
Forth Worth, Tandy	5	1.6(1.0)	600	1	(h)	Trolley	---	---
New Orleans, St. Chas/Riverfront	55	14.0(8.7)	600	(h)	(h)	Trolley	---	100%
Philadelphia, Subway-Surface	167	35.9(22.3)	600	(e)	---	Trolley	11%	89%
Pittsburgh, South Hills	74	27.4(17.0)	640	6	6	Both	90%	10%
San Francisco, Muni Metro	204	35.6(22.1)	600	12	2-8	Trolley	19%	81%
Toronto, Streetcars	616	75.5(46.9)	600	(h)	(h)	Trolley	---	100%
Subtotals	1227	244.7(152.0)	---	---	---	---	---	---
Totals	1554	548.4(340.7)	---	---	---	---	---	---

(a) Includes paired 1-way street single tracks functioning as double track; (b) Type of Construction: Catenary, Trolley, or Both; (c) % of line km(mi) equipped: Blk-Block Signals; Tfc-Traffic Lights; May not add to 100% as some segments have no signals, others both Blk & Tfc; (d) 1.5 and 3.0 mW; (e) 28 major substations serve all electric transit in City of Philadelphia; (f) 4 of 11 substations also serve other lines; (g) Substation also provides power to Red Line rapid transit; (h) Data not available at time of publication; (i) 19 @ 1.5 mW plus 2 @ 3.0 mW

than any other LRT system in this survey. Boston's system of five LRT routes includes North America's oldest transit subway, dating from 1897. There is a strong emphasis on system renovation and renewal.

Breda has been awarded an order for 100 new articulated low-floor LRVs (LFLRVs) to initiate accessible service and replace the remaining Boeing cars. The 22-m (72-ft) cars will have low floors through about two-thirds of their length, with high floors above conventional powered trucks at each end.

Remaining president's conference committee (PCC) cars assigned to the Mattapan-Ashmont feeder to the Red Line rapid transit have been refurbished.

Green Line physical changes contemplated include relocation from elevated structure to subway at North Station and relocation of the Lechmere terminus to a new site that will improve its operation and capacity and set the stage for eventual extension.

Newark

Since its surface streetcar feeders were pruned in the early 1950s, the Newark City Subway has continued as New Jersey's only LRT line. Facilities were largely renewed in the 1980s, but nearly 50-year-old PCC cars continue in service. NJ Transit is working to dovetail their replacement with car purchases for new lines in the Newark area and elsewhere in the state.

Conceptual specifications for vehicles to replace the City Subway fleet of 24 PCC cars contemplate an articulated LFLRV about 27 m (88 ft) long, with about two-thirds of its length at the low floor level between high floors over conventional power trucks at each end. This design might become a standard New Jersey LRV for use on other planned lines.

Introduction of the new fleet is expected to require facility changes, including a new maintenance shop beyond the outer end of the City Subway line, and conversion of the electrification for more powerful, pantograph-equipped cars.

NJ Transit is planning three new LRT lines. The Hudson Waterfront Connector is being readied for implementation under a turnkey contract, and the Newark-Elizabeth Rail Link (which would be physically connected to the City Subway) and a Moorestown-Camden-Woodbury line in southern New Jersey are farther back in the planning pipeline.

TABLE 5 Revenue Service Vehicles

City/System	Car Types	Characteristics of Car Equipment					
		Builder	Fleet	Accelrtn	Max Spd	Length	Weight
	(a)			(b)	(c)	(d)	(e)
LRT-Group I:							
Baltimore, Central Corridor	LRV-6-A	ABB	35	1.3(3.0)	88(55)	29(95)	50(55)
Calgary, C-Train (f)	LRV-6-A	Siemens	85	1.0(2.2)	80(50)	24(80)	32(35)
Cleveland, Shaker Rapid	LRV-6-A	Breda	48	1.3(3.0)	88(55)	24(80)	40(45)
Denver, MAC	LRV-6-A	Siemens	11	1.3(3.0)	88(55)	24(80)	37(41)
Edmonton, LRT	LRV-6-A	Siemens	37	1.0(2.2)	80(50)	24(80)	40(45)
Los Angeles, Long Beach	LRV-6-A	Nippon-Sharyo	54	1.3(3.0)	88(55)	27(89)	43(47)
Newark, City Subway	PCC-4-R	St. Louis	24	1.8(4.0)	72(45)	14(46)	17(19)
Phila. Media-Sharon Hill	LRV-4-R	Kawasaki	29	1.3(3.0)	100(62)	16(53)	27(30)
Portland, MAX	LRV-6-A	Bombardier	26	1.3(3.0)	88(55)	27(89)	42(46)
Sacramento, RT Metro	LRV-6-A	Siemens	36	1.1(2.5)	80(50)	24(80)	36(40)
St. Louis, MetroLink	LRV-6-A	Siemens	31	1.3(3.0)	88(55)	26(86)	41(45)
San Diego Trolley	LRV-6-A	Siemens	71	1.0(2.2)	80(50)	24(80)	33(36)
San Jose, Guadalupe	LRV-6-A	UTDC	50	1.3(3.0)	88(55)	27(89)	45(49)
Subtotals			537				
LRT-Group II:							
Boston, Green Line	LRV-6-A	Kinki	100	1.3(2.8)	80(50)	22(72)	38(42)
(Also In Service)	LRV-6-A	Boeing	110	1.3(3.0)	84(52)	22(72)	30(33)
Boston, Mattapan-Ashmont	PCC-4-R	Various	12	1.8(4.0)	72(45)	14(46)	17(19)
Buffalo, MetroRail	LRV-4-R	Tokyu	27	1.3(3.0)	80(50)	20(67)	30(33)
Fort Worth, Tandy	PCC-4-R	St. Louis	8	1.8(4.0)	72(45)	14(46)	17(19)
New Orleans, St. Chas/Riverfront	VTL-4-R	Perley-Thomas	41(g)	0.8(1.7)	43(27)	14(48)	19(21)
Philadelphia, Subway-Surface	LRV-4-R	Kawasaki	112	1.3(3.0)	80(50)	15(50)	26(29)
Pittsburgh, South Hills	LRV-6-A	Siemens	55	1.3(3.0)	80(50)	26(84)	36(40)
(Also in Service)	PCC-4-R	St. Louis	16	1.8(4.0)	72(45)	14(46)	17(19)
San Francisco, Muni Metro	LRV-6-A	Boeing	128	1.3(3.0)	84(52)	22(72)	30(33)
Toronto, Streetcars	LRV-4-R	UTDC	196	1.5(3.2)	85(53)	16(53)	23(26)
(Also in Service)	LRV-6-A	UTDC	52	1.3(3.0)	80(50)	23(75)	37(40)
(Also in Service)	PCC-4-R	Various	19	1.8(4.0)	72(45)	14(46)	17(19)
Subtotals			876				
Total			1413				

(a) See Note (a) on next page; (b) Initial acceleration: meters/sec/sec(mi/h/sec); (c) km/h (mi/h); (d) Meters (feet overall, to nearest full unit; (e) Metric tons (short tons); (f) Fleet includes 83 cars with DC propulsion plus 2 with AC drives.
(g) Includes 3 ex-Melbourne cars on Riverfront Line.

(*continued on next page*)

Philadelphia

LRT operations on five West Philadelphia lines and the Media–Sharon Hill suburban routes remain essentially unchanged from 1992, except that limited peak-period service using two-car trains has begun on two subway-surface lines. Three North Philadelphia streetcar lines are closed: 15-Girard, 23-Germantown/South Philadelphia, and 56-Erie. Because they are being operated by buses, these lines have been omitted from the data tables.

On a more upbeat note, a new trolley loop opened in 1995 to link the new convention center near the former Reading Terminal with other tourist-oriented places in the center city.

The Southeastern Pennsylvania Transportation Authority (SEPTA) has created a light rail operations unit directed by a chief officer. In addition to having responsibility for day-to-day LRT service, this group is considering the two major related projects. Procurement of new accessible LRVs for subway-surface lines could release enough Kawasaki cars to reopen the streetcar lines in North Philadelphia. SEPTA and the city agree that these three lines will be restored to service by the year 2000. Dedicated street median "transitways" and other "Transit First" measures are being discussed to improve operations.

Pittsburgh

The rebuilt Stage 1 line via Mt. Lebanon currently carries South Hills Village, Library, and Castle Shannon short-turn LRV services from the south into Pittsburgh, with Drake service operating as a PCC shuttle to and from South Hills Village trains.

Reconstruction of the Allentown route over Mt. Washington has been completed and track inside the Mt. Washington tunnel, rebuilt. However, the Overbrook Line on the hillside above Saw Mill Run has been embargoed because of its deteriorated condition. A study of options for Stage 2 of the South Hills rail ren-

TABLE 5 (*Continued*)

City/System	Car Types	Characteristics of Car Equipment: Endedness	Train	Seats	Capacity	AC?	ATS/ATO
	(a)		(b)		(c)	(d)	
LRT-Group I:							
Baltimore, Central Corridor	LRV-6-A	Double	3	84	174	Yes	No
Calgary, C-Train	LRV-6-A	Double	3	64	162	No	ATS
Cleveland, Shaker Rapid	LRV-6-A	Double	2	84(h)	144	Yes	ATS(g)
Denver, MAC	LRV-6-A	Double	3	64	144	Yes	No
Edmonton, LRT	LRV-6-A	Double	5	64	162	No	ATS
Los Angeles, Long Beach	LRV-6-A	Double	3	76	160	Yes	ATS(f)
Newark, City Subway	PCC-4-R	Double	1	54	83	No	No
Phila, Media-Sharon Hill	LRV-4-R	Single	2	50	95	Yes	No
Portland, MAX	LRV-6-A	Double	2	76	160	No	ATS
Sacramento, RT Metro	LRV-6-A	Double	4	60	144	Yes	No
St. Louis, MetroLink	LRV-6-A	Double	3	72	155	Yes	ATS(f)
San Diego Trolley	LRV-6-A	Double	4	64	144	Yes	No
San Jose, Guadalupe	LRV-6-A	Double	2	75	160	Yes	No
LRT-Group II:							
Boston, Green Line	LRV-6-A	Double	3	50	130	Yes	No
(Also in Service	LRV-6-A	Double	3	50	130	Yes	No
Boston, Mattapan-Ashmont	PCC-4-R	Single	1	52	83	No	No
Buffalo, MetroRail	LRV-4-R	Double	3(e)	51	121	Yes	ATS
Fort Worth, Tandy	PCC-4-R	Double	1	60	83	Yes	No
New Orleans, St. Chas/Riverfront	VTL-4-R	Double	1	52	68	No	No
Philadelphia, Subway-Surface	LRV-4-R	Single	1	51	90	Yes	No
Pittsburgh, South Hills	LRV-6-A	Double	2	62	151	Yes	ATS
(Also in Service)	PCC-4-R	Single	1	50	83	No	No
San Francisco, Muni Metro	LRV-6-A	Double	3	62	130	No	ATS(f)
Toronto, Streetcars	LRV-4-R	Single	1	46	95	No	No
(Also in Service)	LRV-6-A	Single	1	61	159	No	No
(Also in Service)	PCC-4-R	Single	1	50	83	No	No

(a) LRV-Light Rail Vehicle, PCC-Presidents' Conference Committee, VTL-Pre-PCC Vintage Trolley; # Axles, 4 or 6; R-Rigid, Non-Articulated, A-Articulated; (b) Maximum Cars/Train in Regular Operation; (c) Comfortable load, seats + standees at ±4/m²; (d) Air Conditioning; (e) 4-car trains for special events; (f) Cab signals; (g) Cab signals, Tower City Center to East 79th Street on segment shared by LRT and heavy rail trains; (h) Seats being reduced from 84 to 80 to make room for chopper ventilation ducts from roof.

TABLE 6 Changes in North American LRT and Streetcar Systems, 1992–1995

City/System	Code(a)	Changes since 1992
LRT-Group I:		
Baltimore, Central Corridor	N	Opened 1992, 35.4 km (22.0 mi)
Calgary, C-Train	-	---
Cleveland, Shaker Rapid	X	Begin Waterfront Extension for 1996 opening, 3.2 km (2.0 mi)
Denver, MAC	N	Opened 1994, 8.5 km (5.3 mi)
Edmonton, LRT	X	Opened 1992, extension to U. of Alberta, 1.6 km (1.0 mi)
Los Angeles, Long Beach	-	Construct Green Line, Norwalk-El Segundo, 32 km (20 mi) to open in summer 1995
Newark, City Subway	-	---
Phila, Media-Sharon Hill	-	---
Portland, MAX	X	Begin Westside and Hillsboro Extensions for 1997 and 1998 openings, 28.5 km (17.5 mi)
Sacramento, RT Metro	R	Double tracking and add two stations: 1 project, 1993-94
St. Louis, MetroLink	N	Opened 1993, 29.0 km (18.0 mi)
San Diego Trolley	VX	Opened 1992, County Center extension, 0.8 km (0.5 mi); delivery of 52 LRVs begun, 1994 (b)
San Jose, Guadalupe	-	---
LRT-Group II:		
Boston, Green Line	R	Begin relocation of North Station area from elevated structure to subway
Boston, Mattapan-Ashmont	-	---
Buffalo, MetroRail	-	---
Fort Worth, Tandy	-	---
New Orleans, St. Chas/Riverfront	-	---
Phila, Subway-Surface	-	---
Pittsburgh, South Hills	R	Complete reconstruction of Allentown line
	V	Delivery of 50 LRVs begun, 1995
San Francisco, Muni Metro	X	Begin Spadina LRT line for 1997 opening, 3.2 km (2.0 mi)
Toronto, Streetcars		

(a) N-New Start, R-Rebuild/Rehab/Expand Facilities, V-New Vehicles, Xextension
(b) Major yard and shop expansion completed 1994

ovation has been completed. Local decisions are pending on the affected line segments: South Hills Junction–Drake, Washington Junction–Library, and South Hills Junction–Castle Shannon via Overbrook.

Planning for the Spine Line, a central area connector, and other extensions is in progress.

Buffalo

Metro Rail operations and facilities in Buffalo remain unchanged from 1992, and ridership is stable at 28,000 per weekday. The Niagara Frontier Transportation Authority (NFTA) has plans for at least four extensions: Tonawanda, Amherst, Southtowns, and Airport. Limited revenues and needs elsewhere on the NFTA system, however, pose a funding challenge likely to prevent near-term implementation.

Cleveland

The Greater Cleveland Regional Transit Authority (GCRTA) is working to correct the long-standing restraint on ridership posed by stopping only once at the periphery of downtown.

Using local funds, GCRTA intends to complete its 3.2-km (2-mi) Waterfront Line for the city's bicentennial in 1996. Operating as an extension of the Blue and Green lines from Tower City, this extension will improve central area passenger distribution and reach several existing and planned leisure venues: a major stadium, the Rock and Roll Hall of Fame, aquarium, and Great Lakes Museum.

To further address the downtown passenger distribution problem, GCRTA is considering additional modified options that would attain the principal goals of the full-subway "dual hub" proposal, but at a lower cost.

New Orleans

The St. Charles Line has become a treasured part of historic New Orleans' scene, whereas the much newer Riverfront Streetcar has proven successful in the tourist market. Since 1992, rehabilitation of the historic St. Charles fleet has been completed.

There are plans to extend the Riverfront Line up- and downstream from its existing terminals as well as to revive streetcar lines on Canal, St. Louis, Rampart, and Esplanade streets. LRT from downtown to the airport is contemplated as a longer-term project.

Fort Worth

The 1-mi Tandy Subway continues to do what it was built to do in 1962: shuttle passengers efficiently from a remote parking lot to a subway station in the Fort Worth central business district (CBD). There have been no significant changes since 1992.

San Diego

It is fitting that the first U.S. new-start LRT, opened in 1981, has grown to the largest new system at 55 km (34 mi) and 71 LRVs. Although the planning horizon of the San Diego Trolley has been stretched by the long-running recession in California, the Metropolitan Transit Development Board (MTDB) continues to make progress on several projects that will further expand the system.

The first of 52 SD-100 LRVs has been delivered from Siemens Duewag's Sacramento assembly plant. These cars were ordered primarily for use on several extensions planned to run generally north from downtown San Diego, and none of them had been placed in revenue service as of early 1995.

With a short link open from the Santa Fe Station to the County Center/Little Italy Station, construction continues on two extensions: 5.6 km (3.5 mi) farther north to Old Town and scheduled for completion in summer 1996, and 5.6 km (3.5 mi) east from El Cajon to Santee. The latter, to open in 1995, includes the first significant section of single track since the original South Line was completed in 1981.

In spring 1995, the MTDB awarded construction contracts on facilities that will form the Mission Valley West extension. From Old Town, this line will operate through the Hotel Circle area and past several regional shopping centers to the Jack Murphy Stadium sports complex.

Los Angeles

The Los Angeles basin's multimodal rail transit system continues to take shape, even as the region's transit organizational structure has undergone major changes, and the pace of rail development has had to slow in deference to the effects of California's extended recesson on local funding. In addition to quick-start Metrolink commuter rail lines and massive Red Line construction, LRT progress continues on several fronts:

- Los Angeles–Long Beach Blue Line weekday ridership has reached 42,000.
- Construction and the initial LRV procurement are well advanced on the 20-mi east-west Green Line, which is expected to open in summer 1995.
- Initial construction work has begun on the 21.9-km (13.6-mi) Blue Line to Pasadena, and studies are in

progress on a subway link under the Los Angeles CBD to link this extension with the line to Long Beach.

Although the Green Line will open with 15 new cars identical to the existing Blue Line vehicles, it will eventually be served by some of the 72 "L.A. standard" LRVs being developed by Siemens Duewag. Although initially they will be set up for manual control, these cars could become North America's first LRVs fitted for automatic operation on fully grade-separated line segments while retaining operator controls for at-grade branches.

Santa Clara County

Since 1992, average weekday ridership in Santa Clara County has leveled at about 20,000 as area residents have discovered the reliability and convenience of LRT. Although a court challenge has slowed the flow of local funding, preparatory work on extensions continues.

Final design has been completed for the 24-km (15-mi) Tasman Corridor Line that will extend the existing Tasman Drive link west past several employment centers to the Mountain View CalTrain commuter rail station and southeast through the community of Milpitas to northeastern San Jose.

Preliminary design is under way for the Vasona Line (San Jose to Los Gatos) and the Capitol Corridor Line.

San Francisco

Deliveries of Muni Metro's new Breda LRVs have begun, and installation of moving block signals in San Francisco's Market Street tunnel is well advanced. In addition, several extensions that will broaden the reach of this heavily used system are in various stages of development.

The San Jose Avenue extension from 30th Street to Ocean Avenue has opened, extending J Line service by 3.7 km (2.3 mi) and reducing deadhead time and mileage for both the J and N lines.

Construction continues on the Embarcadero turnback loop and subway-surface extension through South Beach and Mission Bay to the CalTrain depot at Fourth and King streets. The start of service is anticipated by 1996.

PCC cars will return to Market Street in 1995, operating between Castro Street and the Transbay Terminal. This service will be extended to the foot of Market Street, then turn Northwest on the Embarcadero to Fishermen's Wharf.

Two major extensions are the subject of planning studies. A concept has been completed for a Bayshore Line as an extension south from the CalTrain depot through a hoped for "new town in town" on the site of SP's former Mission Bay freight yards, then on Third Street to CalTrain's Bayshore station. Currently under way is a study for LRT from Market Street west to Park Presidio Boulevard along Geary Street, Muni's most heavily patronized diesel bus corridor.

Sacramento

LRT and total transit system ridership have grown in Sacramento since LRT was introduced, and especially since the spring 1989 schedule changes that implemented the coordinated timed-transfer network envisioned in the original preliminary engineering operating plan. As a result, regional transit enjoyed its highest system ridership ever during 1993–1994, with more than 24,300 weekday LRT boardings on average.

Construction, starting in 1995, on a 4-km (2.5-mi) extension of the Folsom Line east from Butterfield Way to Mather Field Drive will bring LRT service into the large and growing suburb of Rancho Cordova. Further extensions to both ends of the starter line have been designed and construction funds identified, but implementation must await the designation of a guaranteed source of operating funds for Sacramento-area transit.

Construction of a new 18-km (11-mi) line through South Sacramento is planned. An alternatives analysis/draft enviromental impact statement (AA/DEIS) has been finished, leading to a preferred alignment along the Union Pacific railroad line and then east along Consumnes River Boulevard to SR-99. An innovative funding package is being negotiated and must be completed for the project to proceed.

Portland

Local public aud business leaders intend that the single Eastside MAX light rail line will grow into a regional system of trunk lines forming the core of a multimodal, multidestinational system. That this is likely to occur is in part due to a 20-year history of state-mandated land use planning that contains development within an *urban growth boundary*, as well as the willingness of local voters to fund transit operations and the local shares of capital projects.

North America's first low-floor LRVs will enter service as through-routed trains on the East-West Line when the first 18.5-km (11.5-mi) section of the Westside extension opens in 1997. A year later, the Westside extension will be completed with the addition of another 10 km (6 mi) to Hillsboro.

It is anticipated both AA/DEIS and PE/FEIS requirements will be completed by 1998 for a South-North Line to extend 33 km (20 mi) or more from Clackamas Town Center through downtown Portland and across the Columbia River to the northern part of Vancouver, Washington. Regional authorities hope to move this ambitious project into final design and construction upon completion of the Westside extension and start service about 2005. In a 1994 referendum, Oregon voters approved $475 million in bonds backed by property taxes for their portion of the local share. Rejection of a similar measure by the electorate in Clark County, Washington, during February 1995 has required a reevaluation of project end points and implementation timing.

Existing Systems in Canada

Calgary

The Calgary LRT system continues essentially unchanged from 1992 and continues to enjoy the highest ridership of any of the post-1975 new starts: more than 100,000 weekday boardings on the C-Train. The system also leads new starts in productivity, measured in rides per route kilometer and per vehicle (Table 1). Although the city plans an eventual line west from the CBD, constrained finances are expected to prevent its construction until after 2000.

Edmonton

The extension to the University of Alberta opened in August 1992. This was a significant event, because it taps the university's large transit market and because Edmonton's LRT now serves the CBD from two directions. Buses feed south-area riders to LRT at the University Station, mirroring the long-established pattern on the Northeast Line. As a result, patronage has jumped by nearly 60 percent, to 36,000 per weekday.

Plans are in place for further LRT extensions to the south and west from the university, as well as north from downtown Edmonton. Implementation timing is uncertain because adequate funds have not yet been identified.

Toronto

Measured by line length, number of cars, and weekday ridership (Table 1), Toronto's is the largest LRT system in the United States and Canada. Its 10 routes, totaling 75.5 km (46.9 mi), primarily serve local transit needs within and between densely populated city neighborhoods. Most tracks are in street lanes shared with automobile traffic, but reserved medians are being provided on new extensions: the Harbourfront Line opened in 1990, and the Spadina Line under construction and scheduled for completion in 1997.

A Waterfront west extension from the Harbourfront route awaits funding and probably will be built in stages. It is planned to reach out to Etobicoke. The Toronto Transit Commission anticipates its next purchase of LRVs will be for 100 percent low-floor cars.

Existing Systems in Mexico

Guadalajara

After using a turnkey contract to complete its successful initial 15.3-km (9.5-mi) Line 1 in 1989, Guadalajara—Mexico's second largest city—quickly started building a second route. The first phase of Line 2, which extends 8.5 km (5.3 mi) east from a station with Line 1, opened for revenue service in July 1994. Further plans call for extending Line 2 to the west and adding a third line to the northwest. Like Line 1, these two links will reach out to the circumferential highway, *Anillo Periferico.*

Monterrey

Mirroring the pace of LRT construction in Alberta a decade earlier, the 1991 opening of Monterrey's initial 18.5-km (11.5-mi) line followed closely behind Guadalajara's project. Monterrey also used a turnkey contract covering all facilities and equipment. *Metrorrey* also is being expanded at a rapid pace. The first 5.0-km (3.1-mi) section of Line 2 opened in late 1994. Further extensions to and branches from both lines are anticipated to build gradually a regional network of 74 km (26 mi).

Mexico City

The rebuilt and reequipped 14.5-km (9.2-mi) LRT line from the Taxqueña Metro terminus to Xochimilco continues as reported in the 1992 update. Service on the short branch to Tlalpan remains suspended. Running southeast from a common terminus with rubber-tired Metro Lines 1, 5, and 9, steel wheel/steel rail trains collecting power from overhead wires on Line A introduced a version of heavy rail service with LRT overtones that allowed inclusion of a few grade crossings. A second line using this technical approach is now proposed to extend from the heart of Mexico City to growing communities in the northwestern area.

New Start Under Construction in Dallas

Construction is well advanced on the Y-shaped 32-km (20-mi) starter system being developed by Dallas Area Rapid Transit (DART). Like several previous LRT projects, much of the alignment reuses former railroad rights of way. Exclusive lanes in city streets carry the line through the CBD, then twin tunnels provide full grade separation for the first 5.6 km (3.5 mi) of the North Central leg. The 21 stations are spaced at intervals of 1.6 km (1.0 mi) on average. Several stops will serve as transit centers coordinating LRT with DART buses.

Built to a new design, the first of DART's 40 articulated LRVs was delivered in spring 1995. Additional cars have been received since and are active in the system test, training, and start-up program.

Progress is on track to open the downtown and most of the West and South Oak Cliff branches in June 1996. The North Central segment will follow by the end of 1996, with the outer South Oak Cliff link to Ledbetter entering revenue service by May 1997.

Design and Planning for Future New Starts

The success of established new systems in cities such as Calgary, San Diego, and Portland, as well as the latest new starts in St. Louis and Denver, provide encouragement for those places still in planning and design.

Chicago

From its historic start within "The Loop," Chicago's central area has expanded over the past century to cover an area of about 15 km^2 (6 mi^2). This size makes many internal trips too long for walking, yet the areas are not well served by local buses or regional commuter rail and rapid transit lines. The Central Area Circulator LRT system will have four routes totaling 15.6 km (9.7 mi) to accommodate local trips of all kinds, shuttle commuters between regional rail train stations and their places of employment, and serve special events at McCormick Place and Navy Pier. Tracks occupying reserved lanes in city streets will be used by a fleet of 38 articulated LFLRVs to reach 32 initial stations. Proof-of-payment fare collection will be used so that boarding and alighting riders may use all doors and open unfenced station platforms can be free areas. With commitments in place for system implementation, construction and procurement activities have begun.

Salt Lake City

Preliminary engineering has been completed for the 24-km (15-mi) line south from downtown Salt Lake City's Temple Square to the suburb of Sandy. Similar to San Diego's South Line, this project involves the use of reserved street lanes through the city center linked to a railroad line, already purchased by the Utah Transit Authority (UTA). Local freight service is being provided by a short-line contractor to UTA. The authority is working to refine the scope of the starter line and complete a capital funding package enabling the project to progress into final design.

Seattle

In late 1994, a new Regional Transit Authority (RTA) won approval from the councils of its three member counties for a 16-year Phase 1 system plan including LRT on three routes totaling 70 mi. In addition, the plan calls for an 81-mi commuter rail line to link Everett, Seattle, Tacoma, and Lakewood (Fort Lewis/McChord Air Force Base) and improved bus services, all to be united into a seamless regional transit system using timed-transfer scheduling and a single fare system. A "transit federation" is proposed to ensure coordination among regional and local operators, similar to the program in San Diego and common in Western Europe. In a March 1995 referendum, voters rejected local funding for this plan. As a result, the RTA is reevaluating the scope of the plan and timing for a second financing referendum.

Others

Plans for rail transit have been or are being made in several other metropolitan regions. Many places are focusing on LRT as a technology that is affordable yet can provide desired levels of service quality and carrying capacity. Planning or preliminary engineering for new-start LRT projects is ongoing or recently completed in the Minneapolis/St. Paul, Memphis, Austin, Columbus, Cincinnati, Kansas City, Spokane, Hartford, Milwaukee, and Charlotte. Other places that have considered LRT and might revive previous proposals or develop new ones include Orange County (California), Norfolk, Phoenix, Orlando, and Rochester. New York City is evaluating turnkey contractor submittals for the proposed crosstown line on 42nd Street.

Conclusions

As of 1995, rail transit systems of regional significance (i.e., routes serving as the main lines of a regional transit system) are operating or under construction in more than half of the U.S. metropolitan areas of 1 million or more population: 20 of 39 such places in the 1990 Census. LRT lines form all or significant parts of such rail systems in 16 regions (80 percent), up from only 7 when the first TRB conference on LRT was held, in 1975.

The next 20 years could see further additions to the stream of recently completed North American LRT projects. Growing travel demand in candidate corridors and the impossibility of eliminating traffic congestion by building more freeway lanes will require responsible authorities to look at nonroad alternatives. Considering public transit's continuing need to stretch scarce financial resources, the prospects for future new starts would be improved by a renewed emphasis on lower-cost approaches to LRT system design. It appears more and more likely that those major urban regions still without rail lines will want to add them and that factors of demand and finance will lead to selection of LRT as the preferred rail technology.

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The authors retain responsibility for accuracy of the data, analyses, and opinions contained herein.

Sacramento Regional Transit's Light Rail: Approaching Middle Age

Cameron Beach, *Sacramento Regional Transit*

Sacramento Regional Transit's light rail system opened in March 1987. Planning for the system started in the late 1970s and construction began in 1983. The 18.3-mi (29.2-km) line has exceeded all expectations in terms of ridership and community acceptance. As the system approaches its ninth anniversary, it is starting to show signs of "middle age." Actions necessary to keep a system operating at peak efficiency as it enters its second decade of service are described; they include general inspections of vehicles, wayside equipment rehabilitation programs, and changes in staffing levels. In addition, external pressures on today's light rail transit systems in the form of the Americans with Disabilities Act, the Clean Water Act, and the Clean Air Act are discussed. Included is Regional Transit's plan for light rail in the 21st century.

The start-up of Sacramento Regional Transit's (RT's) light rail system on March 12, 1987, heralded the return of electric railway operation to California's capital city. Until January 4, 1947, streetcars and interurbans of the Pacific Gas & Electric Company (PG&E), Central California Traction Company, Sacramento Northern, and their successor Sacramento City Lines plied the streets of Sacramento and the surrounding area. The 40-year hiatus watched Sacramento grow from a sleepy California valley town of 100,000 to a metropolitan area of more than 1 million people.

Sacramento has been the capital of California since the mid-1800s. Unlike other capital cities, however, Sacramento was always the "stepchild" of the state compared with San Francisco, Los Angeles, and San Diego. Into the early 1960s, Sacramento was often thought of as nothing more than a rest stop for travelers between the San Francisco Bay Area and the Reno/Lake Tahoe area of Nevada.

During the California real estate boom of the 1970s, Sacramento remained a bastion of lower-priced residential housing. As homes became less and less affordable in Southern California and the San Francisco area, people began migrating to the Sacramento Valley. During the late 1970s and early 1980s, population continued to grow at a rapid rate. This growth brought the usual urban problems to Sacramento: congestion and air pollution. Freeway and road construction attempted to keep up with the phenomenal growth, hnt the people who had moved to Sacramento feared that this uncontrolled growth would end up duplicating the communities that they had left.

In 1983 it was decided to pursue the construction of an 18.3-mi (29.2-km) light rail transit (LRT) line serving the eastern and northeastern suburbs of Sacramento. Federal Interstate transfer moneys were used to help fund construction of a "no-frills" light rail system, patterned after the very successful San Diego Trolley. Design and construction of a no-frills system involved evaluating every aspect of the system on the basis of what was absolutely necessary rather than what would be nice to have. The initial line was built for less than $10 million/mi, making it the lowest-cost federally funded transit project in the United States.

Service commenced in March 1987; the full line was opened by September of that year. Initial service levels were constrained by a severe lack of operating funds in the first few years of operation. Trains ran no later than 10:00 p.m. during the week and 7:00 p.m. on Saturday and Sunday. In addition, weekend headways were 30 min, compared with the 15-min weekday frequency.

In November 1988, citizens of Sacramento passed Measure A, which dedicated a half-cent sales tax to transportation projects in the Sacramento area, "transportation" being the key word. Two-thirds of this money is to go toward road construction and maintenance, and the remaining third is to be dedicated to operating and capital projects for the transit district. This influx of money, which has amounted to about $20 million a year, allowed RT to replace some aging diesel buses, add some connecting bus service to the rail line, and—most important—bring the rail line service levels up to the 1987 expectations. Trains now could operate on a 15-min headway 7 days a week. Service began at 4:30 a.m. and continued until 1:30 a.m. the following morning. Half-hour headways were operated after the evening rush hour. Timed-transfer connections were made from bus routes at key transfer stations. To handle the increased traffic, 10 additional light rail vehicles (LRVs) were ordered from the builder of the original fleet and placed in service during 1990, bringing the fleet to a total of 36 cars. Four-car trains are operated in the morning and evening rush hours on eight trains, and 32 cars are required for both the morning and evening rush hours.

As originally designed, 60 percent of the system was single-tracked. Double tracking was provided only in areas where train meets occurred and in the downtown area. This constraint kept capital costs to a minimum. It also required precision dispatching and train operation to maintain the 15-min headway. Any delay to a train quickly caused the entire system to suffer late schedules. Fortunately, this did not happen very often.

Starting in 1988, various double-track projects were implemented on both the Northeast (N) and Folsom (F) lines. These projects have changed the lines' configuration such that today's system is 60 percent double track and only 40 percent single track. This addition has provided much more flexibility in operating trains.

Besides the double-track projects, "tail tracks" were installed at both of the terminal stations located at Watt Avenue/I-80 and at Butterfield. This feature allows a disabled vehicle to be removed from the mainline and stored without disrupting regular service. In addition, a "scissors" crossover was installed on the K Street Mall, allowing trains to be turned back in the downtown area.

The double tracking of some station locations required the construction of a second platform. On the basis of early experience, newly constructed platforms had several additional amenities for passengers including lighted kiosks, additional shelter space, and mini-high platform shelters and benches.

With the full line in operation on September 5, 1987, the staffing of RT's light rail department was approximately 90 people. This included all of the transportation, vehicle maintenance, and wayside maintenance functions associated with running a rail transit system. The original staffing levels were based on an operating plan with limited or nonexistent night and weekend service, and the assumption that all new equipment and facilities were relatively trouble-free and under warranty. The original staffing plan was adequate for the start up of revenue service. It took into consideration the needs of a new system with the knowledge that expanded service hours and aging equipment and facilities would require more people.

Today, the staffing level is at 112, reflecting the much higher level of service provided and the age of the system. Figure 1 shows the organization charts from September 1987 and today. The increases are primarily in the operator and mechanic ranks. The additional operators were required to accommodate the substantially higher level of service; the additional maintenance staff were brought on board in a phased pattern that reflected the aging of the system and its components.

Starting in 1993, the system's original 26 LRVs, built by Siemens Duewag, came due for their general inspection. On Sacramento's LRVs, this generally equated to 310,000 mi (500 000 km). The general inspection calls for disassembly of major components, including the trucks, traction motors, motor/alternator set, couplers, and suspension components. In addition, the cam controller is to be removed from the car and inspected and repaired as necessary. The general inspection has produced some interesting results. Even though these cars accumulated more than 500 000 km in less than 8 years, only a minimal amount of work has been necessary during the inspection process. The following items were rebuilt or repaired:

1. Traction motors were disassembled, new bearings installed, commutators were resurfaced, and brushes were replaced. No other maintenance has been necessary to the motors.

2. Gear boxes on the monomotor trucks were removed and disassembled. Approximately a third of the fleet's gear boxes have experienced what RT would describe as excessive wear; they are being rebuilt in the San Francisco Bay Area with parts supplied by the orig-

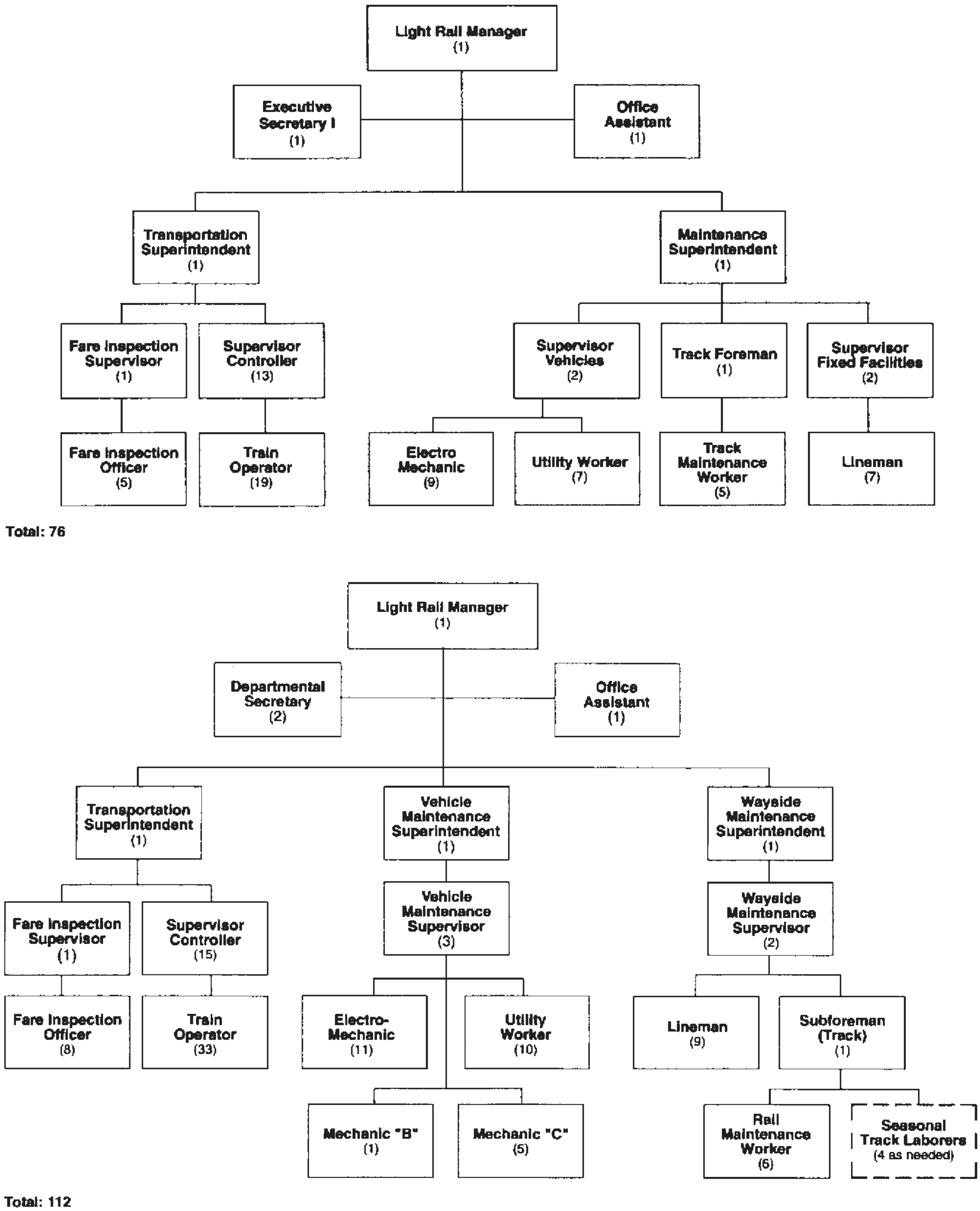

FIGURE 1 Sacramento Regional Transit light rail department organization, 1987 (*top*) and 1995 (*bottom*).

inal car builder. It is important to note that unlike other LRT systems with monomotor trucks, Sacramento has never suffered a catastrophic failure of an LRV gear box. RT is meticulous about wheel maintenance, especially the regular reprofiling of wheelsets. This effort has resulted in its spectacular record of no gear box failures.

3. The electrically operated seven-step brake actuator was removed and rebuilt. RT's experience has shown that it is much more economical to rebuild these components in house. Training for this task was provided by the manufacturer. Shipping the actuators back to the original supplier had resulted in long delays and substantially higher costs.

4. The cam controllers have been disassembled, inspected, and put back together with very minimal parts replacement. Although this technology is "outdated," it continues to work well in RT's application under extremely severe service conditions.

5. Couplers, which have been a problem for several other LRT operations, have required minimal efforts to rebuild during the inspection process. RT couples and uncouples train consists regularly throughout the day. It appears that this frequent operation has contributed to, rather than detracted from, coupler reliability.

In summary, these cars have seen heavy service during the first 8 years of their existence. Regular performance of preventive maintenance has allowed the vehicles to continue to provide extremely reliable service to the citizens of Sacramento.

Wayside equipment is also beginning to suffer a "midlife crisis." Electric switch machines are removed from service, torn down, and rebuilt to original equipment manufacturer standards. It is important to note that switch machines on Sacramento's light rail system throw as often as 140 times a day. This is substantially more often than similar equipment used on many light rail and most mainline railroads. Again, preventive maintenance has enabled this equipment to function almost flawlessly.

Signal relays are removed and recalibrated by wayside staff in the field. RT has been fortunate to have been able to recruit and hire railroad signal maintainers with many years of both field and shop experience. This hands-on experience has allowed RT to develop unique preventive maintenance inspections and rebuild programs tailored to its specific needs. This in turn has greatly increased the reliability of wayside equipment.

In 1993 RT contracted with an outside firm to grind the rail on the entire 18.3-mi (29.2-km) line. Corrugation had begun to develop on portions of the light rail system, resulting in higher noise levels and in some cases deteriorated ride quality. RT does not foresee having to regrind the system for another 3 to 4 years. In addition to the grinding program, several tight-radius curves have required rail transposition or change-out during the past few years. When possible, RT replaces its 115-lb T-rail with a head-hardened version in these tight-radius curves. Restraining rails are used in all curves under a 300-ft (91-m) radius. In some cases, the restraining rails have been extended farther into the spiral to minimize high-wear points.

Virtually all of the grade crossings in private rights of way were constructed of rubber panels installed during original construction. In some cases, these panels have failed over time, especially on streets with extremely high traffic. As the panels wear out, RT is replacing them with either poured concrete or prefabricated concrete panels. Stray current has not been a problem with the concrete panels because of Sacramento's very dry climate.

The original starter line budget did not provide for separate offices for wayside personnel or for storage of track, signal, and overhead contact system materials. A new wayside maintenance building was constructed and placed into service in 1994. This building provides expanded shop space for wayside activities including electronic and welding shops. In addition, there is inside storage of high-value materials, locker rooms, and additional office and training space for the wayside staff.

The starter line budget also did not include a paint and body shop. A single-track metal building addition was grafted onto the east side of the existing facility during 1994. This facility provides for a paint and body preparation area as well as an environmentally compliant paint booth. Before the construction of this facility, minor paint and body work was performed outside the facility. Fortunately, the only major painting required was the result of an accident in 1990 involving Car 105. This vehicle was transported to the builder's plant in Sacramento after the accident, where it was repaired and painted.

To comply with the long-term aspects of the Americans with Disabilities Act, RT is studying various low-floor options for both existing and new LRVs. RT is exploring the idea of constructing a low-floor center section to be spliced into its existing equipment. Doing this would make each of the cars an eight-axle vehicle approximately 120 ft (36 m) long. Remaining questions about this modification address

1. The ability of the existing traction power package (both on the car and the wayside distribution system) to support the performance requirements, and

2. The ability of the modified vehicle to meet the 2-*g* buff strength requirement imposed by the California Public Utilities Commission (CPUC).

New low-floor LRVs are also being considered by RT for future purchases. The performance issue would not be a major problem with new cars, but the 2-g buff strength requirement imposed by the CPUC remains an issue. At this time, there is no way to construct a low-floor LRV that would provide this level of compression strength. Adding structural members to increase body strength also adds weight, which exacerbates the problem. In addition, either retrofit or new purchase of low-floor technology will require some form of platform modifications. As stated previously, RT passengers board from both top of rail height as well as from 8-in. (20-cm) curbs. For low-floor vehicles to function effectively, a 8- to 10-in. (20- to 25-cm) platform may be necessary. There are two issues with this:

1. More than 5/8 mi (1 km) of the line is on a pedestrian mall. Creating curbs where they do not exist today would present an additional barrier to free movement on the mall.

2. Four-car trains are operated by RT in the a.m. and p.m. peak hours. At several downtown locations, these trains extend into intersectons. It would not be possible to place platforms in the middle of these intersections.

In recent years, environmental legislation has been passed at both the state and federal levels. Even though transit is obviously supportive of environmental concerns, the new laws have a substantial impact on a transit system's daily operation. For example, the Clean Water Act has very specific language regarding the use and monitoring of underground storage tanks. This is a relatively minor problem for the rail system (which has one small underground storage tank for waste oil), but RT's bus facility is located where the various predecessor companies ran horsecars, streetcars, and gasoline-powered buses for more than 100 years. Faced with a massive clean-up effort at the bus facility, RT has also had to reevaluate its underground storage tank procedures at the rail facility, resulting in equipment modifications and increased monitoring efforts. In addition, stormwater runoff from the bus and rail facilities must undergo substantial treatment before entering the city's storm drain system. This represents both an additional capital and operating cost to the district that is not directly related to providing service to its riders.

Passage of the 1990 Clean Air Act had a profound impact on RT's operations. Sacramento is considered a nonattainment area for oxides of nitrogen (NOx). Even though almost a third of the daily ridership rides zero-emission electrically powered rail vehicles, the local air quality management district lobbied very heavily for replacement buses that were powered by alternative fuels. This resulted in RT's purchasing 95 compressed natural gas (CNG) buses and building a "fast fill" CNG fueling station at a cost of more than $4 million. These increased capital expenditures cut deeply into the limited moneys available for bus and rail capital improvements.

RT has adopted a master plan for transit in the Sacramento metropolitan area for the next 20 years. The plan calls for substantial increases in bus service and both extensions of the existing rail line and new rail lines to areas currently not served. The master plan envisions a tripling of bus service in the metropolitan area. In addition, it includes an extension from the N Line terminal at Watt Avenue/I-80 to Antelope Road and ultimately into the city of Roseville. The Antelope Road extension would be approximately 6 mi (10 km). An additional 4 mi (7 km) would continue into the city of Roseville and Placer County. The F Line would be extended to Sunrise Boulevard and the community of Gold River approximately 6 mi (10 km). A further extension of this line would continue into the city of Folsom, a rapidly growing suburban community east of the downtown area. The Folsom extension would add an additional 6 mi (10 km) to the easterly extension.

RT has just completed an extensive alternatives analysis/draft environmental impact statement (AA/DEIS) for a 10-mi (14-km) line to the south area of Sacramento. This area provides the heaviest ridership to RT's existing bus system. Included in this study was the selection of a corridor. The two corridors studied were the Union Pacific (former Western Pacific) mainline, which envisions joint use of right of way for both light rail and mainline freight trains. The other corridor is a former Southern Pacific branch line that is currently abandoned but owned by the district. Part of this right of way is currently used by the California State Railroad Museum for steam excursion trains. After a 3-year effort, the RT Board of Directors selected the Union Pacific alignment as its preferred alternative in January 1995.

A short, 1.2-mi (2-km) extension to a new multimodal transportation terminal is also being studied closely. Current plans call for the existing Amtrak and Greyhound terminals to be consolidated in an area northwest of downtown Sacramento that has been used for over 100 years as the main shops of the Southern Pacific. Sacramento has a unique opportunity to redevelop this area, effectively creating a "new" downtown.

Also being studied is the operation of historic streetcars in a downtown circular system. To this end, a citizens support group known as Friends of Light Rail has acquired two old Sacramento streetcar bodies in the hope of restoring them to operation. This idea was fueled by RT's operation of PG&E Car 35, on special occasions, which has been restored by the San Jose Trolley Corporation for operation on Santa Clara's light rail system.

No one doubts that the extensions and increased bus service are needed badly in the area, but there is no current source of operating funding available to make these things happen. RT is in the awkward position of passing up both federal and state capital dollars for worthwhile projects because of the lack of a dedicated source of operating revenue. The board of directors has commissioned a blue ribbon committee to look at long-term funding for the transit system. Until a source of revenue is found, RT's only extension plans will consist of a 2½-mi (4-km) extension from the east end of the F Line at Butterfield to a new station at Folsom Boulevard and Mather Field Road. Plans call for this extension to be under construction in late 1995 and to open in 1996. RT will not be procuring any additional equipment for this extension. The current scheduled recovery time at Butterfield (10 min) will be used to enable trains to continue to Mather Field Road and return. Recovery time at the Mather Field Road station will be minimal; an additional fall-back operator will be necessary at this end of the line to ensure reliable on-time performance.

RT is justifiably proud of its light rail system and the impact that it has had on the community. The efforts made during construction to keep the system simple have paid off in reduced operating and maintenance costs. As RT approaches its second decade of service, it looks forward to resolving its funding issues and expanding clean, low-cost LRT service throughout a rapidly growing metropolitan area.

Updates on New Systems and Extensions

Light Rail Transit Implementation Perspectives for the Future: Lessons Learned in Silicon Valley

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The implementation of the Tasman Corridor Light Rail Transit (LRT) Project is described from inception through final design. First, the project goals and the system layout and operating characteristics are discussed. Subsequently, developments in the physical configuration, corridor land use, costs, institutional environment, and funding arrangements are presented, followed by the lessons that may be learned from the implementation of the project. The Tasman Corridor is a 20-km (12.4-mi) $530 million light rail extension of the Guadalupe Corridor LRT system in Santa Clara County, California, and is an important part of a multimodal regional transportation network that is planned in Santa Clara County. The Tasman Corridor Project's 2-year final engineering phase is essentially complete. The California and Bay Area economic profiles have changed with significant impacts to housing, business, and defense industries. In addition, the local funding environment has become uncertain. The Tasman Corridor Project offers valuable perspectives for the implementation of the LRT systems of the 21st century.

Since 1974 the Santa Clara County Transit District (SCCTD) has played an important role in serving the transportation needs of the 1.5 million residents of Santa Clara County. With a 33.8-km (21-mi) light rail transit (LRT) system and 72 bus routes, SCCTD serves more than 150,000 passengers a day with light rail that connects residential areas with regional employment centers and express and local bus service. As one of three counties forming the Peninsula Corridor Joint Powers Board, the SCCTD also participates in the 125.6-km (78-mi) CalTrain commuter rail system between Gilroy and San Francisco. SCCTD is also responsible for the implementation of the countywide transportation plan, which includes a commitment to an ambitious rail corridor development plan for Santa Clara County. A critical link in this regional rail network is the Tasman Corridor LRT Project (TCP).

The objective of this paper is to discuss the perspectives gained and lessons learned from the TCP implementation from initiation through final design. First, the accepted goals for the project and the system layout and operating characteristics will be discussed. The developments that bave taken place in the physical configuration, corridor land use, costs, funding environment, and institutional arrangements during the period from inception until now will also be presented. Some perspectives on the developments since the inception of the project will be presented, and some comments will be made regarding the effects of these developments as related to the attainment of the project goals and objectives. Finally, some lessons that may be learned from the implementation of the project will be presented.

System Goals and Objectives

The TCP policy oversight committee (POC) and technical advisory committee have developed seven major goals for the project (*1*):

1. *Mobility.* Provide a balanced transportation system promoting safe and efficient movement of people.
2. *Environmental considerations.* Preserve and enhance the environment.
3. *Land use and regional development.* Develop a transportation system compatible with adjacent land uses and consistent with planned regional development.
4. *Economic considerations.* Develop a transportation system providing the most efficient and effective use of limited resources while benefiting the public.
5. *Financial feasibility.* Develop sysrem on the basis of realistic estimate of resources.
6. *Equity.* Provide a transportation system designed to meet the needs of all groups.
7. *Community and institutional considerations.* Maximize community acceptance and political and institutional support.

Each goal is accompanied by specific objectives developed by the project team and the community. The development of the TCP layout and operating characteristics have been based on these goals and objectives.

System Layout and Operating Characteristics

A brief description of the rail system configuration follows. A more extensive description can be found in another paper presented at the Institute of Transportation Engineers' Sixth District Conference in Portland in July 1994 (*2*).

System Plan

The Santa Clara County Transportation Plan, known as T2010 (*3*), provides guidance to the SCCTD and all transportation decision making in the county. The document establishes a program for transportation and land use actions designed to make the transportation system perform more effectively and Santa Clara County a better place to live and work (*3*). As a key component of the transit element, the plan includes the long-range rail master plan as the basis for rail corridor development.

In addition to specific corridor goals, T2010 calls for the development of activity center systems (such as transit-oriented developments and shuttle service) at key locations to support the rail plan and includes a pledge to assess whether rail development plans adequately address systemwide operating issues, intermodal facilities, feeder bus service, and coordination of land use plans. The studies and modeling performed during the preparation of the T2010 plan indicate that transit use would rise substantially if the recommended improvements were made. By 2010, between 6 and 10 percent of work trips would be made using transit, more than doubling the present transit share.

The Association of Bay Area Governments (ABAG) has predicted up to 33 percent growth in employment in Santa Clara County between 1990 and 2010. In addition, ABAG has predicted as much as 8 percent population growth in Santa Clara County between 1990 and 2000. It is clear that this growth in population and employment will increase the demand on the transportation network. As a result of the prospect of this increasing demand, the region has commited to improving the public transit system.

The system as originally foreseen according to the T2010 plan and approved by the transit district board of supervisors in 1992 is shown in Figure 1. The Guadalupe Corridor system was already in operation at that time.

The T2010 rail corridor priorities were established to define clearly the region's priorities for rail corridor planning, design, and implementation. The rail element includes specific corridor completion goals for the years 2000 and 2010 (Figure 1). For 2000, the T2010 plan envisages the completion of the CalTrain Gilroy extension and upgrade, the Tasman Corridor, the Fremont–San Jose Corridor, the Vasona Corridor, and the Capitol/Downtown-Evergreen Corridor (in priority order). As of 1995, the CalTrain project is complete; the Tasman project has completed final design; the Fremont–San Jose corridor has undergone preliminary environmental review; the Vasona project is undergoing environmental review and conceptual engineering; and a preliminary study of the Capitol Corridor segment of the Capitol/Downtown-Evergreen project has been completed.

For 2010, the T2010 plan calls for completion (not in priority order) of four additional rail corridor projects: DeAnza, South San Jose, Stevens Creek/Alum Rock, and Sunnyvale/Cupertino. To date, no studies have been completed on these corridors.

Existing Rail System

The existing 33.8-km (21-mi) Guadalupe Corridor LRT system includes 33 stations, 50 light rail vehicles, and

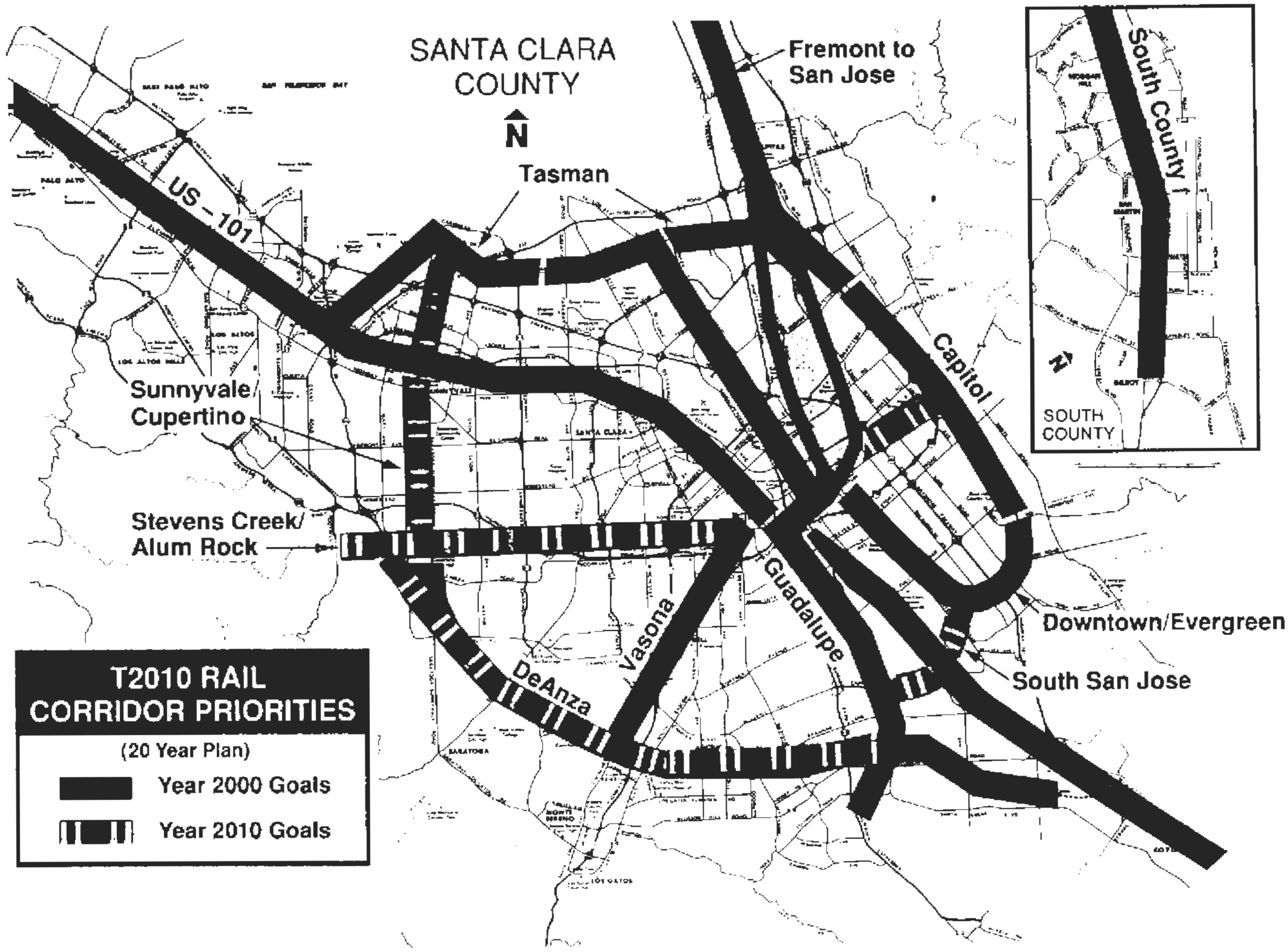

FIGURE 1 T2010 Rail corridor priorities.

11 park-and-ride lots (Figure 2). The first segment, opened in December 1987 (service was extended to the downtown San Jose Transit Mall in June 1988), links downtown San Jose and businesses along North First Street to the industrial centers of north San Jose and Santa Clara. In 1990 LRT service was extended 3.2 km (2 mi) south to the Tamien Station, providing a link to CalTrain, buses, parking, and a new county child care facility under construction. In 1991 service was extended the final 13 km (8 mi) to south San Jose.

Tasman Corridor Project

As recommended in the T2010 plan, a Fremont–South Bay Corridor study was initiated in 1984 by SCCTD and the Metropolitan Transportation Commission, the metropolitan planning organization for the Bay Area. This study included consideration of an extension of the Guadalupe Corridor LRT in what became known as the Tasman Corridor. The TCP POC was formed; it is made up of elected representatives of SCCTD and the five corridor cities.

In 1988 the POC determined that the Tasman Corridor should continue to be studied under the federal alternatives analysis/environmental impact statement (AA/EIS) process, separate from the Fremont–San Jose Corridor. The Tasman AA/draft EIS (DEIS)/draft environmental impact report was issued in May 1991. Final design is now essentially complete, but because of a variety of factors the project may not be fully implemented by the year 2000, as originally envisaged in the T2010 plan.

Corridor Overview

The Tasman Corridor is a 20-km (12.4-mi) east-west extension of the Guadalupe Corridor, with 18 new stations, five new park-and-ride lots, and three intermodal bus transfer centers. The corridor extends through the

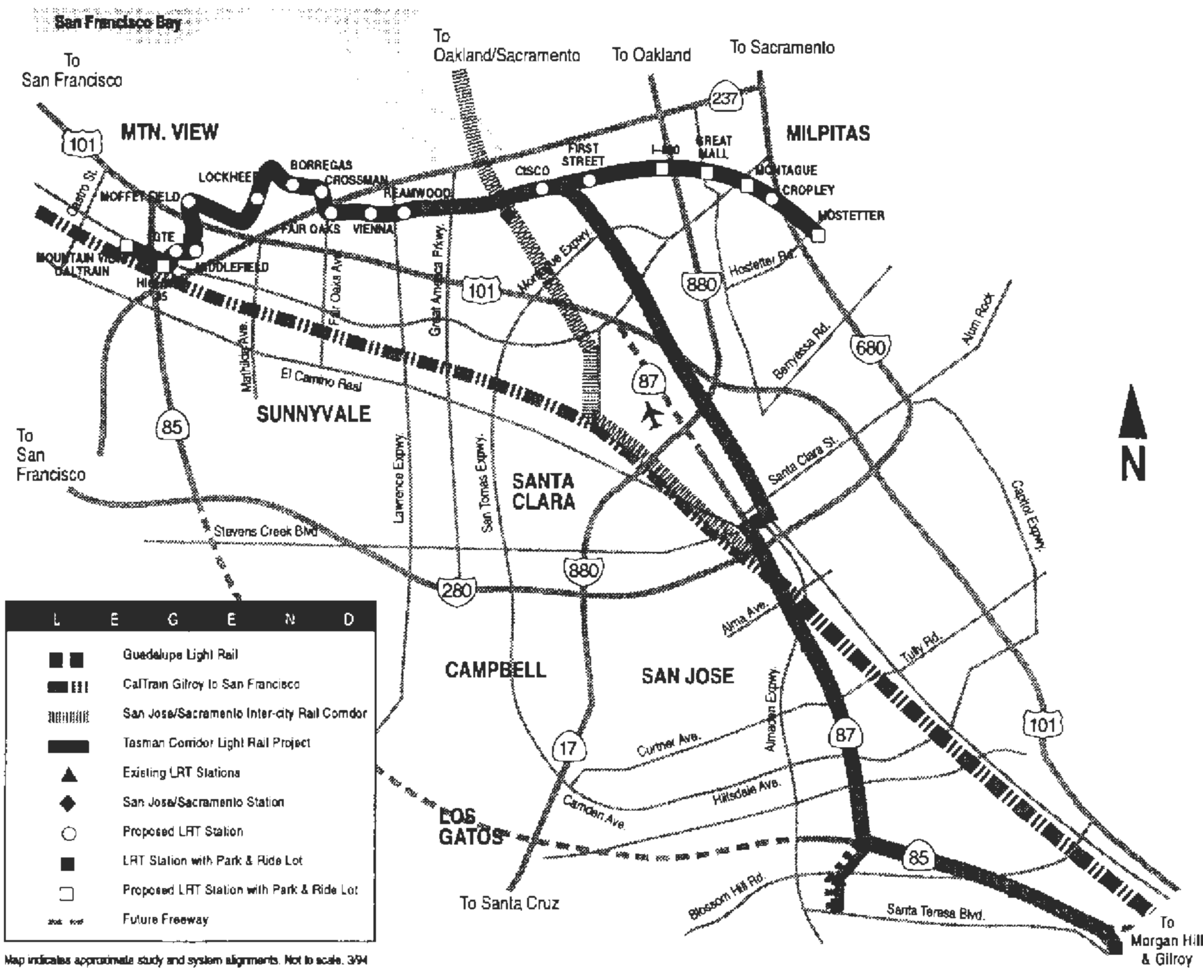

FIGURE 2 Tasman Corridor light rail project schematic.

cities of San Jose, Milpitas, Santa Clara, Sunnyvale, and Mountain View (Figure 2). The purpose of the Tasman Corridor extension is to tap extensive existing residential areas in east San Jose and Sunnyvale and existing and new residential developments in San Jose and Mountain View, including the proposed 850-unit development on the GTE site, and to connect these residential areas with major Silicon Valley employment centers such as Lockheed, the National Aeronautics and Space Administration (NASA), Hewlett-Packard, and other research and development and high-technology manufacturing facilities in the area known as the Golden Triangle.

The east segment of the corridor begins in the established San Jose residential areas near I-680 and continues through the industrial and residential areas of Milpitas, crossing I-880 into north San Jose's employment areas. This segment of the Tasman project joins the existing LRT system on Tasman Drive near North First Street.

Near the Santa Clara Convention Center, the corridor begins its western extension along Tasman Drive through Santa Clara's employment areas and a residential portion of Sunnyvale. Crossing SR-237 at Fair Oaks Avenue, the line continues west to serve Lockheed and adjoining industrial parks. Continuing west, the line parallels US-101 and crosses under the landing path of the NASA/Moffett Field main runway in a depressed section and serves NASA Ames Research Center.

Crossing under US-101, the corridor turns south along an existing railroad right of way, through burgeoning industrial and residential areas in Mountain View. After crossing Central Expressway, the Tasman Corridor joins the Peninsula Corridor Joint Powers Board right of way, paralleling the CalTrain tracks into downtown Mountain View.

Accessibility Impacts

The requirements of the Americans with Disabilities Act (ADA) of 1990 have necessitated changes in the Tasman project design. The existing Guadalupe Corridor uses wayside lifts to provide access for mobility-impaired passengers. During the Tasman Corridor preliminary engineering phase, accessibility options for the Tasman Corridor were reviewed and minihigh platforms were considered as a means to provide level change, based on ADA's level boarding requirements, the desire to retain the existing fleet of LRVs, and the plan to purchase up to 35 new high-floor vehicles. Implementation of wayside lifts similar to those on the Guadalupe Corridor would not have satisfied the ADA requirements if new vehicles were purchased and therefore was not considered at that time.

The final design documents now include high platforms 1 m (39 in.) above the top of the rail for the TCP. Recently, the Tasman Corridor POC voted to take a modified approach to accessibility, which is currently being developed. This approach now includes low 35.6-cm (14-in.) station platforms with minihigh platforms for level-boarding access, and future acquisition of low-floor vehicles.

Traffic Signal Integration

Integration with vehicular traffic is an important achievement for this primarily at-grade LRT system. The corridor consists of several distinct segments with differing impacts on vehicular traffic. The western portion through Mountain View is largely along existing rail corridors. However, the remaining portion of the Tasman Corridor includes seven grade-separation structures, including four existing structures and a new single-column aerial structure spanning two railroads, one expressway, and five arterials. This 2.9-cm (1.8-mi) double-track aerial structure includes two aerial stations and a pedestrian overcrossing. Where not grade-separated, the project includes 30 signalized intersections with LRT crossings, of which 7 are gated LRT crossings (standard railroad gates) and the remaining 23 include LRV control (traffic signals for vehicular traffic and "T" signals for LRVs).

For signalized intersections with LRV control (intersections without standard railroad gates), the design philosophy employed on the Tasman Corridor has been much the same as that used in the postimplementation retrofit of the Guadalupe LRT system (*4*). The Guadalupe system initially experienced accident rates that were higher than expected, largely due to left-turn conflicts between automobiles and LRVs. Whereas the accident rate decreased as the public became familiar with the new LRT system, additional left-turn signal heads, signs, and other traffic control modifications were implemented during a retrofit project. Continuing with the success of the Guadalupe retrofit in reducing accidents, the SCCTD is maintaining a consistent design philosophy for the TCP. On a systemwide basis, this will help to strengthen public consciousness with consistent signing and traffic control patterns. Similar to the current Guadalupe system, the TCP will include

- Separate traffic signal displays, phases, and timing parameters for LRVs;
- A flashing warning sign for left-turn movements similar to the Trolley Coming sign that was part of the Guadalupe retrofit;
- Traffic signal coordination and LRT priority in order to minimize LRT delay, while maintaining acceptable intersection level of service; and
- Railroad gates with standard railroad preemption.

The signal system is being designed with maximum flexibility to allow fine-tuning in close coordination with the California Department of Transportation and the five cities responsible for traffic signal maintenance. As an example, there are three levels of LRV priority (none, partial, and full) that can be varied by time of day and can be operated with or without signal coordination.

Perspective

The design of an LRT system poses complicated problems regarding integration with other modes of transportation and coordination relative to operations among the cities. Even though corridor planning studies are proceeding, the implementation of the individual corridor projects that make up the overall rail system is not occurring according to the original schedule due in part to the present lack of a local funding program. With schedule and priority modifications, the goal of providing improved mobility may then not be attained in the precise manner originally envisaged. Should the projects be completed on a delayed schedule, then changes due to developing in the corridor with corresponding roadway modifications inevitably will take place. These changes ultimately could necessitate significant changes in the design of the LRT system. For example, during a 9-month hiatus between the completion of preliminary engineering and the beginning of final engineering, there were a number of significant changes surrounding the Great Mall in Milpitas. A major roadway extension project was placed on an accelerated schedule, necessitating significant modifications to the Tasman LRT alignment and station locations. Moreover, if the completion of the overall LRT system were to be delayed for an extended period, then land use and development changes would further affect the configuration and operation of the system itself. For instance, the location of stations would be affected as land use densities and configurations change significantly relative to proposed station locations.

INSTITUTIONAL AND LAND USE ISSUES

Institutional Setting

From an institutional standpoint, some significant changes have occurred in Santa Clara County during the planning and design phases of the TCP. Since 1974 the SCCTD had been governed by the SCCTD board of supervisors. This five-member body was also the Santa Clara County Board of Supervisors, responsible for all countywide policy making across the broad spectrum of planning, health, social, and law enforcement issues. The board of supervisors/transit district board arrangement functioned effectively for 20 years during the development and expansion of the bus, expressway, airport, and LRT systems.

In 1988 California voters passed ballot Proposition 111, a transportation measure that mandated the creation of county congestion management agencies (CMAs) in all urban counties in California. The function of the CMAs is to oversee the coordinated prioritization of transportation improvement projects on a countywide basis, taking into account local land use decisions. The CMAs can, for example, prevent a city from approving local development projects unless there is sufficient capacity on roadways and transit systems. The Santa Clara County CMA had a 12-member board made up of elected representatives from the city councils of the 16 cities in Santa Clara County, as well as representatives from the county board of supervisors.

There have been many years of discussion regarding the efficacy of having the county board of supervisors also serving as the county transit district board of supervisors. With the formation of the county CMA in 1988, there were two separate governing boards and one advisory commission (the county transportation commission) dealing with countywide transportation issues. In 1992 in the effort to eliminate possible overlapping responsibilities, the voters of Santa Clara County passed a ballot measure advising that the transit district merge with the CMA. Therefore, on January 1, 1995, the SCCTD withdrew from the county government structure and the CMA staff joined the SCCTD staff as an integrated division. Through special state legislation, the transit district board of supervisors and the county transportation commission have been eliminated and the CMA board has become the new transit district board. The intent behind this merger was to streamline countywide transportation planning and policy, with closer ties to the individual cities and local land use decision making.

It should be pointed out that the previous county transit district supervisors were elected on a districtwide basis, with the districts overlapping city boundaries. On the other hand, the new transit district board is made up largely of individual city council members, many of whom are part-time policy makers (particularly in the smaller cities). The new cross section represented on the board will probably change the way in which transportation projects, such as the TCP, are viewed. The new board may have different rail corridor priorities. The broad city and neighborhood representation may also encourage a project to be developed from the bottom up, beginning with neighborhood and city support, within the context of the countywide plan.

Land Use

All Tasman Corridor cities are projected to experience significant growth in population, number of households, employment, number of employed residents, and household income. Specific growth projection data for 1990, 1995, 2000, and 2005 are given for Santa Clara County and for each corridor city in Table 1. As indicated by Table 1, current trends in the corridor cities call for notable growth in population and employment. Table 2 presents current and future build-out residential population and employment data within a 610-m (2,000-ft) radius of specific Tasman LRT station areas. The future residential and employment figures are based on zoning as of May 1991 and do not include the intensified zoning that is described in detail later in the paper. As indicated by Table 2, even without the transit-oriented projects that are now planned, residential population within the Tasman Corridor would increase more than 100 percent while employment in the corridor would increase approximately 12 percent. As further described, major new residential, commercial, and industrial developments are under way in all corridor cities, contributing to the trend for new development in the Tasman Corridor.

SCCTD is working closely with local cities to further integrate land use and transportation. The regional relationship between transit and land use decisions will be strengthened by the new board made up of city council members and the ongoing CMA programs to closely integrate local land use and development decisions with local and regional transportation decisions. In line with the projections in Table 2, actual commercial and residential development along the Tasman Corridor has been occurring at increased densities. The rail corridor gives planners and developers the opportunity to work together to create and approve transit-oriented land uses for mutual benefit, eventually contributing to the success of the developments and the rail system. Efforts already under way in Tasman Corridor cities are described in following sections.

City of San Jose

The city of San Jose has established the *Housing Initiative* (5) to encourage development of high-density hous-

TABLE 1 Tasman Corridor Growth Projections

Jurisdiction	1990	1995	2000	2005	% Change 1990-2005
Santa Clara County					
Population	1,473,600	1,539,950	1,614,550	1,658,100	12.5
Households	525,900	561,950	596,660	617,490	17.4
Household Size	2.72	2.68	2.65	2.62	-3.7
Employment	881,710	980,550	1,069,810	1,145,950	30.0
Employed Residents	815,900	871,000	925,300	950,700	16.5
Household Income	$52,100	$54,800	$58,000	$60,300	15.7
Milpitas					
Population	47,600	53,200	57,900	59,500	25.0
Households	14,210	16,340	18,050	18,740	31.9
Household Size	3.16	3.10	3.05	3.02	-4.4
Employment	37,820	48,510	56,240	60,050	58.8
Employed Residents	25,200	29,100	31,600	32,200	27.8
Household Income	$51,200	$53,900	$56,900	$60,200	17.6
Mountain View					
Population	66,400	69,400	71,500	72,200	8.7
Households	30,220	31,720	32,660	33,080	9.5
Household Size	2.13	2.12	2.12	2.11	-1.0
Employment	68,040	70,470	75,860	79,340	16.6
Employed Residents	43,500	45,400	47,000	47,300	8.7
Household Income	$41,100	$43,900	$49,400	$51,200	24.6
San Jose					
Population	798,000	837,300	882,500	905,200	13.4
Households	271,380	290,700	312,770	342,850	26.3
Household Size	2.96	2.84	2.77	2.74	-7.4
Employment	300,020	355,480	400,660	444,790	48.3
Employed Residents	423,400	456,400	487,900	503,500	18.9
Household Income	$49,300	$52,500	$55,500	$57,700	17.0
City of Santa Clara					
Population	93,400	97,800	101,500	102,600	9.9
Households	37,400	39,510	41,130	41,670	11.4
Household Size	2.42	2.39	2.39	2.38	-1.7
Employment	119,270	129,100	137,940	144,200	20.9
Employed Residents	58,000	60,800	65,000	65,800	13.4
Household Income	$46,800	$47,700	$50,400	$52,600	12.4
Sunnyvale					
Population	120,400	126,500	131,600	132,700	10.2
Households	50,470	53,240	55,560	56,250	11.5
Household Size	2.36	2.36	2.35	2.34	-0.8
Employment	140,990	143,280	146,650	148,610	5.4
Employed Residents	76,200	78,800	82,200	82,700	8.5
Household Income	$49,600	$51,400	$54,500	$56,600	14.1

Source: Association of Bay Area Governments (ABAG) *Projections 90*.
Notes: Employment indicates total number of jobs in the area, some of which are held by local residents, and others which are held by workers outside the area.
Estimates are for April 1 of each year.
Household Income is mean household income expressed in constant 1988 dollars.

ing near transit. A new general plan land use designation known as transit corridor high-density residential, defined as 30 or more dwelling units per hectare (12 or more units per acre) is applied to sites within 610 m (2,000 ft) of LRT stations. Densities of at least 49 dwelling units per hectare (20 units per acre) are generally encouraged unless a low-density neighborhood exists nearby, which might necessitate a less abrupt transition. The city has also increased the height limit of high-density residential development near LRT stations from 13.7 to 27.5 m (45 to 90 ft).

The new Cisco headquarters includes more than 74 000 m^2 (800,000 ft^2) of industrial and office space for 3,000 employees, supporting the growth of the high-technology communications firm. Included at this large site are pedestrian-oriented design elements next to a proposed LRT station along Tasman Drive. The Renaissance Village housing project is nearby, with 1,500 residential units, a day care facility, and commercial uses.

Passing through a vacant 40-hectare (100-acre) parcel, the Tasman project is establishing the alignment of the future Tasman Drive Connection between San Jose and Milpitas. Studies are under way to determine the best possible mixed use development for this site, along with accommodation of a future LRT station. In this example, the LRT project is establishing the overall transportation corridor location before roadway construction.

City of Milpitas

The city of Milpitas has implemented a major transportation improvement program in conjunction with the conversion of a former Ford Automobile assembly plant to the 120 000-m^2 (1.3 million-ft^2) Great Mall of the Bay Area. The mall is now a dominant destination for shoppers and employees. A pedestrian overcrossing will lead from the new Great Mall LRT Station directly toward the main entrance of the mall. The city's program also includes a Tasman Drive interchange with I-880 and a Tasman Drive connecting arterial between the interchange and Capitol Avenue. This is an example of mutually beneficial coordination among SCCTD, the city, and the developer, reflected by the fact that two LRT bridges are being built as part of the interchange project.

City of Sunnyvale

The city of Sunnyvale's major employers, such as Lockheed and Hewlett-Packard, will continue to employ thousands of commuters in need of transportation alternatives. A comprehensive multimodal transit center at Lockheed is under design to facilitate efficient LRT, bus, employee shuttle, and automobile transfers. Lockheed is the county's largest employer, with 18,000 employees. However, with the downsizing of the defense industry, the number of employees will probably be lower than foreseen during the initial planning of the LRT system.

City of Mountain View

The LRT system will make a direct connection with CalTrain in downtown Mountain View at a multimodal transit center. Construction of a new residential neighborhood is under way, and a network of street connections will combine with the transit hub and recent downtown redevelopment to create a distinctive transit-

TABLE 2 Tasman Corridor Current and Future Station Area Populations

	Residents		Percent	Workers		Percent
LRT Station	Current	Future	Change	Current	Future	Change
San Jose						
Hostetter	4,470	5,700	+27.5	100	100	0
Cropley	4,720	5,890	+24.8	1,080	1,080	0
First Street	1,170	5,150	−340.2	3,080	3,080	0
Champion	0	2,467	+∞	1,450	6,183	+326.4
Milpitas						
Montague	0	0	+0	2,520	3,420	+35.7
Great Mall	900	2,180	+142.2	660	3,600	−600.0
I-880	0	0	+0	1,510	7,010	+364.2
Sunnyvale						
Reamwood	3,430	10,410	+203.4	5,370	0	100.0
Fair Oaks	3,220	11,640	+261.5	2,340	0	−100.0
Crossman	0	0	+0	6,170	12,290	+99.2
Borregas	0	0	+0	1,620	2,660	+64.2
Lockheed	0	0	+0	19,750	22,250	+12.7
Mountain View						
Bayshore/NASA	0	1,270	+∞	11,030	10,400	5.7
Middlefield	0	2,330	+∞	6,160	4,640	−24.7
Whisman	1,420	1,420	0	3,060	3,060	0
Evelyn	830	830	0	2,480	2,480	0
Downtown	5,880	8,400	−42.9	3,900	3,380	−13.3
TOTAL	26,520	57,287	−116.0	72,280	80,863	+11.9

Sources: SCCTD, *Tasman Corridor Project Station Area Planning: Phase I*
Paul Ogren, City of San Jose, *Suburban Mobility Initiatives*
Note: **All values are for area within 610 m (2000 ft.) radius of LRT station.**
Future population estimates based on future plans and or build out of undeveloped land under zoning as of May 1991. Current residents as of April 1989. Current employment as of 1990.

oriented neighborhood environment. The city has also recently approved a new transit overlay zoning designation to further integrate future development with existing and future rail developments. This new designation has already been applied to several parcels adjacent to the proposed Middlefield Station. Studies are also under way to develop 850 new residential units on the GTE site surrounding the proposed Whisman Station.

Perspective

The substantial change in the makeup and possible direction of the new transit district board should affect the future of the LRT system. Priorities may change, and goals and objectives may be reevaluated during the course of project implementation.

The importance of looking at the microscopic impacts of the LRT system on the individual cities as well as the macroscopic impacts on the region should be emphasized. The new transit district/CMA board structure should help heighten awareness of this key relationship.

Land use decisions and the relative success of a transit system are inextricably linked. The ongoing dilemma is usually connected to the fact that transit decisions are made in a forum separate from local land use decisions. It is therefore noteworthy that the formation of the new transit district/CMA board will bolster coordinated decision making about the integration of land use and the LRT configuration and will likely go farther toward attaining the land use and community-related goals established for the project.

To maximize its efficiency and effectiveness, an LRT system must either be located within densely developed areas or facilitate new development or redevelopment of relatively dense, mixed use projects at key activity centers and stations. A proper jobs-to-housing balance must also be located along the corridor so that the system goes where people need to go. In recognition that many LRT riders may be dependent on transit, the demographics of the corridor must be considered carefully so that a balanced cross section of riders is served. And, because many new LRT riders will be former bus riders, a comprehensive analysis and redesign of bus routes must also be included as part of the LRT project so that bus routes do not duplicate new LRT travel patterns.

It must also be recognized that the implementation of an LRT system represents a long-range capital-intensive commitment to transportation infrastructure. In turn, local agencies with land use jurisdiction must commit seriously to making appropriate long-range land use decisions, facilitating the essential types of development required for a transit system to succeed. These local decisions are often seen as unpopular and require regional coordination.

The configuration of the Tasman Corridor alignment is largely dependent on the economic success of significant employers, including Lockheed Martin Missiles and Space, Cisco Systems, and GTE. As a result of the recent recession, defense spending cuts, and military base closures, these types of specific industries have not grown as originally forecast. In fact, most defense-oriented firms have actually decreased their work forces. Long-range planning is essential for a capital-intensive, fixed-guideway system such as an LRT system. However, businesses are driven by short-range, results-oriented economic planning. This situation articulates the difficulty in maintaining a long-range view for transportation while the industries that provide ridership and justification for the system are driven by short-range influences. Thus the need to build flexibility and contingency plans into the LRT system is emphasized.

Ridership and Costs

Ridership projections were performed in 1992 for the horizon year 2005 when the project was assumed to be in full operation. These figures are presented in Table 3. The projected costs for the Tasman Corridor, as updated in 1995, are given in Table 4.

Costs for the Tasman Corridor Project have increased, but not excessively so. Some of the increase was due to the ADA requirements, which were not originally budgeted. Any increase in cost, however, presents a problem in terms of financial feasibility. As a result of the delay in implementation of the LRT system, the expenditure will be higher than anticipated. As a result of changes in land use and other infrastructure, the projected ridership and revenue levels may not be realized as originally projected. Consequently, the goal of financial feasibility may be attained to a lesser extent than anticipated. It may therefore be prudent to study different scenarios of future land use and infrastructure developments, obtain related cost and revenue projections, and then plan the layout and operating system within this framework.

Funding Issues

Conceptual engineering began in August 1991 upon completion of the AA/DEIS phase and continued through January 1992. Preliminary engineering was completed in August 1992. Final engineering began in May 1993 and essentially was completed in May 1995.

TABLE 3 Tasman Corridor Alternative Operating Characteristics

	Riders			Transfers		
Alternative	Daily	Peak	Off-Peak	Daily	Peak	Off-Peak
Existing	20,000	9,900	10,100	0	0	0
A	31,100	20,400	10,700	35	25	10
B	28,500	19,300	9,200	790	540	250

TABLE 4 Tasman Corridor Cost Update, 1995

Category	Total (Million)	Percent
Existing Vehicle Modification	\$8.0	1.5
Civil/Structural Construction	\$152.0	28.7
Station Construction	\$22.2	4.2
Traction Power System	\$22.3	4.2
Signal/Communication System	\$17.6	3.3
Engineering/Management	\$132.2	24.9
Right-of-Way	\$84.5	15.9
Contingency	\$40.4	7.6
Financing	\$50.0	9.4
TOTAL	\$530.0	100.0

Source: SCCTD Tasman Corridor Full Funding Grant Application

Meeting the local funding requirements for the Tasman Corridor remains the top priority for the SCCTD and the TCP team. In November 1992 Santa Clara County voters passed *Measure A*, to renew an existing half-cent sales tax for transportation. Nearly 90 percent of the \$3.5 billion in revenue projected over the 20-year life of the measure is pledged for financing construction and operation of an integrated countywide rail system. In addition to providing the local matching funds for construction of the TCP, six other light rail corridors are included, as well as express bus, highway, and expressway projects.

However, this 20-year, half-cent sales tax measure has been challenged by opponents who believe that the measure required a two-thirds supermajority and not the 54 percent vote received. The Sixth District Appellate Court has rendered *Measure A* invalid, and the implementation of the tax is now pending a decision by the California State Supreme Court. The court has agreed to hear oral arguments in June 1995 and a final decision is expected in August 1995. Assuming a favorable decision, it is projected that construction could start by the end of 1995, with revenue service beginning in April 2000. Due to the local and regional consensus that light rail is a key element of the transporration network, funding the TCP remains a high priority. Federal and state funds have been allocated to match the local resources, although the full funding grant agreement will not be able to be executed until the local funding is in place.

The court challenge to *Measure A* is delaying the completion of the Tasman Corridor and the rest of the rail system significantly. Not only has the local funding situation changed significantly, but so has the transportation funding environment. In California, funding priorities now rest with seismic retrofit of existing highway facilities, and in the past several years voters have repeatedly and soundly rejected statewide rail bond, gas tax, and other bond financing measures. As a result, the

California State Transportation Improvement Program, which sets out statewide transportation funding priorities, is now largely unfunded. It is possible then, that the outcome of the *Measure A* legal challenge may severely affect local funding of transportation projects.

Lessons Learned in Silicon Valley

Some of the perspectives discussed earlier in the paper are essentially not new, although some of the specific circumstances are unique. The authors believe that it is valuable to share specific project experiences and lessons learned with others in the industry. In Santa Clara County, it is realized that delays in implementation, increases in costs, and changes in the environment are not unusual for transportation projects and have been handled in various ways in the past. However, the composite effect of a number of issues including a delay in implementation, a court challenge that could lead to a major loss in local funding revenue, changes in the business climate affecting defense industries, and a change in the governing body is of interest.

As discussed before, the delay in the implementation of the overall rail system will probably have the effect of creating a less favorable land use environment for transit, which will lead to lower revenues, bolstering the arguments of those opposing the funding and hampering the early implementation of the overall rail system. Although there may be advantages in the long term in the reconstitution of the governing board, it may be speculated that in the short term the lack of continuity and perhaps loss of political connections may be a disadvantage. The impacts of these compound effects on the long-term feasibility of the LRT system have not been determined.

It can be concluded that changes will occur over the implementation period of a transportation system. Using the Tasman Corridor as an example, it can be seen that many of the external factors changed to the detriment of the future success of the system. What lessons can be learned?

Notwithstanding the fact that all changes cannot be predicted, it appears logical to attempt to predict the changes as far as possible and plan accordingly. Since the changes that occurred are major and happened at different points in time, planning for a changing environment should be continuous and, if planning resources are constrained, then smaller but more frequent planning efforts should be undertaken. Since the coordination between land use and the LRT system is so important to achieve efficiency, it is particularly important to work continuously with all concerned to create a land use and development environment that will be favorable to successful future completion of the LRT system.

The changes in the prediction of the performance of the system must be communicated clearly to the public, since the public ultimately must authorize funds for the system. Despite the changing economic and political environment, the participants in the process of implementing the LRT system have learned lessons and responded to make implementation successful. One important example is the strengthening of the land use/transit symbiosis that should come about through the reconstitution of the governing body. The design of the TCP was essentially completed in May 1995, and there is confidence that the court ruling on the funding measure will be favorable; if not, alternative funding avenues will be sought to secure the local funds to match pledged state and federal funding.

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Light Rail—A Mile High: The Denver Experience

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Denver, Colorado, one of the fastest growing metropolitan regions in the United States, recognizes the significance of light rail transit (LRT) in addressing the ever-present problems of pollution and automobile congestion. In October 1994, Denver's dream of once again operating electric rail vehicles became a reality. The simple system was 100 percent locally funded from a use tax established in 1989 and was designed from lessons learned from other North American systems. The central corridor, as it is called, provides the spine of the proposed rapid transit system in the Denver metropolitan region. The total budget for the 5.3-mi alignment was $113.7 million. Off-the-shelf technology was implemented whenever possible as the central corridor project was the starter line for the region and it was important for providing the citizens of the region an opportunity to become familiar with the efficiencies inherent in LRT operations. A small design and construction staff team was organized to manage consultants in the design and construction of the project. In this process, the Regional Transportation District (RTD) evaluated every element of the light rail system to ensure that future construction would benefit by the project. In general, RTD attempted to balance the existing project demands with future expansion. Less than 3 years following preliminary engineering, Denver once again is operating electric railway revenue service within its city limits. Metropolitan Denver officials continue to support this mode of transportation and anticipate that future funding will be made available to enhance and complete the proposed regional rapid transit plan, which will include at least four more corridors. The planning has taken decades to accomplish, but light rail in Denver is healthy and rolling along.

Denver's dream of once again operating electric rail vehicles, after their 40-year absence, became a reality on October 7, 1994. Following nearly 20 years of planning, a 5.3-mi light rail starter line was inaugurated with a free fare weekend, carrying more than 150,000 citizens and officials of the metropolitan area. The system was locally funded with simplicity in mind and the idea of designing expansion around lessons learned from other North American systems.

After its first year of operation, the system's peak-hour ridership is at capacity, and six additional vehicles are to be delivered in January 1996. In addition, preliminary engineering for an 8.7-mi extension is complete, and three new corridors are in the major investment study (MIS) phase.

Denver, one of the fastest growing metropolitan regions in the United States, has recognized the significance of light rail transit (LRT) in providing an alternative to the automobile and in addressing the need for minimizing pollution and congestion in its burgeoning downtown area. Metropolitan Denver officials continue to support this mode of transportation and anticipate that future funding will be made available to enhance and complete the proposed regional rapid transit plan.

PROJECT HISTORY

The central corridor provides the spine or center segment of the proposed rapid transit system in the Denver metropolitan region (Fignre 1). With the construction and implementation of the first-phase central corridor, the Regional Transportation District (RTD) will be able to lower the costs of building the remaining corridors substantially, since the downtown segment, as with many other systems, is the most expensive and restrictive to construct. This corridor provides a collection and distribution alignment for connecting all proposed rapid transit system extensions.

Although planning for the metropolitan region's rapid transit system began in the early 1970s, it was not until 1987 that RTD was directed under Colorado Legislature House Bill 1249 to develop a plan for financing and implementing rapid transit within the seven proposed corridors and to submit that plan to the Colorado General Assembly. As a direct result of House Bill 1249, in 1987 the RTD Board of Directors also adopted the "Fastrack Program" and identified the preferred alignment, technology, and financing on each of seven corridors.

In 1989 a Colorado state use tax ruling on appeal allowed RTD to collect a use tax on goods and services

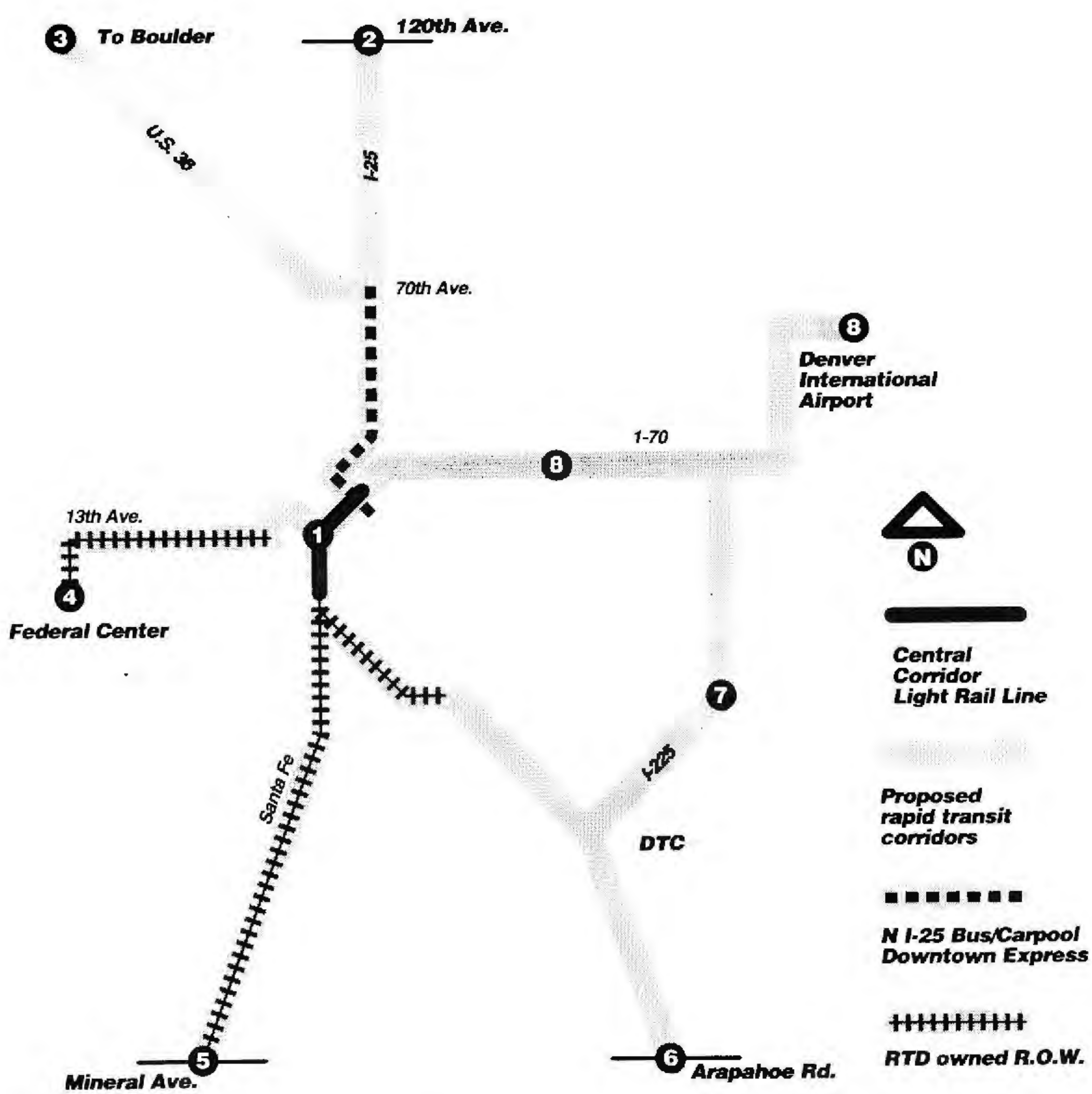

FIGURE 1 Proposed rapid transit corridors.

purchased outside the district for use within, thus providing the 100 percent local funding source for the central corridor. The corridor was selected by the RTD Board of Directors for a rapid transit demonstration line that would connect the Auraria Higher Education Center (a three-college campus with approximately 32,000 commuting students), the central business district (CBD), and Stapleton International Airport and would be funded entirely with local funds or the income generated from the use tax, which was a tax of 0.6 percent on metropolitan region retail sales.

In 1990 light rail technology was selected by a community advisory committee and adopted by the RTD Board of Directors to be used in the Northeast Corridor. Originally, the alignment was to run from Auraria to the old Stapleton Airport. However, because of outcry from residents along Martin Luther King Boulevard near the airport who associated LRT with mile-long freight trains, the line was shortened from Auraria to Downing Street.

In 1991 the conceptual engineering was completed and the starter line designated as the central corridor. Studies began to produce a detailed operating scenario, ridership forecasts and costs, as well as other technical memoranda in order to document the feasibility of the project. Late in 1991, preliminary engineering was initiated and 11 light rail vehicles (LRVs) were ordered.

In 1992 preliminary engineering was completed and approved by the RTD Board of Directors and the Denver Regional Council of Governments (DRCOG). Construction of the LRV maintenance facility and storage yard was started, and vehicle manufacturing began. Later that year, the RTD Board of Directors voted to approve an extension to the project, doubling the original revenue alignment from 2.7 to 5.3 mi along a previously purchased railroad right of way where speeds of 55 mph could be reached and demonstrate more efficiencies of the light rail technology. Since more than 530 bus trips into the CBD would be discontinued and their passengers transferred to light rail, the extension was funded by bonds and financed as a direct result of operational savings. The total budget for the 5.3-mi alignment in the central corridor between Broadway and I-25 on the south and 30th and Downing streets in northeast Denver was $113.7 million, which again was all locally funded.

In late summer 1993 the operations facility was completed, including a 1-mi stretch of double track with catenary for testing of the vehicles. The first LRV arrived in November 1993, and the training of personnel along with the LRV acceptance testing and commissioning process began. RTD also purchased a 9-mi unused rail corridor to the southwest, bringing the total rail corridor right of way owned by RTD to approximately 24 mi within six of the seven proposed rapid transit corridors.

In June 1994 civil construction as well as system elements were completed and integration testing was started. (Integration testing is the process of ensuring compatibility between the operating vehicle and system elements such as track, catenary, signals, and facilities.) Testing was completed approximately 2 months later and prerevenue operation began. On October 7, 1994, free service was initiated for citizens of the metropolitan region for 3 days; estimated ridership was between 150,000 and 200,000. On October 10, 1994, less than 3 years after preliminary engineering, Denver once again was operating electric railway revenue service within its city limits.

Physical Description and Operating Challenges

RTD's light rail starter line is a conventional system running from a southern Denver terminus through the heart of the city and north to another terminus. The line is 5.3 mi long and consists primarily of double track. The southern half of the alignment is located in a former Denver and Rio Grande Railroad corridor with open ballast track, where the LRVs reach speeds of 55 mph. The remaining track alignment is in Denver city streets with maximum operating speed of 30 mph.

Within the heart of the city, the alignment completes a loop that connects major east-west streets and Denver's famous 16th Street Mall for transit and pedestrians as well as the Civic Center and Market Street bus transfer stations. The downtown LRV operation is within a curb-separated, restricted lane in a contraflow direction to automobile traffic.

Traction power at a nominal 750 V direct current (DC) is transmitted to vehicles through simple trolley wire in the downtown section, and compound catenary is used in the high-speed sections of the alignment. Power is supplied by six mainline 1-MW substations and one 1-MW substation dedicated to the operations facility for shop and storage track power. These unmanned substations use state-of-the-art PLC transformer/rectifier units to convert 13,200 V alternating current (AC) power (supplied to RTD by the Public Service Company of Colorado) to the 750 V DC required for operation.

Most of the 5.3-mi alignment is double-tracked, providing for one-way travel on each track under normal operating conditions (Figure 2). The two major exceptions are as follows:

1. In order to provide on-street parking for the Five Points business district, six blocks of single track were constructed along Welton Street in that area.
2. The circulator loop in the downtown area consists of single track along California Street northbound and Stout Street southbound between 14th and 19th streets.

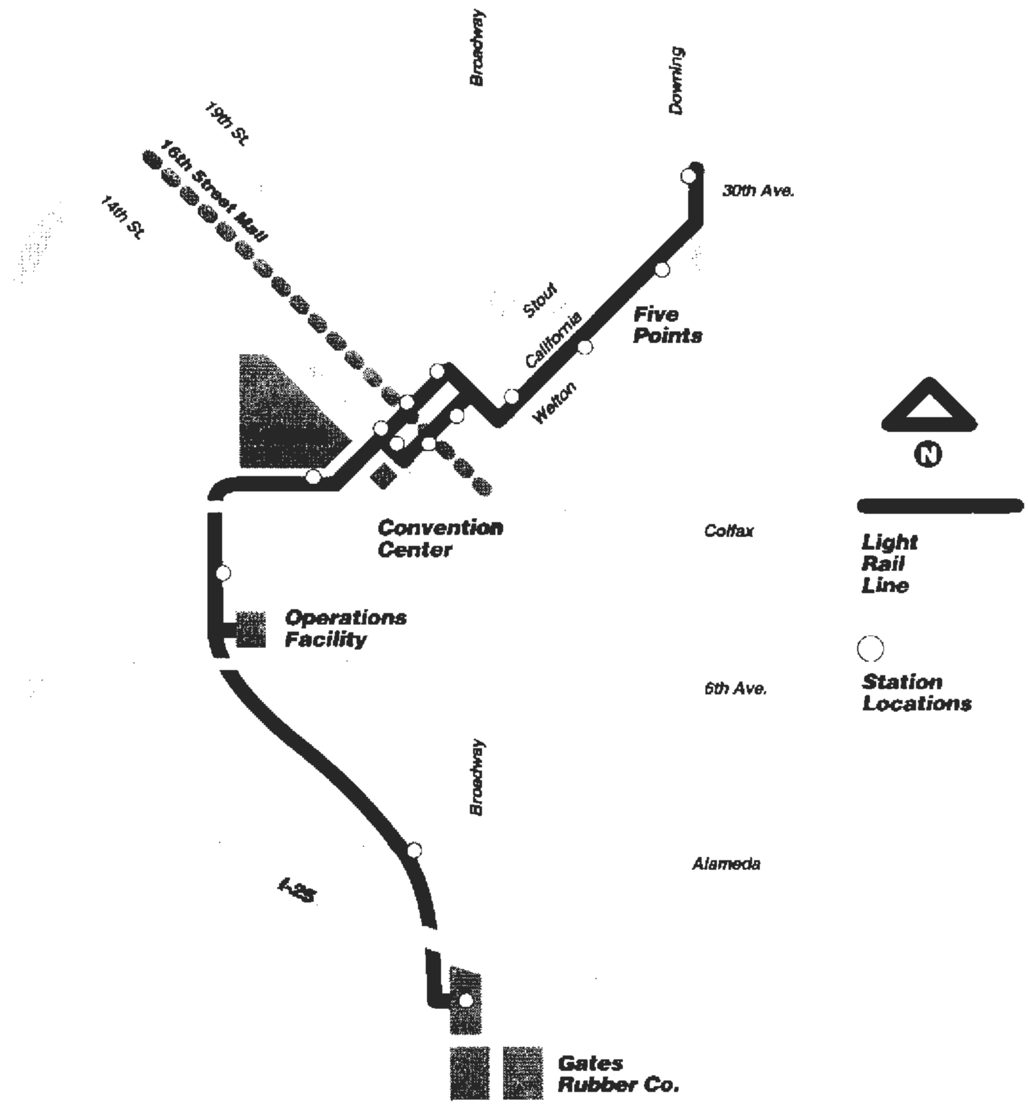

FIGURE 2 Central corridor light rail line.

Track gauge is standard railroad of 4 ft 8½ in. All rail is continuous welded 115 lb and heat-treated in curves. All rails, with the exception of yard storage tracks and switches, are secured on concrete ties with rail clips.

Crossovers between north- and southhound tracks are provided at intervals to permit operation in both directions on a single track during maintenance repairs or service disruptions. Most mainline switches are powered and controlled by the operator via a train to wayside communication system on board the vehicle. All switches are also heated electrically because of Denver's winter climatic conditions.

Rail operation is controlled by automatic block signals in the high-speed sections from Colfax Avenue to the southern terminus. In these areas, trains are protected by the operator's visual observation of wayside signals. Trains are also governed by traffic-type signals in the single-track section through the Five Points business district. All downtown streets are controlled by special transit signals that permit the LRV to proceed when automobile traffic is stopped.

Grade crossing protection in high-speed areas is controlled by typical railroad grade crossings consisting of gates, bells, and flashing lights. In addition, distinct trolley crossing (international trolley symbol) signs with flashing yellow caution beacons are located across from each railroad flasher to supplement the warning (Figure 3).

There are 14 passenger station areas with 24 platforms: 17 single-side platforms and 7 center-island platforms. All platforms are accessible to persons with disabilities via a ramp and minihigh block loading area. With the exception of the center-island type, all stations are initially constructed for two-car trains. The center-island platforms, however, are constructed to the maximum train consist length of three vehicles. The three-vehicle platform length is the result of the length of the shortest city block along the alignment within Denver.

All passenger stations are of similar design, generally consisting of concrete pads or pavers, a vaulted arch-shaped canopy, ticket machines and validators, information displays and signage, benches, and trash receptacles. Three of the station sites have bus transfer facilities, kiss-and-ride areas, bicycle lockers, and parking spaces for nearly 1,000 automobiles. Platform security is provided by a combination of RTD supervisory personnel, Denver police, and contracted security services.

An initial fleet of 11 LRVs (Siemens Duewag Corporation Model SD 100) has been in operation since the October 19, 1994, revenue start date. However, because of extremely heavy peak passenger loads, six more vehicles have been ordered; expected delivery dates are January to March 1996. These vehicles are six-axle, single-articulated, double-ended, and bidirectional. They are approximately 80 ft long, 8 ft 9 in. wide, and 13 ft high and operate on a standard railroad gauge of 4 ft 8½ in. They are powered from an overhead wire by 750 V DC and capable of speeds up to 55 mph. Each vehicle will seat 64 passengers and will accommodate up to an additional 61 standing passengers by the RTD's passenger loading standards. Additional standing passengers may be accommodated at a crush load capacity. All vehicles are accessible to persons with disabilities via an on-board ramp located at

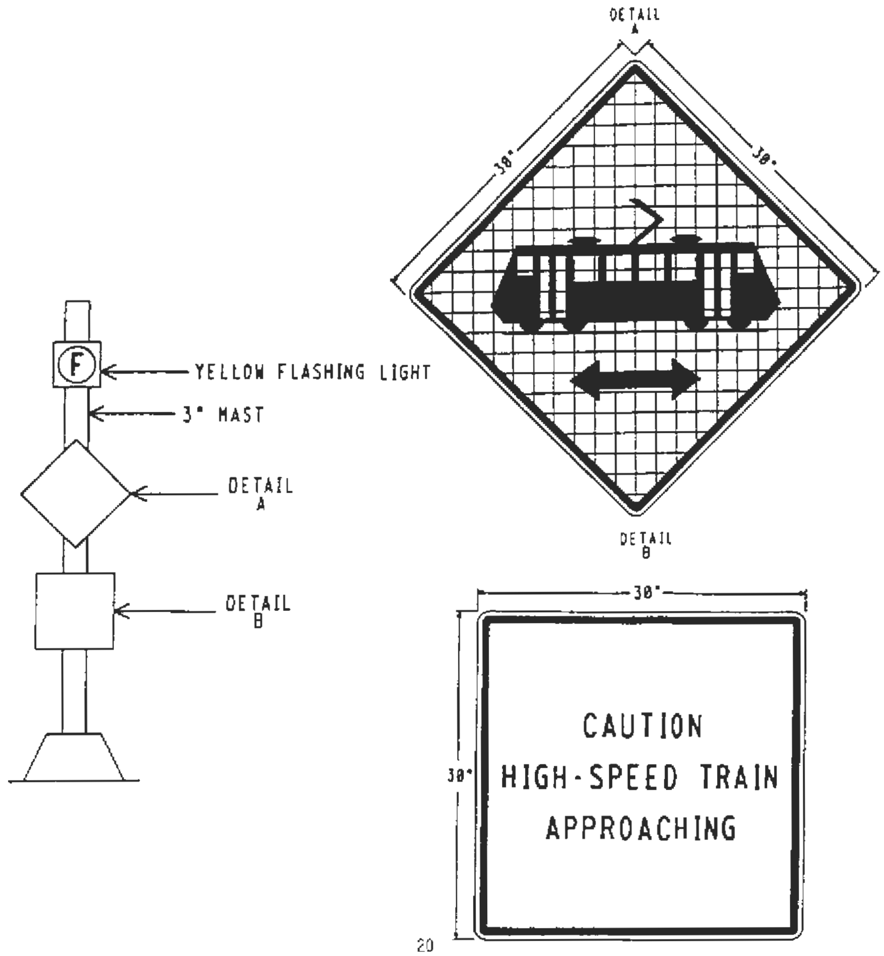

FIGURE 3 International trolley symbol and flashing caution beacon.

the front doors. The vehicles are well lit and equipped with surveillance cameras, passenger emergency intercoms, and adequate heating and air conditioning requirements to meet the demands of the Denver environment.

The light rail operations facility is approximately 45,000 ft^2 and is located on a 5-acre site. The site includes a storage yard for approximately 19 vehicles, maintenance of way (MOW) storage, a vehicle maintenance area of 10 bays that includes exterior wash, body repair, paint room, blow down, inspection pits, mezzanine level rooftop inspection areas, wheel truing machine pit, in-floor jacking system, and a flat truck. In addition, some unit repair and nonrevenue vehicle maintenance as well as inventory storage will be accomplished at RTD's bus facilities. Central control is located on an upper floor of the facility along with all light rail administrative and training offices. The central control is the operational authority for all yard and mainline LRV movements, including the coordination of MOW or contractor activities. Central control personnel (controllers) direct, control, and monitor revenue service operations using radio, a global positioning satellite automatic vehicle location system, telephones, and public address communications systems.

The original fleet of 11 vehicles was designed to accommodate a peak schedule requirement of 10 cars, with 10-min headways throughout the entire alignment, overlaid with short-turn trips between the southern terminus and 19th Street in the CBD in order to create a 5-min peak headway on the south segment (Table 1). However, during integrated testing in August 1994, operating tests indicated that the planned headways were not realistic because many factors had changed during the final design and construction:

- Traffic signal timing was not as efficient as anticipated.
- Trains moved more slowly in the CBD and along Welton Street than planned because of real as well as perceived safety precautions.
- Two additional stations had been introduced along Welton Street.

Ridership forecasts were also increasing. The original forecast was 13,000 weekday riders by 1994; however, by opening day the forecast had changed to 14,000. The transferring passengers from buses would eliminate nearly 530 bus trips from the downtown areas, a commitment given to the city of Denver and its residents as part of the advantages of light rail. The LRV order was already in the delivery stage by that time, and little could be done to alleviate the expected overcrowding immediately after the revenue start date.

As a way to accommodate the greatest numbers of riders and to alleviate the areas where anticipated slower travel times would occur, the line opened with a 5-min peak headway on the south segment from 19th Street to I-25 and Broadway and a 15-min peak headway on the north segment from 19th to 30th and Downing streets. LRVs were deployed in the cycles given in Table 2.

Actual ridership immediately after the start of revenue service was nearly 16,000 each weekday. This increase was generated by transfers to and from buses by customers who had been projected to prefer local bus routes into the CBD and a larger-than-anticipated number of automobile drivers parking near and around the terminus stations. The latter group was particularly significant because it was not predictable by specific train times as were the bus transfers. This unpredictability created overloading of many of the peak trains and, combined with the factors previously cited, created additional schedule problems and resulted in public criticism. Most of the criticism came from long-time suburban express and regional bus riders, who had been accustomed to traveling into the city with no transfer penalty and very comfortable seating arrangements. Other complaints came from local bus riders on the north segment who had experienced 15-min peak service and who saw the difference between the two peaks as unfair and in direct opposition to RTD's "promised"

TABLE 1 Original Vehicle Deployment Plan, Peak Periods

					Hourly Capacity at Peak Load Point		
Cycle	Minutes	Trains	Cars/Train	Total LRVs	Seated	Standee	Total
Whole line	40	4	1	4	384	366	750
19th St.–I-25 & Broadway	30	3	2	6	768	732	1,500
Spares	—	—	—	1	—	—	—
Total		7		11	1,152	1,098	2,250

SOURCE: R. W. Rynerson, Regional Transportation District.

TABLE 2 Opening Vehicle Deployment Plan, Peak Periods

Cycle	Minutes	Trains	Cars/Train	Total LRVs	Hourly Capacity at Peak Load Point Seated	Standee	Total
Whole line	60	4	1	4	256	244	500
19th St.–I-25 & Broadway	30	2	2	4	512	488	1,000
19th St.–I-25 & Broadway	30	2	1	2	256	244	500
Spares	—	—	—	1	—	—	—
Total		8		11	1,024	976	2,000

SOURCE: R. W. Rynerson, Regional Transportation District.

10-min planned headway. The process that led to this situation could be explained to the individual, but technical details were not so easy to communicate to the community.

To alleviate some of the complaints and overcrowded conditions on the trains, less than 2 weeks after revenue operations started, three heavily traveled suburban bus routes were extended to the Civic Center Station in downtown Denver. This was expected to satisfy most complaints and relieve the overcrowding. However, after this rerouting, approximately 30 percent of the riders continued to rely on the trains, decreasing the effectiveness of the rerouting plan.

The combination of bus rerouting and the decreasing numbers of curiosity riders resulted in some ridership drop in late October and early November. After Thanksgiving week, however, ridership again increased with shoppers and participants in holiday events. Again, public criticism increased and RTD responded by rerouting another significant number of bus trips into the downtown Civic Center Station.

After the first few months of operation and the changes in bus transfers at the terminus facilities were reviewed, in January 1995 the peak headways were modified to make additional improvements. Trains on the south segment from 19th Street to I-25 and Broadway now operate every 6 min, and trains through the north segment from 19th to 30th and Downing streets operate every 12 min. With these changes, service reliability and customer satisfaction improved dramatically (Table 3).

Once the six new LRVs are introduced in early 1996, bus routes will be removed from downtown Denver once again. The proposed schedule assigns two-car trains to all trips turning at 19th Street, where loads are greatest and—more important from the customers' perspective—the following advantages will be recognized:

1. Capacity in the peak of the peak period will exceed all observed situations other than those created by special events so that passengers will not be left on the platform.
2. Capacity in the fringe of the peak period will allow for the majority of passengers to be seated.
3. Service will be more reliable, even when buses are delayed and connections made at times when double-car trains are not scheduled.

TABLE 3 January 1995 Vehicle Deployment Plan, Peak Periods

Cycle	Minutes	Trains	Cars/Train	Total LRVs	Hourly Capacity at Peak Load Point Seated	Standee	Total
Whole line	60	5	1	5	320	305	625
19th St.–I-25 & Broadway	36	2	2	4	428	412	840
19th St.–I-25 & Broadway	36	1	1	1	107	103	210
Spares	—	—	—	1	—	—	—
Total		8		11	855	820	1,675

4. The spare ratio will be improved: two vehicles will be available for emergency situations when vehicles must be taken out of service.

Lessons Learned

During the 1980s light rail projects were at a distinct disadvantage since most surface trolley systems were discontinued in the 1950s. The technology had changed, and experienced rail transit personnel were retired and lost to the industry, so a new generation of transit professionals had to be developed in order to accommodate the resurgence of rail projects. After nearly two decades of development, Denver was able to take advantage of new technology and these new-generation transit professionals.

As part of the planning phase, it was decided that off-the-shelf technology would be implemented whenever possible. Furthermore, the design criteria would require the system to be simple and yet expandable. The central corridor project was the starter line for the region, and it was important for providing citizens an opportunity to become familiar with the efficiencies inherent in LRT operations.

A relatively small design and construction staff team was organized to manage consultants in the design and construction of the project. The team was composed of transportation planners, engineers, and project managers with previous experience in light rail design, civil construction, community relations, and light rail operations personnel. In the design and construction process, RTD evaluated every element of the light rail system to ensure that future construction would benefit by the project. The elements specifically addressed were the installation and maintenance for drainage, duct banks, utilities, street pavement treatments, station design and consistency, adjacent facilities, electrification, signalization, and track appurtenances.

Duct banks were designed and built with capacity for a future supervisory communication and data acquisition (SCADA) system to ensure improvements in systems operation, communications, and security as the transit corridors developed. As a means of alleviating additional disruption, adjacent streets in the CBD were paved with concrete so that future paving construction and modifications would be limited. A removable flangeway boot was used instead of flangeway filler to ensure ease of maintenance as well as electrical isolation and possible stray current mitigation. The expansibility of each station was accomplished by making sure that future electrical pull boxes and ticket vending machine locations were constructed so station modifications could be simplified at a later date. All center-island platforms were constructed at minimal costs to meet the future three-car consist so as not to seriously affect operations when platform modifications were eventually required. Substations were designed to allow an easy upgrade from the initial 1-MW output to 1.5-MW as the system expands. All substations and signal relay cases were designed with the ability to be upgraded for SCADA controls. All special track work was of typical American Railway Engineering Association design and standards to allow for efficient modifications and repairs. Concrete ties were used throughout the alignment, except for switches and yard tracks, as a way to reduce maintenance costs. The operations facility was designed and constructed to allow expansion to larger vehicle fleets in the future. The facility was to be utilized as both a running repair and heavy maintenance facility until the fleet size required additional storage spaces, and then it would be a heavy maintenance facility. Additional expansion would require a future running repair facility.

In general, RTD attempted to balance the existing project demands with future expansion and do so within a budget supported entirely by local funds. Lessons learned from other projects prompted many of these considerations. It is the charge of public officials to continue to seek ways to ensure efficiency as well as effectiveness.

Corridor Expansion Since Light Rail Implementation

The southwest corridor (Figure 1), Denver's next transit priority, was selected through the alternative analysis process to be a new light rail corridor and was approved by both the RTD Board of Directors and the DRCOG as the highest-priority transportation project for the region. In the southwest corridor, preliminary engineering and the environmental impact statement process have been completed and the final design is ready to begin. This grade-separated and double-tracked 8.7-mi extension that parallels Santa Fe Drive, a major arterial in the southwest metropolitan area, will have five additional stations. Three of the stations will have large park-and-ride facilities, adding an additional 2,000 spaces, and all five will serve as bus transfer facilities. The estimated ridership in addition to the existing central corridor will be approximately 10,000 passengers per weekday, making the total weekday passenger ridership along the combined 14-mi alignment approximately 25,000 riders a day. The 10-min peak and 15-min base headway in the new extension will require an additional 14 vehicles, increasing the fleet size to 31 vehicles.

Also beginning in the early part of this year, RTD, in conjunction with the Colorado Department of Transportation (CDOT) and DRCOG, initiated three MISs.

The three corridors to be studied include the southeast Corridor (I-25 south to the Denver Tech Center), the west corridor (downtown Denver to Golden), and the east corridor (downtown Denver to the new Denver International Airport).

The primary purpose of an MIS is to provide a decision-making process determining future transit corridor priorities for the metropolitan region. The MIS must contain enough information to measure and evaluate a range of corridor alternatives. Included within the MIS process is a careful and thorough evaluation of a full range of alternatives and an open public process that includes community input for determining the preferred alternative.

The three agencies involved in the studies (RTD, CDOT, and DRCOG) have established a cooperative and collaborative process. Each agency will be responsible for directing the analysis efforts in one of the corridors. RTD will manage the work efforts in the west corridor, CDOT will be responsible for the southeast corridor, and DRCOG will oversee the east corridor. It is the intent of the three agencies to bring each corridor forward in the MIS process to an equivalent point—that being the definition of a preferred alternative that then can be advanced to preliminary design and the preparation of an environmental impact statement. Policy and decision makers at each of the three agencies then will be able to evaluate the technical merits of each corridor and decide which of the three should be advanced to the next stage of development. It is also anticipated that the process will identify which investment may be eligible and thus supported for federal funding in the future. It is expected that the process will be completed for all three corridors about the middle of 1996.

Although the planning has taken decades to accomplish, this brief description of the recent results shows that because of a mile-high attitude, LRT in Denver, Colorado, is healthy and rolling along.

Beyond the Field of Dreams: Light Rail and Growth Management in Portland

G. B. Arrington, *Tri-Met*

The Portland region has received considerable attention for a two-decade experiment balancing land use and transportation. The region took the road less traveled by choosing to grow without the negatives of more automobiles and freeway lanes. Today, Portland offers a quality of life that is the envy of much of the nation. The roots of the Portland strategy are surveyed by examining where the region has been, the results so far, and choices for the future.

The success of Portland's light rail system—MAX—has been the subject of a lot of attention. What is becoming better understood is that MAX is more than a transportation investment, it is part of a conscious strategy. MAX has been a vehicle to move people, shape the region, defer highway investments, clean the air, and enhance quality of life (*1*).

Transit and land use have enjoyed great support in Portland because they are not an end in themselves; they are the tools that community leaders have used to build a more livable community. Light rail is at the forefront of a strategy to shape regional growth by coordinating transportation investments with land use policies. An 18-mi extension of MAX to the west is under construction, and voters recently authorized the local funding for a 25-mi extension to the south and north. The Portland story is one about community building with light rail.

A Choice of Growth

"What Portland offers America is an alternative view for how to grow" (*2*). By any objective standard, the Portland metropolitan area has been successful in integrating land use and transit. Investment in new development adjacent to MAX already exceeds the cost of the project fivefold (Figure 1).

Portland's downtown has not always been healthy. In 1970 its downtown, like most of those across America, was dying. Portland made a choice about how it wanted to grow. On the basis of that success, Portland has shown that it is possible to grow and stay livable. There is no Faustian bargain that says traffic jams and dirty air are unavoidable. They are the results of growing the wrong way, making the wrong choices.

Successes take time and require stewardship. That noted "urbanologist" Mae West was fond of saying that "anything worth doing is worth doing slowly." The Portland region has 20 years of leveraging transit investments to achieve its land use objectives.

Rewards of Growing Right

Downtown Portland provides an example of making smart choices. The key elements in Portland's success include collaboration between strategies and among governments:

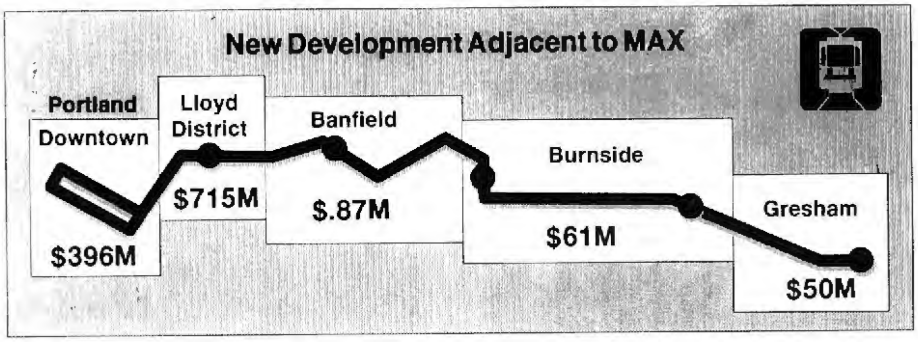

FIGURE 1 More than $1.23 billion worth of development has occurred adjacent to the MAX line since the decision to build the project.

- A downtown plan that focuses the most intensive development adjacent to transit, putting transit in the center of the action;
- Strict limits on parking: tight maximums, but no minimums. The closer one is to MAX and the transit mall, the less parking is allowed;
- Development required at a pedestrian scale—no blank walls, buildings up to the street, and 60 percent of ground floor uses as retail (3);
- An investment in improved transit: the Portland Transit Mall, Fareless Square, and MAX;
- A balanced transportation strategy; for 20 years, no new road capacity has been added to downtown; and
- An urban growth boundary that legally defines what is urban and what will remain rural.

The result is a vital, vibrant downtown, anchored by the Transit Mall and MAX. The downtown area has grown from some 50,000 jobs in 1975 to more than 86,000 today, an increase of over 50 percent. At the same time, air quality has improved markedly. In 1973 Portland's air violated federal health standards 2 out of every 5 days; since 1987 there have been no violations. Transit has done its share. Nearly 40 percent of downtown work trips arrive on transit (4).

As for the transit–land use connection, it is physically irreversible. Even if Portland wanted to change course, it would be difficult, if not impossible. For 20 years, the downtown parking supply and the arterial and freeway grid leading to downtown have been undersized with transit in mind. A 1984 study estimated that without Tri-Met, six 42-story parking structures would have to be added to Portland's skyline and two additional lanes to every major highway entering the downtown (5).

Community Building with Light Rail

The editor of an Eastern business journal was so taken with Portland that he recently wrote that "if Walt Disney had built a city where people really live, [Portland] could be it (6)."

Some cities mistakenly believe that just having light rail technology will ensure the results seen in Portland. Just like a roller coaster in a mountain does not make Disneyland, light rail alone does not make a successful downtown.

Building rail is not an end in itself. The Portland story is more about community building than light rail building. MAX has been an effective means to the end of a livable community. Transit and land use enjoy great community support because they are the tools used to achieve livability.

Partnership for Success: Transit and Land Use

Tri-Met has not sought land use authority. A key to Tri-Met's success is what one could call the Tom Sawyer approach: get someone else to do the land use planning for you. Like Tom Sawyer did when painting his fence, Tri-Met got someone else to do the planning for it. In this case, Huckleberry Finn was local government.

A successful land use and transit strategy requires a working partnership between local governments and the transit district. As in any partnership, each side has expectations of the other. Tri-Met is asking local governments along rail corridors to take action to make development physically more dependent on transit by limiting parking, constraining automobile access, widening sidewalks, improving pedestrian access, allowing a mix of uses, and creating higher-density development. In exchange, governments expect Tri-Met to provide the necessary service to accommodate growth. In more blunt terms, local government is shifting a major part of the cost of growth to transit.

Light rail is the infrastructure investment to handle the transportation pressures of growth in major corridors. Rail then also becomes a powerful tool for governments to help implement its plans. Light rail will not create new growth, but with supportive plans and policies in place, it can influence where development occurs and what it looks like.

Field of Dreams

Today the "Field of Dreams" theory of development—build it and they will come—works only in the movies and at freeway interchanges. A desire to capture the development potential of light rail resulted in a $1.2 million planning program paid for out of the MAX construction budget. The Transit Station Area Planning program (1980–1982) laid the foundation for development along the line by determining market potential, planning for the urban fit of the project, and rezoning station areas. Before construction started on MAX, every station area along the corridor had been rezoned to stimulate transit-related development around the stations. Local governments along the corridor participated in the program because they saw MAX as a way to implement their comprehensive plans. New higher-density zoning, specifically tailored to light rail, was put in place around the suburban stations. At the end of the line in Gresham, the city replanned the downtown around rail (7).

Development of More Than $1.2 Billion

Portland is demonstrating that light rail linked with land use planning can have a dramatic impact on regional growth. With 8 years of operating experience, the results are very promising. More than $1.23 billion of development exceeding 10 million ft^2 is under construction, or has been completed, immediately next to the MAX line since the decision to construct the project in 1979. Plans have been announced for another $440 million of additional improvements. The impact of MAX has been felt from end to end of the line. Development activity is greatest in the downtown and Lloyd Center. In downtown, MAX has accelerated historic renovations, influenced the design of office buildings, and helped make new retail development feasible. Virtually every parcel of vacant land adjacent to MAX downtown has changed hands, been developed, or had development plans announced.

In the suburban section of the line between Gateway and Gresham, development has been slower to start and more modest. More than $125 million in improvements have been made within ½ mi of MAX stations since 1990. Garden apartments typify much of the new development that has occurred at all the Burnside Street stations. To date, there have been more than $30 million of apartments constructed next to the stations.

The development response to MAX has been practically invisible around the three stations in the Banfield section. Here, MAX is wedged into a cut next to an urban freeway that separates it from the neighborhoods it serves.

The impact of MAX on development by all accounts appears to be positive. The assessed values of station area properties have risen faster than the countrywide average, according to a 1993 study. Whereas countrywise assessed values increased by 67.5 percent during 1980–1991, the evaluation of several stations shows a more rapid increase: Lloyd Center grew by 134 percent, 162nd by 112 percent, and 181st by 491 percent (8).

Businesses are reporting higher sales volumes and increased foot traffic because of MAX. In a 1987 survey of 54 businesses near the MAX line, 66 percent of business owners said that their location near MAX had helped business. More specifically, 54 percent said they saw increased sales volume as a result of being near MAX. The strongest benefits of MAX were attributed to increased business visibility rather than to customers' getting off the light rail and making purchases (9).

Long-Term Impact of MAX

As with other rail systems, the major development response to MAX has always been expected to occur after the system has been in operation for several years and its ridership potential fully demonstrated. Three projects illustrate the long-term impact of MAX.

Lloyd District

MAX has changed the shape and configuration of downtown Portland. The Willamette River has always been a physical and psychological barrier constricting the core to the west side of the river. MAX has been given credit for transcending those barriers and transforming the Lloyd District into "downtown east."

The reshaping of the Lloyd District has been impressive—the district has been the beneficiary of nearly $6 out of every $10 invested adjacent to MAX. Four key decisions in the transformation of the Lloyd District are related to MAX:

1. The presence of MAX was a critical factor in the decision to locate the $85 million Oregon Convention Center across the Willamette River outside downtown. MAX is the spine connecting hotels, the convention center, and the downtown. The 400,000-ft^2 convention center has been designed to front onto MAX. A new MAX station and plaza paid for by the convention cen-

ter create the front door for arriving and departing conventioneers. Interestingly, there is no door facing onto the 800-car parking lot.

2. Melvin Simon and Associates cited MAX as a factor in its decision to buy and undertake a $200 million renovation and expansion of the 1.3 million-ft² Lloyd Center Mall.

3. MAX also has been a focal point for Pacific Development in its plans to develop 70 acres of land that it acquired paralleling MAX in the Lloyd Center Area.

4. The decision of the Portland Trailblazers professional basketball team to build a $262 million arena also was influenced by MAX. The 20,340-seat Rose Garden is nestled between the MAX Rose Garden Station and the existing 12,666-seat Memorial Coliseum. The Trailblazers are betting $228 million of their money on a master plan that relies on a strong transit and pedestrian emphasis. Just as its neighbor the convention center, the Rose Garden is designed with transit in mind. It better be—the two projects will have a combined total of just 3,446 off-street parking spaces for more than 1.1 million ft² of space. Of that number, 369 spaces are in Court One (the Blazers' entertainment complex) and will not be available for arena customers.

The *New York Times* summed it up in an August 25, 1991, article:

> The Portland Development Commission estimated that since the Convention Center plan was announced four years ago, more than $500 million in private funds have been invested within a mile of the site. Projects values at an additional $750 million have been proposed.
>
> The linchpin was the completion in 1986 of a light rail system connecting this district to downtown. Four stations serve the roughly 100-block Lloyd District. "The installation of light rail made a big difference," said Bill Scott, president of Pacific Development, a company that bought 70 acres of the district from the Lloyd Corporation four years ago. "The purchase solidified the Convention Center area and made it possible to attract development interests," he said. (*10*)

Pioneer Place

The Rouse company is building a four-square-block, $180 million retail/office/hotel complex at the "100 percent corner" of downtown Portland. The retail and office components, anchored by the region's only Saks Fifth Avenue store, opened in 1990. Transit surrounds the project on three sides with two light rail stations and the Portland Transit Mall. The easiest way to get to Pioneer Place is by MAX. Riders get off MAX, step across the platform (which is also the sidewalk), and arrive at the front door. No automobile can equal this degree of access. For the developer, light rail means a lower parking ratio and development costs, a locational advantage over the competition, and access to a broader retail market.

Winmar/Tri-Met Regional Mall

At the other end of the line in Gresham, MAX held out the promise for changing perhaps the most automobile-oriented type of American development: the suburban mall. After 2 years of planning, Winmar Company of Seattle submitted design plans in April 1990 for a $100 million, 900,000-ft² regional mall to be built over and incorporated directly into the light rail line. The mall, a joint project with Tri-Met, would have been on the cutting edge of suburban development. Like the downtown Rouse project, MAX would be the most convenient way to arrive. A new MAX station would deliver riders right into the middle of the action. For Tri-Met, the mall would have meant increased ridership and a long-term cash flow for the light rail system to make it self-sustaining within 7 or 8 years after the center opened. Congress earmarked $14.5 million in Section 3 funds to be used for Tri-Met's share of the sell-leaseback arrangement.

Unfortunately, not all good ideas make it from the proposal stage to reality. Winmar abandoned the project in early 1992. A variety of factors contributed to its downfall. The federal government's position changed on the use of the funds. While negotiations with the U.S. Department of Transportation dragged on, the market window of opportunity slammed shut as the national recession weakened the prospects for any new projects. Faced with high carrying costs, the developer had no choice but to walk.

Tri-Met, Winmar, and the city of Gresham are now making final a transit-friendly master plan for the 80-acre site. The master plan is intended to identify a development concept to complement Gresham's core and access to transit.

Suburban In-Fill

Changing the character of the Burnside corridor will be a gradual process. Post–World War 2 suburban homes dominate the largely built-out corridor. Planners faced the delicate task of shoehorning in multiple-family zoning around rail stations while preserving stable neighborhoods. What vacant land there is tends to be in small ownerships.

In this difficult environment, the results have been slow but encouraging. Developers have assembled sites up and down the corridor for more than 1,100 multiple-family units. All told, 19 projects next to suburban MAX stations have been built at a cost exceeding $30 million. The average complex has 50 or more units with a project size ranging from 11 to 263 units. Project densities are conventional, 20 to 25 dwelling units per acre, averaging 1.5 parking spaces per unit. Like the rest of east Multnomah County, occupancy rates are in the high 90th-percentile range. The presence of MAX commands a slight premium on rents, according to apartment managers (*11*).

Some higher-density products are now in the pipeline and may foretell a trend. At 143rd and Burnside, work is being finished on the 24-unit Glen Fair Apartments built at 40 dwelling units per acre.

Beyond Planning

One of the important lessons from MAX is that it is not enough just to plan. Planning has to be followed up with implementation. In too many instances, that was not the case with MAX. The planning was funded, but not always the implementation.

For the general public, the success of planning is measured by the experience on the ground—the level of congestion on the way to the store, for example. The public also notices whether the new development next door gives them access to a nature trail or a safe way for kids to get to school that never existed before. Those opportunities are spelled out on plans. They become missed opportunities or reality on a case-by-case basis.

Ensuring that what is planned becomes implemented requires someone to hammer out the details of planning, implementation, and design that live or die in the supportive ordinances; just as well, local planners must follow through to get the details right. Otherwise, growth is just more cars on the neighborhood street and too many people living too close together.

The plans themselves can also be an unintended barrier to implementation. Special regulations tailored to transit can create the misperception of a "regulatory desert," stopping (not fostering) transit-supportive development. A successful planning program will look for and provide incentives to development, not just extra regulations. The strongest development response to MAX has come when

- Land for development was consolidated under single ownership,
- Multiple public and private objectives were being pursued, and
- Implementation tools were available.

Changing Direction

Up to now the Portland story has largely been the story of MAX and a revitalized downtown. The challenge is to apply those lessons on a regional scale. Many of the same trends that have overtaken other cities are at work in Portland's suburbs: disappearing open space, increased dependence on the automobile, and an explosion in vehicle miles traveled (VMT).

"Unless we change the direction we are going, we may end up where we are headed" (Chinese proverb). Increasingly, the Portland region is headed down a road that does not lead where Portland wants to go. The region's current plants for transportation and land use are a good case in point. If the region was "successful" in implementing those plans, congestion on a regional basis would increase by 146 percent in the next 20 years. That success, however, would be considered failure by most citizens (*12*).

New Generation of Growth Management

A new generation of transportation and growth management strategies is taking hold in Portland at the local, regional, and state levels. Once again, the Portland region has responded to a perceived threat to its quality of life by creating a legal and policy framework to shape the future. Oregon's rich palette of land use laws makes it unique and easy to dismiss for not being applicable elsewhere. People often lose sight of the fact that the motivation to create the kind of future that citizens wanted came first, then the laws followed. Portland has succeeded because its citizens cared enough to create the tools to preserve the region's livability.

The initiatives increase the reliance on light rail as a planning tool. A common thread in each of them is a desire to

- Grow without putting livability at risk;
- Contain growth by growing up, not sprawling out;
- Increase density in existing centers and along transit corridors; and
- Ensure that new development is designed to be served by transit at a pedestrian scale with a mix of uses.

Local governments are being required to change their plans to comply with new state and regional mandates to guide growth around transit. The new requirements, among other things, call for a 10 percent reduction in VMT and parking per capita in 20 years, adoption of local regulations to allow transit-oriented development, and tight regional parking ratios for nonresidential uses.

Westside Light Rail: A $1 Billion Development Gamble

The region's most aggressive venture into balancing transportation investments and land use policy is the

Westside Light Rail Project. By 1998 riders will be able to take MAX from downtown Portland 18 mi west to downtown Hillsboro.

The success or failure of the public's nearly $1 billion investment in the Westside will be determined in large part by what happens around its 20 stations. As *Newsweek* put it, "In Portland, Oregon, they're building the transit line first—putting stops literally in the middle of empty fields—in the expectation that the development will follow" (*14*). Unlike the Eastside MAX line, a substantial amount of land around the Westside is vacant and prime for development. From the air, some of the Hillsboro station areas resemble a "Field of Dreams." There is more vacant land around one station in the Hillsboro segment than existed around all the Eastside stations combined. All told, there are approximately 1,500 acres of vacant, developable land in the vicinity of Westside stations. That is nearly three times the amount of vacant land on the Eastside.

Urban Laboratory

The Westside carries with it a significance beyond the corridor. The project is being transformed into an urban laboratory. The growth management strategies being debated in the rest of the region will be tested on the Westside.

The Westside project now has national policy significance as well. The Portland region's commitment to integrating transportation and land use made the critical difference in getting a full funding grant agreement for the 6-mi extension of the Westside project to Hillsboro. The Office of Management and Budget recommended against funding the Hillsboro extension, citing its cost-effectiveness. The Federal Transit Administration (FTA) successfully argued that Hillsboro would be a worthy investment if the benefits of future land use were considered consistent with the guidance in the Intermodal Surface Transportation Efficiency Act, or ISTEA. In an unprecedented action, FTA's approval of Section 3 New Start Funding was explicitly contingent on the enactment of and local compliance with Metro's Region 2040 concept plan, creation of local station area plans that positively impact ridership, and adoption of policies to meet the state transportation planning rule. With the reward comes responsibility. The full funding grant agreement will be held open for 5 years after the project opens. If local governments do not produce the promised land use actions by then, Tri-Met is on the hook to refund the federal government $75 million (*15*).

The area around each Westside station is undergoing an intensive station community planning and development program modeled on the experience with MAX. The $4 million effort includes the four local governments: the Oregon Department of Transportation, Portland's regional government, Metro, and Tri-Met. Funding is divided equally between Tri-Met general funds and regional and state flexible federal surface transportation program funds. By the spring of 1996, new land use plans, development codes, capital improvement plans, and implementation strategies tailored to light rail will be adopted and in place for ½ mi around each station (*16*).

Planning Twilight Zone

Planning on the Westside actually started nearly 2 years before station community planning. Tri-Met was concerned that local governments lacked the legal leverage to ensure that only transit-supportive development occurred adjacent to Westside stations (*17*).

To address the interim period of 2 to 3 years before station community plans are adopted, three of the four local governments in the corridor adopted a coordinated set of interim zoning regulations for the areas within ½ mi of Westside stations. Complementary regulations are expected to be adopted soon by the remaining government. The interim zoning

- Establishes a list of prohibited uses in station areas,
- Sets minimum residential and commercial densities,
- Creates maximum parking limits, and
- Applies a design overlay that requires pedestrian connections and building orientation to the light rail station (*18*).

Light Rail: Good Servant, Bad Master

It is often said that the automobile has been a good servant and a bad master. The same can be true of light rail. To maximize the land use opportunities afforded by light rail, it is critical not to let the technology or the engineers become the master. If Tri-Met is really in the business of community building, the design of light rail must be responsive to a variety of constituencies. That has meant a gradual change in how Tri-Met approaches the planning and design of light rail facilities. For example, more attention to land use, development, and the pedestrian environment is now given earlier in the design process.

Tri-Met assembled a team of architects and planners before preliminary engineering started on the Hillsboro segment to work with the engineers. Its charge was to better integrate the project into the community while reducing costs. The team was able to eliminate two stations identified in the alternatives analysis and move four stations. The result is lower capital costs, a faster preliminary engineering phase, less community controversy, and a design that maximizes the opportunity for transit-supportive development (*19*).

Public/Private Master Plans

Making changes during final design to capture opportunities is possible, but more problematic. Immediately south of Nike's world headquarters, light rail will bisect a 122-acre vacant prime development site known as Beaverton Creek. A station was originally planned for the edge of the site because there were no roads or development plans to indicate where the station belonged. At the urging of station area planners, Tri-Met initiated a site planning study with the land owners and development consultants and succeeded in relocating the station to the middle of the vacant site (*20*).

Moving the station turned out to be fortuitous. Tri-Met is now a partner with four land owners and several developers in preparing a master plan for the site. The $344,000 master plan is funded equally with public and private funds. The proposed master plan establishes the parameters for a financially feasible, transit-supportive project that maximizes density and minimizes parking. The opportunities are tremendous. On the basis of the proposed master plan, Beaverton Creek would include a minimum of 1,325 dwelling units as well as retail, office, and natural areas. The minimum multiple-family density is 25 units per acre, and the minimum single-family density is 12 units per acre, which equates to a new residential minimum of more than 22 units per acre. Maximizing those opportunities required Tri-Met to modify its design so that transit facilities enhance, not detract from, the marketability of the site.

The Westside station community planning program is intended to be nimble enough to allow for public/private development master plans at other stations with short-term opportunities. Master plans are proceeding at two of the Hillsboro station sites, where the city of Hillsboro has signed agreements with property owners to share the cost of major plans.

Good Policy and Good Politics

The marriage between growth management and MAX has proved to be more than good policy—it is also good politics. Given the cost of new rail lines, it is a rare community that has enough wealth to build rail just to move people. In Portland, MAX has been part of a strategy to revitalize the downtown, defer highway investments, clean the air, and shape growth. Those multiple objectives have helped guarantee a return on the public's investment and leverage the broad base of political support necessary to secure the funding to build a rail line.

For more than 5 years, MAX has enjoyed public support at the 90 percent level (*21*). Support for building more roads, on the other hand, has diminished. In a recent survey, only 14 percent of the region's voters favored expanding the road system over adding more transit. In focus groups, people tended to see spending more money for roads as "keeping up" or "fixing up" —necessary but not very positive. Spending for MAX had more of a pull as an antidote for some of the pains of growth.

The political link between MAX and Portland's livability twice has been affirmed by voters. In 1990 and 1994, expanding MAX was positioned in campaign advertising as an investment in livability, an opportunity to avoid the gridlock, sprawl, and dirty air that have plagued other cities (Figure 2).

The first vote came in 1990, when Portland voters were asked to approve a $125 million Westside light rail GO bond measure. The verdict was a resounding 73 percent in favor. In the November 1994 Republican landslide, only one transit measure in the country was approved. Portland voters approved a $475 million MAX GO bond with a 63 percent vote. Those bonds will serve as regional matching funds for a 25-mi, $2.85 billion South/North MAX line connecting Clackamas County, Oregon, and Clark County, Washington, to downtown Portland. In two successive measures, voters approved expanding Portland's light rail system by nearly fourfold—from 15 to 58 mi.

That string of successes suffered a setback in February 1995 when voters in Clark County, Washington, rejected funding their piece of the South/North line. Local officials have 2 years to assess whether to proceed with an Oregon-only project or for Washington State to fund its share.

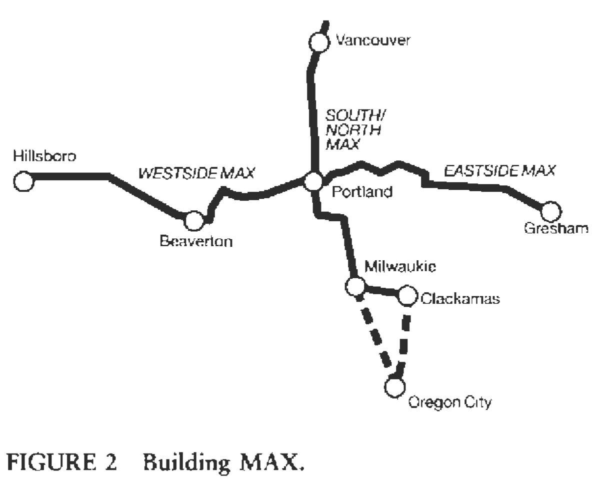

FIGURE 2 Building MAX.

What Kind of a Future Do We Want?

The expectations for MAX and land use have risen to new heights with Metro's Region 2040 project, the region's long-range transportation and land use plan. Region 2040 asks, "How do you want to grow? What do you want the region to look like? How will we get there? " (*22*).

Region 2040 has two fundamental differences from traditional regional planning exercises: first, it tests both alternative land use and transportation futures; second, the legal authority and political will to start implementation of the regional plan is in place.

Crash-Test Dummies

In1990 Portland's voters gave Metro the legal authority to require local governments to change their plans and zoning codes to be consistent with Metro's adopted regional framework plans. The lengthy process of changing plans and funding priorities to use transportation investments explicitly as a tool to help leverage the land use future that Portland seeks is now under way.

Over the last 3 years, Metro, Tri-Met, and local governments developed and evaluated three basic alternative growth concepts. The idea was to frame a range of reasonable choices. Like crash-test dummies, the concepts were not designed to survive the analysis. The best elements of each concept were crafted into a recommended alternative and adopted in December 1994. With that decision in place, a legally enforceable 20-year regional framework plan is scheduled to be developed and adopted by summer 1996, addressing the region's urban growth boundary, transportation plan, housing density, urban design, green spaces, and elements such as transit corridors and urban centers.

The three growth concepts analyzed were as follows:

- *Concept A*: Continue outward with current trends, allowing the region to grow out by expanding the urban growth boundary.
- *Concept B*: Freeze the region's urban growth boundary and substantially increase density in transit corridor.
- *Concept C*: Decant some growth to satellite cities and focus density in centers (*23*).

Building Blocks for Future

The 2040 recommended alternative adopted by Metro builds on the region's past successes by focusing on transit and a tight urban growth boundary as a means to grow and preserve its livability (Figure 3). The building blocks are the following:

- Maintaining a tight urban growth boundary. The plan forecasts a 77 percent increase in population and just a 6 percent expansion of the urban area in 50 years. Seattle, for example, saw a 38 percent increase in population and expanded its urbanized area 87 percent in 20 years.
- Focusing two-thirds of jobs and 40 percent of households in existing centers and along corridors served by buses and light rail.
- Preserving residential neighborhoods as the dominant land use. To accommodate increased densities, inner neighborhoods would have smaller lot sizes. The average new single-family lot size would drop from 8,500 to 6,600 ft^2.
- Developing a system of urban green spaces for active use and nature. The plan calls for about 34,000 acres in open space, or about 14 percent of the land in the urban growth boundary.
- Expanding MAX and the bus system as the primary means to accommodate increases in regional travel (*24*).

More Ridership with Less Service

The 2040 analysis powerfully illustrates the payoffs of balancing transportation and land use. With the recommended alternative, less turned out to be more. Compared with current trends (Concept A), the recommended alternative has 53 percent more transit riders with 3 percent fewer service hours, and 33 percent fewer congested road miles on a road network which has 5 percent fewer lane miles.

The results of the modeling are particularly revealing for MAX. Although each of the concepts had essentially the same level of transit service, ridership varied tremendously. For the Westside, daily ridership ranged from 31,800 in the base case to 81,300 in Concept B—a difference of more than 250 percent.

In the altered reality of regional planning models, the 2040 recommended alternative shows that it is both cheaper and better to grow right. The bigger question is, "Is this a future anyone wants to live in?"

Swimming Against the Tide

Region 2040 assumes a big change in local land use plans and a shift in growth trends in order to ensure regional mobility and livability. That vision is popular with the region's citizens and governments. Making it happen will be a tall order. Future demographic trends

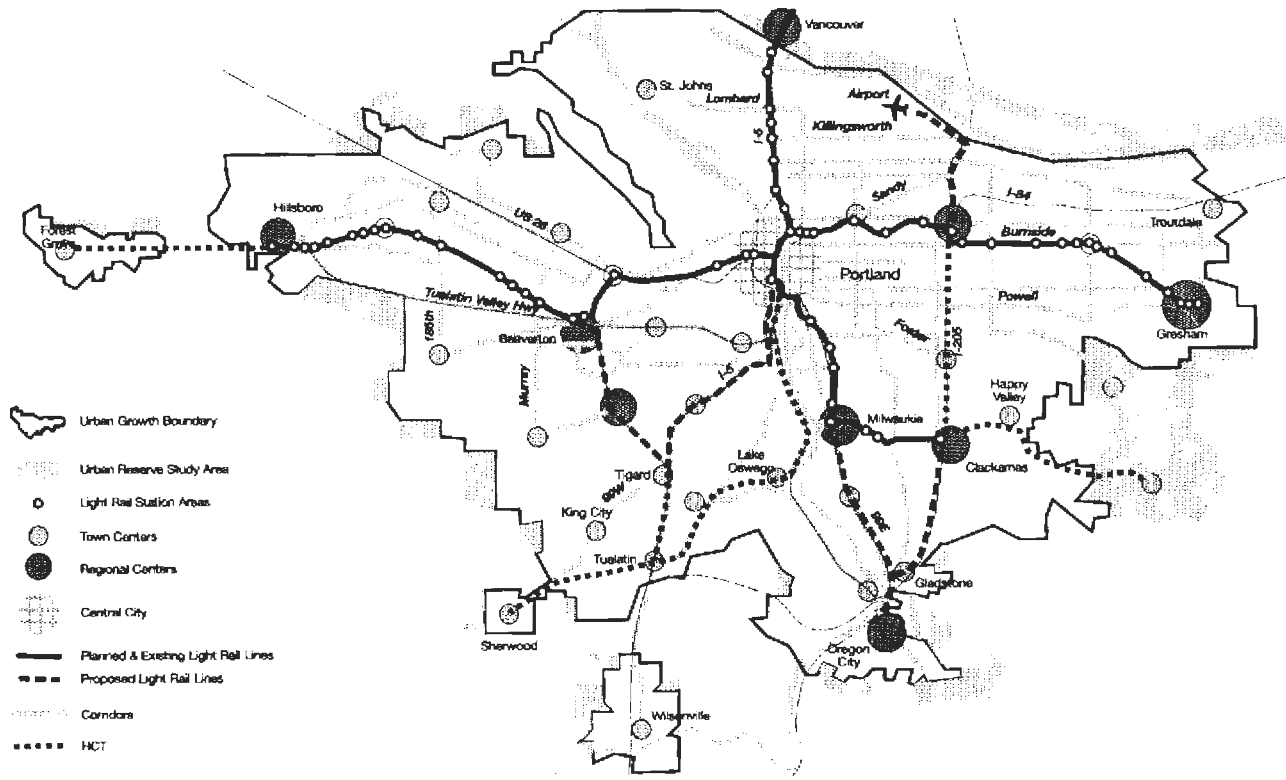

FIGURE 3 Region 2040 growth concept.

give some credence to the strategy, but national trends appear to be moving in the opposite direction:

- Containment of growth versus dispersal outward,
- Redevelopment and in-fill versus growth primarily on greenfield sites,
- Growing downtowns and urban centers versus edge cities and declining cores,
- Increased use of transit and walking versus increased use of cars and congestion.

Perhaps planners in Portland are a bit like the endangered salmon swimming upstream of the Columbia River: in the past they have been successful swimming against the current. But so far, Portland's planners, unlike the salmon, have stayed off the endangered species list.

Past Success: A Prologue for the Future

The Portland story is more about community building than MAX building. MAX has been a vehicle to move people, shape the region, defer highway investments, and enhance the quality of life. So far, more than $1.23 billion in new development has occurred next to the line.

MAX is not a silver bullet; having it will not make your main street Disneyland. MAX and supportive land use planning have enjoyed great support in Portland because they are not ends in themselves. They are the tools that Portland's community leaders have used to build a more livable community.

The marriage between growth management and MAX is not just good policy—it is good politics. As Portland looks to the future and the pressures of 700,000 new residents, MAX is being asked to play an even bigger role. With two funding measures, Portland's voters approved nearly a fourfold increase in the size of the system. The expanded MAX system has been embraced as the cornerstone of the region's strategy to create a kind of compact livable future. Getting there won't be easy. To paraphrase Yogi Berra, the region must uot make the wrong mistake.

The challenge that Portland faces is to apply the successes of downtown and MAX to the rest of the regional community. It is—after all—one region, one marketplace, one airshed. If one part of the region fails, it all fails. Nothing less than the region's livability is at stake.

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Edmonton Light Rail Transit Experience

Larry McLachlan, *Edmonton Transit*

Edmonton's light rail transit (LRT) line has now been in operation for more than 17 years. A summary of Edmonton's LRT experience in terms of system design, ridership, service, incident management, system performance, underground versus surface, staffing and security, fare payment, accessibility, and operating costs is presented. The experiences shared relate the lessons learned as well as the many improvements and quality initiatives undertaken. Edmonton's light rail operations are fully integrated with the city's overall transit network. Ridership has climbed from 12,000 passengers a day in 1978 to 36,000 today. The line is 12.3 km long, 4.7 km underground. There are six underground and four surface stations, several park-and-ride lots, and a fleet of 37 cars based at a modern maintenance department.

The city of Edmonton is located 670 m (2,200 ft) above sea level at 53½ degrees north latitude in the province of Alberta, Canada. Edmonton is the provincial capital and the center of the province's public administration.

Although government is Edmonton's major "business," the energy and petrochemical industries are of comparable importance. Large coal reserves and many producing oil wells exist within a short distance of the city. The refining of crude oil is centered in "refinery row" east of the city.

The Edmonton area is composed of a number of communities surrounding the city of Edmonton. They include the city of St. Albert; the counties of Strathcona, Leduc, and Parkland; and the municipal district of Sturgeon. The combined population within the Edmonton area is approximately 810,000, and the 1993 city of Edmonton population is 627,000.

Annual temperatures in Edmonton can vary substantially between winter and summer. The warmest monthly average for July was 19°C (66°F), with the warmest recorded summer temperature being 37°C (98°F). During winter, cold spells of −37 to −43°C (−34 to −45°F) lasting several days can be experienced. The lowest recorded average temperature for January was −27.7°C (−18°F). Average annual rain and snowfall are approximately 450 mm (17.5 in.). During December the city receives approximately 203 mm of snow (8 in.); the maximum recorded snowfall in December was 813 mm (32 in.).

Edmonton Transit Overview

Edmonton Transit began operations on November 1908 as the Edmonton Radial Railway with a fleet of seven streetcars and 12 route-mi of track. By 1938 the Radial Railway had expanded to 74 streetcars and 54 route-mi. Annual passenger volumes reached 14.2 million.

Beyond 1938, the street railway system gradually downsized as motor buses and electric trolley buses replaced streetcars. The first motor bus service was introduced in 1932, and electric trolley bus service began in 1939. As more and more trolley and motor buses became part of the public transit network, the name of Edmonton Radial Railway was changed in 1947 to its current name, the Edmonton Transit System. By the end of 1951, streetcars ceased to be a part of Edmonton Transit.

Edmonton Transit continued to expand as the city grew from a population of approximately 159,000 in 1951. By the early 1960s the city's population had grown to 337,000, bringing with it growing traffic congestion. During the following years various transportation studies were conducted to address this growing congestion. One of these studies, prepared in 1972, encouraged the use of a modern Enropean-style light rail transit (LRT) system. In 1973 city council approved the construction of the Northeast Rapid Transit Line as approved by the Utilities and Engineering Committee. Construction began on September 30, 1974.

On April 22, 1978, Edmonton became the first city in North America of under 1 million residents to open a new LRT system (Figure 1).

LRT System Overview

This year marks the 17th anniversary of Edmonton Transit's light rail line. When it opened on April 22, 1978, there were 6.9 km of double track and five stations, served by 14 light rail vehicles (LRVs). Today, after three extensions, the line is 12.3 km long, 4.7 km of which is underground. There are six underground (Figure 2) and four surface stations (Figure 3), several park-and-ride lots, and a fleet of 37 cars based at a

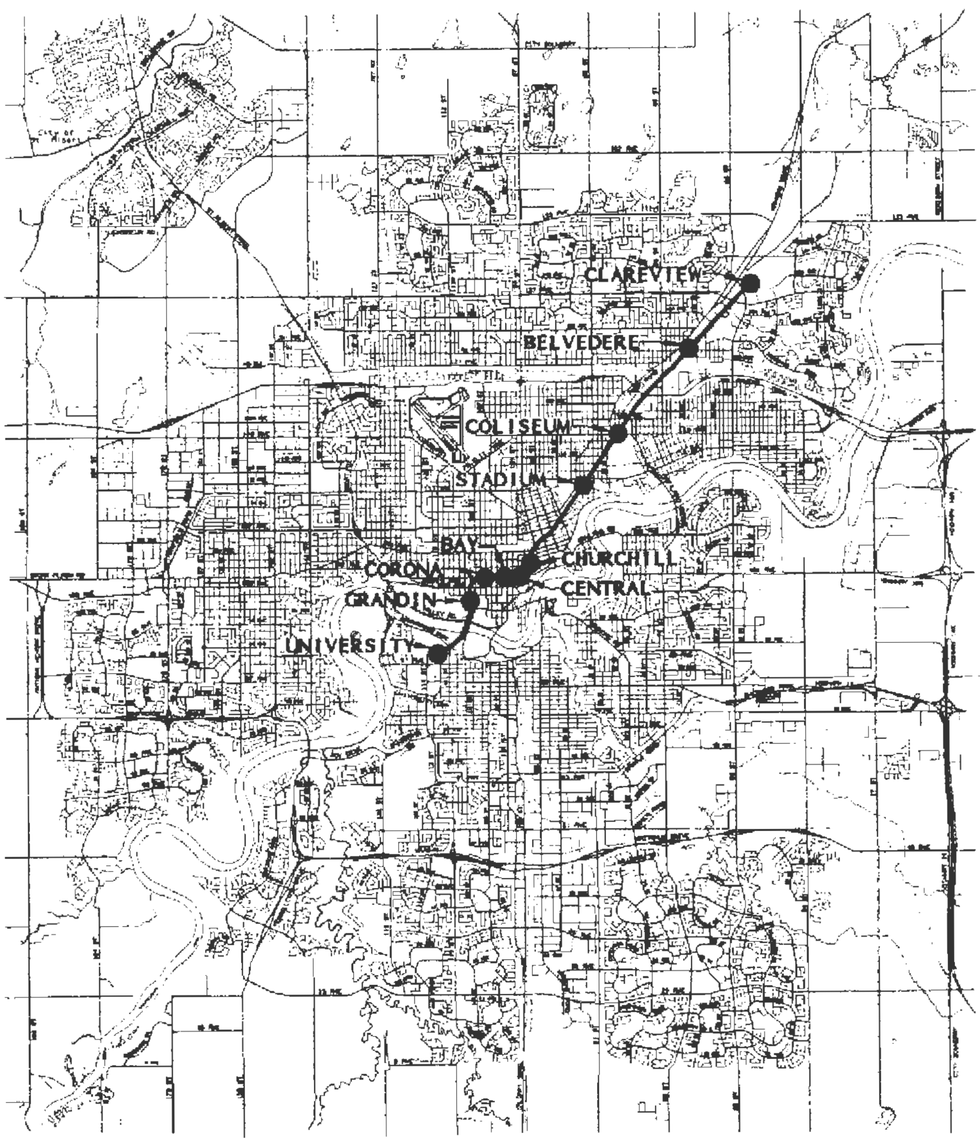

FIGURE 1 City map with LRT line superimposed.

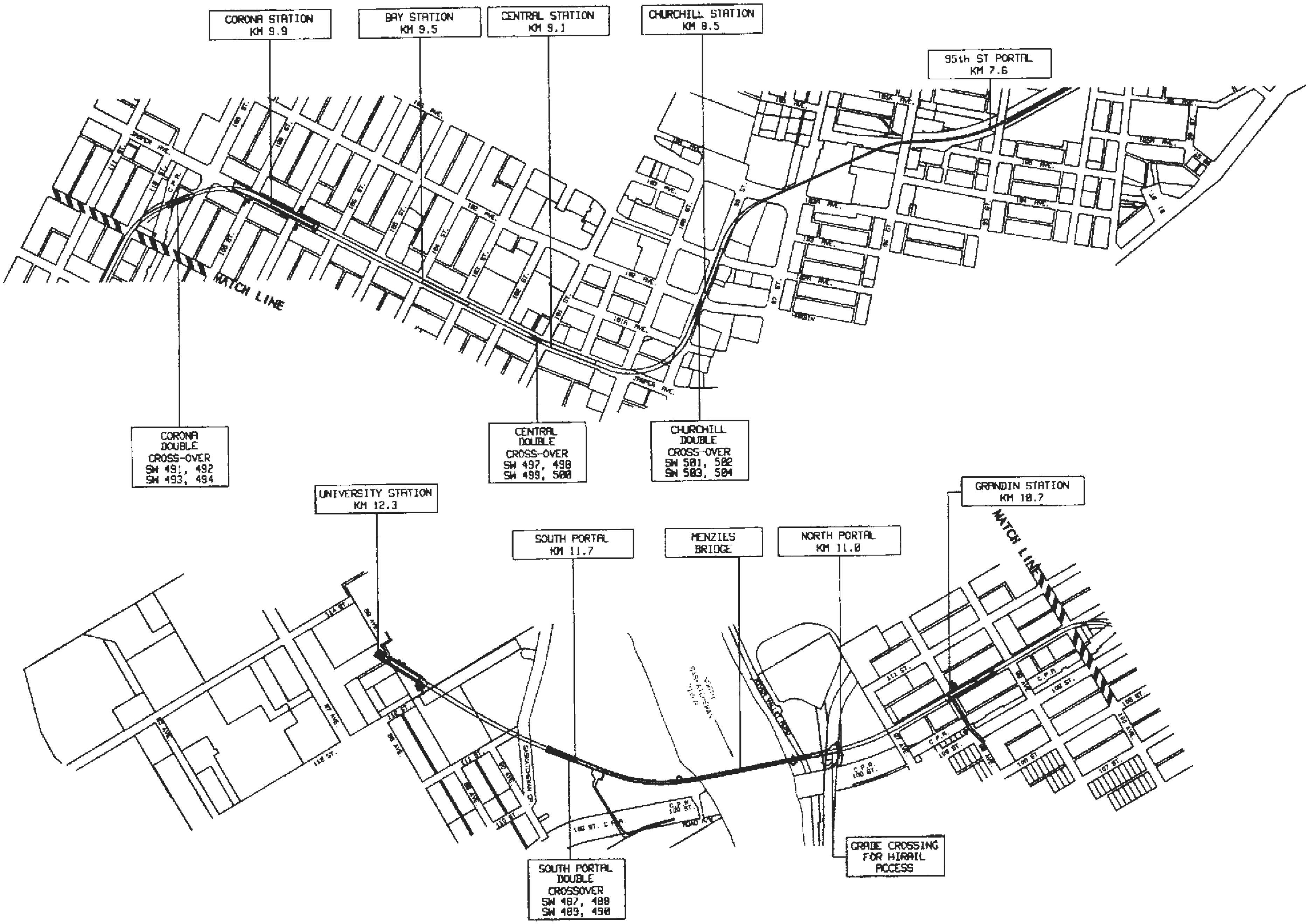

FIGURE 2 Underground track, Edmonton Transit.

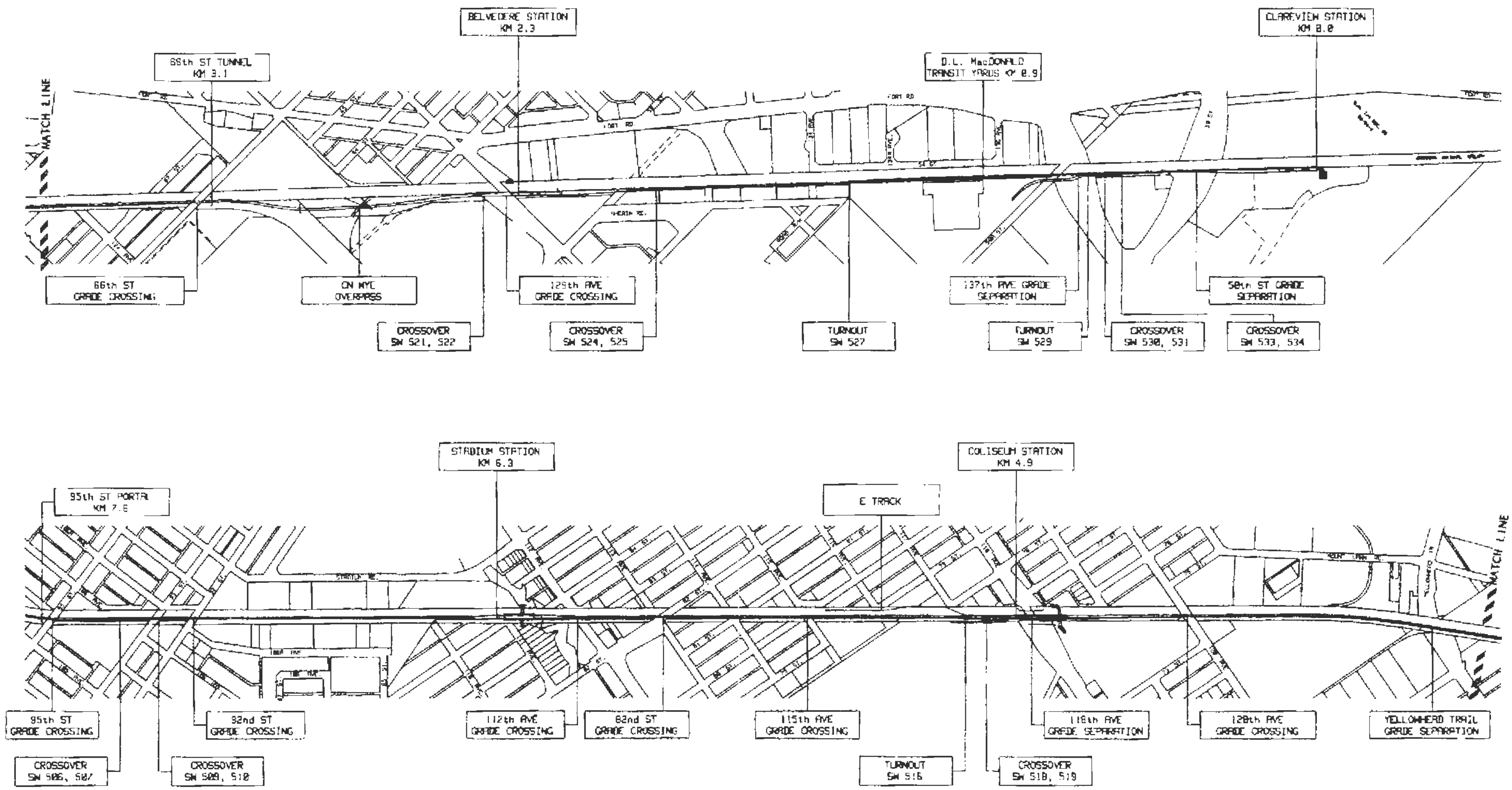

FIGURE 3 Surface track, Edmonton Transit.

modern maintenance depot. Total capital investment has reached approximately $343 million (Canadian dollars).

Starting from Clareview in the northeast, the light rail line runs on the surface parallel to Canadian National (CN) Rail tracks toward the city center (Figure 4). A tunnel through the central downtown area leads to a bridge over the North Saskatchewan River, which brings the route to an underground terminus beneath the University of Alberta. There are eight level crossings on the surface section, equipped with federally approved protection. Also situated along the surface route is the Northlands Coliseum, home of the National Hockey League's Edmonton Oilers, and Commonwealth Stadium, which is the venue for the city's professional football team and various other special events.

The last extension was completed in 1992 to the University of Alberta. Construction of the 2.5-km extension from Corona to the university began in 1986. Approximately 20 prime contractors and 100 subcontractors were involved in this highly technical project, wbich included tunneling under high-rise structures through a variety of soil conditions and building a bridge across the North Saskatchewan River. A combination of tunnel horing and sequential excavation was used on the section between Corona and the north bank portal, including Grandin (Government Center) station, which opened in Septemher 1989.

The Dudley B. Menzies Bridge, which parallels the High Level Bridge, was constructed from precast concrete segments. Although built exclusively for the light rail line, it incorporates a suspended footway and cycleway connection across the river. The south portal and tunnel under the university were built using sequential excavation.

University station was built by the tangent pile cut-and-cover method used for the earlier city center stations. Given the elevation of the single track leaving the southern end of the bridge, the station is the deepest in Edmonton, with the platform 23 m below road level. The station was opened in August 1992, completing the 6-year, $150 million extension.

Edmonton Light Rail Experience

Over the past 17 years Edmonton Transit has gained a great deal of experience, some of which the author would like to share. The experiences have been both good and had, hut for the most part good.

Ridership

Light rail operations are fully integrated with the city's overall transit network. The network is designed on a

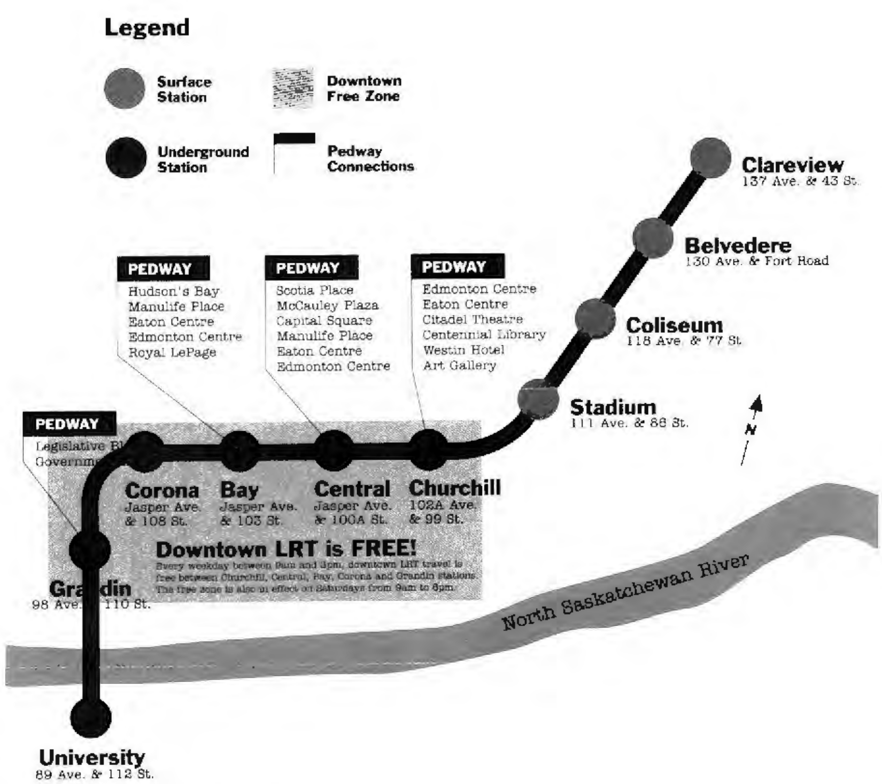

FIGURE 4 LRT link and route map.

hub-and-spoke basis, with transit centers (including the LRT stations) acting as hubs. Buses from residential areas feed into the hubs and provide direct links between transit centers; timed transfers allow connections onto other buses and light rail services.

During the first 15 years, light rail ridership rose from 12,000 to 36,000 passengers a day; two-way peak-hour demand currently stands at 5,300 (i.e., a.m. peak-hour ridership is 4,440 in the southbound direction and 860 in the northbound direction).

The opening of the university extension in 1992 brought a 50 percent increase in ridership, which can be attributed to two factors. First, bus services in the area were realigned, with direct services from the university to the central area eliminated in favor of transfers onto the light rail line. More significant, new riders have been attracted by the convenience of light rail. University students have the opportunity to live in lower-priced accommodations farther from campus while maintaining quick and direct access via the LRT. Since the extension opened, demand for park-and-ride lots has exceeded the capacity of 2,000 spaces.

Service

The basic light rail service operates every 10 min, with 5-min headways at weekday peak hours and 15-min intervals in the evenings and on Sundays. Trains of up to three articulated units can be accommdated at all stations, although there is provision for extension to five-car sets should this be warranted in the future. Formations are adjusted to match capacity to demand and optimize operating costs and customer satisfaction.

Incident Management

Incident management is an important element in the design and operation of an efficient light rail system, and Edmonton Transit is fortunate that the track layout provides a degree of flexibility in operations. Unforseeable incidents can and do happen that render certain sections of track impassable and risk stranding large numbers of passengers in trains or at stations. By designing the track layout so that services can be operated around any trouble spots, the incident management objective is to maintain at least a 10-min headway at all times.

Organization and Staffing

The light rail section of Edmonton Transit employs 111 staff, of which 58 cover operations: motormen, inspectors, fare agents, and dispatchers. Another 28 are employed in vehicle maintenance, 5 in fare equipment maintenance, 14 in plant maintenance, and 6 in administration and engineering.

System Performance

System performance factors are recorded and reported monthly (Figures 5 and 6). Factors measuring the reliability of the LRVs, signal system, traction system, track, motorman performance, and miscellaneous system performance are combined into an overall system performance measurement. Overall system performance is based on the number of runs delayed more than 5 min within a given month. Experience to date has been outstanding: schedule adherence averages 99.6 percent throughout the year. When delays do occur, they generally result from LRV or traction system problems (Figure 7). Traction system problems usually involve the overhead catenary snagging the vehicle pantograph; this usually occurs two to three times a year and can cause considerable system delay.

LRV problems occur more often and usually involve two factors, mechanical or electrical component failure and operational training. In most situations a mechanical or electrical component failure on the LRV will not render it immobile, as most LRVs are designed with considerable redundancy. With the right training, operational staff should be able to assess the problem quickly and decide whether to operate the vehicle or remove it from the line. However, often what occurs is that too much time is spent trying to fix the problem rather than concentrating on maintaining scheduled service.

Rolling Stock

Edmonton has 37 light rail vehicles of the Frankfurt U2 type, similar to the vehicles used in Calgary, San Diego, and Sacramento. The cars were purchased in three separate orders: the first 14 in 1977, the next 3 in 1980, and the remaining 20 in 1983. The reliability of these vehicles has been remarkable. Each of the first 14 cars underwent a major inspection at 500 000 km, the result of which showed no significant problems. Most of these cars have exceeded the 1 000 000-km mark, with most of the vehicles still using the original major components, such as traction motors, camshaft controller, gear boxes, and couplers. Because of this experience, major inspections have been increased to 750 000 km. Routine inspections are carried out every 10 000 km.

To track vehicle reliability, a computerized job costing system has been developed. The system maintains

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YTD	[illegible]	PREV.YR.
SYSTEM PERFORMANCE															
SHEDULE ADHERENCE															
INCIDENTS >= 5 & < 10 MINS															
INCIDENTS >= 10 MINS.															
SYSTEM DELAYS >= 5 & < 10 MINS.															
SYSTEM DELAYS >= 10 MINS															
INCIDENT SEVERITY															
CUSTOMER SATISFACTION															
VEHICLE PERFORMANCE															
INCIDENTS >= 5 & < 10 MINS. DUE TO LRV															
INCIDENTS >= 10 MINS. DUE TO LRV															
SYSTEM DELAYS >= 5 & < 10 MINS. DUE TO LRV															
SYSTEM DELAYS >= 10 MINS. DUE TO LRV															
SIGNAL SYSTEM PERFORMANCE															
INCIDENTS >= 5 & < 10 MINS. DUE TO SIGNALS															
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SYSTEM DELAYS >= 5 & < 10 MINS. DUE TO OPERATIONS															
SYSTEM DELAYS >= 10 MINS. DUE TO OPERATIONS															
MISC. SYSTEM PERFORMANCE															
NUMBER OF SIGNAL PENALTY STOPS															
TRAINS STOPPED DUE TO SPEED CHECKS															
LRV PASSENGER INCIDENTS															
STATION PASSENGER INCIDENTS															
INCIDENTS >= 5 & < 10 MINS. DUE TO ACCIDENTS / INCIDENTS															
INCIDENTS >= 10 MINS. DUE TO ACCIDENTS / INCIDENTS															
ESCALATOR / ELEVATOR REPAIR CALLS															
SERVICE COMPLAINTS															
VANDALISM															
STATION INCIDENTS															
LRV INCIDENTS															

COMMENTS

FIGURE 5 LRT system performance report.

TIME INCREMENTS

INCIDENTS > = 5 MINS	5 minutes represents peak hour LRT freqency
INCIDENTS > = 10 MINS	10 minutes represents the LRT incident management Service Frequency Objective.

SYSTEM PERFORMANCE

SHEDULE ADHERENCE	SHEDULE ADHERENCE	= (number of runs - (number of incidents + number of delays)) / number of runs - expressed as a percent
INCIDENTS > = 5 & < 10 MINS	INCIDENTS > = 5 & < 10 MINS	= An incident effecting a single train within a local area.
INCIDENTS > = 10 MINS	INCIDENTS > = 10 MINS.	= An incident effecting a single train within a local area
SYSTEM DELAYS > = 5 & < 10 MINS	SYSTEM DELAYS > = 5 & < 10 MINS	= An incident effecting all trains causing the LRT Line to stop for 5 to 10 minutes or schedured service can not be maintained to within 5 minutes of the published schedule. ie. 5 minute service reduced to 10 minute service
SYSTEM DELAYS > = 10 MINS	SYSTEM DELAYS > = 10 MINS	= An incident causing all or part of the LRT Line to stop or regular scheduled service can not be maintained to within 10 minutes of the published schedule ie. 5 minute service reduced to 15 minute service.
INCIDENT SEVERITY	INCIDENT SEVERITY	= (number of system delays / (number of incidents + system delays) expressed as a percent
CUSTOMER SATISFACTION	CUSTOMER SATISFACTION	= 1 - (number of service complaints / number of platform hours) expressed as a per cent. measurement base: 34,620 annual platform hours & 36,000 passengers per day = 1

VEHICLE PERFORMANCE

INCIDENTS > = 5 & < 10 MINS. DUE TO LRV	An incident caused by a Light Rail Vehicle.
INCIDENTS > = 10 MINS. DUE TO LRV	An incident caused by a Light Rail Vehicle.
SYSTEM DELAYS > = 5 & < 10 MINS. DUE TO LRV	A system delay caused by a Light Rail Vehicle.
SYSTEM DELAYS > = 10 MINS. DUE TO LRV	A system delay caused by a Light Rail Vehicle.

SIGNAL SYSTEM PERFORMANCE

INCIDENTS > = 5 & < 10 MINS. DUE TO SIGNALS	An incident caused by the Signal System.
INCIDENTS > = 10 MINS. DUE TO SIGNALS	An incident caused by the Signal System.
SYSTEM DELAYS > = 5 & < 10 MINS. DUE TO SIGNALS	A system delay caused by the Signal System.
SYSTEM DELAYS > = 10 MINS. DUE TO SIGNALS	A system delay caused by the Signal System.

TRACTION SYSTEM PERFORMANCE

INCIDENTS > = 5 & < 10 MINS. DUE TO TRACTION	An incident caused by the Traction System
INCIDENTS > = 10 MINS. DUE TO TRACTION	An incident caused by the Traction System.
SYSTEM DELAYS > = 5 & < 10 MINS. DUE TO TRACTION SYSTEM	A system delay caused by the Traction System
SYSTEM DELAYS > = 10 MINS. DUE TO TRACTION SYSTEM	A system delay caused by the Traction System.

TRACK PERFORMANCE

INCIDENTS > = 5 & < 10 MINS. DUE TO TRACK	An incident caused by the Track
INCIDENTS > = 10 MINS. DUE TO TRACK	An incident caused by the Track
SYSTEM DELAYS > = 5 & < 10 MINS. DUE TO TRACK	A system delay caused by the Track
SYSTEM DELAYS > = 10 MINS. DUE TO TRACK	A system delay caused by the Track

OPERATIONS PERFORMANCE

INCIDENTS > = 5 & < 10 MINS. DUE TO OPERATIONS	An incident caused by Operations
INCIDENTS > = 10 MINS. DUE TO OPERATIONS	An incident caused by Operations
SYSTEM DELAYS > = 5 & < 10 MINS. DUE TO OPERATIONS	A system delay caused by Operations
SYSTEM DELAYS > = 10 MINS. DUE TO OPERATIONS	A system delay caused by Operations

MISC. SYSTEM PERFORMANCE

NUMBER OF SIGNAL PENALTY STOPS	Number of signal system penalty stops.
TRAINS STOPPED DUE TO SPEED CHECKS	Number of trains stopped due to speed checks.
LRV PASSENGER INCIDENTS	Number of LRV passenger incidents.
STATION PASSENGER INCIDENTS	Number of station passenger incidents.
INCIDENTS > = 5 & < 10 MINS. DUE TO ACCIDENTS / INCIDENTS	An incident caused by an accident or other non specified incident.
INCIDENTS > = 10 MINS. DUE TO ACCIDENTS / INCIDENTS	An incident caused by an accident or other non specified incident
ESCALATOR / ELEVATOR REPAIR CALLS	Number of escalator and elevator repair calls.
SERVICE COMPLAINTS	Number of customer service complaints as compiled by the Customer Service Section

VANDALISM

STATION INCIDENTS	Number of station vandalism incidents.
LRV INCIDENTS	Number of LRV vandalism incidents

FIGURE 6 LRT system performance definitions.

records of all faults and repairs on each vehicle. It also keeps track of major components, wheel wear records, and scheduled inspections (as well as payroll records). The data base was put into operation in 1982 and provides an invaluable history of vehicle performance.

Stations

Edmonton has 10 stations, 6 underground and 4 on surface. The physical plant includes the tunnels, track, signal system, traction power, and communications. Underground station maintenance has proved to be a very expensive proposition. On average underground stations cost approximately $300,000 in annual maintenance, which includes custodial services, utilities, and general maintenance.

The major station maintenance problem is escalators. Edmonton Transit's experience with escalators has not been good. They stop frequently, inconveniencing passengers; are expensive to repair; and require constant

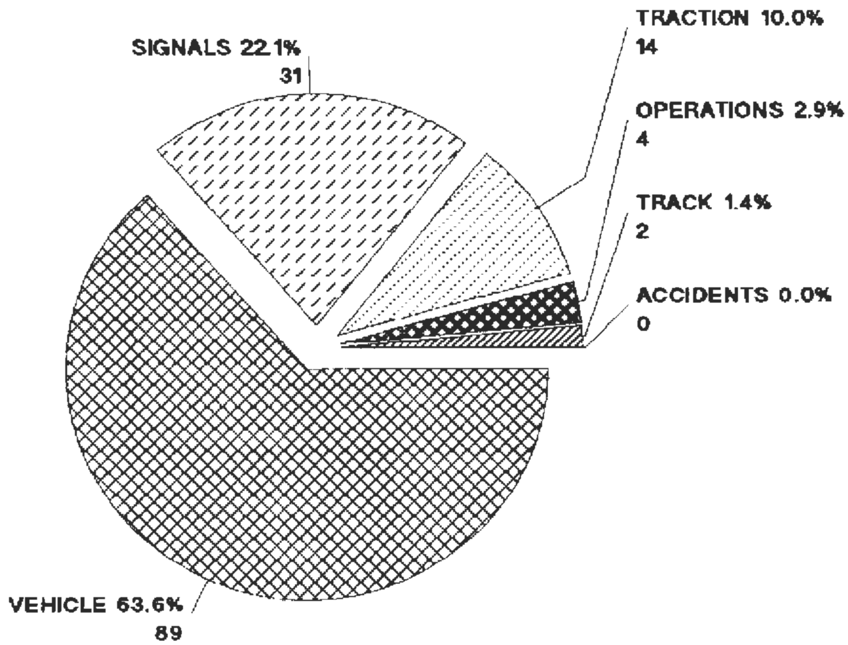

FIGURE 7 LRT system delay incidents, 1994.

maintenance. The root of the problem can be traced to the original purchase of the equipment, where common regular-duty escalators were specified instead of the heavy-duty type suited for public transit use.

Water leakage is another major problem with underground stations. The membrane covering the original two underground stations, Central and Churchill, has failed. When it rains or when the snow melts, water flows into the stations, resulting in considerable damage. A program is in place to carry out the required repairs over the next several years to prevent any long-term structural damage. The water leakage problem can be avoided in underground stations by using the proper sealing techniques during construction. Since the Central and Churchill stations were constructed, sealing techniques have improved considerably. Fortunately, these new methods have been employed on the newer stations with good success, and water seepage has been kept to a minimum.

Water seepage, especially in the winter, can be a problem in the tunnels. In extremely cold conditions the groundwater entering the tunnels freezes as the cold air makes its way through the tunnels. As the water freezes it can build up around and over the rails with serious consequence. Edmonton Transit experienced freezing problems in the LRT tunnels once opened at both ends with the university extension. Because the tunnel has an elevation difference between each end of approximately 26 m, a "stack" effect is created. The stack effect causes the tunnel to behave like a chimney: it draws air from the lower portion of the tunnel and exhausts it at the higher end. As the cold air rises through the tunnel, the surrounding structures begin to lose their heat, eventually causing the groundwater to freeze. The effect also creates low ambient temperatures in the stations, which results in discomfort for customers.

The freezing problem has been corrected by the installation of natural gas heaters at the lower end of the tunnel on either end of the bridge. When outside air temperatures reach a critical temperature, the heaters will start, heating the air as it enters the tunnels. This solution has resolved the groundwater freezing problem as well as improved the ambient air temperature in the stations. The operating cost of the heaters is approximately $25,000 a year for each.

Signal System

The signal system used on the LRT system is a European design using fix block signals and discreet speed checks. A mimic board at the central control room monitors the movement of the trains throughout the system. The controller is able to see where the trains are located and effect route changes as required. System reliability has generally been good; there have been a few problems with the speed checks.

On the university extension, a North American–type signal system was installed and integrated with the existing system. The decision to change was primarily economic, but there was also a desire to convert from the

European technology because of availability and shorter delivery times of the North American equipment.

Traction System

The traction power used on the LRT system is nominal 600 V-direct current (DC). The power is supplied to the vehicles by an autotensioned simple catenary system. The autotension system is used to compensate for the significant expansion and contraction that takes place between summer and winter. Generally, reliability of the system has been good. However, the vehicle pantograph will get caught in the catenary occasionally, causing considerable damage. Most often, the cause of these incidents is extremely difficult to pinpoint because of the dynamics involved between the vehicle and the catenary wire.

Communications

Radio communication is provided throughout the system. Central control keeps in constant touch with the trains, work crews, and security. The communication system is the lifeblood of the system, enabling controllers to provide advisory information and respond to emergencies.

Track

Good track design and maintenance is an important element of the LRT system. Poor track systems can result in serious safety concerns and passenger discomfort due to poor ride quality. Edmonton Transit has worked on improving ride quality over the past few years. Because of a number of factors—such as climate, vehicles, installation, and the fundamental differences between heavy rail and light rail track requirements—the ride quality on the system has not been as good as it should be.

In 1990 Edmonton Transit asked the consulting firm Advanced Rail Management (ARM) to review its track with the object of improving ride quality. Following an extensive evaluation of the system, ARM recommended a new rail profile that it believed would greatly improve ride quality and reduce wheel wear. The recommendation was accepted, and a test section of rail was selected for grinding in October 1991. The results were impressive—ride quality improved substantially—so an additional section was ground in 1992. It was also discovered that rail icing problems were almost eliminated in the areas of profile grinding because of the narrow contact band. Reprofiling of the remaining surface rail was completed in 1994.

Experience with road grade crossings has demonstrated the importance of design. The road sand, salt, and water, combined with poor drainage, have contaminated and deteriorated most of the crossings, necessitating major repairs after only 10 years of service. Most of the crossings have been replaced at a cost of approximately $200,000 each. The new design includes proper drainage, concrete ties, and panels with Epflex flange ways; design life is estimated at 25 years.

Safety and Security

The safety and security of the passengers is of paramount importance. To ensure safety and security, closed-circuit surveillance cameras have been installed in all stations and pedestrian areas. The cameras are monitored on a 24-hr basis and the stations patrolled during operating hours by 25 fare agents. The fare agents provide both fare payment enforcement and security functions. Public washroom and elevator access is controlled remotely and monitored to ensure the safety of those persons using the facilities.

Edmonton Transit recently installed a passenger assistance communication system on board the vehicles that allows passengers to contact the train operator from anywhere on the train. Passengers can respond to an on-board emergency by either pulling a red handle at alternate passenger doors or pressing a touch strip above the seating area. Once the system is activated, the passenger and operator can talk to each other. The system also allows central control to make public address announcements directly to the trains.

The Edmonton LRT system has benefited from its exclusive right of way and tunnel sections by reducing the number of accidents associated with surface-operated LRT systems. Since 1978 the LRT system has had 20 major accidents. Of those, 15 occurred at level crossings, 3 were along the right of way, and 2 were derailments. Pedestrian accidents accounted for eight of the level crossing accidents. In all there have been five fatalities.

Pedestrian safety was of major concern at the Belvedere LRT Station. Belvedere, a center-platform station, is situated immediately east of the CN mainline. It is a high-volume station with numerous parking lots surrounding it; a bus transfer terminal sits next to it. To access the station from the bus terminal and some of the parking lots, passengers are required to cross both the CN track and the southbound LRT track. The pedestrian sidewalk across the tracks is protected by crossing arms and an audible alarm.

There were two problems with the Belvedere crossing. First, when a train arrived at Belvedere Station, passengers generally were unwilling to obey the warning and control devices out of fear of missing their transfer. (This applied to passengers transferring either to bus or rail.) The second problem was that when a CN train passes through the area it is generally extremely long and can delay passengers for up to 5 min. When passengers see the CN train coming, there is usually a rush to beat the train to the crossing, even if the crossing protection is active. Occasionally, the CN train will stop, blocking the crossing, and some people will climb between the cars. Fortunately, there have been only two accidents at the crossing in the past 17 years, but there have been many near misses. To control this problem, the station entrance and crossing arrangement were redesigned. Originally it was the intent to provide an elevated walkway over the tracks; however, the costs of such a solution proved prohibitive. A much less expensive design changed the station entrance design to improve the sight lines. Additional pedestrian gate arms were installed for each track, enabling gate activation times to be adjusted to reflect the available crossing times more accurately. Edmonton Transit has since experienced a significant drop in gate violators.

Fare Payment

The fare collection used on the LRT system is the proof-of-payment system. Passengers are required to obtain their proof of payment prior to entering the "fare paid area." Their proof of payment may be a single ticket bought at one of the many machines situated in the stations, a monthly pass, a multiride ticket, or a bus transfer. To enforce fare payment, fare agents roam the system and randomly check passengers. Occasionally, the fare agents will conduct a check of all passengers as they exit the station platform. This type of fare system has worked well. The operational cost savings are considerable by not requiring ticket agents at each station. Fare evasion averages 1.5 to 2.5 percent, which is consistent with many other LRT operations.

Accessibility

The accessibility to Edmonton's light rail system has been an important design consideration throughout the development and expansion of the service. The object has been to provide barrier-free facilities that provide access to all those who choose to use the LRT sysrem. Elevators and escalators are provided at all stations except for Belvedere and Clareview, where ramps provide wheelchair access to the platform. Work is ongoing at making further improvements such as automatic opening doors and improved signage. LRV access is currently the major accessibility issue being addressed. Groups representing the physically challenged have advised that the vertical gap of approximately 80 to 100 mm between the vehicle floor and the station platform presents an obstacle to them. To address this problem, Edmonton Transit has initiated a pilot project for the design and installation of a test ramp that would reduce the vertical gap. The ramp will be integrated into the car and deploy automatically upon request. Operator assistance will not be required.

Accessibility issues are a continuing concern that is addressed through regular meetings with the disabled community. The Disabled Adult Transportation System is under increasing demand for its services. However, service delivery on the system is very expensive, and as demand increases it will have a sizable impact on Edmonton Transit's budget. The more that the LRT system can be made accessible to all members of the community, the more that individuals with special needs can be mainstreamed, helping to reduce operating costs.

Operating Costs

Edmonton Transit's annual operating budget is approximately $12 million (Canadian), to which must be added between $1 million and $2 million for capital expenditure on major rehabilitation of equipment and infrastructure (Figures 8 and 9).

The underground operation bears heavily on the operating costs of the light rail system. Typically, underground stations cost three to four times as much as the surface stations for utility and maintenance expenses. The opening of the university extension saw a fall in unit operating costs despite the addition of another underground station, a large bridge, and 1.6 km of track (Figure 10). The corresponding increase in ridership has more than offset the higher operating costs, showing the efficiency of carrying large numbers of people. Unit operating costs have fallen by 24 percent, to $1.04 (Canadian) per passenger journey. Add to this the annual savings of $500,000 in reduced bus operating costs directly attributable to the extension, and it has provided a valuable boost to the efficiency of the LRT. Any further extension beyond the university will be on the surface, which will further improve the per-unit operating efficiency and negate the higher costs associated with the underground section.

Quality Initiatives

Over the past few years, many initiatives have been undertaken to enhance comfort, safety, security, and accessibility.

MEASUREMENT FACTORS	PLATFORM HOURS	MONTH	YEAR TO DATE	BUDGET
	REGULAR	2,737	32,845	32,845
	SPECIAL EVENTS	148	1,780	1,780
	TOTAL	**2,885**	**34,625**	**34,625**
	KILOMETERS	**MONTH**	**YEAR TO DATE**	**BUDGET**
	REGULAR	204,182	2,350,337	2,300,000
	SPECIAL EVENTS	14,405	191,975	200,000
	TOTAL	**218,587**	**2,542,312**	**2,500,000**

PERFORMANCE INDICATORS		ACTUAL YTD		BUDGET		% BUDGET	
		COST/HR.	COST/KM.	COST/HR.	COST/KM.	COST/HR.	COST/KM.
ADMIN & TECHNICAL	650	$20.03	$0.27	$20.15	$0.28	99.38%	97.73%
FLEET INS. & LIC.	652	$13.35	$0.18	$13.35	$0.18	100.00%	98.34%
	SUB-TOTAL	**$33.38**	**$0.45**	**$33.50**	**$0.46**	**99.63%**	**97.97%**
EQUIPMENT MTCE. & SERVICE	651	$48.75	$0.66	$56.84	$0.79	85.76%	84.33%
CLEARING & REVENUE	653	$0.00	$0.00	$0.00	$0.00		
FARE COLLECTION SYSTEM MTCE.	654	$9.85	$0.13	$12.96	$0.18	76.05%	74.78%
POWER	692	$16.84	$0.23	$19.11	$0.26	88.12%	86.66%
	SUB-TOTAL	**$75.44**	**$1.03**	**$88.90**	**$1.23**	**84.86%**	**83.44%**
OPERATIONS	502	$31.03	$0.42	$29.72	$0.41	104.41%	102.68%
INSPECTORS	507	$24.24	$0.33	$22.72	$0.31	106.72%	104.95%
BYLAW ADMINISTRATION	508	$31.21	$0.43	$32.51	$0.45	96.00%	94.41%
DISPATCH & TRAINING	509	$3.30	$0.04	$3.23	$0.04	102.05%	100.35%
SPECIAL EVENT SERVICE	557	$4.16	$0.06	$2.46	$0.03	168.89%	166.08%
	SUB-TOTAL	**$93.95**	**$1.28**	**$90.64**	**$1.26**	**103.64%**	**101.92%**
LRT RIGHT OF WAY MTCE	531	$19.12	$0.26	$18.62	$0.26	102.66%	100.95%
LRT CATENARY & SUB-STATION	532	$8.06	$0.11	$9.14	$0.13	68.20%	86.73%
LRT SIGNALS MTCE	533	$12.31	$0.17	$11.76	$0.16	104.70%	102.95%
COMMUNICATIONS & SURV.	534	$13.62	$0.19	$12.84	$0.18	106.07%	104.30%
	SUB-TOTAL	**$53.11**	**$0.72**	**$52.36**	**$0.73**	**101.43%**	**99.74%**
D.L. MACDONALD GARAGE	661	$9.49	$0.13	$10.14	$0.14	93.61%	92.05%
LRT STATION MAINTENANCE	620	$77.78	$1.06	$79.88	$1.11	97.38%	95.76%
	SUB-TOTAL	**$87.28**	**$1.19**	**$90.02**	**$1.25**	**96.96%**	**95.34%**
	TOTAL	**$343.14**	**$4.67**	**$366.42**	**$4.92**	**96.54%**	**94.94%**
INTERPROGRAM BILLING	OBJ. 95	($11.12)	($0.15)	($8.36)	($0.12)	133.07%	130.85%
INTER-DEPARTMENT BILLING	OBJ. 99	($2.16)	($0.03)	$0.00	$0.00		
OUTSIDE REVENUE	OBJ. 98	($0.82)	($0.01)	($1.17)	($0.02)	70.30%	69.13%
	SUB-TOTAL	**($14.10)**	**($0.19)**	**($9.53)**	**($0.13)**	**148.04%**	**146.57%**
	TAX LEVY	**$329.04**	**$4.48**	**$346.90**	**$4.79**	**95.13%**	**93.54%**

COSTS		YTD COST	BUDGET	Comments
ADMIN & TECHNICAL	650	$693,528	$697,835	
FLEET INS. & LIC.	652	$462,126	$462,126	
	SUB-TOTAL	**$1,155,654**	**$1,159,961**	
EQUIPMENT MTCE. & SERVICE	651	$1,687,818	$1,968,034	- Parts and materials purchases deferred as a budget
CLEARING & REVENUE	653	$0	$0	control initiative.
FARE COLLECTION SYSTEM MTCE.	654	$341,100	$448,540	
LRT POWER	692	$583,100	$661,692	- Mild winter resulting in lower energy usage.
	SUB-TOTAL	**$2,612,018**	**$3,078,266**	
OPERATIONS	502	$1,074,518	$1,029,089	- Voluntary retirement program payouts.
INSPECTORS	507	$839,407	$786,535	- Voluntary retirement program payouts.
BYLAW ADMINISTRATION	508	$1,080,778	$1,125,757	
DISPATCH AND TRAINING	509	$114,261	$111,971	
SPECIAL EVENT SERVICE	557	$143,924	$85,216	- Offset by obj. 99 Re: switch tender costs.
	SUB-TOTAL	**$3,252,888**	**$3,138,568**	
LRT RIGHT OF WAY MTCE	531	$661,860	$644,718	
LRT CATENARY & SUB-STATION	532	$279,116	$316,457	
LRT SIGNALS MTCE	533	$426,344	$407,219	
COMMUNICATIONS & SURV.	534	$471,447	$444,473	
	SUB-TOTAL	**$1,838,767**	**$1,812,867**	
D.L. MACDONALD GARAGE	661	$328,716	$351,146	- Utility costs lower due to mild winter.
LRT STATION MAINTENANCE	620	$2,693,238	$2,765,780	- Utility costs lower due to mild winter
	SUB-TOTAL	**$3,021,954**	**$3,116,926**	
	TOTAL	**$11,881,281**	**$12,306,588**	
INTERPROGRAM BILLING	OBJ. 95	($384,961)	($289,313)	
INTER-DEPARTMENT BILLING	OBJ. 99	($74,861)	$0	- Switch tender billing Re: SLRT.
OUTSIDE REVENUE	OBJ. 98	($28,529)	($40,582)	
	SUB-TOTAL	**($488,371)**	**($329,895)**	
	TAX LEVY	**$11,392,910**	**$11,976,693**	

FIGURE 8 LRT performance measurement indicators, 1994 budget.

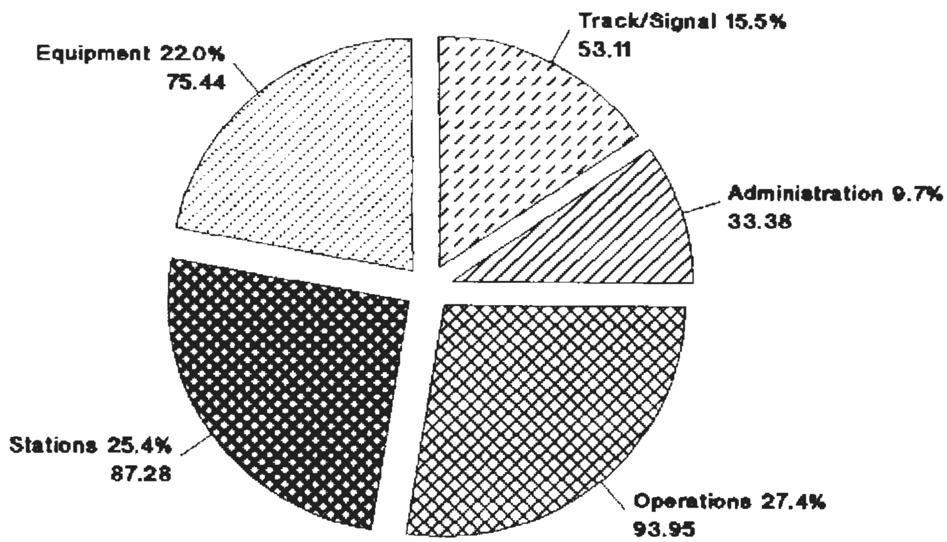

FIGURE 9 LRT cost per platform hour, 1994.

All LRV's have been equipped with the passenger assistance communication system, enabling riders to communicate directly with the operator from anywhere on the train; yellow touch strips along the windows connect that area directly to the motorman via a two-way intercom. Similarly, blue emergency phones have been installed at several locations on the platforms and at mezzanine level in each station, providing a direct customer link to the LRT control center for emergency assistance. Additional customer information panels have been provided, with communication lines to the customer service office.

Accessibility has always been an important design consideration. Although all stations were equipped with

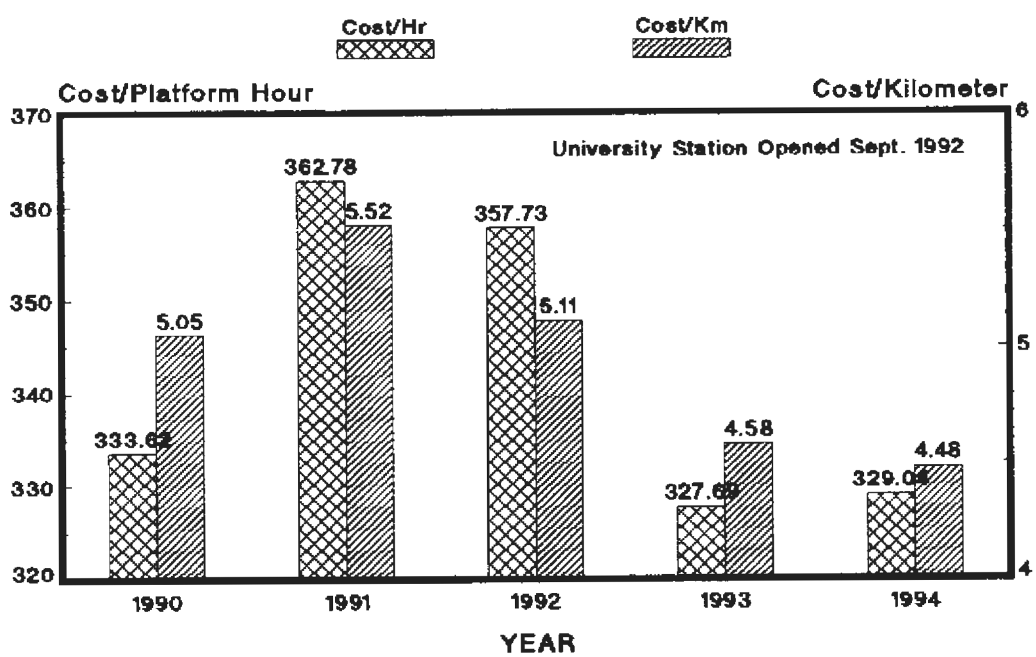

FIGURE 10 LRT costs per platform hour and per kilometer, 1990–1994 (1994 $).

elevators and escalators, work is under way on further improvements, such as automatic doors, improved signage, a reduced horizontal and vertical gap between platforms and car floors, and pay phones at each station equipped for hearing-impaired customers.

An electronic message and station announcement system has been fitted to all LRVs, and all door controls have been modified to incorporate enhanced safety features. Station washrooms and elevators have been fitted with remote access control and are opened only by central security staff upon customer request. This has improved personal safety in these areas and has greatly reduced the former levels of vandalism. Improved ride quality has resulted from the rail profile grinding program mentioned earlier.

The Future

Ever since the first stage of the light rail system opened, Edmonton Transit has had plans to expand. Further extensions are highly desirable, but unfortunately construction funding is not available in the current 5-year capital plan. Nevertheless, planning for future alignments continues on a limited basis, as it is hoped that all quadrants of the city eventually will be served by light rail. Two of the most favored extensions would continue beyond the university: a surface link south to the existing Southgate Transit Center, and a part-underground route running westward to West Jasper Place and the giant West Edmonton Mall shopping complex.

Light Rail in Switzerland: Case Study of Bern Suburban Area

Peter Scheidegger, *Regionalverkehr Bern-Solothurn, Bern, Switzerland*

Bern, the capital of Switzerland, has only 330, 000 inhabitants. It has preserved a comprehensive streetcar and bus network within the historic city. Some suburbs are served by a separate four-line light rail transit (LRT) system, which has been upgraded progressively during the past 30 years and today enjoys a high level of technical and operational success. Thanks to the flexibility of LRT, investments could be concentrated on the sections that needed them most. Special operating concerns were increasing speed and reducing the demand on rolling stock. A new type of car with a partly low floor and enhanced comfort level was introduced in 1993. In the last 10 years, the share of commuter traffic to the city (modal split) improved from 50 to 60 percent. Popular concern about the environment motivated the issue of cheap season tickets throughout Switzerland. This national policy, coupled with the unbalanced peak and off-peak loading patterns typical of metropolitan transit systems, means that LRT fares do not cover all of its costs. Even so, fares cover 60 percent of operating costs.

Although it is one of the world's wealthiest countries, Switzerland has never stopped emphasizing public transportation. The share of the market captured by public transportation is given in the following table:

Segment	*Share (%)*
Nationwide	18
In cities	30–50
Peak hour toward central business district (CBD)	50–80

Reasons for these statistics include the following:

- *Topography.* Towns in valleys and along rivers and lakes are lined up like pearls on a string. One single line of bus or rail can serve these locations economically.
- *Comprehensive network of public transport.* Thanks to federal, state, and local subsidies, not only cities and their suburbs, but all towns and all tourist resorts can be reached by public transportation.
- *Land use planning.* Offices are still mainly in the central business districts (CBDs) of cities. Housing areas have greater density than they do in the United States.
- *Environmental concern.* Switzerland—a typical tourist country—has always been concerned about its environment. As more dead trees in the European forests were detected after 1980, a green movement emerged within most political parties. Voters did express their wishes for better public transportation through popular referendums (*1*).
- *Social behavior.* Even the most prestigious Swiss bank managers use clean and reliable buses, streetcars, or trains to go to work.

The Swiss rail network is summarizing in the following table (2):

Rail Network	*Length (km)*	*Passengers per year (millions)*
Standard gauge	3 707	318
Meter gauge regional	1 402	78
Meter gauge local (streetcar)	181	365

Most meter gauge rail lines may be regarded as light rail transit (LRT), although a great variety exists. In the cities of Basel, Bern, Geneva, and Zurich, streetcars run mainly on the road surface. But in mountain regions, locomotive-hauled electric trains with up to 12 coaches operate on a 375-km meter gauge network. Because they have aluminum bodies, these 16-m-long coaches weigh only 15 T, so this system may still be called light rail. Between these two extremes, there are all intermediate types of LRT for suburban, regional, and even rural services.

LRT lines have been improved step by step, according to available financial resources and operational needs (e.g., separation of tracks from roads). Because of the adaptability of LRT, only a few rail lines had to be closed. However, the scope for new lines is small: in 1992 Lausanne opened an LRT line on a totally segregated alignment (but with at-grade crossings), connecting the city center with suburbs and a new university. In 1995 Geneva is opening a second streetcar line.

The main activity lies in technical and operational improvements. Three features now adopted worldwide were developed in Switzerland:

1. *Open access.* Ascom-Autelca and Sadamel installed in the late 1970s ticket vending and canceling machines at every stop of the streetcar lines. This is now common practice even on regional and suburban trains of the Swiss Federal Railways (heavy rail).

2. *Low-floor streetcars.* The first modern low-floor car was introduced in 1987 by the Swiss manufacturer Vevey Technologies on the Geneva system. This idea has spread to France and Germany as well as to the bus industry.

3. *LRT and bus priorities at traffic lights.* Such priorities were already commonly used during the 1970s (*3*). In addition, Switzerland was the second country after the Netherlands to adopt coordinated regular interval time tables for all intercity and regional rail services and most connecting bus services on a nationwide basis.

Bern

Within a metropolitan population of 330,000, the city of Bern itself has only 130,000 inhabitants but offers the same number of jobs, mainly in offices. The CBD has a medieval layout. In a circle of 1-km radius around the main station, there are a first-class shopping center and 60,000 jobs but only 6,000 public and private parking spaces. In several referendums, voters have accepted a very constricting parking policy to reduce traffic and maintain ecological goals (*4*).

The table presents a summary of public transportation in the Bern area:

Mode	*Approximate Journeys per Year (millions)*
Local streetcars and buses	125
Standard gauge commuter rail (excluding intercity trains)	19
Meter gauge commuter rail (LRT)	18
Regional buses	7

Approximately 40 percent of all journeys in the conurbation are made by public transportation. The number of rides by public transportation per capita each day is approximately 1.4 in the city and 0.8 in the suburbs served by LRT.

Bern Suburban LRT

History of Regionalverkehr Bern-Solothurn (RBS)

Four meter gauge LRT suburban lines were opened between 1898 and 1913. They all entered the city on local streetcar tracks on the surface; the cars looked like narrow U.S. interurbans. Although private car ownership grew very fast after World War 2, ridership on these lines grew, too, because of suburban development, limited parking space in the city, and a frequent train service with well-located stops. The growing private traffic and the long trains in narrow streets and on busy at-grade crossings interfered with each other more and more over the years.

Modernization

In the 1960s, a comprehensive modernization program started that was financed and implemented step by step. After each step, taxpayers could assess the progress. The flexible adaption of LRT technology enabled the effort to be directed first to the sections nearest the city center, where traffic volume was highest and improvements were most urgent. In 1965 a tunnel was opened to the city center (main station) for the two most heavily used lines (like the Blue Line entrance to the Los Angeles CBD). In 1974 a third line was diverted into this tunnel, so that today only the fourth line, which is of more streetcar character, still runs on street trackage into the city. The first three lines now run on exclusive right of way, although there are still some mostly full-gate-protected at-grade crossings in the suburban and interurban area. Outside the common trunk route, most sections are single track, although there may be up to 16 trains per peak hour (standard is 8 trains per hour).

In the past 30 years ridership has doubled, from 9 million to 18 million per year. The fare-box recovery rate is approximately 60 percent (operational costs including track renewal).

Elements of Success

Several aspects of Swiss LRT—which may differ from U.S. practice—are described:

- The tree principle (cooperation of rail and bus),
- The cascade principle (adaption of rail service to demand on longer suburban lines using zone express scheduling),
- The drop-and-catch principle (coupling and uncoupling of rolling stock en route),
- The novelties-without-risk principle (low-floor rolling stock with standard trucks),
- The subway principle (layout of the vehicle entry vestibule), and
- The diversity principle (different seating layouts).

All of these elements were copied from other rail operators and developed over the years to fit like a puzzle and create an attractive and economic way of operation.

Tree Principle

RBS's service philosophy can best be explained by the tree symbol (Figure 1): a ***trunk*** (rail, which has a big

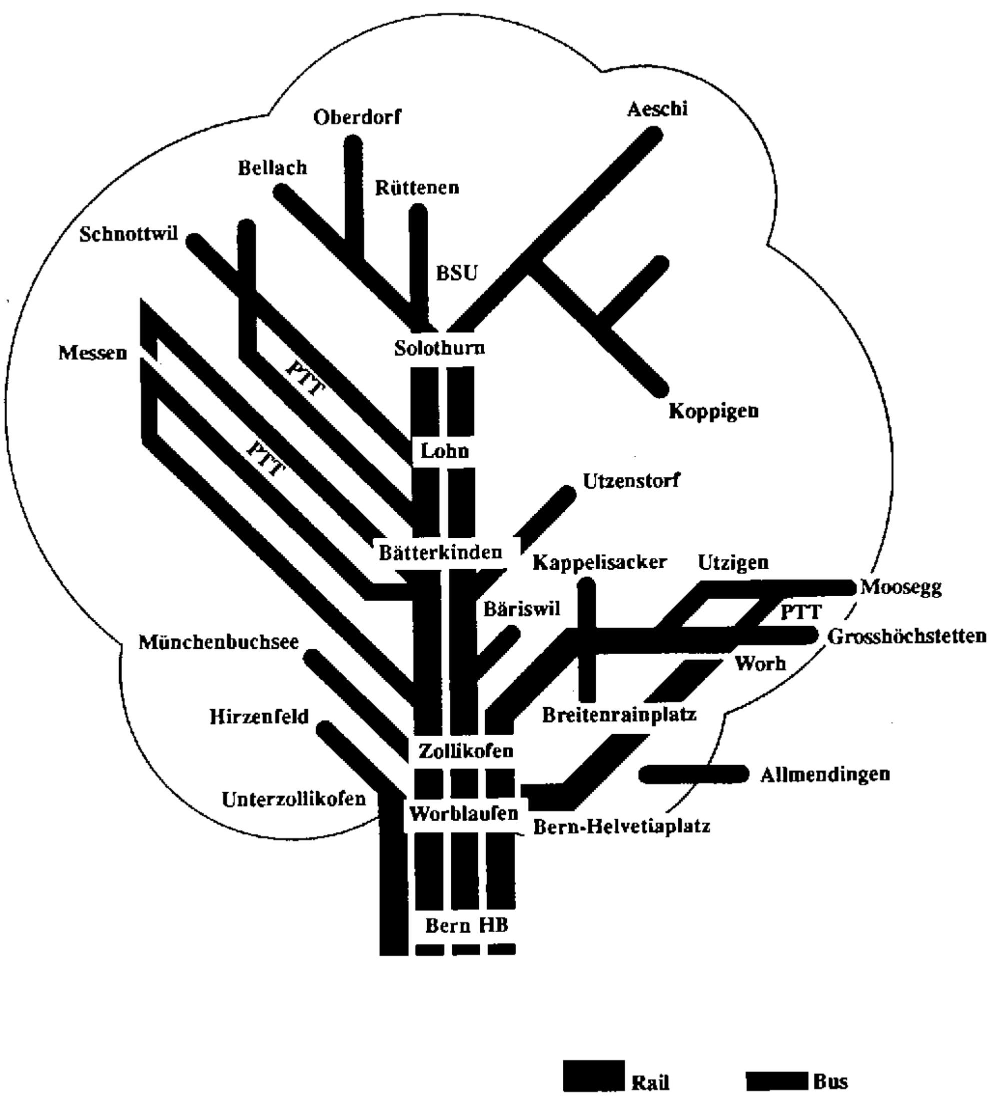

FIGURE 1 Network tree.

capacity but is expensive) can live only if it is fed by *roots* (urban streetcars and buses) and *branches* (suburban and rural feeder buses). Following this principle, RBS created new bus lines with local grants and connected them as closely to the LRT as possible (timetable coordination, through-ticketing, and cross-platform interchanges between rail and buses) (Figure 2).

Cascade Principle

To serve the Bern-Solothurn corridor, RBS has adopted the same practice as the French railways for the Paris suburban area. The corridor is divided into three sections (Figure 3). The first type of train serves the inner suburban area; the second type serves the outer suburban area, not stopping in the inner suburban area; the third type is the interurban, running nonstop to the end of the outer suburban area. This type of service has two advantages:

1. *Economy of rolling stock.* Passenger demand on suburban lines is extremely one-sided. Starting at the city-boundary end, demand is at the maximum, whereas on the last section of the line, only a few passengers are still on the train. Instead of conveying many long trains

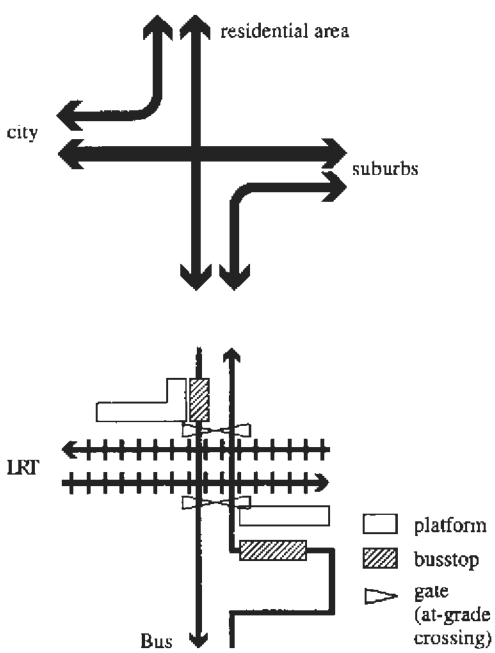

FIGURE 2 Bus-LRT interchange: *top*, main traffic flows; *bottom*, layout (Papiermühle/ Bern).

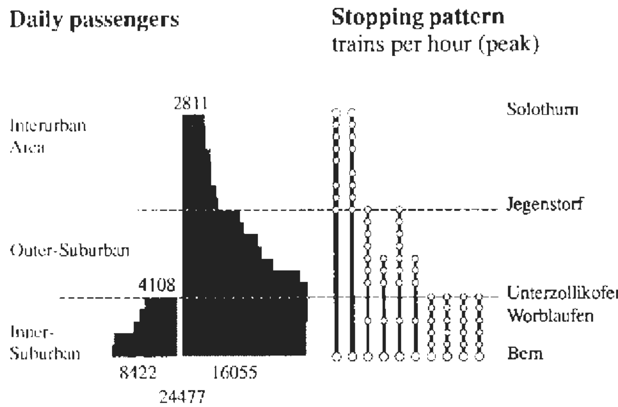

FIGURE 3 Traffic demand and stopping pattern.

to the end of the line (or running more frequent services with LRT), the cascade principle caters to the demand on each section and therefore economizes rolling stock (and sometimes staff).

2. *Increase of speed.* Approximately 1 min is gained by leaving out one stop. Therefore, the interurban service between Bern and Solothurn has a commercial speed of 54 km/hr, compared with the standard 35 to 40 km/hr on the suburban services that stop every 1 to 1.5 km. Thus, the cascade principle economizes a further train set, plus it gains time for passengers.

Drop-and-Catch Principle

On another line, RBS must run six-car trains on the first section because of capacity needs, but the length of passing tracks and platforms on the outer section limits train length to four cars. At a station before the middle of the line, passengers disembark from the last two cars on the train from the city; these two cars are dropped and the train continues as a four-car set [Figure 4(*top*)]. Passengers bound for the city may already begin boarding the stationed two-car set. Some minutes later, the next inbound train enters the same station track, couples to these two cars, and departs as six-car train toward the city [Figure 4 (*bottom*)].

Thanks to a modern, fully automatic coupling system (+GF+) with remote-controlled uncoupling and braking test, uncoupling consumes only the standard 20-sec stopping time, and coupling and changing of cabs happen within 30 to 50 sec, both without any extra staff.

Novelties-Without-Risk Principle

A 30 percent increase in the number of passengers from 1985 to 1991 made it necessary for RBS to purchase

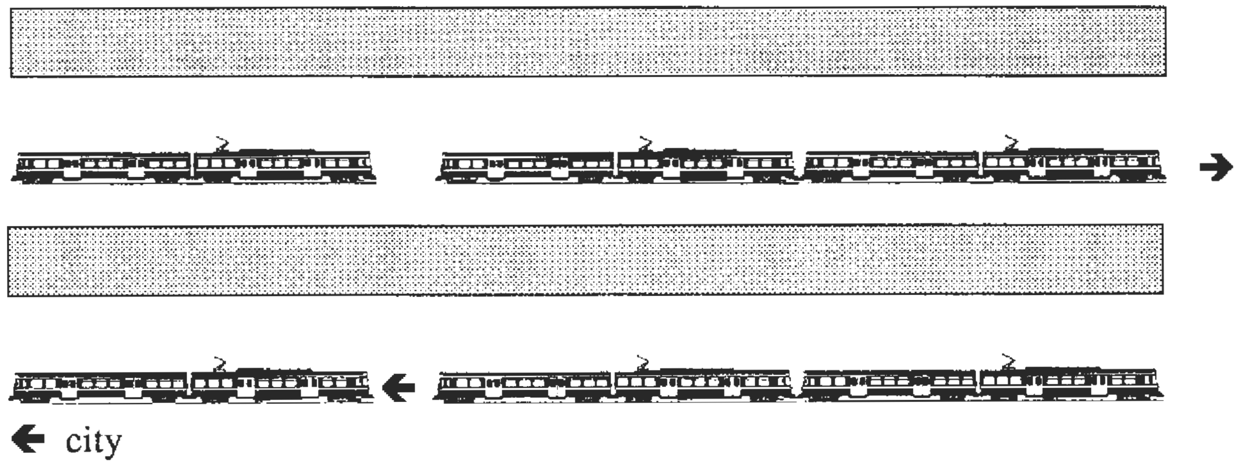

FIGURE 4 Dropping and catching train segments: *top*, from city; *bottom*, 5 min later.

more rolling stock. Schindler and ABB delivered 23 twin-car sets in 1992–1993 to three Swiss suburban railways (11 to RBS). Eight unpowered intermediate cars to form three-car sets were manufactured in 1994 for RBS.

Swiss rolling stock must run for at least 40 years, so a farsighted modern concept had to be chosen. Without a prototype, however, and with only a few technical staff members, RBS could not take a great technological risk. Therefore, an innovative low-floor concept was selected, but with standard trucks. Sixty percent of the car length is low-floor—39 cm above top of rail (TOR) (Figure 5).

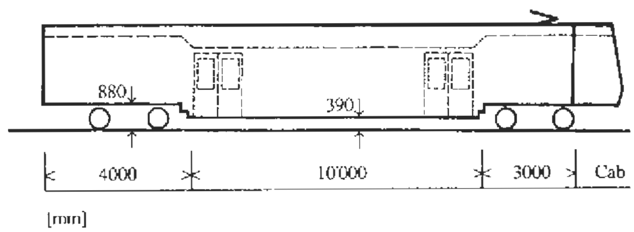

FIGURE 5 Low-floor railcar (half unit).

From standard platform height (18 cm TOR), parents with baby carriages as well as most passengers with disabilities (even in light wheelchairs) have easy access to the train. Furthermore, in the future, raised platforms (32 cm TOR) will make the train accessible even for people in heavy electric-driven wheelchairs (Figure 6). These provisions are being made even though in Europe there is no legal equivalent to the United States' Americans with Disabilities Act.

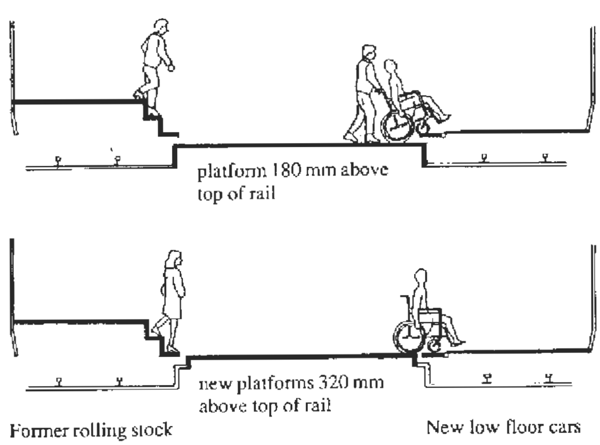

FIGURE 6 Platform heights and access to new rolling stock.

Subway Principle

In the subway principle, both doors are placed in the low-floor part. The "vestibule" is designed according to urban rail principles: an unobstructed space (Figure 7),

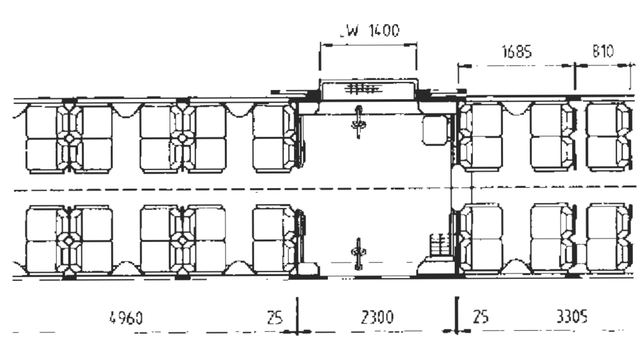

FIGURE 7 Vestibule of new rolling stock.

which can be used for different costumers' needs according to the changing travel hours (e.g., enough space for standees, baby carriages, luggage, and ski and bike storage). The most important and often neglected need is enough room for standees on both sides of the doors, so that standing passengers do not obstruct the entrance. Between this vestibule and the seating area is a glass partition to provide an unobstructed view of the entire car and to show entering passengers the location of free seats. This concept was introduced during 1973–1978, when 21 twin sets were bought for suburban traffic. It proved successful, particularly to deter vandals.

Diversity Principle

To attract automobile drivers as transit passengers for rides up to 20 mi or 37 min, comfort must be better than that of spartan LRT vehicles. But what is comfort? Every passenger has his or her own preferences. Therefore, the new rolling stock offers, in the same body shell, different elements catering to different desires:

- First- (interurban only) and second-class accommodations,
- Nonsmoking and smoking sections (second class only),
- Seats back to back and one behind the other,
- Accommodations with and without tables, and
- A study compartment (no noise).

These combinations give a total of nine different seating layouts. Regular passengers select their seats according to personal preference. It is a pity that such variety, which gives trains an edge over buses, is seldom adopted.

In the same line of thinking, the basic twin set (ideal for inner-suburban service due to good acceleration) can be enlarged to a triple set by adding an intermediate car (without motor drive) (Figure 8). So triple sets—which are cheaper per seat—are formed for interurban service, where lower acceleration is less of a disadvantage because there are fewer stops (Table 1).

The main new technical features of the low-floor cars include

- AC drive (ABB),
- Light alloy body (Schindler), and
- Trucks with pneumatic suspension (SIG).

To reduce the risk of squeaking noises and the higher operation costs in later years, the cars have no articulation. The main feature, however, is the ability of a single staff member to operate six-car trains (120 m including 348 seats and 400 standing passengers).

Conclusions

Between 1985 and 1991, the number of LRT passengers in Bern grew by 30 percent. The modal split of commuters from the suburbs served by LRT to the city grew from 50 to 60 percent between 1980 and 1990. During the same period, traffic volume on many roads remained stable, although the population of the suburbs grew steadily. This success is based on

- Land use planning coordinated with public transportation, especially rail stations;
- Restricted parking policy, first in the city center but now also in the suburbs;
- An attractive offer of public transportation (e.g., coordinated rail and bus schedules and tickets);
- Enhanced passenger comfort to attract automobile drivers: easy access (low-floor) trains and a choice of seating layouts.

This success in gaining passengers unfortunately is not reflected by a smaller deficit: with heavy peak loads and fewer off-peak passengers on one hand and the political pressure to offer cheap commuter tickets on the other, it is impossible to balance the account. But the fare-box recovery rate of 60 percent is far better than

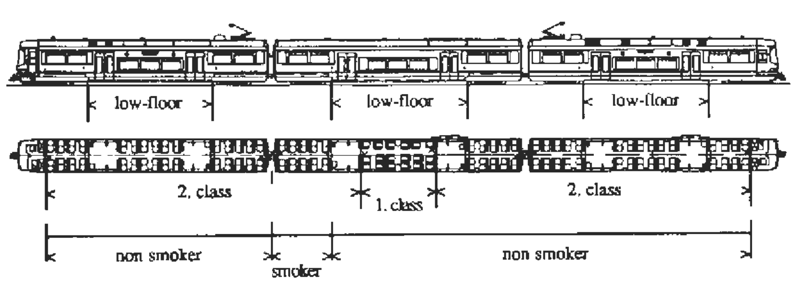

FIGURE 8 Different interior layout of triple set.

TABLE 1 Main Technical Data

	Twin-Set		Triple-Set
Nominal line voltage (direct current)	V	1200	
Maximum gradient	%	4.5	
Minimum curvature	m	50	
Axle arrangement	Bo'2 + 2'Bo		Bo'2+2'2'+2'Bo'
Mass in running order	t	58	80
Number of seats 1st/2nd class		0/120	18/156
Number of traction motors		4	
Continuous rating at motorshaft	kW	640	
Starting tractive effort at wheel rim	kN	107.5	
Maximum power rating at wheel rim	kW	1114	
Maximum speed-operating (design)	km/h	90(100)	
Length over automatic coupler	mm	40000	59730
Overall width	mm	2650	
Door width	mm	1400	
Distance between trucks pivots (one vehicle)	mm	14000	
Truck wheel-base for motor trucks	mm	2000	
Truck wheel-base for unpowered trucks	mm	1800	
Diameter of wheels	mm	720	

that of most heavy rail systems and, thus, further proof of the economy of LRT systems (6).

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Urban Design and Aesthetics

Public Art and Public Transportation

Craig Amundsen, *BRW, Inc.*

Building communities that rely on transit and walking will require greater attention to humanizing transit stations and integrating them into their surrounding context. Public art has a role in this process: it can help make transit stations more than just places to wait. To build the image of transit as an amenity in the community requires recognition of and sensitivity to the fact that the quality of the transportation experience directly affects the quality of the lives of transit users. The experience of travel by transit should be an attraction in itself. To build transit systems that are competitive with, if not better than, the experience of moving by automobile requires attention to those things that make the public spaces serving transit successful. Spaces that serve to accommodate waiting, as well as sidewalks and paths to stations that connect surrounding activity centers and land uses to transit, can be more interesting and made more secure by including public art in their design. Public art can draw out the identity of a space, aid the understanding of the historical or cultural significance of a neighborhood and its residents, and help to forge a connection to the social needs of the 1990s. Combining the skills of artists with those of transit engineers, planners, and architects in the design of public spaces related to transit has been successful and at times difficult. Involvement of public art in the design of transit-related public spaces is not a mere aesthetic issue. It has become a means whereby community values are expressed and a sense of ownership is fostered between the community and the transit-related facilities. As a result these transit spaces have become more secure and active by virtue of the stewardship assumed by the community. Artistic expression, though, at times has been at odds with public opinion. There can be an underlying fear of public art and the inclusion of artists in the design of transit-related spaces. Public art can be too provocative and seen as appealing to an elite audience rather than to regular people. Where has the inclusion of public art in transit projects been successful? What methods have been used to achieve positive results? How do constructive collaborations between artists, designers, and engineers happen? In what ways has the inclusion of public art served to encourage pedestrian access to transit stations? These questions are addressed.

The purpose of this paper is to examine success factors in transit-related public art and architecture. Believing that the quality of the transit experience directly affects ridership levels, the author will examine how public art affects this experience by looking at examples and reviewing case studies of places, methods, and processes that have achieved some success in public art for transit.

Success Defined

Public art that has been highly successful reveals certain common features that transit system planners should understand: high-quality design, timeless appeal, environmental enhancement, and functionality.

High-Quality Design

The first success factor is excellence in the overall architectural design and engineering. Artists cannot transform poorly designed, ugly projects by adding artwork later. Public spaces need to be inviting and pleasant in themselves as well as functional and safe. This means that planners, architects, and engineers must strive to plan quality and attractiveness into public transit designs. In any field, a truly excellent design is simple and functional and integrates each part effectively into the whole.

The result of the pursuit of excellence is continuity, and this becomes aesthetically evident during the design decision-making process. There is great pressure to cut amenity budgets in order to solve utility or other civil engineering problems. The execution of the design will affect results aesthetically. In many cases, the choice of building materials will influence the perception of the transit-related space. No amount of public art added later can overcome the image projected by low-quality materials. Space, however, is not artifact. Public art has long held a place in public spaces as an artifact that expresses a community's values and beliefs.

Scattering historical symbols about does not create a true sense of place. The inclusion of artists in the early architectural programming for a transit-related space has become popular as a better way to achieve more humanized public spaces while avoiding the "plop art" syndrome. This has become known as environmental art and has resulted in more successful realizations of the objectives in public art inclusion.

Timeless Appeal

Another feature of successful public art is that it endures not just physically, but also in its appeal. Plans, projects, and public art that are well designed will endure, because the public will like them and keep coming back. This quality of physical endurance is inherent in public art, since once it is incorporated into a public space, unless damaged, it becomes permanent. Large outdoors statues, murals, and other kinds of public art will be in the public eye indefinitely. It is important to their success that the style of art chosen be enduring in the public favor. If so, area residents and travelers will still want to look at it 20 years later, and, when the need arises, they will be willing to contribute to its restoration.

Timelessness is a difficult accomplishment. Society is caught up in fashion. The primacy of style over substance is what contemporary society is all about. One of the main points of style is that it will not remain current. In traditional societies, public art imagery was used to invoke perpetuity. Today, style speaks to a society in continual search for something new. Style has always been an elitist idea. The answer to finding timelessness lies in appealing to popular taste.

Successful public art has come out of the museum circuit that defines what is good and bad art. Art critics have almost no place in reviewing the success of public art, or of public spaces for that matter. What will endure must be drawn from what is meaningful to the residents of the surrounding communities and the users of the transit systems.

Despite its price tag, there was virtually no opposition to the Grand Central Station restoration project currently under way because the enduring beauty of its architecture, statuary, and Works Progress Administration (WPA) murals has made it one of New York City's landmarks. This is success in public transit art and architecture on a grand scale. There is still an element of prestige in entering Manhattan through Grand Central Station, but what made the station meaningful was the work of the WPA artists who worked during the Depression to connect the station to its community.

As excellent public art endures, its value appreciates, bringing enhanced prestige to the city or development. The very best public art endures so well that it is transformed into a landmark that symbolizes its city.

Public Acceptance

An obvious but sometimes neglected success factor in public art and architecture is whether or not the public likes it. A piece of modern sculpture that would look provocative in a museum may not be what people want to look at every day as they pass by on their way to work.

A case in point is Andrew Calder's *Flamingo*. It is considered by professionals to be great art, but few ordinary Chicagoans like it. It's too big, too red, and too reminiscent of something residents would prefer to forget: Chicago's short but virulent mosquito season. Popularly named the "Mosquito," the Calder sculpture looks to pedestrians like a giant predator from a science fiction movie. It is used by some particularly jaded Chicagoans as evidence that the mosquito is Illinois' state "bird"! Public art that succeeds is attractive to ordinary citizens rather than appealing to elite taste. But this does not necessitate reduction in quality. Another piece of public art located just a few blocks away holds a similar artistic value but much greater favor with the public. Created by another famous artist, Marc Chagall's mosaic uses softer colors and a much less severe style to please commuters as well as art critics.

Popular public art attracts people to business areas. In New York City, sculptures of angels blowing trumpets are erected in Rockefeller Center every Christmas season. Fifth Avenue is lined with colorful, larger-than-life-size Nutcracker figures. Because of this, people from suburbs saturated with shopping malls come every year by train and subway, bringing their children—and their credit cards—to begin the Christmas shopping season in the city.

Similar success can be seen year-round in New York at the Statue of Liberty. It is not generally considered to be great art, but people come from all over the globe to see it, bringing in lots of revenue to the city via tourism and sales. Planners who want similar success would do well to provide the public with what it likes rather than what art critics think it ought to like.

Environmental Enhancement

Improvement of Appearance

Art has always been used to beautify, and successful public art improves the appearance of its surroundings.

Carl Nesjar's sculpture fountain at Nicollet Mall in Minneapolis, Minnesota, designed in collaboration with BRW, not only withstands Minnesota's brutal cold, but capitalizes on it. The steel sculpture fountain, lovely in itself, serves as a framework on which winter wind and cold create ice sculptures. This ever-changing interaction between art and nature can encourage commuters struggling to get to work in Minnesota's infamous weather. While sprucing up the appearance of the mall, it also improves the morale of transit patrons.

Harmonization with Context

Successful public art is well integrated with its surroundings to enhance rather than disturb its environment. Designers may find inspiration in the materials, colors, and shapes of the existing or planned structures or from the indigenous natural environment. These then become design elements for art objects or larger plans. Much art is conceived to jar the senses, to call attention to itself. This approach is anathema to good public transit art. Remember that public dollars are usually funding transit-related public art. The public relations problems of the National Endowment for the Arts in recent years serve to point out the public's expectations in this regard.

Multiculturalism is an important aspect of public art, and society as a whole. Many questions are being raised regarding what is proper for socially responsible art.

BRW's design for the West River Parkway in Minneapolis linked the city to the river while developing it for commercial and recreational use. The natural features of the shoreline, historic sites, and buildings were preserved carefully. The design, which extends over 6 mi, changes to suit varying landscapes and buildings. The result is that the natural landscape is enhanced while its potential for transportation via river, sidewalk, and roadway is developed. The involvement of public art served to harmoniously tie the site to its history.

Reinforcement of Community Values

Consciously or not, art reflects a society's characteristics and values. Good art expresses and thereby reinforces the best qualities of its culture. In Portland, the Metropolitan Arts Commission has charged public artists to remember that "the art be the common language of all those using the system, connecting riders with their environment, their history, and with the technology that moves them" (*1*, p. 13).

Artist Kirk Newman reinforced the experience of subway riders by creating whimsical, shadow-like silhouettes of dashing figures on the walls of the Michigan Avenue Station in Detroit. In Boston, Mags Harries' bronzed items (gloves dropped by commuters) transform lost items into sculpture.

Diversity is the cornerstone of interest. Artists bring varying points of view to a project that might otherwise be focused by only one designer's vision. Public spaces can be given layers of meaning when several artists are included. This makes them interesting places to be and to revisit, an important aspect for transit spaces used every day by transit patrons.

Elimination of Negative Expression

Public art can be provocative. Whose taste should prevail? Translating values into spatial or artifact design is not new. These projects cross cultural boundaries from the high to the low brow. The abstract is not always seen as practical. The ideal is not always pragmatic. Members of the cultural elite see a role for themselves in defining what should happen in transit-related public spaces. This can lead to an exclusionary reaction because public art is seen as just too much trouble.

Some may question spending the money needed to include public art. But these dollars are an investment that will build the community as well as its infrastructure. On the other hand, neglecting these concerns creates a vacuum that tends to be filled in unwanted ways. Blank walls and ugly places attract amateur "artists" whose efforts are not appreciated. Short-sighted planning produces waste through vandalism, street crime, and the need to make major changes later on. Art and cleanliness must be maintained: attractive, inviting public spaces invite responsible use rather than graffiti and vandalism.

On the Nicollet Mall project, extensive glass in the transit shelters was etched by an artist to reflect the various periods of architecture and culture in Minneapolis' history. The main concern in making the investment was that replacing the large glass panels would be expensive compared with replacing unembellished panels. To everyone's surprise not one of the etched panels has been damaged since the opening of the project 5 years ago. A plausible explanation is that the public appreciates the art and has chosen to preserve rather than to destroy it.

Stimulation of Public Interaction

Public art can also invite and inspire creative activity. Some artists have created works that invite public interaction.

A highly imaginative piece is *The Kendall Band* by Paul Matisse, a set of large-scale musical instruments hung over the subway tracks at Cambridge, Massachusetts' MIT station. Waiting commuters can play chimes, a gong, and a thunderous sheet of steel by manipulating cranks and pulleys from the platform. A less intentional example is the excellent acoustics built into many a subway and station tunnel that attract amateur musicians to play for donations from the waiting public. Here, excellence in architecture (as well as a lot of hard surfaces) have produced public spaces that invite the public to interact in an aesthetic way. Some places, like Grand Central Station in New York, schedule young musicians to play, thus providing performance opportunities for students from New York conservatories while promoting New York's culture.

Functional Utility

Whether providing beauty or enhancing design, good public art should serve a positive function. Examples of public art that is also functional are the wooden benches sculpted by William Keyser, Jr., for the Alewife subway station in Cambridge, Massachusetts. Here, the artist has met a practical need for public seating while adding much-needed warmth and beauty to the station. The result is a sculpture that would not be out of place in a fine museum.

An example of an aesthetic and functional architectural design is Sixth Street Station in Minneapolis. Echoing traditional vaulted European train station designs in a contemporary style, the architect has created an open, inviting gateway as well as a waiting area. This gateway shelter connects the street with a plaza and pocket park behind the station, where people can relax or enjoy outdoor performances. The enclosure is transparent, allowing views of approaching buses while sheltering passengers from wind and weather. This elegant, arched shelter, with its glass and brass portal, is both functional and beautiful, enhancing public activity and access to transit. It also serves as a performing space for the adjacent Hennepin Center for the Performing Arts. Located on the site of a former vaudeville theater frequented by Charlie Chaplin, the center has helped the community to celebrate the connection of past and present.

Success Achieved: Case Study Processes

The success factors in public are high-quality aesthetic design, enduring appeal, public acceptance, environmental enhancement, and positive function. Now comes the perennial question of transit planners: how do we get there from here? What are the methods and processes that create excellent, enduring, functional public art that enhances its environment?

Basically, two approaches toward public art have been taken in this country in the past 20 years. The earlier approach was to make funds available for commissions for artists to create pieces for projects that were already designed (and, in some cases, already built). The second, more recent approach has been to involve artists early in the project's planning and design, replacing plop art with an artist-based conception. Artists have been given an increasing role and influence in these projects. This has developed into a third approach, in which an artist's concept defines the entire project design.

The case study approach will be used to look at a project in which artists were included from the beginning of the process and collaborated with architects and engineers to produce excellent aesthetic design of the overall system and its individual elements.

Next, the author will examine how artists commissioned to embellish already-designed transit spaces with art works fostered a sense of ownership between the community and the transit project by including the public in the process of creating works of art that reflected their values and culture.

Finally, ways of incorporating art to increase the appeal of public transit by creating a welcome walking experience, which is an attraction in itself, will be presented.

Creating Aesthetic Design Continuity Through Collaboration—St. Louis MetroLink

Planning

The St. Louis MetroLink, 16 m of which opened in July 1993, is a case study for developing excellent aesthetic design. This project's success resulted from planning, unifying design concepts, collaborating, and responding to the community. The collaboration among artists and civil engineers in designing the overall system was just one success factor in a system that attracted six times the estimated ridership in its first year, 76 percent of which were new public transit riders.

The Bi-State Development Agency's goal was high-quality design. Reaching this goal took a team approach that involved artists with architects. Bi-State formed AIT, Arts in Transit, to select artists to work with architects and engineers to design the new system under the guidance of a design review committee of outside experts. Two visual artists and two landscape artists created a master plan. Their approach was to integrate art and artists into the design process rather than simply to commission separate art works.

Funding was allocated from the National Endowment for the Arts, the St. Louis Regional Arts Commission, and the Urban Mass Transit Administration, now the Federal Transit Administration (FTA).

Six nationally known visual artists developed their ideas about design goals and features: Alice Adams, Gary Burnley, Jody Pinto, Lella Daw, Michael Jantzen, and Anna Valentina Murch. The senior architecture and engineering firm was Kennedy Associates, Inc., of St. Louis. Tod Williams & Billie Tsien, A New York City architectural firm, was hired because of its successful record on projects involving artists and builders.

Unifying Design Criteria

Having planned for a workable collaborative process, the agency charged the artists with developing a unifying design theme. The following criteria were established:

- The system should grow from what is native to and characteristic of St. Louis.
- The system should be a whole set of related components—a single entity, like a work of art.
- The system should be considered from the viewpoints of the transit rider, the neighbor, the passerby, and others who will be affected by it.
- The design should be dynamic rather than static and should incorporate changeable elements.
- The design should orient people to their location and direction.
- The functional and working elements of the system should be made visible.
- The design should deal with the ordinary as if it were extraordinary, making use of what is there in a new and poetic way.

The first design criterion identified the arc as the outstanding feature of St. Louis' best existing public designs, such as the St. Louis Gateway Arch, Union Station, Eads Bridge, and Lambert International Airport, all adjoining the MetroLink alignment. This led to the adoption of the arc as the basic unifying design element for the entire project.

Collaboration by Artists, Architects, and Engineers

Artists, architects, and engineers, using agreed-upon design criteria and the unifying principle of the arc, worked together to produce improved engineering and architectural designs that gave the overall system an aesthetic unity. Two specific examples of aesthetic designs developed through collaboration were the bridge supports and the station canopies.

Artists worked with engineers to modify a heavy post-and-lintel bridge design that was considered unappealing by those who reviewed the drawings at the 30 percent stage. A good deal of give and take was required before a solution was developed, as engineers' attempts to cut costs detracted from aesthetics. Artists were challenged to create a design that would be practical and within budget as well as aesthetically pleasing and would fit in with the overall arc theme. The result was an elegant design featuring slingshot piers and a haunched superstructure. "Their aesthetically pleasing and unusual shape received positive media attention and considerable community response, and have served as a marketing tool" (A. R. Ruwitch, *Building Bridges: Artists Collaborate as Designers for a Light Rail System*, March 1992, unpublished manuscript).

A second collaborative challenge for St. Louis MetroLink was designing the canopies for outdoor station platforms. Practical issues included the needs to offer protection from weather extremes while providing a safe, open area; allow maximum light; enable ease of maintenance; and ensure coordination with platform features. Design goals were to incorporate the arc and a sense of movement and direction into a design that would fit historical, business, and residential station areas. The canopies needed to look consistent while varying in length. All six artists worked on the design, and Kennedy Associates brought in an architect with an interest in integrating art, architecture, and engineering. "The approach taken by the team regarding the canopy's architecture was to understand and appreciate its function and reveal its engineering" (2, p. 41). The result: Plexiglas-covered arched steel struts with winged flanges.

Through collaboration by artists, architects, and engineers, the arc theme was designed into every major part of the MetroLink project. Underground stations were built with curved ceilings. Park-and-ride lots retained the curved contours of the natural landscapes. "Successful design work depended upon a willingness to expose early concepts to study by colleagues; success of the final product depended upon the ability of the larger community to grasp the importance of a sound and comprehensive aesthetic philosophy for this new urban component" (3). Stephen E. Willis, Deputy General Manager of MetroLink, sums up: "I knew we had started something by having engineers work with artists, but I was cautious with my expectations. I was wrong. It's terrific!"

Responsiveness to Community

MetroLink's collaborative method went beyond relationships on the design team. In addition to good planning, a unifying theme, and collaboration among architects, engineers, and artists, an important factor in the overall success of the MetroLink project was community participation.

Projects such as school programs, art exhibits, and public speakers were organized to involve the public and elicit its input on the unique qualities of its neighborhoods. These qualities were then reflected in graphics on or in the station walls. Landscape and visual artists on the right-of-way design team studied the areas between station sites along the MetroLink route and created a comprehensive plan for opportunities. The purpose was to highlight existing features to the riding public. A variety of methods were used, including creating distinctive plantings that could be viewed along the alignment. An artist-in-residency program expresses the buildings' industrial activity to MetroLink riders. Art pieces were created to underline the historical and cultural significance of various sites. "A Bi-State bus [was] refitted and transformed into a colorful traveling art gallery to bring exhibitions out past Art Link projects and information materials about MetroLink to multiple sites and neighborhood events . . . Art Link projects helped to build relationships with neighborhood leaders, created a core of supporters for MetroLink and set the tone for a high-quality arts program" (2). Arts in Transit is continuing to market MetroLink through a series of public arts projects in station areas. These and other community efforts, including offering free fares the first 2 days, generated so much public interest in the project that when MetroLink opened, people waited for hours for the chance to ride.

The St. Louis MetroLink project demonstrates how involving the viewpoints and efforts of artists in planning, design, and community involvement phases can create a light rail system that generates public enthusiasm, support, and ridership.

Creating Enduring Appeal Through Timeless Design with Broad Public Appeal—Minneapolis Nicollet Mall

Purpose

The Nicollet Mall was redesigned and rebuilt in 1989 and 1990 to overcome several of the shortcomings of the first design, which opened in 1967. In its first incarnation the Nicollet Mall grew to become the main retail street, main public space, and main transit street in downtown. Its park-like design imposed many limitations on its use, and inadequate maintenance of low-quality building materials led to the need for total reconstruction. In the 23-year life of the first mall, the retail environment around it changed significantly, evolving from a street of shops into a series of internally oriented retail complexes connected by skyways.

The objectives of the new design were to make it more flexible in its accommodation of public space activities both known and unpredictable, to expand its transit ridership capacity, and to help the retail environment be competitive with suburban regional centers. Designed as a quintessential snapshot of what was fashionable in landscape architectural design of the times, the first mall was also more kitsch than desired.

BRW designed the new mall of sustainable materials, (granite, bronze, and steel with indigenous landscape materials) in a timeless vocabulary. Although the designers frequently recommended that artists be made a part of the interdisciplinary design team, there was an extended reluctance on the part of the client board to the involvement of artist-based visions that, like the first mall, may be quickly dated.

Process

The notion that artists were too uncontrollable prevailed until the final design drawings were out for bidding. It was then believed safe to include the work of artists in the project. The design team had incorporated several ideas on ways in which public artists could contribute to the design throughout the design process, so it was still possible to bring artists on board, albeit in a more limited manner than the designers considered ideal.

A selection process was conducted that called for national artist interest by a committee of the board and the project architect. Several environmental artists were interested in the project, but it was mutually agreed that the project was too far along for them to be involved in the design in a manner considered appropriate. Eight artists were ultimately selected to contribute to the project: five local and three national and international.

Nine shelter glass etching projects were conducted by a single artist previously described. The ice fountain celebrating Minneapolis' winter season was also previously described. A single artist designed two granite boat hulls as functional benches. Other projects included a fountain featuring regional bird species, manhole covers highlighting several Minnesota agricultural and wildlife themes, a Native American pavement mosaic, another bench, and an abstract work.

Almost $1.5 million representing 5 percent of the project budget was invested in these eight works. The process of artist selection and implementation took almost 2 years to complete and close out. What was learned?

Popular Appeal

The art on the Nicollet Mall appeals to popular taste, in the sense that critics are at a loss to describe it to their elitist audiences, as they are also at a similar loss to describe the design of the entire mall space. This has not in any way detracted from the enjoyment of the mall by its users. The temptation to cater to highbrow territorial behavior with respect to public art should be avoided. Public art in transit-related spaces is not a social filter. It should be designed to draw people together. Highbrow art belongs in museums, where everyone expects to see it.

Clients and in fact the public at large can be apprehensive about the inclusion of public artists in the design process. Artists have, in some cases, a deserved reputation for catering to their own individualized visions. Public art is not as yet a collectivist process. Many artists fight for their right to express personal political or social viewpoints that are unpopular. Many people believe that art should be about form and beauty, not controversy. Involving a review committee in the selection and periodic monitoring of artists' works as they evolve can solve this problem in part.

This apprehension can lead to the reduction of artist involvement to the mere adding of ornamentation. On the Nicollet Mall this was mostly avoided by the early inclusion of ideas for the involvement of artists in an effective retrofit. These ideas were integrated into the design of components in a way that made the late entry of artists effective and efficient.

Public Realm

Public art can address substantially the desire for a public realm with meaning. The public spaces in the United States have been devastated by the focus on consumerism and privatization of those spaces that serve as stages for shopping activity. There is a pent-up yearning for a public realm in which genuine mixing of the classes can take place. If properly designed, transit spaces can serve as a well point for social interaction. Transit can serve as a link to a sense of a larger purpose.

Combining the skills of design professionals and visual artists can ensure that public spaces related to transit become inviting to all users. The more activity that can be encouraged in public space, the more secure and otherwise successful those spaces will be. Often it is necessary to sequence the involvement of designers on a project for reasons listed earlier as well as others. This sequential involvement need not lead to the exclusion of effective public art if proper planning and understanding of the role of public art in humanizing transit spaces are present on the design team.

The process of design collaboration is not simple. Artists, engineers, and architects at times appear to speak a different language. Facilitating the process of collaboration takes special skills and commitment to the ideals of what can be accomplished. This genuine commitment seems to be a differentiating factor in determining the success of public art on transit projects.

Terminal for Tomorrow: Integration of Art, Architecture, and Music—Chicago United Airlines Terminal

Michael Hayden's "Sky's the Limit," United Airlines Terminal for Tomorrow, O'Hare Airport, Chicago, is a good example of a different kind of involvement. Here is a familiar situation with a difference. Like most public art projects, especially early ones, the artist was brought in after the buildings were designed and built and was asked to create a work of art to fill the space. What created success here was the selection of the right artist and the provision of artistic freedom to execute his vision as well as the budget to make it a reality.

This artwork incorporates light sculpture, music, and architecture to create a 744-ft-long aesthetic environment that projects 1960s disco happenings on a grand scale. Created to enhance United's 900-ft people-mover tunnel joining its two concourses, Hayden's sculpture uses white and colored neon lights—466 of them—that create a rainbow of abstract shapes over a full hour to music by Gary Fry. Since travelers along the people-mover pass through the sculpture in 3 to 5 min, each trip can be a different experience. This transforms the mundane need to shuttle people from one place to another into a breathtaking multimedia experience. Tourists travel hundreds or thousands of miles to view such examples of public art as the Statue of Liberty. Works like "Sky's the Limit" could well become tourist attractions in their own right, drawing business to the airport. A similar effect is possible on a smaller scale at transit situations.

Case Study Research

Boston/Cambridge, Massachusetts

Arts on the Line

The success of the 1985 Red Line Northwest Extension in Boston, which was the first American city to put art in its subway stations, is a tribute to the courage of those who stood up and said "no" to more highways through their communities, to the vision of the leaders who found the way to take highway funds and build mass transit, and to the skills and labor of the craftsmen who built the line. Although the "T," as Boston's Massachusetts Bay Transportation Authority (MBTA) is called, was the first organization to place works in the Boston subways, the Cambridge Arts Council's Arts on the Line has become a baseline of sorts for similar projects elsewhere (*4*). Arts on the Line began as a design initiative of the U.S. Department of Transportation (DOT). Joan Mondale helped to spearhead this policy shift at a national level: 1978 initiatives by DOT include airport art in Atlanta, architectural restoration of Baltimore's railroad station, and the pilot for subway art, Cambridge. Most installations for Arts on the Line were completed by 1985 with the opening of the Alewife Station at the end of the line.

Mid-1960s Modernization of Turn-of-Century Stations Arlington Street Station is one of the oldest stops, dating to the turn of the century. It was assigned to the architectural firm Cambridge Seven, which installed some graphics and some photomurals of the neighborhood at the rehabilitated station. These photomurals show underground riders where they were as well as brighten the underground environment. They are still in place.

Park Street Station, built in 1897, is the oldest subway station in the country. The architects for that job, Arrow Street, and MBTA selected artists to create art for the site. The choice was a ceramic by Lili Ann Killen-Rosenberg, *Celebration of the Underground*. The ceramic and found-object mural incorporates old trolley parts and rusty tools, nails, fossils, and horseshoes unearthed on the site into scenes of Boston's transportation history.

Flaw in "T" Program As far as the arts community was concerned, the program's main flaw was its failure to work out a selection process for choosing artists. One earlier project did not use a competitive selection process; the architectural firm asked a well-known artists to design something for the Harvard Station, and there had to be negotiations for the architectural firm to accept other artists. Gyorgy Kepes was the artist selected for the Harvard Station, and his work, *Blue Sky on the Red Line*, a 110-ft-long stained glass wall, has been described as one of the glories of the transit system.

To select permanent works, the Cambrige Arts Council worked hard to develop procedures that would involve users, neighbors, artists, historians, local businesses, and public officials. Each station had a committee and a jury.

Other Artists and Works The firm Cambridge Seven encouraged artists to wander around the neighborhood and fantasize. The firm used some of its own design money to support the artists' brainstorming.

Artist Joyce Kozloff did a ceramic mural based on *New England Decorative Arts* for the Harvard Station. Mags Harries produced the most significant work of any "T" station: the famous *Glove Cycle* formed with lost gloves cast in bronze that appear as scattered items alongside an escalator.

William Wainwright's *Light at the End of the Tunnel*, a mobile that refracts daylight underground, won a Governor's Design Award. *The Kendall Band* is a work that enjoys a big crowd at the Kendall/MIT Station. A set of large-scale musical instruments designed and tuned by Paul Matisse hangs between the tracks, safe from vandals. By a system of cranks, pulleys, and hammers located on the platforms, a set of aluminum chimes, a gong, and a slab of thunderous sheet steel can be played by commuters waiting for their rides.

Lesson Artists must be involved from the beginning—to work with designers, architects, contractors, and the community—to make public art more public.

Boston Artery Arts Program

The Boston Artery Arts Program, sponsored by the Massachusetts Highway Department, must be included in any discussion of public art (*5*). Boston's mission is to create a comprehensive program of public art in public spaces. The Artery Arts Program invited professional artists to submit slides and register with an Artists' Bank. Twenty permanent public artworks were selected for the Central Artery (I-93)/Tunnel (I-90) project. Funding sources include the Massachusetts Highway Department and Federal Highway Administration with a proposed budget of between 0.25 and 0.5 percent of total project construction and program costs and recommended target of $20 million. Private funding will be sought as well.

The Artery Arts Program fosters a collaboration among artists, architects, and city planners. A high degree of community participation is involved in the selection and design process. Public art selected by and for Boston's diverse neighborhood communities will invite communication by all and encourage these groups to share in creating an inviting environment.

Dallas, Texas

Initial light rail transit service by the Dallas Area Rapid Transit (DART) will consist of 20 mi of light rail development linking the Dallas central business district (CBD) with residential and other activity areas within the North Central, West Oak Cliff, and South Oak Cliff corridors. The initial starter system will have nine line sections.

The DART art program and policies were adopted by the DART Board of Directors in June 1990 (6). Development of the program was funded by a grant from the City of Dallas Cultural Affairs Office, a grant from the Texas Commission on the Arts, and local DART funds. DART is building a transit system to link communities in its region, and it will also structure a public art program that enhances these linkages.

Public Spaces and Local Culture

The transit systems of cities in other countries, such as Amsterdam, Paris, Seoul, and Stockholm, as well as those in Atlanta, Boston, Buffalo, and Pittsburgh illustrate the contribution of public art as a tool in establishing relations with the community.

Research into the strengths and weaknesses of transit system art programs indicates that separating the artists and the art program from the rest of a systems' design process creates major coordination and installation problems. When art is applied as an afterthought, there is limited success. The DART art and design program is a team effort that include communications staff (community), facilities planning, and engineering staff, and section design team and artists.

The DART program requires that artists, architects, landscape architects, and engineers collaborate at the beginning of the design process. Funding and budgeting can then be structured in the most cost-effective way, because locations for art opportunities may be provided during the design and construction stages.

In addition, art projects will he designed with consideration to minimum maintenance requirements and maximum resistance to vandalism.

Funding

The budget to develop and implement art projects for the light rail and commuter rail stations is based on an assessment of up to $50,000 per station or facility as determined by the DART art and design program. Opportunities identified for the prototype station will enhance the facilities' capital budgets. For example, a floor or wall in the facility budget could be developed from the overall facility budget and not from art program funds. Each artist finalist (individual or team) will be paid a $500 proposal fee, which is paid after the delivery of a completed proposal.

Denver, Colorado

Mayor's Office of Art, Culture, and Film Master Plan

Denver Mayor Wellington E. Webb initiated Ordinance 717, which was passed by the city council in 1991 and requires the allocation of 1 percent of eligible city projects for acquiring public art. The Mayor's Commission on Art, Culture, and Film has developed a public art master plan. Under the ordinance any city project that provides public service is eligible (hospitals, parks, recreation centers, airport, etc.). The money is allocated within the actual construction or renovation of eligible projects.

Artists apply through "calls for entries" advertised through the media and mailed directly to all eligible artists on file with the Mayor's Office on Art, Culture, and Film. Artists may also leave slides and support material on file with their registries.

Artwork is selected by a project evaluation panel (PEP) with consideration of Denver's public art master plan. Whenever possible, an artist or team of artists is selected at the design stage of a project so that the selected artist, or team, can work with the design team or integrate artwork into the project site. A new PEP is organized for each project by the Mayor's Commission on Art, Culture, and Film.

A commitment to public art helps to create goodwill. It shows that a developer has the community's interest as well as its own financial interest in mind, and experience demonstrates that attractive public spaces are less prone to vandalism.

Denver Airport Art

The art at Denver International Airport represents one of the largest and most impressive public art programs in the entire United States. Thirty-nine artists created original works for the project, integrating the art itself into the design and structure of the airport.

"Journey" is the unifying theme of the program, relating to the concept of travel that the airport itself embodies. The idea of journey plays on another level, too, as people constantly move from one place to another in their lives.

To some artists, the journey relates to the history of the land on which the airport sits as a Native American migratory land. To others, it is the journey of air travel or the journey west as America explored the frontier.

Dade County, Miami

Metro-Dade Art in Public Places

Since 1978 federal Art in Transit programs have accompanied new rapid transit construction in the United States. In South Florida, art for 16 Metrorail stations was developed with federal funding during the multiyear construction of the system. As a group, these works represent major trends in contemporary American art and an evolution in the relationship between a public artwork and its site. Like many other areas, Metro-Dade has a depository or registry for artists that may be reviewed by consultants and architects.

Funding For more than 9 years Art in Public Places has recommended the purchase of close to 400 artworks, for a total of more than $2 million. Its funding was derived from 1½ percent of the construction costs of these buildings. At that time the county manager was responsible for the purchase of artwork, on the recommendation of the Art in Public Places Council.

Community The master plan developed by the Dade County Art in Public Places includes a section on *Responsibility to the Community* that states, in part, that

> The trust recognizes that works of art often significantly alter public places, becoming a major new presence in the environment. In recent decades, visual art has rapidly evolved and diversified, creating at times a gap between contemporary art and its appreciation by the general public. The program shall endeavor to bridge this gap, by broadening community awareness of the issues involved in contemporary art and its historical context, and encouraging informed debate among all segments of the community.

Conservation and Maintenance Arts in Public Places has also established, under county ordinance, funds for conserving and maintaining its collection. It is actually a part of the commissioning process whereby the artists' proposals are reviewed by a qualified specialist conservator and that person works with the artist to draw up a schedule of maintenance and instructions for the maintenance department of the facility housing the work.

Artists

In May 1994 Metro-Dade Art in Public Places announced that eight art installations were created for the new Metromover stations. Included are Buster Simpson's sculptural seating installations at three stations and Noreen Morelli's a ceramic mural created with students from Design and Architecture Senior High School for the School Board Metromover Station. "New Calypso" at the Park West Station, an old neighborhood in Miami, is a floor formed from bluestone slabs that become a circular cosmogram; artists are Houston Conwill, Estella Conwill Majozo, and Joseph DePace, all of New York City. They worked closely with the Black Archives Foundation to identify historical figures and sandblasted poetic texts and song lines into the stone. Other artists include Connie Lloveras, who created a ceramic mosaic at the Brickell Station.

Los Angeles

Los Angeles Metro stations along the 22-mi Blue Line (Long Beach to Los Angeles) and the 20-mi Green Line (Norwalk to El Segundo) will feature installations and designs by artists. Los Angeles County Transit (LACT) policy allocates half of 1 percent of the rail project's construction costs for public art.

LACT Chairwoman Christine Reed believes that "this art program will help build neighborhood interest in the rail lines and a sense of pride. The more people who enjoy the system, use it and respect it, the bigger success it will be" (*7*, p. 8). And Mary Kilroy, a public art consultant, noted that "Los Angeles, like many large cities, is most concerned with the creation of vibrant streetscapes—places where people want to be. Public art enhances that goal. Our cities are discovering that their public spaces should symbolize their commitment to their future" (*1*, p. 12).

Phoenix, Arizona

Commission's Book on Public Art

Public Art Works: The Arizona Models is "a collaborative project funded and published by the Phoenix Arts Commission, the Arizona Commission on the Arts, the Design Center for American Urban Landscape and the University of Minnesota" (*8*). Elegantly designed and rich with colorplates, the book includes projects related to three categories: (*a*) building construction, interior or exterior; (*b*) outdoor spaces; and (*c*) infrastructure, networks, and systems.

Artists and Funding

The three transportation-related projects described here are the Thomas Road Overpass, Patrick Park Plaza, and Dunlap Avenue Tree Guards. With funding from Percent for Art funds from the City of Phoenix Street Transportation Department, artist Marilyn Zwak worked with Cannon and Associates, Inc.; the City of Phoenix Street Transportation Department; and the Phoenix Arts Commission. Marilyn Zwak's artistic concept for the three-bridge structure was motivated by two concerns: How could art serve as a healing factor for the wounds inflicted on the neighborhoods bisected by the Squaw Peak Parkway? and How could the historical significance of the parkway/Thomas Road site, where remains of more than 40 Hohokam Indians were discovered, be acknowledged and preserved? Plans included inviting public citizens to develop their own designs in the freshly laid adobe. Hand prints, initials, abstract scribbles, and even images of "teenage Mutant Ninja Turtles" have been etched into the wet adobe surfaces.

Artist Jody Pinto jumped in with the construction workers as she worked on a double-spiral fountain spanning 85 ft in a small park on Southern Avenue near 30th Street: the construction foreman stated that this was the only project that he had worked on with an artist who got right in and helped. The fountain consists of a shallow concrete channel that coils into a pair of flat spirals at ground level; the spirals resemble a nautilus shell split in half. Water will flow from the nearby San Francisco Canal into the channel and then back into the canal. Concrete benches shaded by elm trees will surround the fountain.

Artist Garth Edwards has designed and produced a series of individualized tree guards for the newly widened streetscape of Dunlap Avenue. They feature larger-than-life-size cut-out metal shapes of human figures that represent typical and not-so-typical residents of Sunnyslope.

Neighbors' Battle

An article in the *Phoenix Gazette* tells how a South Phoenix neighborhood won a battle with the city over road design.

> Residents fought for two years to get what they wanted, against the city's original vision of an unadorned six-lane highway. They even got an artist to design their park. A homeowner said they wanted an exceptional street because of people's negative perception of the South Mountain community. They asked the Phoenix Arts Commission to become involved—wanted the money that this project generated for the Arts Commission to come back to this community. Under the city's 1% for arts construction budget, this community battled for their fair share. (9)

St. Louis, Missouri

St. Louis' MetroLink AIT program, described earlier in the paper, is an excellent example of the successful integration of public art and public transit. Ann R. Ruwitch, AIT director, wrote in 1992:

> For the first time on a large public works project, visual artists worked as equal partners in a collaboration with engineers and architects designing all aspects of the infrastructure. The following case study highlights the process for the design of new bridge structures for Metro Line, the St. Louis light rail system. Arts in Transit, the sponsoring organization, is a national model and project of the Bi-State Development Agency.
>
> A team of visual artists critiqued preliminary engineering for MetroLink, and developed aesthetic criteria for the project. Subsequently, the artists worked on design development for all the functional elements of the system. In collaboration with the civil engineers, the artists designed a distinctive new bridge structure featuring a slingshot pier and haunched superstructure. This design is part of a unified concept which ties together various parts of MetroLink and relates them to structures in the St. Louis region.

San Francisco, California

Capp Street Project is a nonprofit arts organization, announced in July 1994; six artists and artist collaboratives will participate in Art in the Urban Landscape, the new public art program. Each recipient will be given a grant from the Wallace Alexander Gerbode Foundation and Capp Street Project. All of the art selected for the program is temporary (2 to 5 years).

Artist Connie Hatch's photographically based project will be located in several transit stations. For more than a decade, artist Carolyna Marks has created "peace walls," ceramic tile mosaics devoted to the theme of world peace. Her most recent wall is located in a San Francisco Bay Area Rapid Transit (BART) district station in Oakland's Fruitvale neighborhood. Marks says she sees the public art installation as a way for the Fruitvale community to claim BART as its own—it will not be an "ugly, anonymous place any longer. Kids claim walls all the time with graffiti. This will provide a more positive space." Tiles have been painted by local schools, community groups, merchants, BART officials, and local politicians. Other contributors include members of the Oakland-based Golden State Warriors basketball team, actress Whoopie Goldberg, and the family of U.S. Transportation Secretary Federico Peña. Marks hopes that this "ceramic quilt" peace wall will cover the entire transit station over the next several years.

The Capp Street Project complements a larger effort to redevelop the area surrounding BART into a pedestrian plaza with a mix of retail shops, affordable housing, cultural facilities, and offices for local social service agencies (*10*, p. 12).

Seattle, Washington

In 1984 Seattle's Metro Council elected to dedicate to art 1 percent of the cost of the stations and surface improvements for the 1.3-mi Downtown Seattle Transit Project (DSTP). "The objective of the Metro (DSTP) Arts Program is to transform a functional transit facility into a place of human interest and creativity. The program will add inspiration and delight to the rider's experience of comfort and efficiency."

Seattle prepared a big, practical handbook intended to be used by anyone contemplating planning a public arts program (*11*). The index covers every possible subject from design team approach to contracts and how to pay the artists. It was also designed to be read and used.

Architect, landscape architect, and engineer, plus an artist, equal the design team. The central assumption is that by incorporating the artist's perspective—from the inception of the project—in materials selection, spatial considerations, overall design approach, and the inclusion of artwork, facilities can become more aesthetically fulfilling and humanly oriented places.

The players are as follows: Metro Council, Metro, the Metro Arts Committee, the arts program coordinator, the community, the Metro project manager, the art and architecture coordinator, engineers, architects, landscape architects, and artists.

Sally Turner offered one viewpoint of the collaboration: "Engineers are nuts and bolts people—you do things this way because . . . . Engineers are comfortable with parameters, linear progression. Art doesn't have parameters. It makes [most] engineers nervous" (*11*, p. 73).

In the appendix of the handbook, the prospectus for the DSTP (scope of work definition) was written by someone whose philosophy would probably be shared by many professionals; it is stated in full as follows:

> The foremost objective of the Metro Arts Program is to transfer a functional transit utility into a place of human interest and creativity; it should add inspiration and delight to the transit rider's experience of comfort and efficiency. The design team approach is intended to create artwork which will integrate these objectives and communicate to the transit rider both a sense of continuity through the tunnel and a sense of neighborhood in the stations. Three to five artists shall work together as a team in developing the overall design concept for the Downtown Seattle Transit Project with [name of engineering firm] and shall make proposals for the inclusion of artwork in the final design.
>
> The proposals shall include drawings and written materials with regard to types of art, sites, scope of work (i.e., scale), utility requirements and budget estimates. Artists' approach may include works of art which are an integral part of the architectural and functional aspects of the project and/or additional or separate elements of the DSTP. All elements of the project may be considered by the design team artists including sound, light, color, surface treatments, and circulation. (*11*)

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Art Integration: An Essential Design Component and Vehicle for Community Commitment in Santa Clara County

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The objectives are to relate the way in which an integrated art program can be developed successfully during the light rail transit (LRT) design process in an extremely cost-effective manner, using the Tasman Corridor light rail project in Santa Clara County, California, as a case example; to describe valuable lessons learned in Seattle during the implementation of the Downtown Seattle Transit Project; to discuss the value of an integrated art program as an integral, valuable component of LRT design; and to present the unique community relationships and support that an integrated art program can engender. The Tasman Corridor LRT project is a 20-km (12.4-mi), $530 million light rail extension of the Guadalupe Corridor LRT system in Santa Clara County. The Tasman Corridor final design was completed in May 1995.

It has long been recognized that art is an integral component of society and its constructed environment. It is generally accepted that the sensitive use of design and art in transit systems makes public spaces vibrant and presents an image of the local culture and architectural heritage. Transit systems in Amsterdam, Paris, Seoul, and Stockholm as well as Atlanta, Boston, Buffalo, and Pittsburgh bear out these facts. More recently, the power of artists' work as a tool in establishing relationships with a community has been recognized. Recent experience has shown that transit facilities that respond to and reflect a community's identity create places where people want to be.

With these principles in mind, the Santa Clara County Transit District (SCCTD) and the Tasman Corridor Light Rail Transit (LRT) project design team, led by Parsons Brinckerhoff/Morrison Knudsen (PB/MK), have developed an integrated art program. The Tasman Corridor LRT project is a 20-km (12.4-mi) $530 million light rail extension of the Guadalupe Corridor LRT system in Santa Clara County, California, as shown in Figure 1. The integrated art program will develop a comprehensive cultural arts element, integrated with and responsible to the overall system's design process, resulting in an extremely visible and exciting cultural resource at a very small cost.

The program's mission statement reflects the project team's commitment: to establish a public art integration program for the Tasman Corridor project that involves the community in the organized review of the aesthetics of the built environment.

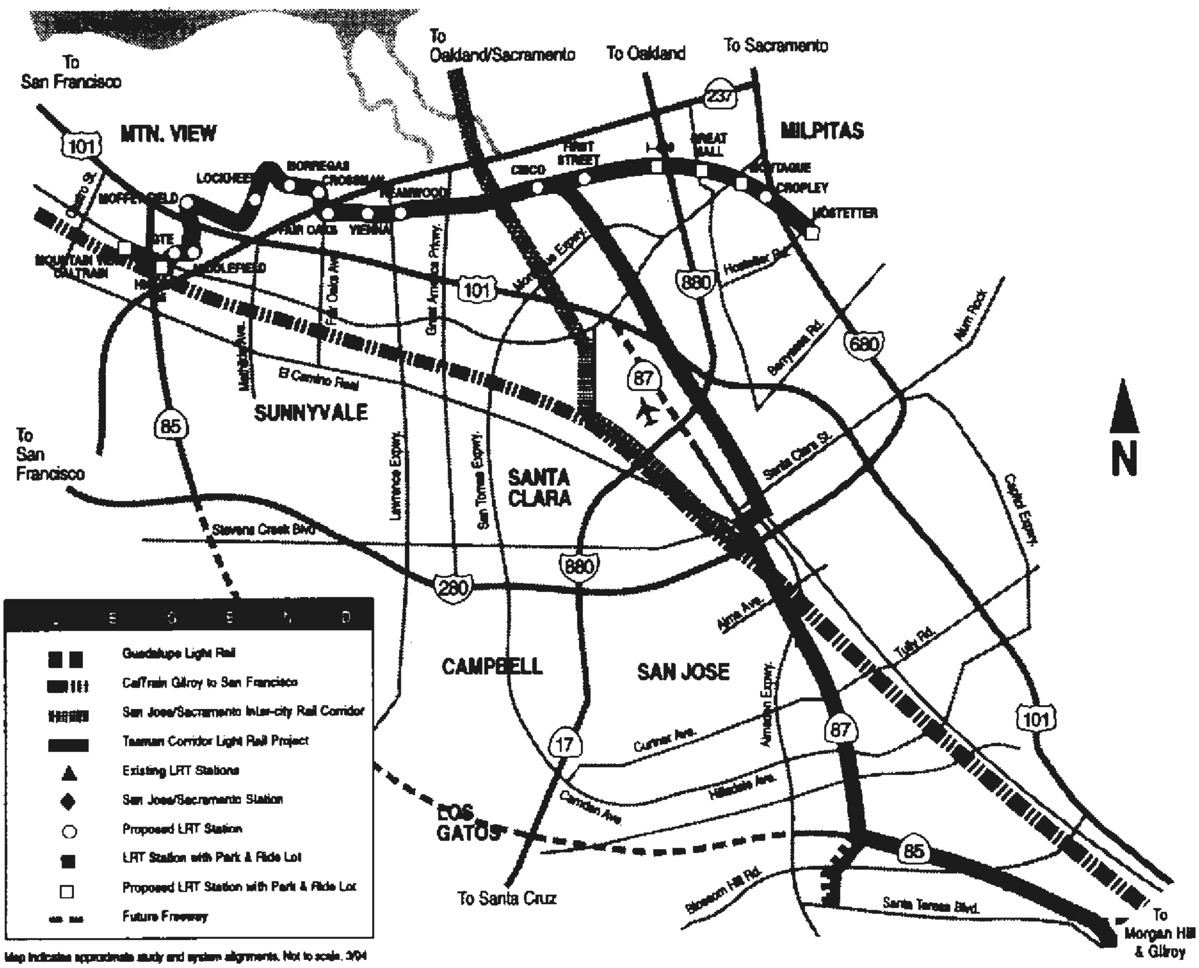

FIGURE 1 Tasman Corridor LRT project map.

The integrated art program, led by a committee of elected officials, is involving local artists, citizens, and existing arts groups. Through the public art integration process, the community is developing a heightened sense of ownership and pride that will carry over beyond the design and construction phases and will make them partners in the future operation and maintenance of the system.

Benefiting From Seattle Experience

The Tasman integrated art program has benefited greatly from projects such as the Downtown Seattle Transit Project (DSTP). The DSTP consists of a 2-km (1.24-mi) transit tunnel separating high-volume bus lines from surface traffic, five underground stations, and surface improvements along the tunnel route. The new dual-powered buses operate on diesel power on the surface and change to electric operation in the tunnel. In the future, the tunnel and stations can be converted to rail transit operations.

This project, which demonstrates how art can be integrated into transit design, offered to the Tasman design team both proven procedures for integrating art and seasoned experts in the field. Project manager William Barnes and project artist Jack Mackie, a Seattle-based public artist, developed and tested these procedures together in Seattle's unique urban setting.

Integrating art into the system's design was first contemplated during the DSTP's design phase. Since Seattle has a strong public art program, a relatively generous budget (1 percent of construction budget) was allocated for art. From the beginning, it was apparent that many entities would be involved, each of which could significantly affect success of the art program. The players included

- Seattle Metro, the agency/owner;
- Other public agencies such as King County and the city of Seattle;

• Individuals who had been involved in past art and transit programs such as city councilmembers Jim Street and George Benson;

• The project's general design consultant (Parsons Brinckerhoff) and its architectural subconsultant (TRA); and

• The artists themselves.

Early in the DSTP's planning phase, it was decided that each of the five stations would reflect the features of the surrounding neighborhood, bringing that neighborhood's character into the underground station. Many transit systems throughout the world have integrated art into their design. However, the collaboration of artists, architects, and even engineers early in the DSTP design process was a somewhat new concept. Seattle Metro contracted directly with the artists, who worked with the architects and engineers; the general design consultant provided the office space. The general design consultant had extraordinary staff members who could supervise the design project and integrate the activities, such as the late Ed Elliott, who followed the plan through planning, design, and construction. Carol Valenta, the arts program coordinator for Seattle Metro, administered the program with an enlightened view. Another important element was the architecture subconsultant, TRA, which provided another leg of the "art-itecture" design team approach.

Issues surrounding the International District Station typified the assorted players, personalities, and design approaches that defined the DSTP. Situated in a vibrant community of downtown apartments, shops, and restaurants, the community rejected the initial station design because it did not accommodate the community's needs beyond providing access to the transit system. They intimated that they would block design and delay construction if their needs were not served. Through working sessions within the public art and design team process, they requested that the station accommodate a small community gathering area and weekend marketplace. Seattle Metro directed the designers to incorporate these ideas into the station's plaza design. Having participated in the design process, the community understood what the agency could build and how the design would benefit them. The community subsequently allied with the agency through the long and arduous construction process. The artistic processes and review procedures of the public art program gave citizens an avenue for participating in the project. By becoming invested in the project, the community worked toward implementing it rather than opposing it.

More than 20 artists created over 50 artworks for the stations and surface sidewalks and streets, and the project has won many awards for its quality. Early collaboration contributed greatly to the finished product. As Ed Elliot described it, the collaboration produced "an art gallery through which buses run".

The collaborative design process also fostered a goal of the DSTP art program to create stations that are unique and individual expressions of each of the neighborhoods that the system serves. This goal also guides the Tasman Corridor's integrated art program.

Developing Santa Clara County's Program

Santa Clara County's existing Guadalupe Corridor LRT System (Figure 1) sufficiently meets the corridor's transit needs, but its design lacks vitality and a sense of place. To give vibrancy to the public spaces of the light rail system, the general design consultant, PB/MK, proposed initiating an integrated art program. Project manager William Barnes and civil coordinator Robert Bertini contacted project staff to inquire if such a program would be welcomed. The transit district policy makers responded positively, and Carol Valenta and Jack Mackie joined the project design team to develop the Tasman Corridor's integrated art program. Mackie has collaborated with artists, engineers, architects, urban planners, and others in major construction and redevelopment projects. Valenta, the art program coordinator for Seattle Metro, brought a crucial agency perspective to the program.

At this point, the support of the Tasman project design and management team and the leadership from San Jose city councilmember Margie Fernandes, a member of the corridor's policy oversight committee, were critical. Through these efforts, the SCCTD committed $1.2 million to develop and administer the integrated art program and to construct the resulting artwork (this figure represents approximately 0.2 percent of the total project cost).

In early 1994 the SCCTD approved the plan for the Tasman Corridor project integrated art program, which Valenta and Mackie developed as part of the PB/MK team. One of the plan's major recommendations was that the SCCTD institutionalize the art integration program within the agency. The agency appointed Gail Collins as the art program administrator from the SCCTD planning and programming division staff. This was done to ensure that the program will continue after the design is complete and the consultant team has completed its work. In addition, it sets a precedent to include integrated art programs in future LRT corridors and for other projects.

The goals of the program are to

• Foster creative collaboration between the design team and the communities to be served,

- Mitigate the sense of uniformity and loss of human scale generated by a large-scale transit project,
- Maximize funding resources by including art that is integral to the rail system, and
- Create high-quality works of art that respond to and reflect the cultural identities of the communities served and that contribute to a positive experience for the rail line's future riders.

The Tasman Corridor, a system with 21 stations over 20 km (12.4 mi), passes through five different cities, each with its own design characteristics and identity, level of urban sophistication, and approach to public art. An important task of the art integration program was to develop a comprehensive plan that could represent each of these city's unique personalities while supporting a systemic approach to design. To that end the program moved forward with a plan based on ensuring community participation in design review, integrating art into the system's design, and using the region's artists to develop artworks that reflect the residents of the area.

Art and Aesthetics Committee

As proposed in the integrated art program plan, the Tasman Art and Aesthetics Committee was formed in late spring 1994 to oversee the corridor's aesthetic design issues and the funding allocated for the integrated art program. Each of five cities has two representatives on this committee: one from its arts community and one from its architectural and engineering design staff. San Jose city councilmember Margie Fernandes chairs the aesthetics committee (she also chairs the transit district board and serves on the Tasman policy oversight committee). The mayor of Santa Clara, one of the corridor cities, also serves on the committee.

Development of Elements Plan

After the integrated art program was adopted, Mackie became the lead project artist as part of the PB/MK team. At this point, the corridor's design was approximately 65 percent complete. In addition to implementing the program, he assessed the design completed to date and developed a master list of opportunities for design collaborations and art enhancement. This included cataloguing critical path elements and prototypical elements that can be modified to give identity and focus to each station.

Mackie's primary focus at this point was to work with the Tasman Corridor project engineers and architects to direct enhancement efforts to areas of the system that care for the passenger and to parts of the system that have substantial visual impact on the corridor communities. Mackie worked closely with project architect Shirley Bassett, principal of SBA Architects, to integrate these enhancements into the contract documents. Included in this effort were stations, sound walls, traction electrification system (TES) poles, park-and-ride lots, landscaping, and the 2.9-km (1.8-mi) double-track aerial guideway.

Selecting Segment and City Artists

In fall 1994 three artists from the Santa Clara County region—Deborah Kennedy, Diana Pumpelly-Bates, and Dan Dykes—joined lead artist Jack Mackie and the design team. These artists first worked with each of the five cities' existing arts committees to develop an aesthetic values statement for each city. These statements define each city's character, history, aesthetic priorities, and artistic vision. The aesthetic values statements are

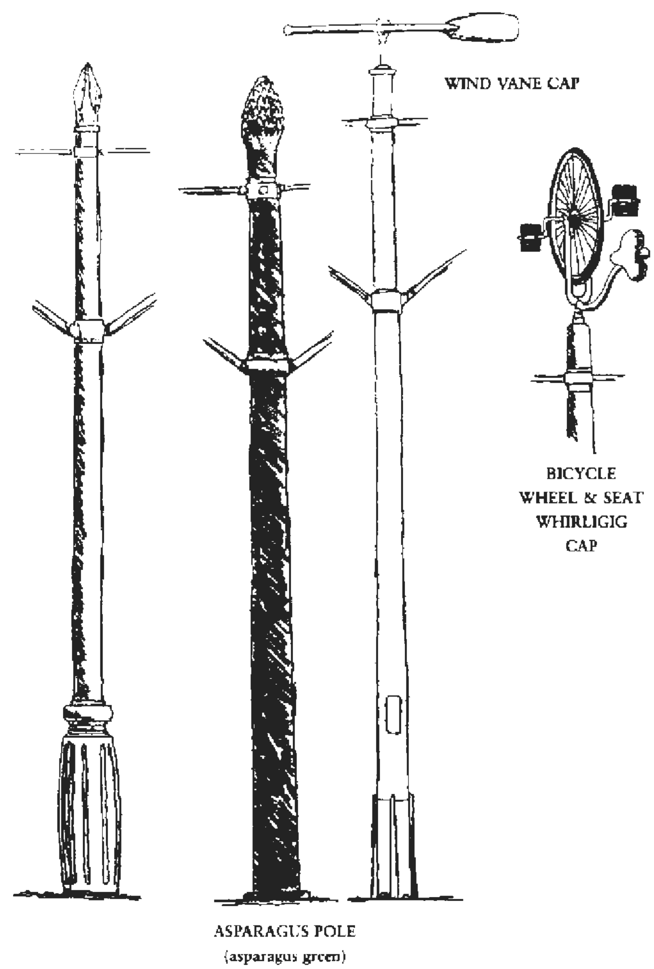

FIGURE 2 TES pole enhancement concepts. (***continued on next page***)

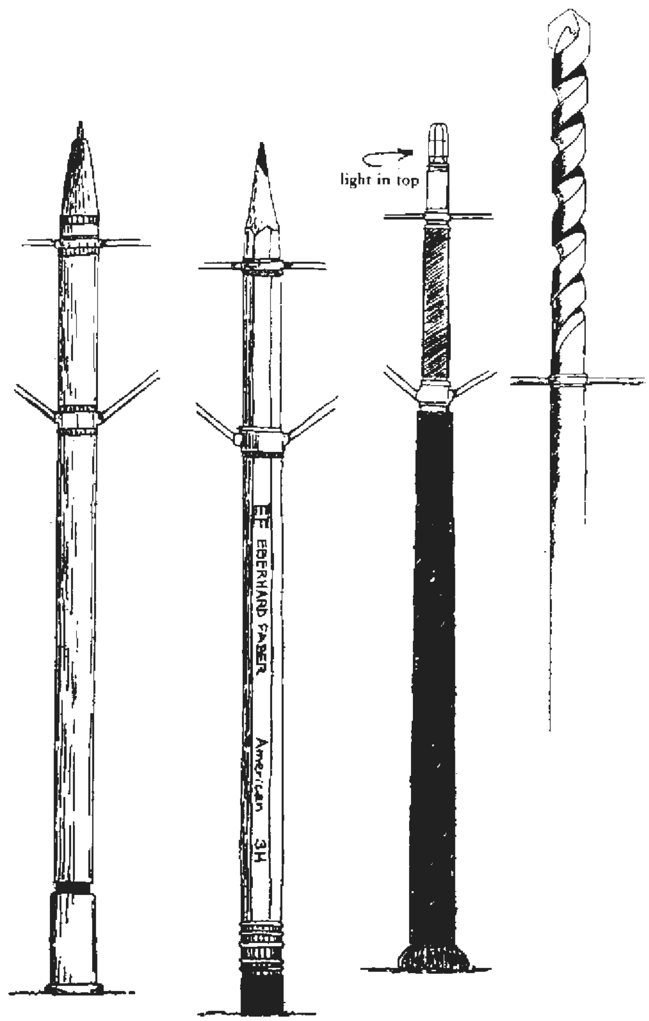

FIGURE 2 (*Continued*)

used to develop site-specific artwork commissions for each of the stations. The intention of these commissioned works is to reflect each city's vision of itself and the memory that each city wishes to extend to the transit rider.

For example, the values statement for the city of Milipitas emphasizes pride in being a city composed of citizens with very diverse ethnic heritages. It also refers to the city's geographic location that historically made it a crossroads for travelers between the northern and southern regions of San Francisco Bay. One of the new Tasman stations in Milpitas has been located to potentially connect the Tasman Corridor and a possible future Bay Area Rapid Transit extension, making it a crossroads. In the station's immediate neighborhood, residents speak 32 languages. These combined themes of a historic crossroads and ethnic diversity have suggested art elements for the station that draw on the city's multicultural heritage and support the station as a cultural crossroads. These features will assist the

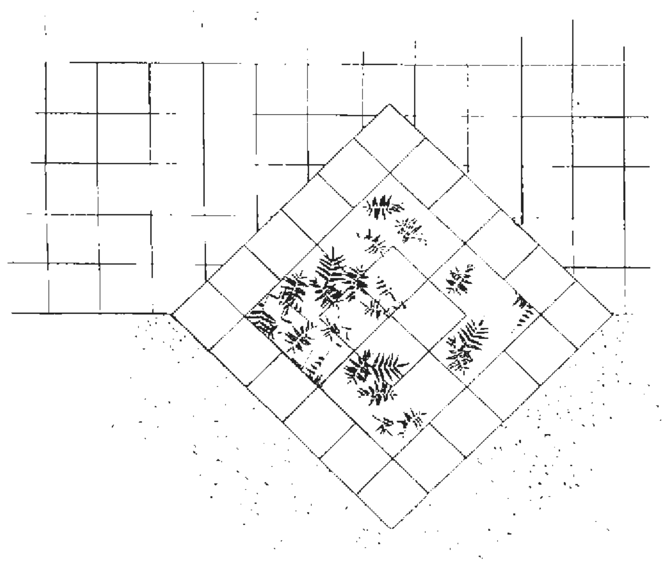

FIGURE 3 Typical station paving medallion.

SCCTD in building the station around and for the people who will use it.

As another example, in the city of Mountain View, the downtown Mountain View Station is emphasized as a gateway into the city, connecting the newly revitalized downtown with the light rail corridor's western terminus. A concept for a *portal sculpture* will have a prominent location. The artistic emphasis changes to a garden theme where the line runs along an exclusive right of way of an existing rail spur line; native plantings and trellises will provide the desired effect. At the Bayshore/NASA Station, the theme of flight will be incorporated into the station with a landmark sculpture. The idea of flight emerged as the theme because of the station's proximity to the National Aeronautics and Space Administration (NASA) Ames Research Center, which includes a federal airfield and a World War 2–vintage dirigible hangar, and to the San Francisco Bay Shore and its large bird populations. The city's artist has collaborated closely with the city Visual Arts Committee,

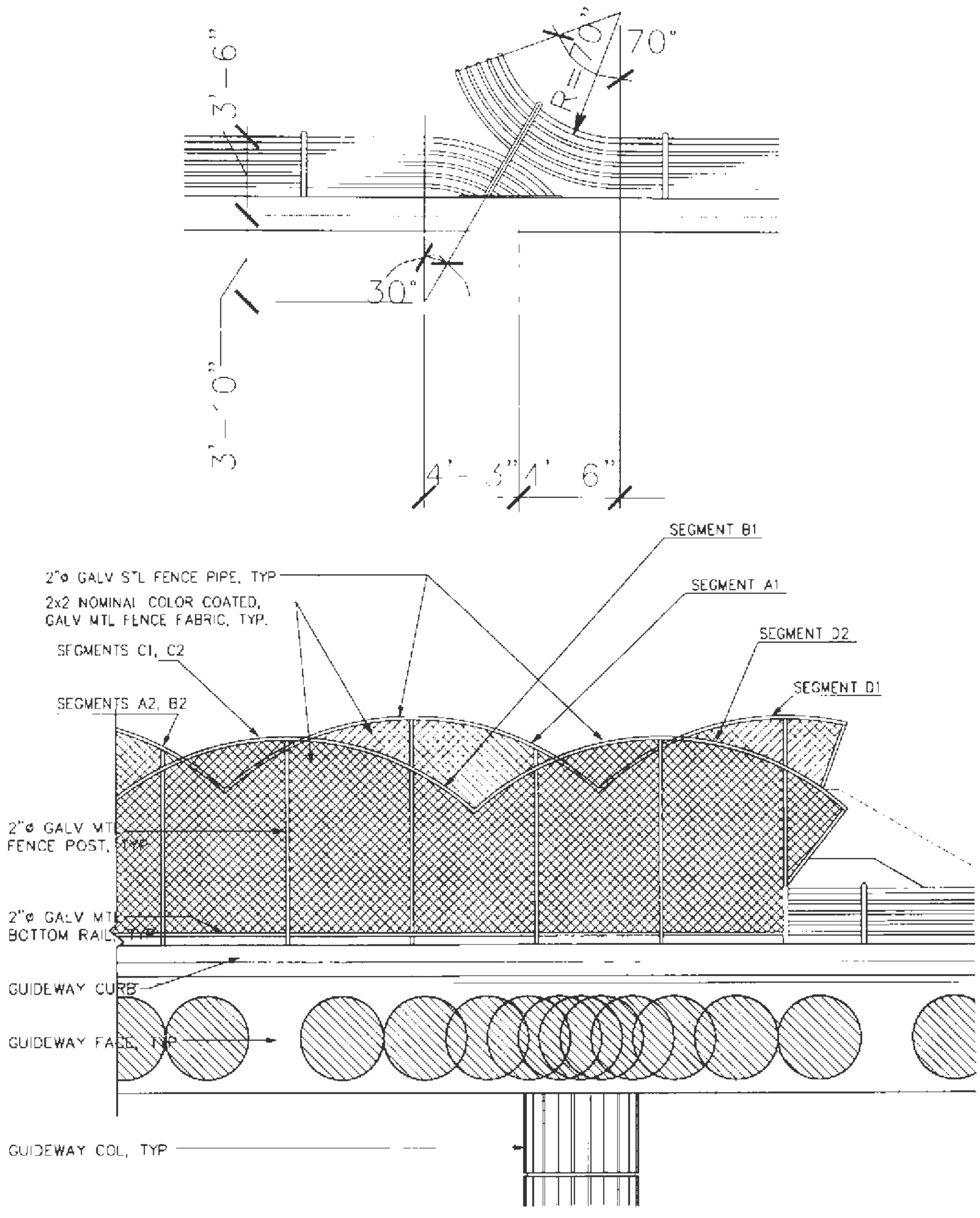

FIGURE 4 Aerial guideway rail and safety screen.

the Downtown Revitalization Committee, and the Tasman Art and Aesthetics Committee to set the tone for the Mountain View LRT segment.

Through design consultations, segment artists were brought into the design process at the earliest possible point. As design consultants, they developed designs that enhance the prototypical station or alignment elements. Three basic areas for artistic expression and design opportunities have been established:

- *Intrinsic design opportunities* are possible at all stations and in some alignment components within the basic budget or may be supplemented by the aesthetic enhancement budget. Examples include platform paving, color of canopy or shelter, landscaping, guardrails, handrails, fences, graphics, seating elements, tree grates, sound walls, TES poles, aerial guideway concrete color, and retainiug walls.
- *Functional art opportunities* are areas open for special design or treatment requiring added use of the enhancement budget. Specific examples include windscreen and glass treatments, station welcome mats, paving inserts, guardrail inserts, light poles, crosswalks, and trackway fencing.
- *Specific art opportunities* exclusively require the aesthetics enhancement budget. Examples include canopy frieze or cap, tree guards, station clocks, sound and light installations, station and park-and-ride entry markers, free-standing sculpture, information kiosks, sound wall and retaining wall murals, trellises, and claddings.

Working as a team, the artists determined that their design focus would involve several elements, including the TES poles and station components such as paving, glass panels and windscreens, benches, and planters. The artists viewed the TES poles as forming an open *fence* along the LRT route. Because of the poles' high profile, the artists suggested that the poles should respond to their setting in the changing landscape. Figure 2 shows some concepts for artistic and design enhancement opportunities for the TES poles. Figure 3 shows a typical station paving medallion that has been proposed, incorporating trowelling of natural leaves into the surface of the concrete. (Figures 2 and 3 have been created by Jack Mackie.) Figure 4 shows typical aerial guideway rail and safety screen details, and Figure 5 shows a typical aerial guideway column detail. Figure 6 shows how the combination of the aerial guideway rail, safety screen, and other artistic enhancements of the cast-in-place concrete structure will fit together. A structural steel pedestrian overcrossing will connect the Great Mall aerial station to the parking lot of the new 120 000-m^2 (1.3 million-ft^2) Great Mall in Milpitas. Figures 7 and 8 show the results of an artist working with a team of architects and structural engineers early in the design process. (Figures 4 and 8 have been prepared by SBA Architects.)

These collaborations among the artists, architects, and engineers have resulted in design enhancements that are now part of the base project. The designs are documented in either the architectural or engineering plans and are not specifically noted as the integrated art program. There is no associated cost drawn against the integrated art program except for the artist's fee and any

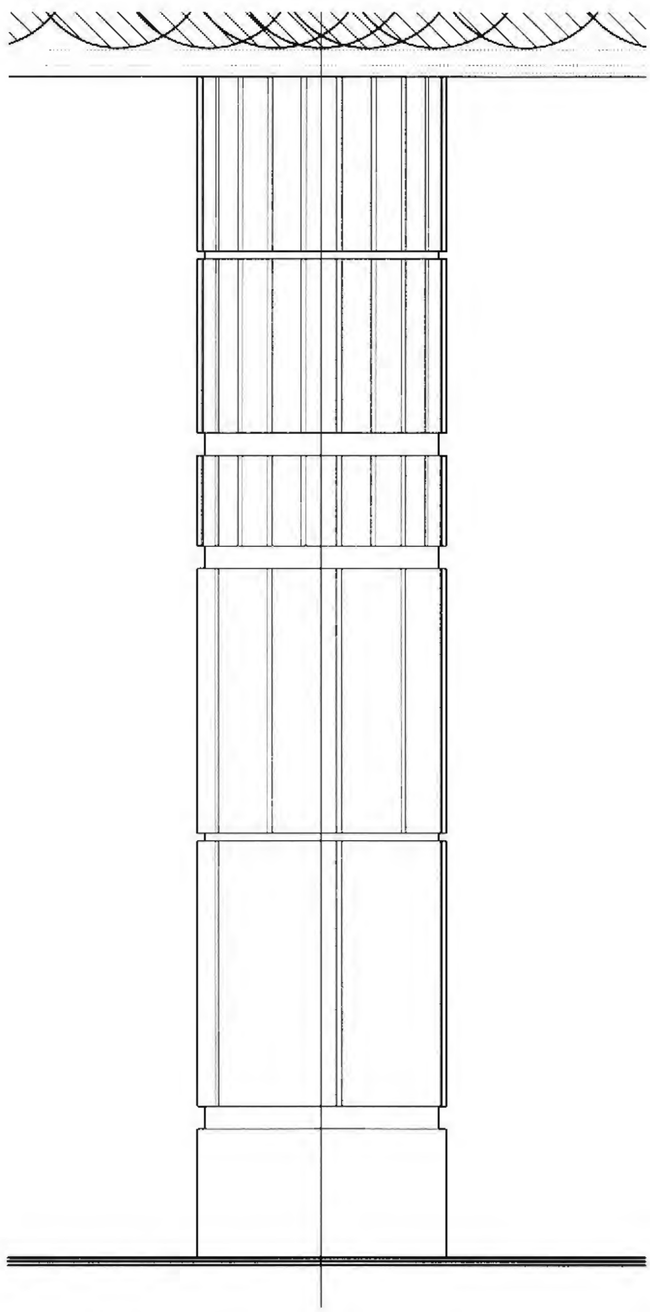

FIGURE 5 Aerial guideway column details.

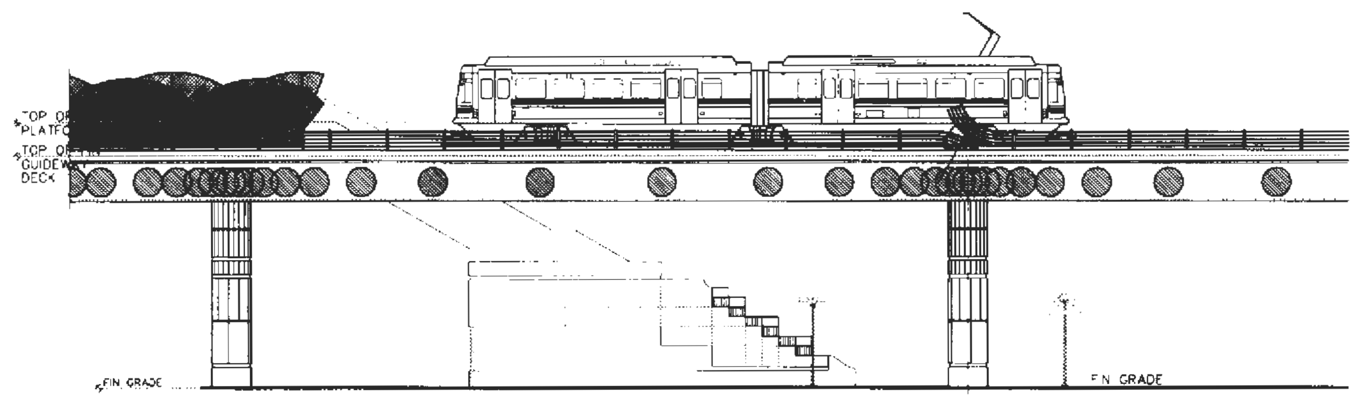

FIGURE 6 Aerial guideway.

exceptional architectural or engineering documentation. The general contractors will construct these projects under normal SCCTD construction contracting and bidding procedures.

Integrated Design and Commissions

The artists' commissions currently being developed must consider not only the design aesthetics of the Tasman Corridor communities but also the design realities of the system. The project construction budget ($530 million) is large but far from extravagant. The $1.2 million set-aside for the integrated art program is just enough to affect each station if approached via traditional methods for art in public places (i.e., placing commissioned art works after construction has been completed). However, if the program is developed through an integrated art and design process, additional resources become available, which enriches the final design product.

Using this approach, the Tasman integrated art program uses, as often as possible, the system's prototypical components. This is done for two primary reasons. First, reaching into the strengths and weaknesses of transit art programs indicates that involving artists as early as possible in the design process is desirable; second, integrating art into the project design maximizes the available budget and minimizes operation and maintenance problems and costs.

By including artists early in the design, artwork can be accommodated in construction documentation (plans and specifications), and work previously completed by other disciplines does not need to be redone to include requirements of the artwork. Budgets can be accessed realistically by people familiar with rail construction costs. If artists are included as integral members of the design team, they can focus on designs for the system components that are basic requirements of the light rail line. For instance, the Milpitas art project discussed earlier will be built directly into the station's paving because the artwork will be the station floor itself. The artist's materials will meet all mandatory safety standards. Paving samples will be tested for durability before project approval to assess any unusual

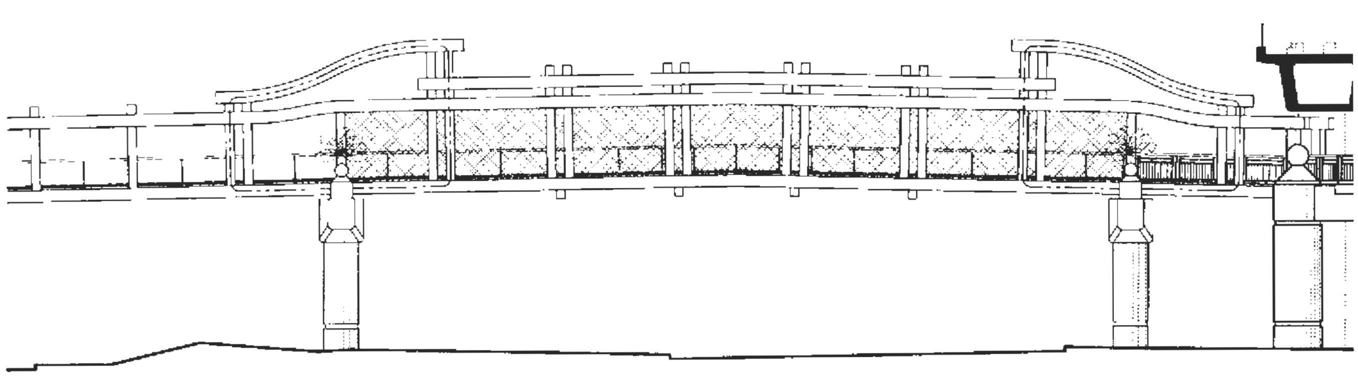

FIGURE 7 Great mall pedestrian overcrossing.

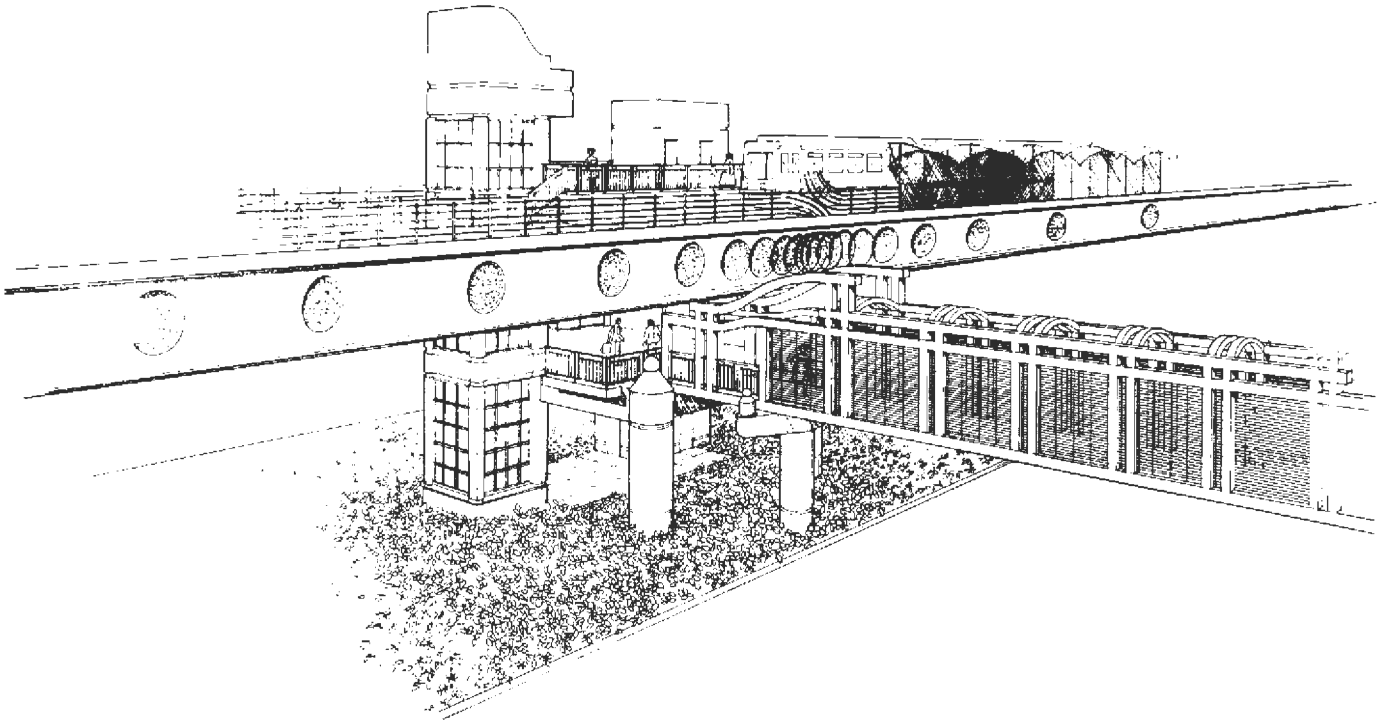

FIGURE 8 Great mall station perspective.

or unacceptable maintenance issues. Through this approach, the system also gains the additional limited art funds that can create an unusual and exciting paving out of what would have otherwise been an acceptable but ordinary paving. Other such integral art projects incorporate the artist's work into safety railings, aerial guideway columns and structure, station shelter glass, systemwide color plans, furniture, and landscaping.

Summary of Status

Throughout the Tasman project's final design process, four artists have worked with the design team and the communities along the corridor. As final construction funds and potential supplemental funds from cities and the private sector become available, the project may engage as many as 30 more artists. These artists will develop projects specific to the neighborhoods that the stations will serve, and representatives of these neighborhoods will act as reviewers. Each art project will respond to the social, industrial, and cultural history of the area and its residents. The artworks will support the ideas and visions of each community and will describe their ambitions and the unique qualities of their lives. In so doing, the integrated art program supports the efforts of the transit district to build a new rail line to link the region's communities. The integrated art program enhances these links by building stations and creating places where people will want to be.

PART 2
LRT ADMINISTRATION AND GENERAL MANAGEMENT

How Do Others See Us?

Citizen Involvement in Planning Light Rail Systems in U.S. Cities

Harriet Parcells, *Campaign for New Transportation Priorities*

Citizen organizations have long been active in transportation and land use projects taking place in their communities. The Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) have renewed the impetus and importance of citizen involvement. In communities from coast to coast, citizens are calling for investments in light rail as cost-effective and environmentally sound alternatives to highway expansion. The experience of citizen organizations that worked with their regional planning agencies to promote light rail is presented. Examples discussed are the New Jersey Hudson River Waterfront Project; the East-West Corridor in Milwaukee, Wisconsin; "visioning" in the Washington, D.C., area; and experience in Fresno, California. The role of national organizations that act as important resources to local citizen groups is also discussed.

From New Jersey to California, citizens are becoming involved in the transportation decisions made by their metropolitan planning organizations and states—decisions that citizens understand not only affect their future mobility options but influence land use and the overall quality of life in their communities. Prompted by concerns about air pollution, congestion, sprawl, loss of open space, and social equity, citizens of all ages have started working with state and local planners and elected officials to help create a vision of a better future for their communities. As part of their efforts, in many cases, they are advocating investments in light rail as a sensible alternative to roadway expansion.

Federal laws enacted in recent years have given greater impetus to citizen involvement and calls for improved public transportation. The Clean Air Act Amendments of 1990 set deadlines by which metropolitan areas must achieve health-based air quality levels and have focused attention on the need to reduce mobile source emissions. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) enacted a year later requires increased citizen involvement in metropolitan and state transportation planning and gives communities unprecedented flexibility to use highway funds for investment in a broad range of transportation modes. Together, these laws provide a solid foundation for citizens to be active players in the transportation decisions made for their communities and states.

As citizens have become more engaged in these activities, they have turned to national organizations as resources to provide technical assistance, information about federal transportation laws, and other help. Organizations such as the Campaign for New Transportation Priorities, the National Association of Railroad Passengers, and the Surface Transportation Policy Project provide various types of information—such as the relative cost and energy and environmental benefits of different modes—and inform activists about what has worked in other communities.

New Jersey Waterfront: Role of Citizen Involvement in Selection of Light Rail Over Alternatives

After years of analysis and input by New Jersey citizens and local officials, the New Jersey Transit Corporation (NJ Transit) in 1993 selected light rail, rather than a busway or monorail, as the "locally preferred alternative" to improve mobility in New Jersey's Hudson River Waterfront. In December 1994, NJ Transit announced the specific alignment that the light rail would follow. If all goes well, groundbreaking for the first phase of the project will occur in 1996 with initial service to begin in 1998.

The long path to approval of the light rail route is instructive in how informed, committed citizens can play a crucial role in the transportation solutions that ultimately will have a far-reaching impact on the quality of life in their communities.

The roots of transit planning for the waterfront date to 1985, when Governor Kean announced the state's support for a transit policy that included rail for the New Jersey Hudson River Waterfront. The governor's announcement received media coverage and editorial support from local newspapers. Citizen organizations active on transportation issues, such as the New Jersey Association of Railroad Passengers, applauded the state's position.

From 1983 to 1989, despite prodding by transit activists and other citizens, NJ Transit took little action to develop a rail transit solution. NJ Transit's Waterfront Development Office appeared preoccupied with a dedicated busway solution and bus improvements that they termed an "interim" solution. Transit activists and many local officials, however, were vocal in their opposition to the bus solution, convinced that it would only worsen traffic congestion and pollution. In addition, they expressed fears that the interim solution would become the final solution.

Hoboken councilmember Tom Newman stated in 1988, "We expressed opposition to the interim busway because our fear is that interim is going to be permanent" (*1*, p. 8). There were also concerns that the bus solution would not help alleviate the region's serious air pollution problems. The president of the New Jersey Association of Railroad Passengers, Doug Bowen, noted that "a busway along the Palisades would create a diesel curtain around Hoboken" (*1*, p. 8). In 1990 environmentalists and local officials continued to express opposition to the bus proposal. "What the region really needs, they say, is a long-term solution, preferably a light rail system, to link developments on the revitalized waterfront" (*2*, p. 3).

Adding to the possible transit solutions for the waterfront, the New Jersey Turnpike Authority, in summer 1989, announced support for a monorail that could be incorporated into its $2 billion turnpike widening project. Although the monorail was presented by its supporters as "complementing" light rail (embodied in the Governor's Mobility Plan), it was clear that, in fact, the two were competing options and in the end one, not both, would be pursued (*3*). By fall 1989, cost estimates of the proposed monorail were being questioned. A New Jersey newspaper stated that the proposed monorail linking the Meadowlands and the Hudson River Waterfront "could cost the state twice as much as the Secaucus developer has projected and would require construction of a larger tunnel through the Palisades than originally planned" (*4*).

In April 1991 the NJ Transit Waterfront Development Office was still pursuing the idea of a dedicated busway as an interim solution. Citizen organizations—which now included the New Jersey Association of Railroad Passengers, New Jersey Environmental Lobby, New Jersey Public Interest Research Group, Sierra Club, and others—as well as local officials such as Hoboken mayor Pat Pasculli, Weehauken mayor Richard Turner, and state senator Robert Menendez continued to oppose the bus solution and urge NJ Transit to pursue light rail as a cost-effective, environmentally sound alternative (*5*).

As NJ Transit examined alternatives under the alternatives analysis/draft environmental impact study (AA/DEIS) over a 3-year period, the agency was guided by a 70-member advisory committee made up of state and local officials, environmental groups, and other concerned citizens who set the goals of the study. Nine alternatives were studied. Of these, five featured light rail, one was an all-bus option, one was a monorail alternative, and two were required by the Federal Transit Administration (a no-build alternative and a transportation systems management alternative).

After extensive public input, light rail was selected as the locally preferred alternative. Throughout the lengthy process, citizen groups presented useful information on the economic and environmental benefits of light rail over the other alternatives that helped educate the public and contributed to the statewise debate. National organizations such as the National Association of Railroad Passengers and the Campaign for New Transportation Priorities were called on to act as resources to local citizen groups.

The light rail system selected is 20.5 mi long, with the first 11 mi extending from Hoboken Terminal south to Bayonne and west to Jersey City. Some of the federal funds for the light rail will come from ISTEA, which earmarked some $634 million for the Northern New Jersey Urban Core project (*6*).

The project may be implemented as a pioneering "super-turnkey" development, according to Frank Wilson, New Jersey Transportation Commissioner. Under such a turnkey development, a private contractor would be responsible for the design, construction, and operation of the light rail line for an unspecified period. The New Jersey project could become the first such super-turnkey development in the United States, although other cities such as Chicago and New York are also examining the approach. In addition, citizens and others have urged NJ Transit to pursue a low-floor light rail car for this system as well as other systems under consideration in New Jersey. Low-floor light rail is being used in cities throughout Europe; in the United States, Portland, Oregon, has selected low-floor for its new order of light rail cars, and Chicago, Boston, and Toronto are moving in the same direction (6).

Citizen transportation organizations and activists continue to monitor carefully the development of the Hudson River Waterfront light rail project. They remain actively involved in transportation planning and project decisions on a broader scale, both at the state and regional levels, advocating light rail where it makes sense (e.g., Newark-Elizabeth light rail), as well as other forms of public transportation.

Citizens, Labor, and Business Community Promotion of Light Rail in Milwaukee

Since 1990 citizen organizations such as the New Transportation Alliance and labor organizations such as the Amalgamated Transit Union in Milwaukee, Wisconsin, have been advocating improved public transportation, especially light rail, in Milwaukee's East-West Corridor. More recently, the business community weighed in on transportation by forming in May 1994 the Alliance for Future Transit, a coalition of 26 major Milwaukee-area businesses. All of these groups recognize that the Milwaukee area's transportation system is at a critical juncture and believe that greater investment in mass transit, especially light rail, must be part of the solution to ensure the region's future economic vitality.

Transportation alternatives for the East-West Corridor in Milwaukee have been examined for many years. Potential light rail alignments have been a prominent feature of the transit options under consideration, with strong support from the public.

In January 1995 transportation alternatives analysis for the East-West Corridor resumed in earnest. The East-West Corridor transportation study will combine various transit alternatives that have been under study for the corridor with the highway improvement options for I-94 that have also been examined.

Under the transportation study, detailed light rail and highway lane alignments will be presented, as well as the benefits, costs, and impacts of each alternative. Ten alternatives are under consideration. Light rail options have been narrowed down to two alignments, both starting in Glendale and extending south to Milwaukee's central business district and from downtown, extending west to the county line using city streets and existing railroad right of way. A 5-mi spur along Fond du Lac Avenue was added to the light rail alignments that has strong potential to encourage new development and to provide access for inner-city workers to an expanding job market in the outlying suburban areas (7, p. 2).

At two public hearings held in February 1994 by the Wisconsin Department of Transportation, support for light rail was voiced repeatedly. Light rail supporters included business representatives, labor, transportation activists, environmental groups, and minorities. Citizens indicated that they preferred combined bus and light rail improvements over bus-only improvements (7, p. 2). The AA/DEIS is targeted for completion in August 1995.

As with many major transportation investment projects, legislators representing urban areas and those from the suburban areas often differ as to what constitutes the best transportation solution. Light rail in Milwaukee is no exception, with many suburban Waukesha legislators opposed to the light rail investment. In June 1995 the Wisconsin legislature, which changed leadership after the November 1994 elections, took action, as part of its work on the state budget, to eliminate the light rail options from the alternatives analysis. It is unclear at this writing what light rail's status will be when the budget is made final.

National organizations such as the Campaign for New Transportation Priorities have provided helpful information, when asked, to local groups in Milwaukee.

A New Approach Advocated by Citizens in Washington, D.C.

In the Washington, D.C., region, citizens and environmental, public health, and consumer organizations joined together in 1992 to form the Washington Regional Network for Livable Communities (WRN), whose purpose is to provide a unified voice for "transportation investments and urban land forms that are efficient, promote communities and protect the land, air, environment and quality of life in the National Capital Region" (8, p. 1). The Chesapeake Bay Foundation acted as the catalyst in bringing the groups together.

Responding to the enhanced citizen involvement mandates of ISTEA, Washington's regional metropolitan planning agency, the Metropolitan Washington Council of Governments, sought greater input from citizens. WRN became an effective voice in presenting ideas to the regional planning agency's transportation planning board (TPB). The TPB amended its bylaws to establish a public comment period at the beginning of its meetings, as requested by WRN, and to allow the TPB to call special "briefing" meetings of the public on key issues before the regional planning agency. In addition, the TPB formed a citizens advisory committee (*8*).

In 1992 the WRN held a 2-day meeting at Catholic University of citizen groups and activists to brainstorm on a new transportation and land use vision for the Washington, D.C., region. Recommendations that grew out of the meeting were issued in a document titled *A New Approach: Integrating Transportation and Development in the National Capital Region.* The document was reviewed by several hundred national, state, and local organizations and the recommendations further refined and detailed. The "New Approach" was presented to the TPB in November 1992 (*8*).

The "New Approach" pursues three major goals:

1. Invest in the existing transportation system and use existing road and transit infrastructures more efficiently;
2. Make transit, bicycle, and pedestrian investments a much higher priority; and
3. Develop new residential and business developments around urban and town centers.

Included in Goal 2 is investment in light rail. "The WRN-revised plan emphasizes light rail, express bus and commuter rail upgrading" (*9*). The document includes a one-page "Primer on Light Rail" and recommends construction of various light rail lines in the Washington, D.C., area (*9*).

WRN continues to be an effective voice on transportation and land use issues in the Washington area; it provides regular input to the TPB on transportation projects under consideration and speaks for a more sustainable vision for the region.

Pavement Solution Chosen by Fresno

Fresno, California, provides an example of city whose leadership decided to pursue a traditional pavement solution, opting last year for construction of a new multilane freeway, SR-168, instead of the light rail proposal endorsed by many local citizens.

Citizen action in Fresno began when citizens saw that a majority of funds from Measure C, a half-cent sales tax approved by voters in 1986 (which voters believed would be used to finance the repair of deteriorating roads in the city and county), were instead targeted for construction of a new north-south freeway. The proposed six-lane freeway, connecting Fresno with neighboring Clovis, would cut a wide path through local neighborhoods, require the taking of many homes and businesses, and seriously erode the quality of life for those who remained (*10*).

Hundreds of Fresno residents appeared at Fresno City Council meetings to voice opposition to the freeway. A citizens organization, Sane Transportation Alternatives for Neighborhood Defense (STAND), was formed to advocate mass transit, light rail in particular, as a sound alternative to the highway. Volunteers from the organization collected more than 1,200 signatures on petitions expressing opposition to the proposed freeway. Other local groups such as the Sierra Club (Tehipite chapter) and the San Joaquin Greens joined the battle (*10*). The groups advocated investment in a multimodal transportation system, including light rail as an alternative that would better address the mobility needs of the community, enhance neighborhoods, and contribute to a cleaner environment. Citizens argued that Fresno had the opportunity to abandon plans for 9 mi of unwanted freeway and build a 30-mi light rail network instead.

For the first time, important voices in the Fresno community were examining the potential of a different route to mobility—light rail. The *Fresno Bee* in a January 1993 editorial called the "dismissiveness about light rail . . . galling." The newspaper asked, "Why haven't we started planning [a system] yet? We may very well wish we had in another decade" (*10*).

In 1994, however, despite citizens' visions of a future based on improved public transportation, a majority of the Fresno City Council and Board of Supervisors voted to approve construction of the new freeway. Citizen activists in Fresno oppose the direction being pursued but continue to attend meetings of their regional planning agency and stay informed and involved in transportation issues.

Conclusions

Citizens from coast to coast are becoming involved in the transportation and land use planning and decision making in their communities and states and providing valuable input to the projects under consideration. Greater investment in light rail is an integral part of the vision that many citizen organizations advocate, as illustrated in this paper. The views and information contributed by committed citizens groups has helped frame the debate and educate the broader community and elected officials on the economic, environmental, and social benefits of investing in public transportation. Recently enacted federal laws such as ISTEA have given new impetus to citizen involvement and, although it has taken some adjustment by state and regional planners, there appears to be a consensus that there are clear benefits from having citizens at the table when decisions are being made about the future mobility options and quality of life in their communities.

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Review of Recent American Light Rail Experiences

Robert T. Dunphy, *Urban Land Institute*

A review of new light rail systems opened in the United States since 1980 is presented using generally available transit system characteristics, U.S Census data, and selected additional information. An update of experiences with the three cities studied in the last major federal assessment is contrasted with an overview of San Diego, which was not included, and five new light rail systems. Recent market trends for individual regions are presented, as are current local development policies.

The typical measure of success in a new light rail system is ridership. Because this number is the most understandable to the public—and therefore to the media—it is often the single metric used to determine whether a new system is a winner or a loser. To develop a more complete understanding of ridership success, however, it is important to evaluate not only the goals of the project, but also the broader travel trends in the target market.

Ridership: Market Success or Bean Counting?

Most major transit investments (all of those with federal funding) have a number of stated ridership goals that can be used to rate the results. The least reliable, but most carefully scrutinized, are the estimates of ridership on the initial operating segment. As the clock ticks down to opening day, the pressure is on the transit agency to predict the number of riders. As factors that affect the ridership—the strength of the economy, fares, changes in bus service, and so on—become more clear, it is possible to "refine" the estimate of initial ridership, usually with technical procedures different from those used for the longer-range forecasts. Often the transit agency estimate is revised downward, so that initial ridership exceeds the forecasts and the system is proclaimed a success. The cynics have seized on these revisions, however, to charge that the numbers have been manipulated to make the transit agency look good.

Serving the Market

A major trend faced by most transit systems is that they are losing market share, primarily because of major changes in the commuting market. Figure 1 shows the trend for the prime commuting market: workers who live and work in the central county. Both Denver and St. Louis showed an actual decline in such workers between 1980 and 1990, and Buffalo and Portland grew only slightly. The major growth counties were in San Diego, Sacramento, and Los Angeles, although it is likely that in Sacramento and Los Angeles, especially, much of this growth consists of people living in the suburbs and working at suburban job locations not well served by the new rail lines. Policies to encourage de-

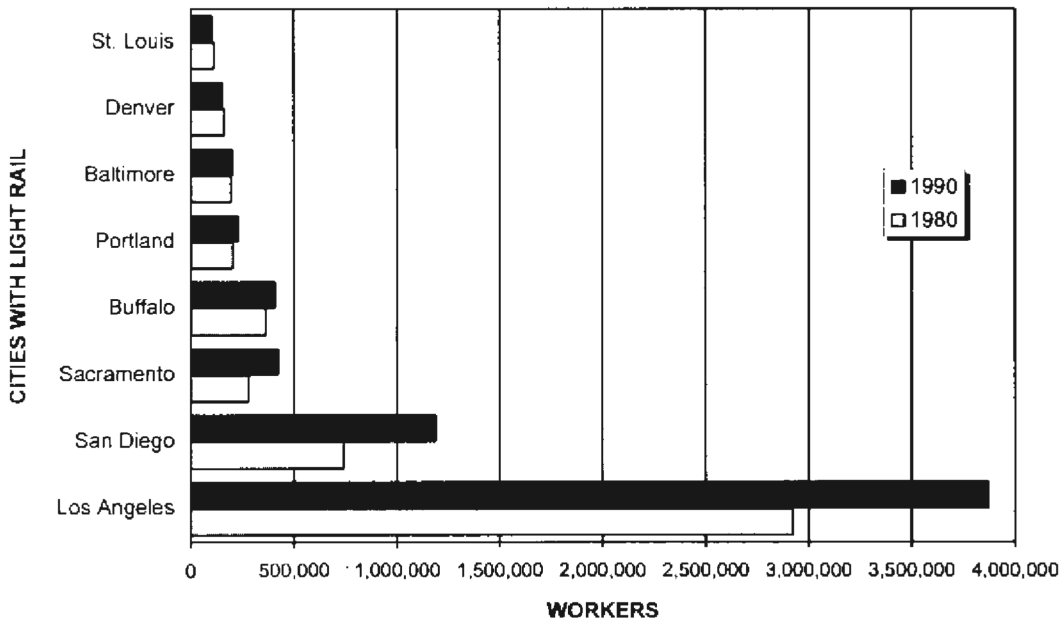

FIGURE 1 Workers living and working in central county of transit market (7).

velopment in the city of San Diego have probably kept the new workers closer in, thereby supporting transit. The trends suggest that most new light rail cities are fighting a suburbanizing labor market, both new workers living outside and out commuters from the city, both of which are less likely to use transit than workers who actually live in the city.

Recent trends in the number of commuters using transit for their usual commute mode (a decennial census definition) are compared for the new light rail cities and other selected urban areas (Figure 2). Two of the 1980s' light rail cities showed significant loses in total transit commuting: Buffalo (−25 percent) and Portland (−20 percent). One the plus side, San Diego racked up the largest relative increase in transit commuting of any large urban area: 43 percent. Sacramento was slightly in the black at a modest growth of 2 percent. Among other light rail systems that have opened since 1987, all were in cities with a net loss in transit commuting during the 1980s: San Jose, Denver, Baltimore, and St.

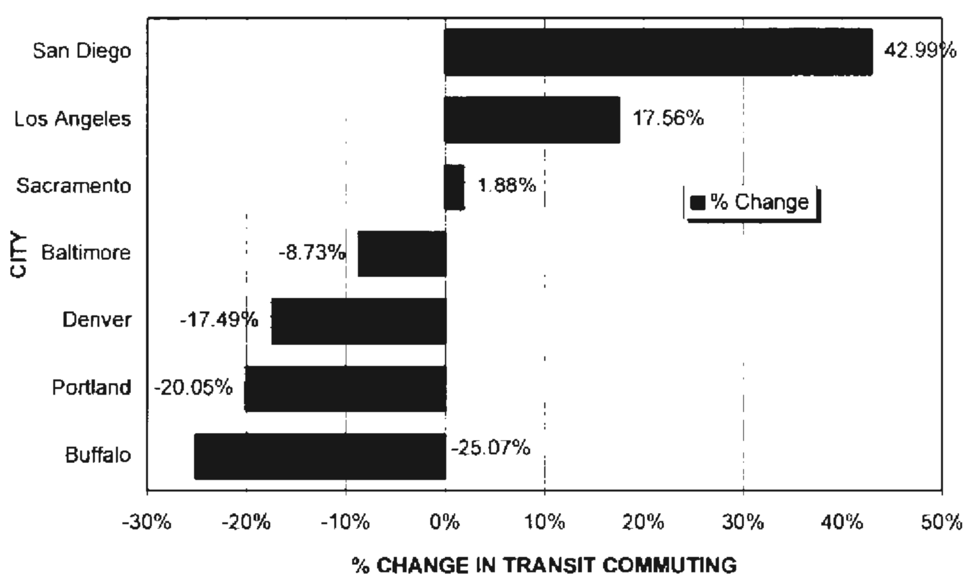

FIGURE 2 Percentage change in transit commuting, 1980–1990 (7).

Louis. The worst of these was St. Louis, where commuting by transit plummeted by 42 percent.

Trends in the transit market share for commuting shown in Figure 3 indicate that only San Diego increased the regional percentage of workers using transit to work. This finding simply confirms the powerful locational trends indicated earlier, in which much of the growth in the commuting market consists of workers who live and work in the suburbs and commute by automobile.

Meeting Expectations

Another way to judge the ridership figures is to compare them with what was expected. As indicated, this comparison is complicated by the diversity of assumptions on transit operations, regional growth, and other transportation policies. One attempt at such comparisons was made by the Volpe Transportation Systems Center in what will be referred to here as the TSC study (*1*). It analyzed four heavy rail systems, four light rail systems, and two people-movers. The study, described in a *Seattle Times* article as "widely criticized, but never discredited," hit some sensitive nerves. Of the four light rail systems it covered, the three new ones were in Buffalo, Portland, and Sacramento. The TSC study estimated that the Portland rail line carried about half of the projected ridership, whereas Buffalo and Sacramento ridership was only about a third of that projected. The TSC study did not include projects that did not receive local funding, the most prominent of which was the San Diego Trolley, where the initial line was constructed with only local and state funds. San Diego estimated a ridership of 50,000 during the 1990s, a target that was reached early, before the deteriorating economy took its toll on ridership.

One criticism of the TSC study was that it was undertaken too early, before the systems had a chance to mature. There is now about a decade of experience in Portland and Buffalo, and there has not been dramatic ridership growth to change the early assessment. The Sacramento system will be 7 years old this year and shows no significant upward move in ridership, in part because of the California economy.

Among the newer systems, the next three to open—San Jose, Los Angeles (LA) Blue Line, and Baltimore—followed the pattern identified in the TSC report of overestimating ridership and underestimating costs. There was one upside surprise in St. Louis, where the initial ridership was substantially higher than anticipated and the construction was completed on time and within budget. The hope is that agencies and consultants are getting better at both cost estimating and projections. Indeed, the Santa Clara County Transportation District revised its travel forecasting models and ran a

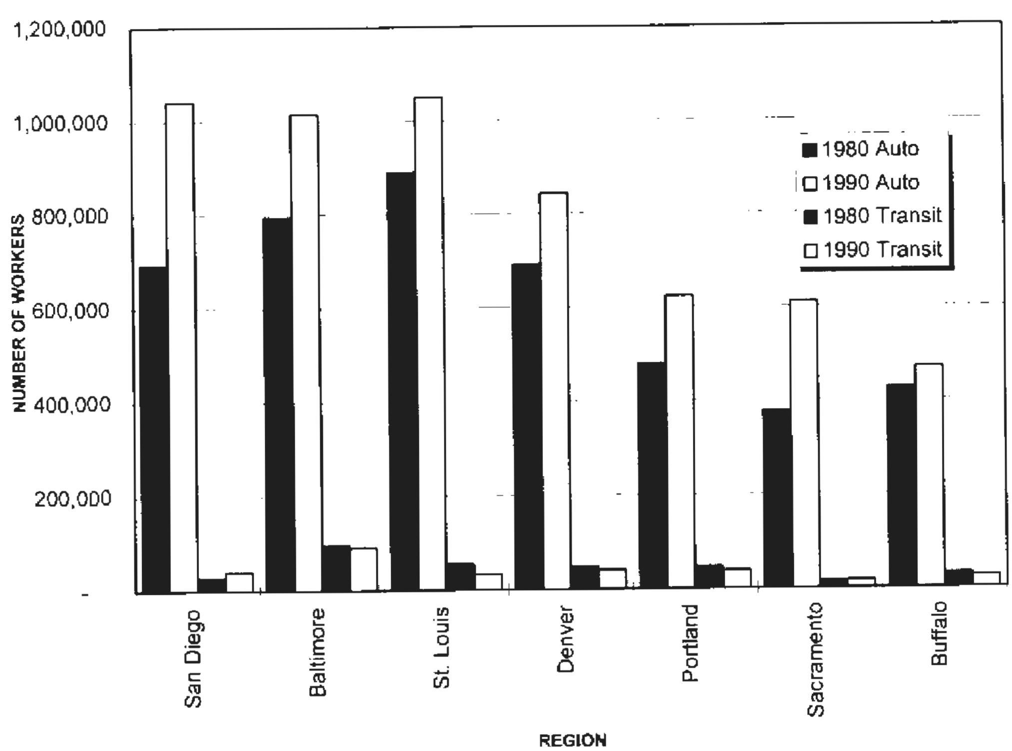

FIGURE 3 Commuting trends, automobile versus transit (*7*).

current estimate that came close to today's ridership levels.

Total Transit Trip Volume

The final perspective on ridership is simply the volume of rail trips. The best of the new light rail systems is that in Calgary, which carries 110,000 daily trips. The only two other systems that carry at least 40,000 riders daily are San Diego and St. Louis. Estimated 1995 ridership in San Jose and Baltimore is only about 20,000 daily, whereas the new 5-mi line opened in Denver in 1994 carries about 14,000 riders. Most of these numbers are expected to be much higher, in some cases because of system expansion. Lower ridership numbers can be justified if the costs are scaled down properly, but their regional impact will be substantially lower. Figure 3 shows the dramatic growth in commuting trips made as automobile drivers and passengers between 1980 and 1990. Clearly, for transit to make a difference in regional mobility, substantially higher levels must be attained.

Affordability For the 1990s

The second most closely watched numbers on new rail systems are the cost indicators. One of light rail's attractions to smaller cities that cannot justify heavy rail is its affordability (2). In fact, the title of one TRB Light Rail Conference was "Successful Systems at Affordable Prices" (3). However, if judging ridership is complicated, it is child's play compared with judging cost. Three perspectives at affordability are taken here: the investment cost per trip, current operating costs, and "sticker price" from the perspective of the local buyer, transit agency, and participating governments.

Capital Investments

The most difficult concept for many in the transit community is the Federal Transit Administration (FTA) cost-effectiveness measure of cost per incremental rider, which has both technical and philosophical problems. One of the gripes of many transit advocates is that federal criteria would always lead to the least-cost investment, and that this ignores the fact that different transit investments (notably bus and rail) have different status. In the context of consumer decisions, for example, one might choose to buy a flashy car when one could have gotten by with a $6,000 used car. If this same approach is taken to recent light rail investment, it is possible at this stage to see what people eventually bought, without making value judgments for now whether it was worth it. Using the data from Table 1, it is possible to calculate an investment cost per daily rider that might compare, for example, with an individual's investment in a car. This assumes that each rider makes two round trips daily. The results show that, using 1995 numbers,

> San Jose, LA Blue Line, Buffalo, and Baltimore were the luxury models of the new light rail systems. Picking typ-

TABLE 1 Regional Statistics for New Light Rail Systems, 1995[a]

	LRT Line Miles	1995 Weekday Riders	Aver. Rider per Line - Mile	Capital Cost 1994 Total	per Line Mile	per Weekday Round Trip[b]
Calgary	18.2	110,000	6,044	$560	$30.8	$10,182
Edmonton	7.6	36,000	4,737	$229	$30.1	$12,722
Denver	5.3	14,000	2,642	$109	$20.6	$15,571
St. Louis	17.0	40,000	2,353	$361	$21.2	$18,050
San Diego	34.5	44,000	1,284	$388	$11.2	$17,517
Sacramento	18.3	23,000	1257	$225	$12.3	$19,565
Portland	15.1	24,000	1,649	$284	$18.8	$22,811
Baltimore	22.5	20,000	889	$449	$22.2	$44,900
Los Angele- Blue Line	22.0	38,000	1,727	$963	$43.8	$50,684
Buffalo	6.4	29,000	4,531	$751	$117.3	$51,793
Santa Clara	21.0	20,000	952	$641	$30.5	$64,100

[a]Source: Unpublished data from BRW Inc.

[b]Assumes Average Rider makes two trips per week day.

ical vehicles, for example, the San Jose system, with an investment of $64,000 per daily rider, is in the top-of-the-line BMW category, which is probably fitting for Silicon Valley. The LA Blue Line and Buffalo's expensive underground construction put them in the Lexus LS400 category, while Baltimore's light rail prices out at about a Cadillac Seville.

Portland, San Diego, and Sacramento fall in the middle range with investments of about $18,000 to $23,000 per daily rider, respectively—about the level of a Ford Taurus. St. Louis' new line also falls in the same cost range.

The economy models are the new Denver line—which is roughly equivalent to a Honda Civic—Calgary, and Edmonton, which were even more affordable than the U.S. systems. Their construction costs were higher, but the ridership is substantially more so.

These, of course, are not directly comparable investments, because cars probably have a useful life of about 10 years whereas the light rail system has an economic life of two or three times that. It does, however, add a different perspective on investment costs. Assuming that about half of the rail riders are "new" to transit, loading the investment costs only on them, the way FTA criteria suggest, would double the investment levels. These costs could come down as ridership grows on the existing lines. In most cases, however, the case for growth in ridership is based on new extensions, so that only if the incremental costs of new riders are lower than today's averages will the overall per-capita investments come down.

Operating Costs

Capital costs may be of greater concern to federal officials, but the major cost burden of new rail systems to local agencies is the operating costs. Part of the rationale for major transit projects is that a capital investment will offer more economical operating costs. The costs of transit trips on different systems are presented in Table 2. Comparing them with driving costs requires that the fixed cost and the operating cost be separated. One of the criticisms of automobiles is that they are expensive to operate if all costs are taken into consideration but that drivers often ignore the ownership costs of depreciation, insurance, and such as a fixed cost that they will have unless they sell the car—an unlikely prospect.

Ideally, a light rail system has two advantages over buses: it is cheaper to run because one operator serves a whole train, and fares can be higher than buses because it is considered premium service. This appears to be true in San Diego, Portland, and Buffalo. However,

TABLE 2 New Light Rail Systems, Current Daily Costs ($)

	1994	1993 Operating Cost per Rider[a]			
	Fixed Cost	Light Rail			Bus
	per Trip[b]	Fare	Subsidies	Total[c]	Total
Calgary	1.34	-[d]	-	-	-
Edmonton	1.68	-	-	-	-
Denver	2.05	-	-	.93	2.00
St. Louis	2.38	-	-	2.01	2.10
San Diego	2.31	.78	.42	1.20	1.60
Sacramento	2.58	.61	.1.79	2.40	2.40
Portland	3.00	.72	.78	1.50	1.80
Baltimore	5.91	1.28	2.32	3.60	1.40
Los Angeles- Blue Line	6.67	1.13	2.57	3.70	1.60
Buffalo	6.82	.55	1.05	1.60	1.90
Santa Clara	8.44	.37	2.73	3.10	2.90

[a]Fare and Subsidies were projected by assuming the % of operating funds from fares were the same for all modes.

[b]Annual cost calculated using OMB recommended discount rates at 4.8% for a 20 year period (factor= 0.0792). Source: May 24, 1995 letter from Samul L. Zimmerman of the FTA. Annual ridership estimated at 300 x weekday ridership.

[c]*Data Tables For the 1993 National Transit Database Section 15 Report Year.* U.S. Department of Transportation, 1994, except for San Diego and Portland reported separately, St. Louis and Denver from survey of light rail projects conducted by Santa Clara Transportation Agency, 1995.

[d]Data not available for Canadian and recently completed light rail systems.

the operating costs of new lines in Los Angeles ($3.70) and Baltimore are more than double the costs of the average bus trip. In Baltimore, light rail operating costs are even more expensive than Baltimore's subway costs (that is a whole different story). The fact that both are in a startup mode certainly contributes to this, as do the currently low ridership levels. In San Jose and Sacramento, the current costs of rail and bus are about equal.

Affordability

The critical factor of the affordability of a new transit system appears to be similar to that of a family buying a new car; it is not whether it can be justified, but whether it can be paid for. This is no problem for systems paid for with federal or state money. In St. Louis, for example, the local match for the initial federal grant was $109 million in asset values of donated rights of way. In Baltimore, the state of Maryland picked up the full local match for the heavy rail system. The initial 22.5 mi of the light rail system were financed without federal funds, and the three counties put up $45 million, 13 percent of the costs. In San Jose, where bus and rail operating costs are significantly higher than in Sacramento and San Diego, and where 85 percent of the cost is subsidized, there appears to be no concern on the part of the public to pay the cost. In fact, citizens voted an increase in the sales tax in 1992 (still pending a legal challenge) to support these services.

If voting with your pocketbook is a means of support, the clear winners are in Portland, where area voters approved in November 1994 a $475 million bond issue to finance the local share of a $2.85 billion north-south light rail line. In nearby Seattle this spring, however, voters turned down the $3 billion needed to match a $6.7 billion regional system. Sticker shock may be responsible for drastic cutbacks in the light rail system in Los Angeles from 296 to 95 mi.

Relieving Congestion

One of the best selling points for new light rail systems is that they can help relieve congestion by attracting drivers off the road. The FTA cost-effectiveness criterion is directly relevant, counting only new-to-transit trips, generally automobile travelers who would not have used the next best transit alternative. The congestion argument is complex, in part because transit works best when the road system is congested so it can provide a better option. Most of the analyses show that congestion will be reduced compared with the alternative future scenario. Those who inhabit the real world will never see the more congested alternative to know how much better things are—they will only observe that congestion is getting worse even with transit. Even if analysts describe properly the congestion relief aspects of new transit proposals, it is easy for plan proponents and the media to pitch this more sexy goal. As shown in Figure 4, congestion at the regional level has continued to worsen for all of the new light rail cities. Of course, most of the systems are too new to make a difference. In San Diego, for which there are 10 years of congestion data after the initial opening, congestion has grown the fastest—mainly because of the explosive growth of the 1980s. Beginning in 1989, congestion growth slowed in a number of current and future rail cities, probably because of the economic recession.

Another angle on the reduction of congestion is that significant transit investments will allow people to drive less. As shown in Figure 5, however, there is significant variation in comparative levels of driving and transit among different regions. Among the nine new rail cities studied, the one with the most driving is St. Louis, which also had the second lowest per-capita transit use in 1990. Baltimore's transit riding was twice that of Buffalo, but people in Baltimore also drove more. A review of these comparisons, as well as the full range for all cities (e.g., Atlanta residents used transit at a level of 50 percent higher than those of Portland and drove twice as much) suggests that there is a much more complex interaction between driving and transit, with influences due to demographics and geography as well as the transportation systems.

Making Land Use Connection

Getting serious about transit involves making a deliberate connection between transit investment and land use decisions. It is not enough to follow the "field of dreams" model—build it and they will come. As demonstrated, there are strong market pressures for decentralization, which can undermine even the best planned rail lines. In many cities it is relatively easy to build popular support for light rail. It is much more difficult to achieve consensus on building the communities needed to make them work.

Development Trends and Prospects for New Light Rail Cities

A brief rundown of regional development trends in the new light rail cities, beginning with the oldest systems, finds the following (4):

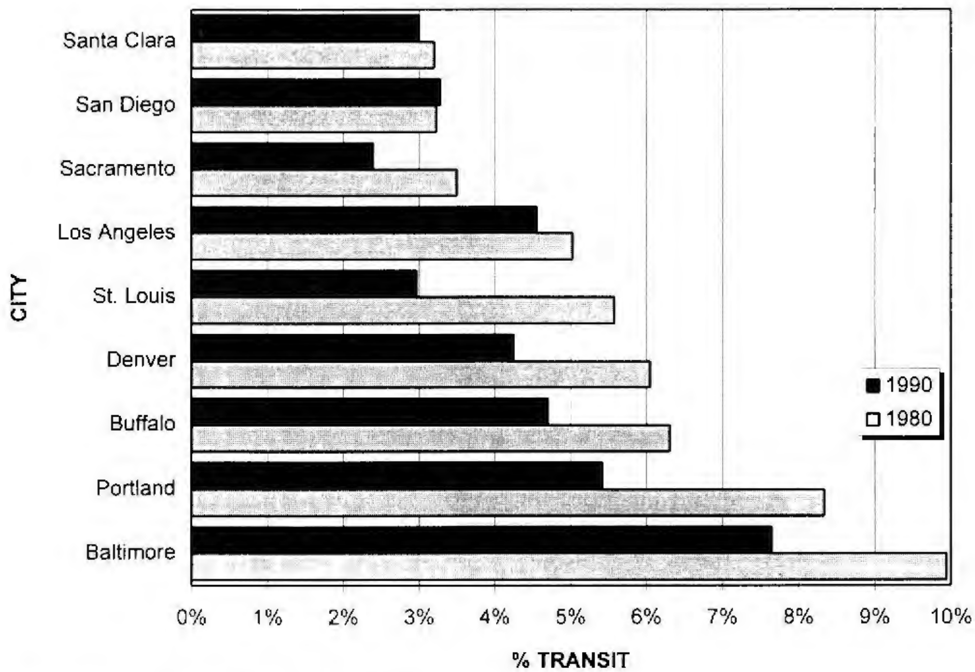

FIGURE 4 Percentage of transit trips (*7*).

San Diego

San Diego's initial success was despite, rather than because of, regional development policies. It has only been since the 1990s that the city and the transit agency have embraced transit-oriented design guidelines. The initial light rail line took advantage of an opportunity—the flooding of a railroad line that presented the opportunity to acquire the right of way. After strong growth in the 1980s, San Diego is mired in the recession that continues in California. The good news is that the Urban Land Institute's (ULI's) recent survey suggests that San Diego is one of six markets to experience significant positive shifts in momentum (four of the other five are also in California). Moreover, the most important new transit-oriented design project is now under construction.

Portland

Among the most bullish prospects for the next year for overall rental rates or sales price improvements, Portland is also on the top 10 list of Ken Rosen of the University of California–Berkeley for near-term growth. There is a regional growth boundary to limit leapfrog development and strong regional support for focused development around transit. The transit agency is actively involved in a major transit-oriented design project around a future station.

Buffalo

Buffalo is among the least bullish markets in the ULI survey. Light rail in Buffalo has not sparked the economic resurgence that backers had hoped to see. Clearly, more is needed to turn around Buffalo's moribund economy.

Sacramento

Sacramento is also on Ken Rosen's top 10 list among low-cost inland markets. Sacramento was one of the first cities to adopt transit-oriented design guidelines and has one of the first projects, Laguna West. But there are vast areas of the surrounding county without development restrictions, and no reasons that developers should stop at the city line.

Santa Clara County

Santa Clara County is one of the leaders for positive momentum shifts. There have been attempts to achieve agreement on development among participating jurisdictions, but there are still problems in reaching regional consensus on growth. There have been some recent initiatives for joint development and transit-oriented development, in some cases through the reuse of parking lots.

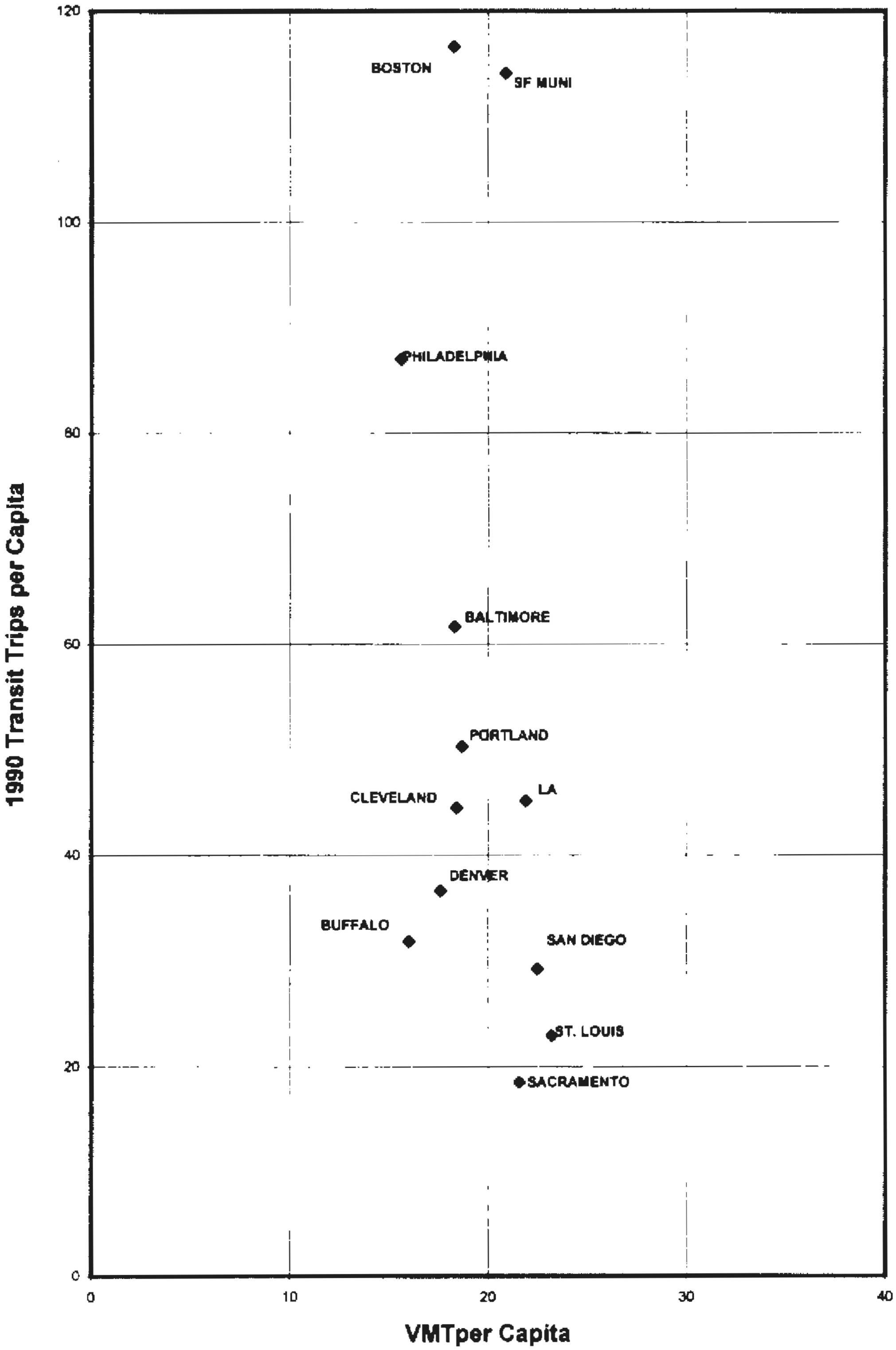

FIGURE 5 Transit trips versus vehicle miles traveled, 1990.

Los Angeles

The Los Angeles story is much bigger than light rail. The region has opted for transit improvements in a big way, with aggressive light, heavy, and commuter rail. There are some major planning policies and a few deals to clusrer development near some of the future rail terminals.

Baltimore

The Baltimore economy showed negative momentum on rentals and sales. Despite extensive state transit funding, Maryland's mass transit administration has no formal mechanism for involving local governments in transit-friendly land use discussions. According to a spokesman, Todd Spangler, "We're very hands off about that. We don't get involved unless we're asked to, and we've never been asked that I know of" (5).

St. Louis

The ULI survey showed the momentum in St. Louis is negative. There is much enthusiasm over the new rail line, and the transit agency has commissioned studies on how best to capture the value for development purposes.

Denver

The Denver economy appears hot these days. It is on the favored growth list of both Ken Rosen and Bill Wheaton, of the Massachusetts Institute of Technology. One concern for transit will be in growing the prime transit market, central city workers, which declined slightly in the 1980s.

Transit-Oriented Design in San Diego

The first transit-oriented development (TOD) in San Diego is Rio Vista West, a 90-acre mixed-use development adjacent to the future Mission Valley East Trolley line. It was approved by the city council in December 1993, and construction began in 1994. The plan called for more than 1,000 units of moderate-density housing, 165,000 ft^2 of office space, and 325,000 ft^2 of highway-oriented retail. The developer, Don Cerone, vice president of CalMat Properties and a participant in the development of the city's TOD guidelines, supported the general concept of developing in a transit-friendly way. Nonetheless, some points of contention arose between developer and city objectives for Rio Vista West (as well as between the objectives of different city agencies):

- The developer found himself in the middle of a battle between the planners, who wanted narrow, walkable streets, and the public works staff, who were concerned about substandard streets and potential liability problems.
- Citing the importance of clustering people around transit, the city and the Metropolitan Transit Development Board (MTDB) argued for a higher residential density than the developer proposed. The developer successfully argued that 30 units per acre was the highest that was economically feasible.
- Although a highway-oriented shopping center with a 120,000-ft^2 discount superstore, supermarket, and drugstore appeared inconsistent with the philosophy of transit orientation, this component was critical to the project's economic feasibility. In the interest of getting a TOD under way, the city went along, a decision that was made easier by the developer's incorporation of several design strategies to weave the shopping center into the fabric of the community.
- MTDB has encouraged the city to require property owners along the Mission Valley line to dedicate right of way and pay some construction costs for the rail line as a condition of zoning approval. In this case, the developer argued successfully that he should not have to subsidize rail construction costs. After all, he was providing land to MTDB and, as a TOD, a much more extensive street grid than a suburban-style development. The streets are estimated to cost $2.5 million, which is more than the value of the land contributed for the trolley line (6).

This project demonstrates both the vision and the flexibility needed to take a concept and implement it in ways that satisfy current codes, transit goals, and market needs.

Light Rail in 1995: Lessons Learned

A recent article by Ken Orski pointed out light rail is now in the mature phase, characterized by "mature design, high level of engineering knowhow and confident estimates of construction and operating costs, which began with the St. Louis and Denver systems" and will continue with the opening of lines in new cities and extensions to current lines (2). It is hoped that past problems with overly optimistic projections of ridership and costs will be replaced with more realistic assessments. A badly needed resource is a thorough, objective evaluation of what has been learned among the nine new light rail cities, similar to the research that FTA has already begun on the new heavy rail systems in San Francisco and Atlanta. To be most useful, this study should include candid assessments by transit principals about what went right, what went wrong, and what will be recommended next time. It is especially important to suggest improvements to the technical procedures needed to produce credible forecasts. Many new cities are waiting in the wings; they are not well served by unduly positive reviews. Lacking such a thorough assessment, anyone can offer opinions, such as those of the author:

- *Light rail is expensive.* All of the recent data show that light rail represents a major expenditure of local and, especially, federal and state funds for the levels of ridership. The two obvious way to change the results are to reduce costs or increase ridership. It is hard to do much on the cost side. In fact, there are pressures to enhance mitigation and improve the quality of design that are likely to increase, not reduce, costs. The emphasis must be on increasing riders.
- *Light rail will not reduce traffic congestion*, at least on the scale in which it is practiced in the United States. G.B. Arrington, of Portland's Tri-Met, points out that "the choice is between futures where congestion will be higher than today, even for the best transit option." Congestion relief should be one of the best sales tools, though, since few residents will use transit but all would gain benefits from less congestion.
- *Light rail must be an effort in community building.* As indicated, the way to make rail systems more cost-effective is to increase ridership, which requires supporting the investment with consistent community development decisions. That means a decision on where the community wishes to grow, with appropriate policies to encourage growth in those places. It also means effective policies to preclude development in areas where land is less expensive and development costs may be cheaper. It could even go so far as parking policies that price parking to cover all costs and toll charges that vary between peak and off peak. Since pricing is so controversial, perhaps starting with the easy part—consistent development policies—is best.

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Perspectives on Standardization

New Jersey Light Rail Transit Standardization Issues

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Transit projects are in planning or preliminary engineering in three diverse New Jersey corridors. At least two will use light rail technology. How can they be standardized? The Hudson–Bergen Light Rail Transit (LRT) System is a 22-mi route, generally running north–south near the west bank of the Hudson River and operating on former railroad rights-of-way, on boulevards, and on city streets. The Newark City Subway, an existing 4.2-mi light rail line on private right-of-way, will be modernized. Extensions in planning range up to 10 mi using various operating environments. The Burlington-Gloucester Transit Study is planning major improvements on two corridors radiating from Camden; technologies being considered include light rail. Standardization begins with choosing a technology, and light rail implies electric vehicles running on rails singly or in short trains. An overhead contact system supplies direct current power at 750 V. Most track is at surface level with varying degrees of separation from automotive traffic. There are several fundamental choices for vehicle design. The car can be optimized for street service or for high speed. It is possible to use lifts, mini high-level platforms, full high platforms, or cars with partial or full low-floor design to make the system accessible to persons in wheelchairs. Car length generally ranges from about 45 to 90 ft, with zero to two articulations, although other variations exist. New Jersey (NJ) Transit has selected an articulated partial low-floor car design, double ended and about 90 ft long by 8.8 ft wide, with about 70 percent of the car floor 14 in. above rail. This configuration permits installation of four doors on each side, all in the low-floor section. The top speed is to be 55 mph; minimum curve radius will be either 60 or 80 ft. Light rail lines will use proof-of-payment fare collection. Cab signals will be installed except where operation is on or adjacent to streets and drivers follow traffic rules. Wayside signals will be used only at interlockings, which will be driver-actuated using a system like VTAG. The Newark City Subway will be converted in stages to proof-of-payment, 750-V power for pantograph-equipped cars, and minimum curve radii that match the vehicle capability. Stops will have remote-controlled public address systems with a visual display of messages. Call-for-aid telephones will be provided at each platform, in elevator cabs, and at each elevator landing. The telephones will be monitored by slow-scan television. Elevators will be equipped for remote locking and unlocking. These systems and the ticket machines will be derived from existing designs now used on the commuter rail lines and the Newark City Subway.

Transit improvements are in planning or preliminary engineering in three diverse New Jersey corridors: along the Hudson River waterfront, in the Newark-Elizabeth area, and in South Jersey between Camden and suburban areas to the north and to the southeast. Light rail is an existing mode in Newark, has been selected for the Hudson waterfront, and is one option in South Jersey. Each project has its own characteristics. How can they he standardized?

Three Projects

Hudson-Bergen LRT System

This line (Figure 1) has a defined 22-mi route and is in preliminary engineering. The northern end is at a park and ride lot on the New Jersey Turnpike near the Bergen County border. It will run south on former railroad rights-of-way and cross eastward under the Palisades in an existing tunnel. A deep underground station will serve Bergenline Avenue in Union City. The line emerges on the river front in Weehawken and continues south. In Hoboken it runs alongside a street east of Stevens Technical Institute and on street to Hoboken Terminal, a hub for commuter rail, bus, Port Authority Trans-Hudson (PATH) rapid transit, and ferry services.

The light rail line will turn west to Marin Boulevard, then south under the rail yard in a street underpass and continue south and east on right of way into Jersey City. A stop at Pavonia Street will serve the Newport development and PATH trains to midtown New York. At Exchange Place there is more development and PATH trains to the World Trade Center in lower Manhattan. Then the line will go south on Hudson Street and west on Essex Street. Entering a presently undeveloped area, it will turn south and pass west of the Morris Canal

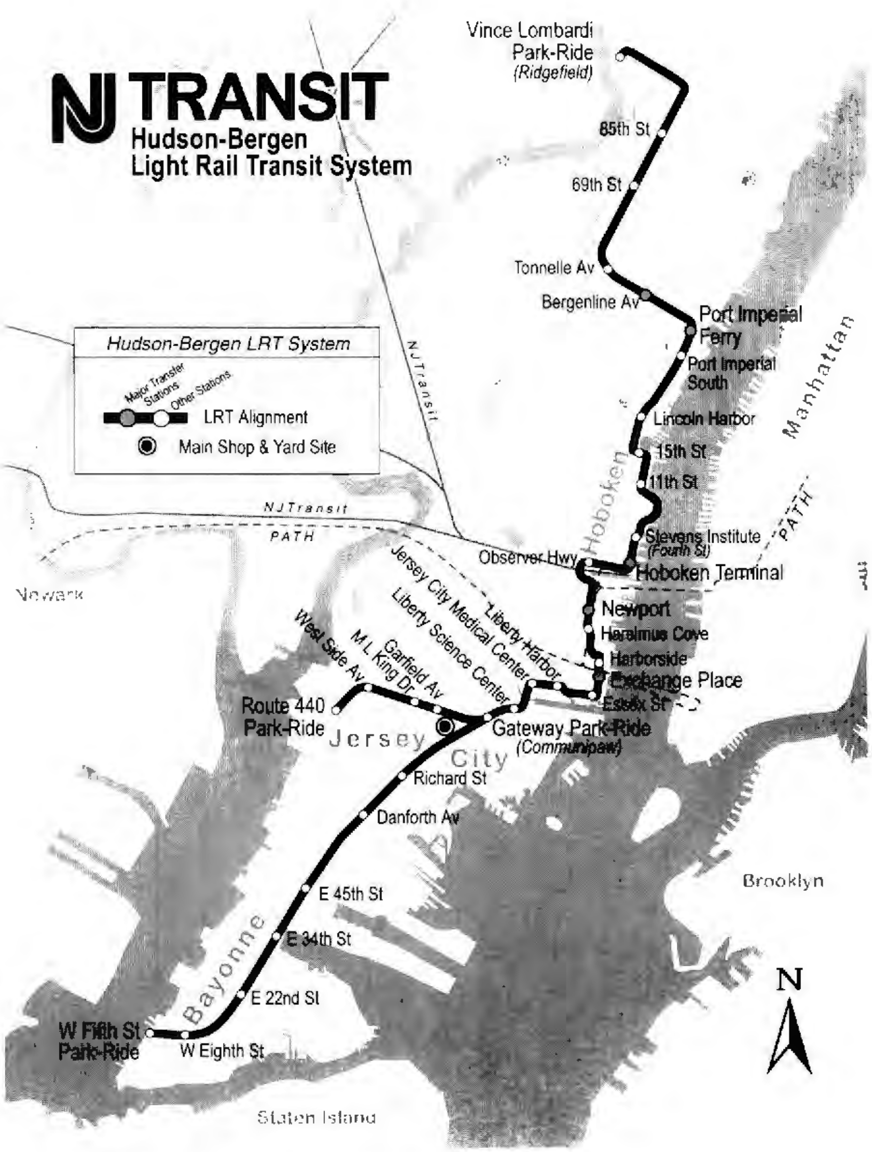

FIGURE 1 Hudson-Bergen Light Rail Transit System.

Big Basin and Liberty State Park, which is at the site of the former Jersey Central Railroad Terminal.

A park and ride station, a junction, and the operating/maintenance depot will be located here. One branch continues south on railroad right-of-way to southern Bayonne. Three stops will have park and ride lots and three others will not. Near the southern end of the route, a mile of single track will support late-night Consolidated Rail Corporation (Conrail) freight operations. The other branch will go west across Jersey City on a former railroad line. The final two stops will be near a major highway with park and ride lots.

This is a very demanding route, combining high passenger volume, fast running on railroad rights-of-way, operation on streets, and compatibility with railroad freight that will use some of its track. Some stops will be located in the street environment, where the length of trains cannot exceed the distance between cross streets. Two such stops, at Hoboken and Exchange Place, will handle large passenger volumes.

Newark City Subway

The Newark City Subway (Figure 2) is a 4.2-mi light rail line, the only remnant of the once-extensive Public Service streetcar system. Built in the 1930s on the bed of the Morris Canal, it runs from the Newark-Belleville border, south toward downtown Newark alongside Branch Brook Park. After it crosses over the Morris & Essex commuter rail line there is one at-grade street crossing. The line then curves to the west and enters a mile-long subway on its approach to center city. A long 4 percent grade in the tunnel was once the site of an inclined plane on the canal. The final stop is under Newark Penn Station, where the maintenance depot is located. A fleet of 24 President's Conference Committee (PCC) streetcars built between 1946 and 1949, acquired second-hand in 1953, is still in service.

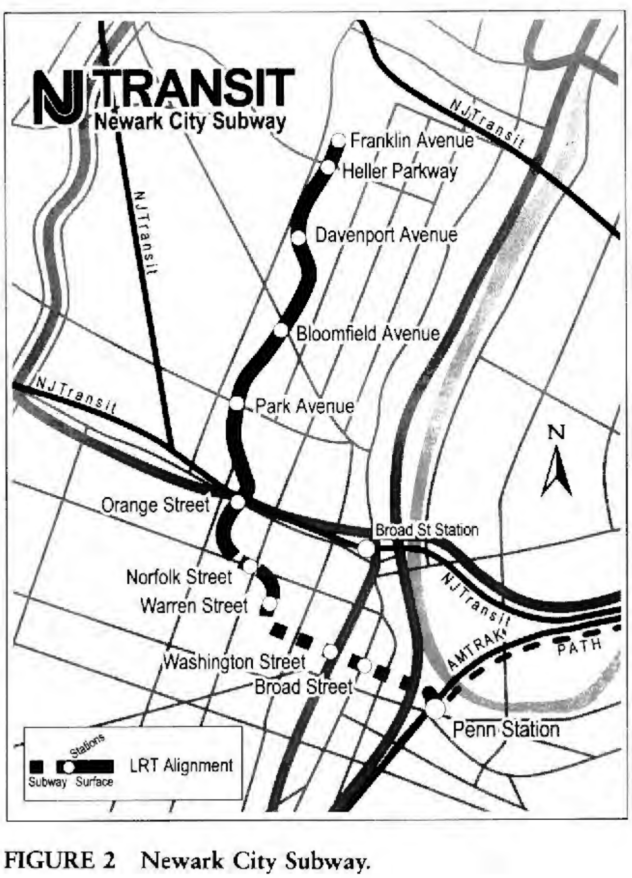

FIGURE 2 Newark City Subway.

Present plans are to replace the cars with modern light rail vehicles (LRVs), build a new operations and maintenance facility on a short extension to the northwest, upgrade the electric substations, and renew the overhead contact system. Studies have been conducted on an extension southward to connect Newark's two railroad stations, provide improved access to Newark Airport, and encourage development in Newark and Elizabeth. Passenger volume on this route is somewhat less than expected on the Hudson-Bergen project. The proposed extension through Newark to Elizabeth would have a significant amount of operation on streets, but its shorter trains present fewer problems in station design.

Burlington-Gloucester

Historically, New Jersey suburbs east of Philadelphia were served by commnter rail from a ferry terminal on the Delaware River in Camden. Railroad operations in Camden were replaced in 1969 by the Port Authority Transit Corporation (PATCO) rapid transit line (Figure 3), nsing an existing Southeastern Pennsylvania Transportation Authority (SEPTA) rail line over the Ben Franklin Bridge and continuing for 12 mi on the railroad right-of-way to Lindenwold. Commuter trains were operated until late 1980 between Lindenwold and Atlantic City, with a branch to Cape May. The railroad to Atlantic City was rebuilt in 1987 and NJ Transit commuter trains (Figure 4) operate between Atlantic City and 30th St., Philadelphia, via Conrail's Delair Bridge, also connecting with PATCO at Lindenwold.

The Burlington-Gloucester Transit Study has identified two corridors, north and southeast from Camden, for improved transportation service. The southeast corridor to Glassboro wonld follow a railroad right-of-way. The northern corridor to Burlington has two alternates, either on a railroad line or in the median of Interstate 295. Technologies under study include

- Rapid rail extensions to PATCO;
- Modified rapid rail extensions with grade crossings and overhead current collection;

FIGURE 3 Lindenwold park-and-ride station, PATCO line. The 22-km (14-mi) route from Center City Philadelphia ends here.

- Light rail, passengers transferring to PATCO in Camden; and
- Busways, with service into Philadelphia via the Ben Franklin Bridge.

WHAT IS STANDARD?

Standardization begins with choosing the technology: *light rail* implies electric vehicles running on rails as single cars or short trains. Many light rail systems share the following characteristics. Power is supplied from overhead wires as direct current at 750 V. Vehicle width is compatible with street traffic, on the order of 2650 mm (8.5 ft). Track gage is standard 1435 mm (56.5 in.). Most track is at surface level, streets may be crossed at grade, and some operation may be in the street. Signal systems are provided except in streets, and car operators select routes at track switches. Stops have dedicated platforms, low level or high level. Shelters are provided. Fare collection is barrier free, using proof-of-payment rules.

FIGURE 4 NJ Transit operates commuter rail service between Atlantic City and 30th Street, Philadelphia. Absecon station is shown here.

Variations on these norms are frequent. For example, in North America there is full underground subway construction on portions of light rail lines in Boston, Newark, Philadelphia, Pittsburgh, Cleveland, San Francisco, Guadalajara, and Edmonton. Turnstiles are used for fare collection in some of these underground stations. Proof-of-payment fare rules generally apply in new systems but not on older U.S. systems upgraded from streetcar days. The fully elevated Monterrey and Manila systems are considered to be light rail. SEPTA's Norristown line has third-rail electrification.

Light rail is sufficiently standardized that it is sometimes possible to take cars from one system and use them on another. The Newark PCC cars were purchased used from Minneapolis. New Orleans recently acquired some used PCCs from Philadelphia; although purchased for parts, one car was taken for a test trip on the St. Charles line. Calgary and Edmonton have exchanged cars; the cars are the same but wheels had to be changed. Contrast light rail with "people mover" technologies, which are generally proprietary.

DESIGN OF THE CARS

Strassenbahn versus Stadtbahn

The street railway, or Strassenbahn, is alive and developing in Germany along with light rail, or Stadtbahn, systems. Distinct cars are used for each. Streetcars are optimized for ability to negotiate sharp curves and for easy boarding from railhead level; light rail cars are optimized for speed and comfort. German streetcars typically are 1 m narrow gage, and have 2300 mm (7.5 ft) bodies; most new streetcars there have 100 percent low-floor construction with unconventional running gear. Light rail cars more often are standard gage and have a 2650 mm (8.5 ft) body. Recent examples are articulated partial low-floor designs with conventional powered trucks at the ends and an unpowered center truck that has individual wheels. The floor is at about 300 mm (12 in.), except over the powered trucks.

The PCC car (Figure 5) is a streetcar, able to negotiate curves of about 12 m (40 ft) radius, with 660 mm

FIGURE 5 The PCC streetcar was developed by a committee of presidents of transit operating companies. Standardized cars of this type were manufactured by two builders between 1937 and 1952.

FIGURE 6 The high-floor articulated Model U-2 car by Siemens-Duewag operates on several North American light rail lines, including St. Louis.

(26 in.) wheels and a floor 813 mm (32 in.) above rail. The trucks swivel to a wide angle, as do the couplers, if provided. Top speed is about 70 km/hr (44 mph). PCC cars were generally 8.5 ft wide, but those on the Newark City Subway are 9 ft wide. A more recent streetcar is the Boston Type 7 car, which is articulated and can negotiate sharp street-type curves. In Newark and Boston, the route is light rail but the cars are streetcars. The 26 in. wheels appeared in the United States before World War I and were standard (not universal) for city cars built in the 1920s and 1930s.

New light rail systems typically are designed with 18 or 25 m (60 or 80 ft) minimum radius curves. The larger radius eases car design requirements for extreme angles on truck swivel, coupler angle, and articulation performance. The car floor often is higher, 1 m (39 in.) above rail, so larger wheels and larger diameter motors can be used. This makes it easier to design for high speed. The Siemens-Duewag U-2 type car (Figure 6), operating on several properties in North America, has a single large motor, or monomotor, on each powered truck. It sits longitudinally between the wheels, and each end of the armature shaft drives one axle. Top speed is about 80 km/hr (50 mph).

Boarding the Car

New projects have to comply with the Americans with Disabilities Act and be accessible to patrons who use wheelchairs. Light rail lines recently built in the U.S. generally use cars with a 39-in. floor height. Boarding and exiting at street level is a chore even for the able-bodied, as the cars are too narrow for ideal steps, and do not have the easy boarding of the PCC streetcar with its 32-in. floor. Those unable to climb stairs need another route to the floor level: on-board lifts in San Diego, station lifts in Portland (presently) and San Jose, or mini high-level platforms (high-blocks) in Sacramento, Baltimore, and on the Buffalo transit mall.

An excellent solution from an engineering perspective is the high-level platform as used in Los Angeles-Long Beach (Figure 7), Calgary, Edmonton, and St.

FIGURE 7 High-level platforms provide level entry to high-floor cars. Integrating such platforms into the city scene can be done attractively, as in Long Beach, California.

Louis. The matching high-floor car has a simple body structure. It can have conventional trucks with large-diameter wheels. This type of car should afford the lowest construction and maintenance cost. It is the ideal solution for a line that operates entirely on a former railroad or other private right-of-way.

For on-street operation, vehicles with a floor height of about 330 mm (13 in.) provide easy access. Level boarding is afforded from a curb-height platform (Figure 8). If it is necessary to board from the street, it is only a single step up to floor level. A ramp can be deployed for riders who use wheelchairs and are boarding from the street. Streetcars with full low floors are popular in Europe, but most are complex and unconventional in design. Like the PCC, the top speed is usually about 40 mph.

What about a route that has enough private right-of-way to allow high-speed operation, but must operate in the street part of the time? Will the city fathers permit block-long high-level platforms in the streets? Should a complex low-floor car be chosen? Partial low-floor cars, as used in several European cities, including Paris (Figure 9), offer a compromise. As with most compromises there are disadvantages. A typical 70 percent low-floor car has steps or ramps to the higher floor at the ends. The steps, leading to an isolated high area, are seen as a major disadvantage to this design. A ramp can replace the steps if low-profile powered trucks are supplied. With this layout it is more difficult to place a door near the driver so that he or she can inspect tickets of boarding passengers.

Vehicle Standardization at NJ Transit

An early decision is that the Hudson-Bergen Light Rail System and the Newark City Subway will be light rail lines, not commuter rail or rapid (heavy) rail. From this beginning, there are several choices to make.

FIGURE 8 Low-level platforms are not as intrusive on a city street as are high-level platforms. This stop is in Paris.

FIGURE 9 All passenger entry doors in a partial low-floor car are the low-platform level, typically about 330 mm (13.5 in.). This example is operating in Paris.

Length and Width

The PCC cars on the City Subway route are 46 ft long, and during the peak hour a 2-min headway is required to attain the needed capacity. The Hudson-Bergen line expects a maximum one-way per-hr demand of 8,000 riders. On a 3-min headway, this amounts to 400 riders per train. The South Jersey routes will have peak loadings that make large cars appropriate.

Single-body cars are in the minority today in North America (Buffalo, Philadelphia, Toronto). Articulated vehicles are used in Baltimore, Boston, Calgary, Edmonton, Pittsburgh, Sacramento, San Diego, San Francisco, San Jose, St. Louis, and Toronto (uses both types). Most cars are about 2650 mm (8.5 ft) wide, with Baltimore an exception at 9.5 ft.

Standardization differs from optimization. The Hudson-Bergen line will need 28-m (90-ft) articulated cars, operated in two-car trains, to achieve its planned capacity with a practical minimum headway of 3 min through congested intersections. During peak hours, the City Subway can make use of these large cars operated singly with headways increased from 2 to perhaps 4 min. However, many City Subway patrons use the line for trips under 1 mi. If service is not frequent some will just walk and save the fare.

Minimum Curve Radius

The Hudson-Bergen line is being built with curves of 25 m (80 ft) radius or greater. On the City Subway the approximate radius of the loop at Franklin Avenue is 12 m (40 ft), and one at Newark Penn Station is 18 m (60 ft). We can choose the minimum radius for the cars:

- 12 m, raising the cost of the cars and constraining interior design;
- 18 m, having less impact on the car design but the existing outer loop at Franklin cannot be used; or
- 25 m, requiring reconfiguration for double-ended operation without loops.

Ends and Sides

The Newark PCC car is single-ended and single-sided. Loops now exist at each end of the line, and all stations have side platforms. Most light rail cars today are double-ended and have doors on both sides.

Floor

The structure of the car is seriously affected by the floor arrangement. A high floor allows for a simple structure, with strong elements under the doors. A 100 percent low floor is more complex, requiring projections into the passenger space for wheels, suspension elements, and perhaps drive components. The partial low-floor design requires main body elements at two different levels. Each design has its collision protection challenges.

Propulsion and Speed

The new standard of a 750 VDC power source offers an advantage over the U.S. streetcar standard of 600 V or less, especially when trains of heavy articulated cars are to be operated. New light rail lines are generally built for top speed of about 90 km/hr (55 mph). Three-phase asynchronous AC motors are smaller than the DC equivalent and commutator maintenance is eliminated. However, the electronic inverter for the AC motor is larger and more complex than a chopper for DC motors. The propulsion system must be correctly sized to handle the grades encountered on the route.

Choosing the Characteristics

Turnkey Contract

Although the engineers make recommendations, the choices ultimately are made by management. One such decision is that the Hudson-Bergen line will be built by a design-build-operate-maintain or "turnkey," contractor who will also prepare final designs and order the fleet. The current schedule calls for this contractor to receive a Notice to Proceed in mid-1996. With preliminary engineering complete before that time, an order for cars should be placed by the end of 1996.

Vehicle Fleet

The initial operating segment of the Hudson-Bergen line would require about 35 cars. The Newark City Subway has 24 PCCs and would need 12 to 15 large cars. It will use the same cars as the Hudson-Bergen line. Follow-on orders for later phases of Hudson-Bergen and possible City Subway extensions would call for a similar car, leading to a total fleet of perhaps 100 to 120 cars. As this is written it is too early to make firm predictions for the South Jersey project, which may not choose light rail technology.

Low-Floor Car

Management has also decided that high-level platforms are too intrusive for street deployment in Jersey City and Hoboken. Level entry from a platform 13 in. above rail height is desired, which could be achieved by a partial low-floor vehicle. A baseline design has been developed (Figure 10), resembling the new Portland partial low-floor vehicles.

1. Double-ended articulated car, standard gage, length 26.7 m (90 ft), width 2680 mm (8.8 ft).
2. 70 percent low floor at 350 mm (14 in.), 30 percent high floor (at ends) 720 mm (28 in.) desired, 990 mm (39 in.) acceptable. Level change by ramp desired, steps acceptable. Four double stream doors on each side of the car at low-floor level, 1320 mm (52 in.) opening, plus two drivers' doors.
3. A small center body mounted to the unpowered "axle-less" middle truck, providing 1162-mm (46-in.) width at low-floor height as aisle/leg space for longitudinal seating.
4. 72 seats and standing space for 120 at 4 passengers/m^2.
5. Maximum grade on routes designed is 6 percent. One car should be able to push one dead car up any grade on the system. The 6 percent grade now identified is under 100 m long, but a 4 percent grade in the City Subway is about 1000 m long.
6. Top speed 88 km/hr (55 mph). Propulsion system to use four asynchronous 3-phase motors fed from nominal 750 VDC source, and controlled regeneration is desired. The car must be capable of operating on 600

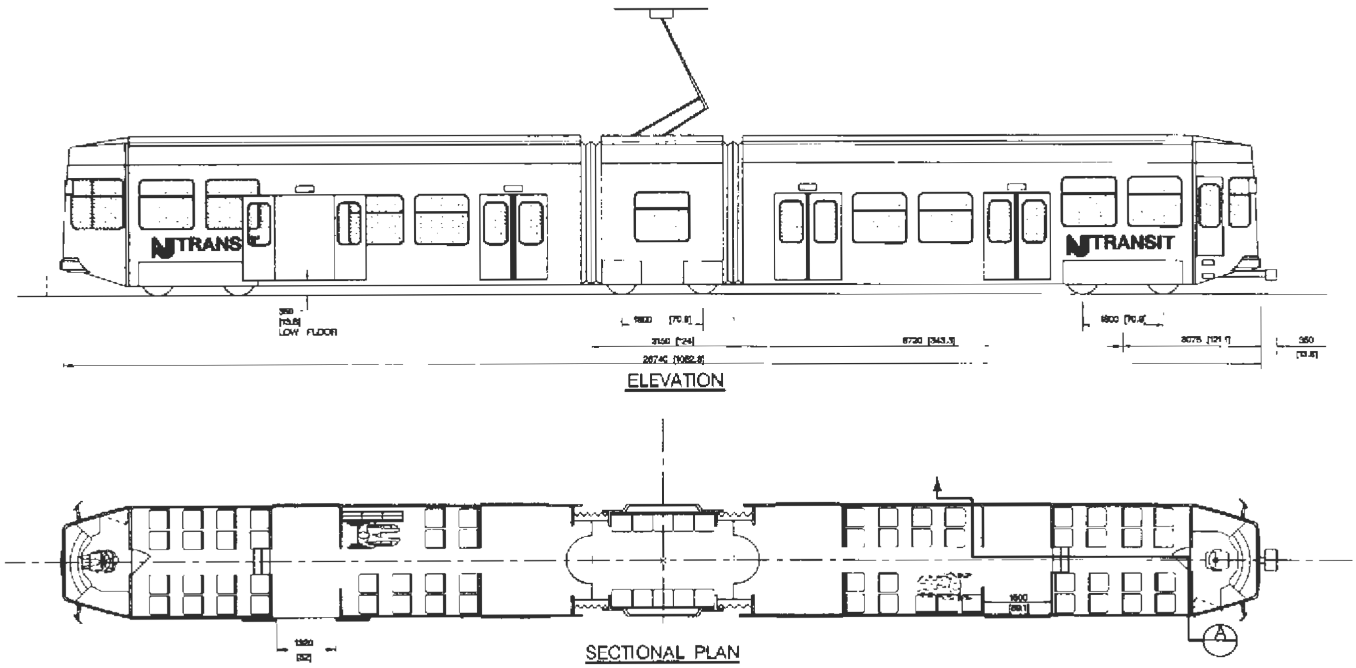

FIGURE 10 Partial low-floor concept car developed for NJ Transit by Parsons-Brinckerhoff.

VDC in the City Subway until the PCC cars are all retired and new substations have been constructed. During this period, somewhat reduced acceleration and top speed would be acceptable.

7. A low-profile powered truck is preferred, with wheels 590 mm (23 in.) in diameter used on both the powered and nonpowered truck. Should this not be practical, a conventional powered truck with wheels 711 mm (28 in.) in diameter will be accepted, and the nonpowered truck would have smaller wheels, that is, 660 mm (26 in.).

Presentations from two potential car builders have focused on their 100 percent low-floor car designs. The presenters assert that these vehicles can meet NJ Transit's performance requirements. The baseline 70 percent low-floor design is not a hard requirement, and it is possible that, in the end, a full low-floor vehicle will be selected.

System Standards at NJ Transit

Fare Collection

A proof-of-payment fare system has been selected for light rail lines at NJ Transit. An implementation study is under way for the Newark City Subway, and preliminary design for Hudson-Bergen is based on this concept. With on-street stations, a barrier system for the latter line would not be practical. The partial low-floor car with raised ends is not well suited to farebox collection at the driver's location, and a second employee in the rear car of a train is not economical. NJ Transit intends to adopt the design of ticket machine now in use at bus terminals and on the commuter rail lines. These machines will be standard across transit modes and can sell one-way tickets, multiride tickets, passes, and magnetic encoded PATH multiride tickets. Cash and credit or debit cards are accepted.

Electrification

Catenary energized at 750 VDC will be used on the Hudson-Bergen route, except in the street environment where simple trolley wire or a low-profile catenary will be specified. The Newark City Subway has a typical streetcar electrification, with simple trolley wire energized at 600 volts. Wire support structures and wire frogs are designed for trolley poles and shoes, not pantographs. NJ Transit intends to accomplish a staged conversion to an overhead contact system that is compatible with light rail cars equipped with pantographs and operating at 750 volts. In the early stages of conversion modifications will be made to allow both PCC and LRV operation. Later, the electrification can be modified for optimal performance of the LRVs.

Signals

A signal system was chosen for the Hudson-Bergen LRT that will have cab signals and automatic train protection. Wayside signals will be placed only at interlockings. The signal system will not be carried into slow-speed operating areas in or adjacent to streets; at these locations traffic rules will apply. When not under cab signals the maximum vehicle speed will be reduced. Operators will select routes at track switches, using an electronic control system such as VTAG. Signaling standards are not yet firmed up for Newark City Subway and its possible extensions. Route selection today uses streetcar technology, which measures current draw as the car passes a trolley wire contactor.

Communications

Radio communications on light rail routes are and will continue to be governed by the standards of the existing bus system. Modern bus radio systems allow fleets of vehicles to be defined, with each fleet talking (relatively) privately among its members and its controllers. NJ Transit police use a VHF radio system that is compatible with the railroad, and its coverage will be enhanced for use on the light rail lines.

A remote-controlled public address system will be used to advise patrons at stops about service irregularities and the like. It will he patterned generally on standards developed for commuter rail. Routine message phrases are prerecorded in computer memory and concatenated into complete sentences for transmission to one or more stops. A text version is also transmitted for display on signs at stops. This system allows the operator to set up a series of messages that will be customized, both in content and timing, for each stop.

Passenger security will be enhanced by installation of call-for-aid speaker telephones (without handset) on each platform, each in view of a closed circuit TV camera. When a patron activates the phone, the camera is also activated to send still pictures to the control center. Where elevators are provided, there will be phones (with camera) at all landings and in the cabs. Access to elevators will be under remote control. When and where vandalism is likely to occur, a remote operator can speak to and observe the patron before granting access and also can observe the patron using and departing from the elevator. Standards for public address and security systems are derived from those on the commuter rail services and the City Subway. Dispatchers will use radio and bus-type Automatic Vehicle Locator systems to control vehicles on the road.

Conclusion

Even within one agency, standardization does not come easily. Each of the projects has its own characteristics, and it is easiest and (in the narrow view) cheapest to optimize the fleet and fixed systems to the project. With a single car for all, it will be necessary for each route to make some adaptations and live with characteristics that are less than ideal. Standardization will, however, pay off in the long run. Three small, distinct, and incompatible fleets would be expensive to buy, difficult to commission, and a challenge to maintain. As time goes on, it would become harder and harder to keep personnel up-to-date on repair skills and to obtain the large variety of parts. Furthermore, if the same car is used on the three route systems, it will be possible to adjust service to demand by moving cars from one route to another.

Standards for infrastructure should follow industry norms as much as possible to keep costs moderate and avoid "inventing" technologies. Customers should perceive transit services as a system, with a logical fare system allowing easy use of bus, light rail, commuter rail, and PATH.

New Jersey Transit Light Rail Transit Initiatives

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New Jersey Transit currently has four light rail transit initiatives under way in the state of New Jersey: the Newark City Subway rehabilitation, the Hudson-Bergen Light Rail Transit System, the Newark-Elizabeth Rail Link, and the Burlington-Camden-Gloucester Transit Corridor. An overview of each of the prospective light rail systems is presenred along with comparative information of interest to the professional transit community. Physical descriptions of each corridor and line are given, and the unique conditions that pertain to each project are discussed. Efforts to coordinare the planning of all four initiatives in the interest of achieving agencywide consistency on such issues as operations and safety, engineering and design standards, standardized equipment (including vehicles), procurement procedures, and documentation are discussed.

New Jersey Transit (NJ Transit) is a statewide agency created in 1979 to provide public transit service for the state of New Jersey. NJ Transit carried 173 million passenger trips in 1994 and serves an area of 5,325 mi^2 (13 792 km^2). NJ Transit rail service encompasses 12 commuter rail lines, 464 mi (747 km) of track, 157 stations, and a fleet of 715 rail cars. The agency operates 1,843 buses over 152 bus routes. In addition it provides 848 buses to an additional 110 private bus operators. Included in the bus operations figures is NJ Transit's only light rail transit operation, the Newark City Subway, a 4.3-mi (7.0-km) line that is the last vestige of the 800-mi (1290-km) streetcar system operated by Public Service Coordinated Transport, portions of which remained into the 1950s.

NJ Transit has four major light rail transit initiatives under way in 1995. These initiatives are the modernization of the Newark City Subway and acquisition of a fleet of low-floor light rail vehicles (LRV)s, the Hudson-Bergen Light Rail Transit System, the Newark-Elizabeth Rail Link, and the Burlington-Camden-Gloucester transit project.

Newark City Subway Modernization Project

The Newark City Subway was constructed between 1930 and 1935 through the city of Newark in the bed of the then-abandoned Morris Canal. It runs in subway for 1.3 mi (2.1 km) and in open cut for the remaining 3 mi (4.9 km) (see Figure 1). The subway was originally conceived as a trunk route to reach Newark's Penn Station and accommodated, in addition to the Number 7 City Subway service, surface trolley lines operated by Public Service Coordinated Transport including the Numbers 21 Main Street, 23 Central Avenue, and 29 Bloomfield. By 1952 only the Number 7 line remained in place, and arrangements were being made to pur-

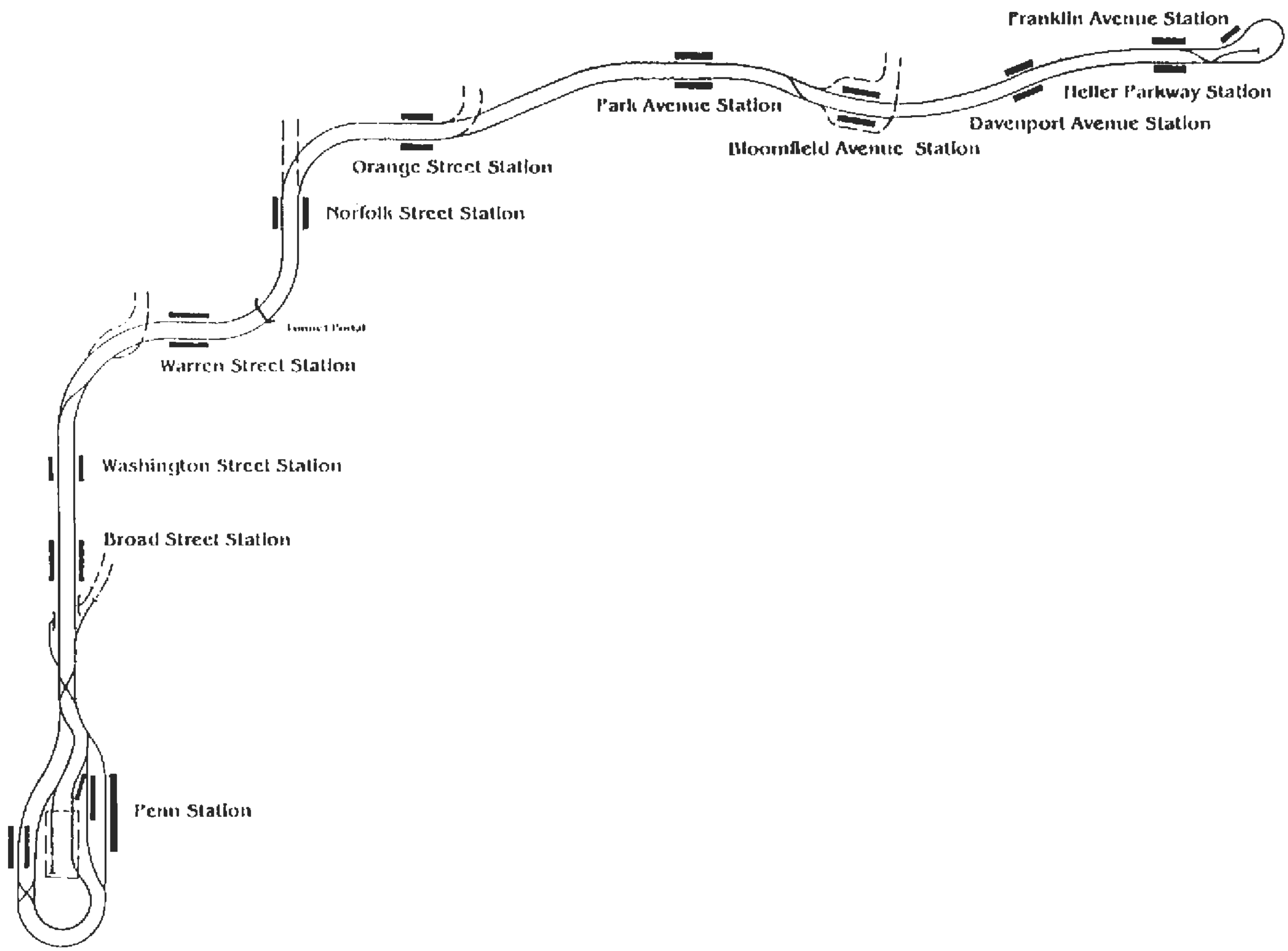

FIGURE 1 Newark City Subway.

chase 30 second-hand PCC cars from Twin Cities Rapid Transit Company to replace obsolete cars.

Currently, the City Subway is operated with the remaining 26 Presidents Conference Committee (PCC) cars, which were built between 1946 and 1949. The subway carries 16,900 weekday passengers over the 4.3-mi (7.0-km) route at headways ranging from 2 min in the peak to 6 min base, to 30 min in late evenings.

A comprehensive engineering study for the subway has been completed that evaluated all elements of the existing system including vehicles, maintenance facility, electrification, signals, track, stations, and operations. Work is currently under way on major improvements needed to continue safe operations and support the procurement of a fleet of modern LRV.

A new sprinkler system to service Penn Station and a dry standpipe system to provide fire protection for the existing 1.3-mi (2.1-km) subway tunnel have been designed, and construction began in December 1994. Also included in the project is a supervisory control and fire alarm network.

In December 1993 a contract was awarded to design a smoke suppression and evacuation system for the existing Penn Station Shop and subway tunnel. This system will provide up-to-date ventilation for the subway tunnel, which currently relies upon surface grates and the "piston effect" of the movement of rail cars to create ventilation.

A contract was awarded in January 1995 to design additional facilities and systems and upgrade the traction power electrification system. The design is expected to include five new substations, feeder and return systems, and a supervisory control and data acquisition (SCADA) system. The upgrade of the existing overhead contact system and support structure will allow voltage to be increased from the existing 600 VDC to 750 VDC to accommodate modern LRVs.

A significant outcome of the modernization study was a recommendation to replace the existing PCC cars with a fleet of modern LRVs. The PCC cars, although exceptionally well maintained, are almost 50 years old. The inevitable corrosion and aging of materials, as well as the scarcity of spare parts, will impose an increasing maintenance burden and reduce service reliability over time. In addition, NJ Transit has an obligation to bring its facilities into compliance with the Americans with Disabilities Act (ADA). Existing ADA standards require that the horizontal gap between rail vehicle and platform cannot exceed 3 in. (76 mm), and the vertical gap cannot exceed 5/8 in. (16 mm). These standards, coupled with the advanced age of the PCC cars, make it impractical to retrofit the existing fleet to achieve ADA access. New cars will be needed.

The Newark City Subway Modernization Study also examined the existing maintenance facility. When the subway was first constructed, cars were maintained at the Roseville Car House. In the 1950s, however, the connection to the car house was severed and all maintenance was conducted under Penn Station, where a running repair facility had been located. Through extraordinary efforts, City Subway staff have been able to use these cramped and substandard quarters to successfully maintain the curreut fleet.

New cars are expected to be nearly twice as long as the existing PCC cars and are likely to have much roof-mounted equipment. Elevated work platforms, longer inspection pits, and high-capacity lifting equipment will be required to maintain these vehicles. Consequently, the existing Penn Station subway maintenance facility is inadequate to maintain a fleet of replacement LRVs.

New Vehicle Maintenance Facility

A modern LRV maintenance facility for the Newark City Subway would require a level site of about 13 to 15 acres (5.3 to 6.1 ha) to provide adequate space for the maintenance facility, storage yard, and test track. Such sites are scarce in the densely built up area served by the Newark City Subway, and none exists adjacent to the line. A suitable site, however, was located approximately 1/2 mi (0.8 km) from the City Subway on Consolidated Rail Corporation's (Conrail's) Bloomfield Industrial Track, which passes about 400 ft (122 m) from the northern terminal of the City Subway at Franklin Avenue (see Figure 2). By obtaining rights to use the Bloomfield Industrial Track and constructing a link between the two lines, a suitable maintenance facility site could be accessed from the City Subway. The availability of additional vacant land close by the maintenance facility in proximity to Bloomfield Avenue, which serves major feeder bus routes, led to a proposal to construct a new bus transfer and park and ride terminal station for the Newark City Subway at Grove Street and Bloomfield Avenue in Bloomfield, adjacent to the proposed maintenance facility.

Hudson-Bergen Light Rail System

Planning for the Hudson-Bergen Light Rail System began in the mid 1980s when New Jersey's Hudson River waterfront facing Manhattan began a transformation from land use, characterized by decaying piers and abandoned rail yards, to a vibrant new development area with projections of up to 17 million ft^2 (1.58 million m^2) of office space, 2 million ft^2 (186 000 m^2) of retail space, and 30,000 new residences. Bounded on the east by the Hudson River and on the west by steep cliffs, called the Palisades, the Hudson River waterfront is a narrow shelf of land. Transportation access to the waterfront is made difficult by the topography and the pervasive congestion problems created at the major highway crossings into New York City. To achieve its development potential, the waterfront, which spans two counties, would need additional transit capacity.

The Hudson-Bergen System is a proposed independent light rail transit (LRT) system with a planned length of 20.5 mi (33 km). It will not connect with the Newark City Subway. The system, shown in Figure 3, will include a yard and shop at Gateway. Three branches will emanate from Gateway: one to Vince Lombardi park and ride in the north, one to the west to Route 440, and one to the south of 5th Street park and ride at the tip of Bayonne. The 1990 estimated cost of the total system is $775 million with an escalated cost estimate of $1.4 billion.

A decision was made in the late summer of 1994 to implement an initial 10-mi (16-km) operating system, using a turnkey procurement. It is envisioned that this procurement will include private funding, design, construction, operation and maintenance. The estimated cost of this initial system is ahout $800 million including all soft costs, such as engineering, administration, insurance, startup, and the like.

Preliminary engineering and preparation of the environmental impact statement are under way. In addition, to expedite the project the property acquisition process has been initiated. All project activities leading to securing a turnkey contract are scheduled to be completed by mid-1996. On the current schedule, it is hoped to begin LRT operations in 1999.

The total system will have five regional park and rides with over 5,000 parking spaces. There will be four major intermodal transfer points—Exchange Place [Port Authority Trans Hudson (PATH) service and

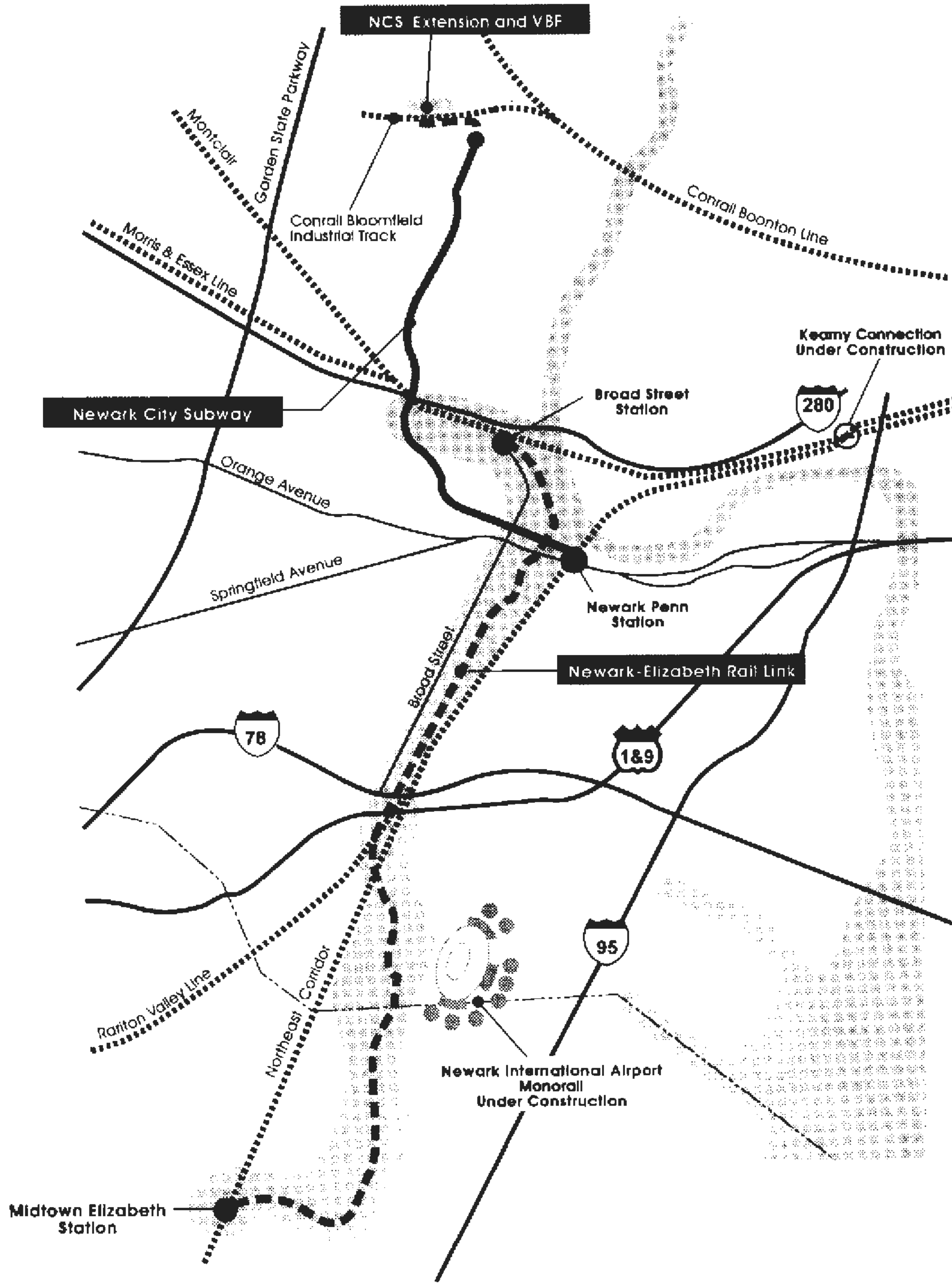

FIGURE 2 Newark-Elizabeth Rail Link and Newark City Subway vehicle base facility.

buses], Pavonia/Newport (PATH), Hoboken (NJ Transit Rail, PATH, bus, and ferry), and Port Imperial (ferry) —to provide for the trans-Hudson commuters who are expected to constitute 50 percent of the LRT riders. The total daily number of trips in 2010 is projected to be about 100,000.

Newark-Elizabeth Rail Link

Planning for the Newark-Elizabeth Rail Link (NERL) began in the mid 1980s when Newark International Airport, located in the cities of Newark and Elizabeth, New Jersey, experienced significant growth. In addition,

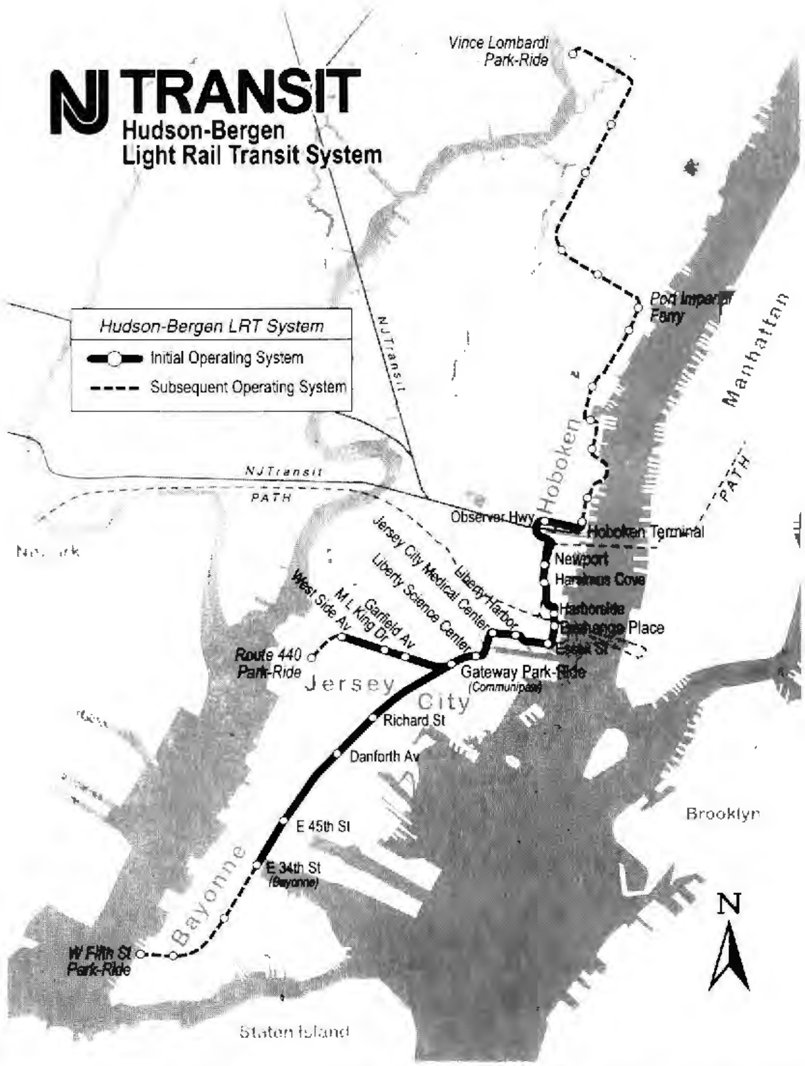

FIGURE 3 Hudson-Bergen LRT System, initial and subsequent operating systems.

a major increase in intermodal container traffic was being experienced at the ports of Newark and Elizabeth adjacent to the airport. Seeking to capitalize on the economic generators of the airport and the port, Newark and Elizabeth began to conceive plans for major office and commercial development in the 9-mi (14.5-km) corridor linking the airport with the downtowns of the two cities.

Their studies, completed in 1989, indicated that a fixed guideway transit system could be implemented in the corridor. It would help achieve economic development goals and provide additional transportation to help relieve the congested highway grid in the project area. Federal grants were earmarked to study transit improvements in the area. The Newark-Elizabeth Rail Link was included along with other projects in the North Jersey Urban Core Program, which received an authorization of $634.4 million in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

A major planning study for the corridor, the Newark-Elizabeth Rail Link Options Study, was completed in June 1992. The study set the stage for selection of a locally preferred alternative, which included a 9-mi (14.5-km), 12-station LRT line linking Newark to Elizabeth and configured as an extension of the Newark City Subway, shown in Figure 2. By configuring the NERL systems as an extension of the Newark City Subway, it would be possible to share the same fleet of cars and maintenance facility and to offer through-routed service.

The study also concluded that a new rail station on the Northeast Corridor linked within the Newark International Airport by a proposed extension of the on-airport monorail would complement the LRT system and provide for regional access to Newark Airport. During 1994 and 1995, the NERL project conducted preliminary engineering studies and completed a draft environmental impact statement for the project.

When the NERL Core System was introduced to the public in a series of environmental impact statement scoping meetings held in December 1993, many comments were received urging that the project be extended to include rail passenger service to a number of additional communities by restoring existing or abandoned rail lines. In response to those requests, NJ Transit initiated studies to determine the effect of proposed extensions on the core system for documentation in the impact statement (see Figure 4).

At the south end of the proposed rail link, extensions to Plainfield, Summit, and Elizabeth Port were studied. An existing four-track former Central Railroad of New Jersey rail right-of-way between midtown Elizabeth Station and Cranford is not currently used by freight or commuter rail. In addition, an abandoned freight rail line, the Rahway Valley Line, remained largely intact between Cranford and Summit, and was slated for acquisition and preservation by the New Jersey Department of Transportation under a rail preservation bond issue.

At the northern end of the proposed NERL system, two extensions were examined. One extension would begin at the proposed NCS vehicle maintenance facility

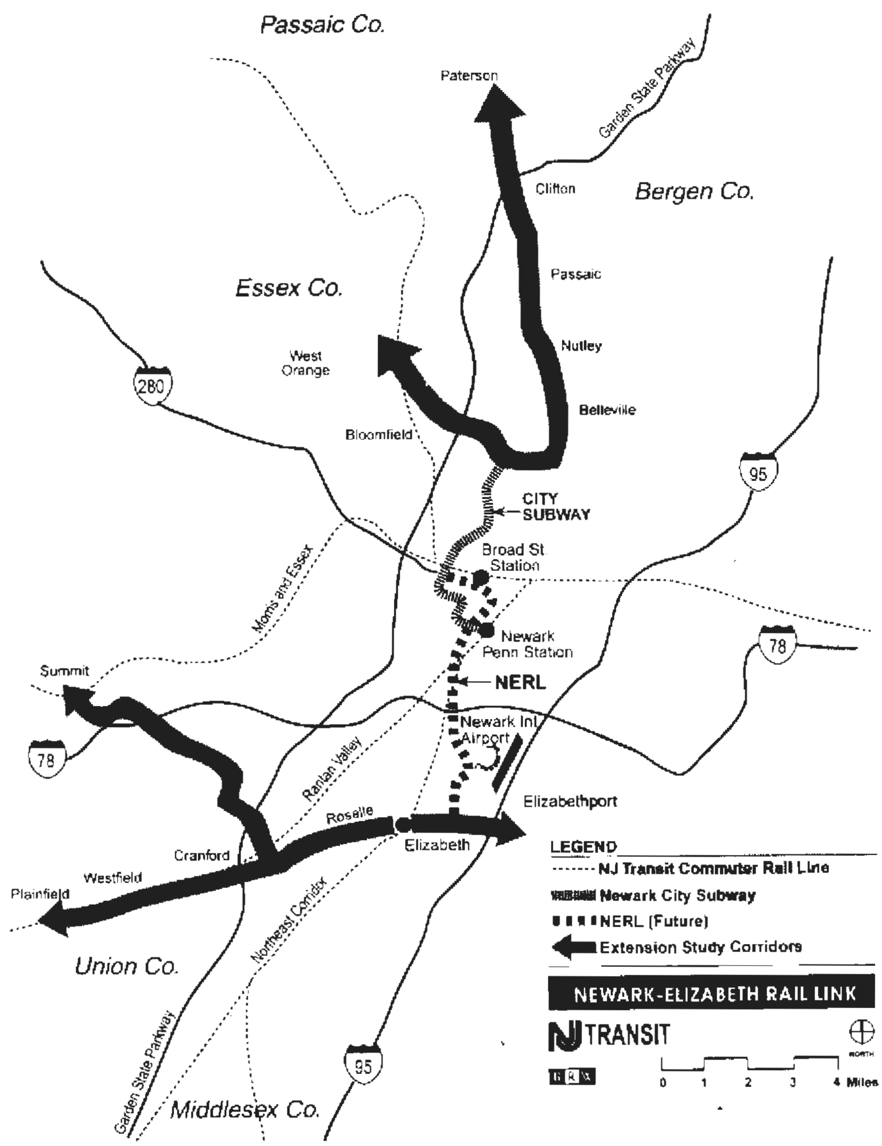

FIGURE 4 Future candidate extensions.

in Belleville and Bloomfield and continue west along the former Erie Orange Branch to West Orange. The second extension would begin at the current Newark City Subway terminus at Franklin Avenue and continue east along the Orange Branch to connect with Conrail's Boonton Line. There, the right-of-way would continue north using Conrail's Newark Industrial Track, which extends through Belleville, Nutley, Passaic, Clifton, and Paterson.

The extension studies were designed to determine if the rail lines under study are available for use. Workshops were held with local officials and interested citizens to identify issues and concerns in each corridor. Specific transit alternatives were defined including station locations, park and ride lots, and the operating characteristics of each extension and associated feeder bus routes. Ridership estimates were prepared, and operating and maintenance costs were calculated. The results of the extension studies will lead to assessments of extending the proposed NERL core system along each of the potential corridors. If the extensions are determined to be feasible and cost-effective, subject to approval from local state and federal authorities, major investment studies may be undertaken in one or more of the corridors.

Burlington-Camden-Gloucester Transit Project

In 1968 the Delaware River Port Authority constructed a 14.2-mi (23-km) state-of-the-art rail rapid transit system, the Port Authority Transit Corporation (PATCO) High Speed Line, between Philadelphia, Pennsylvania, and Camden and Lindenwold, New Jersey. In its 25 years of operation, the PATCO line has become regarded as a highly successful transit operation. A number of extensions have been proposed for the line.

Most recently NJ Transit began planning for an improved rail transit system for Burlington, Camden, and Gloucester counties. Included in the most recent study are several rail alternatives, including extending PATCO, constructing a commuter rail operation, building busways, and constructing LRT (see Figure 5).

Two variations of LRT service are being considered. In one, a conventional light rail line would be constructed that would operate within existing rail rights-of-way and a short segment of city street in Camden, and would connect to PATCO via a transfer at the Walter Rand Transportation Center in Camden. This option would provide intracounty transit connections and serve the developing Camden waterfront, as well as af-

FIGURE 5 Burlington-Camden-Gloucester transit study area and possible alignments.

fording the opportunity to reach Philadelphia by PATCO or bus.

An additional option under study would be to develop a modified PATCO system, which would operate within existing rail rights-of-way at-grade similar to light rail but would merge with the existing PATCO line in Camden to provide service to Philadelphia without a transfer.

The latter option would require a vehicle capable of drawing power both from a third-rail system that PATCO uses and from an overhead catenary system required for use in areas of at-grade operation. The vehicle would conform to PATCO vehicle dimensions, which are not the same as typical light rail cars.

The study of Burlington-Camden-Gloucester transit alternatives is currently being advanced as a major investment study (MIS) under the newly established guidelines promulgated by the Federal Transit Administration. At this stage, analysis is still under way, and no major conclusions can yet be drawn as to the nature of the alternatives to be ultimately advanced into subsequent stages of engineering.

Coordination of NJ Transit Light Rail Projects

Light rail projects span three functional departments at NJ Transit: Bus Operations, New Rail Construction (NRC), and Planning. Within these departments are the LRT Operations Division (within Bus Operations, responsible for the Newark City Subway), the Hudson-Bergen LRT Division (within NRC), the Newark-Elizabeth Rail Link Division (within Planning), and the Project Planning Division (within Planning, currently responsible for the Burlington-Camden-Gloucester Transit Project). At the conclusion of the MIS for the Burlington-Camden-Gloucester Transit Project, that project will transfer to NRC.

An LRT Technical Coordinating Committee was created to facilitate interchange of information and to serve as a forum for discussion of design issues that would affect LRT standardization. Comprising representatives of each of the units mentioned above, the committee meets monthly. Consultants working on the various projects also participate in the meetings. One of the main functions performed by the committee was to review design criteria developed by the consultant team for the Hudson-Bergen LRT System. Because that project had been in existence longer than the other initiatives and was further along in development, its design criteria and specifications became the baseline for development of agencywide standards and documentation for LRT projects. The committee also spawned the vehicle concept evaluation team discussed below.

Standardized Light Rail Vehicle Configuration

To determine appropriate design parameters for LRV for the various projects, NJ Transit assembled an evaluation team of senior level managers from NJ Transit and experts from three consulting firms under contract to NJ Transit for each respective LRV project.

It was concluded that a single standardized vehicle type would be desirable to serve all of NJ Transit's current light rail initiatives. Adoption of a single vehicle type would result in cost savings to NJ Transit through economies of scale in vehicle procurement, standardized operator and maintenance training, and efficiencies in ordering and stocking spare parts.

NJ Transit's evaluation team concluded that a vehicle configuration that would best fulfill the agency's requirements for a standardized light rail transit vehicle would be an articulated six-axle car with approximately 70 percent of the passenger compartment floor at a level approximately 14 in. (350 mm) above top of rail. Motorized trucks at both end of each vehicle would provide motive power at sufficient levels to provide 55-mph (90-kph) running speeds. Floor levels over the power trucks would be up to 39 in. (1000 mm) above top of rail. These areas of the cars would be accessed by interior steps or ramps. The center truck, beneath the articulation joint, would utilize special technology to allow the low floor to continue through the articulated center section. The selected vehicle configuration is referred to as the 70 percent low-floor LRV.

All four NJ Transit light rail transit projects discussed in this paper are considering some form of joint operations with rail freight lines and some operations in urban areas on-street. The 70 percent low-floor design offers the greatest flexibility in adapting to the planned operating environment. This design allows for low platforms, simplifies station designs in urban areas, and simplifies requirements for joint freight and light rail operations in areas where freight service operates past LRT stations.

Boarding and Fare Collection

One of the primary reasons for constructing LRT lines in New Jersey is the need to accommodate high volumes of passengers at greater levels of operating efficiency than can be achieved with buses. Light rail vehicles typically have three to four pairs of double width doors on each side, which facilitate more rapid loading of passengers than is possible with buses.

To make optimum use of multiple doors, most North American light rail systems operating at-grade have selected a proof-of-payment system. The analysis that led to selection of a low-floor vehicle assumed that a proof-of-payment system will be adopted for all NJ Transit light rail systems, and that vehicle operators will not be required to participate in inspection or collection of fares onboard the vehicle. That assumption simplified the evaluation of vehicle options, because by making the assumption of proof-of-payment, fare collection ceased to be a factor in the comparative analysis of potential vehicle configurations.

The study of proof-of-payment also involves an agencywide coordination effort. Initial coordination meetings organized by the Planning Department involved the Corporate Affairs Division, External Affairs Department, Bus Operations, Rail Operations, Law Department, Procurement, Business Planning, Engineering Development and Construction, Marketing and Communications, and the NJ Transit Police. Ultimately, responsibility was passed to the Senior Director of Corporate Affairs for drafting legislation authorizing the issuance of citations, assessment of fines, and indemnification of personnel involved in fare inspection and enforcement. The LRT Operations Division, assisted by the Communications and Revenue Services Division and the Newark-Elizabeth Rail Link Division, initiated a competitive procurement of consulting services to assist in developing and conducting a proof-of-payment pilot test in the Newark City Subway.

Conclusion

As can be seen from the foregoing project descriptions, NJ Transit has an ambitious program under way to examine light rail transit in a number of corridors throughout the state, although many of the projects described remain in the planning stage, and funding remains a thorny issue. The efforts currently under way represent a major commitment to advancing public transportation.

Through the broad-based efforts to involve all concerned units within NJ Transit in the light rail projects early in the planning phases, the agency has adopted an approach that would make the most of the opportunity for agencywide standardization among its several light rail transit initiatives.

Standardization: Historic Perspectives on Modern California Light Rail Transit Systems

Paul O'Brien, *Sacramento Regional Transit*

Since the first TRB Light Rail Conference 20 years ago, California has been the leader in introducing new light rail systems to the nation. Those systems and the impact of standardization in six key areas—light rail vehicles, fare collection, grade crossings, communications, accessibility, and organization—are reviewed. Each property is compared and contrasted in each category, and a brief rationale is given for decisions made to either emulate the practice at other systems or pursue alternative strategies. Current standard practices are summarized. It is concluded that standardization is less likely to be a priority as the individual systems expand.

Nowhere has the light rail renaissance been more pronounced than in California. In San Diego, Los Angeles, San Jose, and Sacramento, California's new light rail systems have provided mobility and transportation alternatives not seen in the state since freeways overtook and banished the interurban systems of the past. Although it is all light rail, each California city has taken a unique approach to the mode with a resulting diversity of applications. Yet within this remarkable diversity there has been a surprising amount of standardization.

Historically speaking, each system has been influenced more by the wants, needs, and financial realities of its service area than by the influence of a strong central state government role, such as in New Jersey. Some would argue that the standardization among the California systems is not really surprising because the light rail renaissance arose from a common approach that emphasized simple and affordable technology. When these systems were being proposed, it was clear that the Metro model (in Baltimore, Atlanta, Miami, and Washington) was not an affordable alternative. In a sense, the California properties, in particular San Diego and Sacramento, demonstrated that light rail was a credible alternative mode. Their success led directly to the acceptance of light rail as a viable technology in Denver, St. Louis, Baltimore, and Dallas. Although this paper focuses on the California systems, Portland, Oregon, also should be recognized as an example of how a basically "low tech" system demonstrated that light rail was an alternative deserving of serious consideration.

San Diego opened its original 15-mi line in 1981. Extensions since then have brought total route mileage to 33. Sacramento opened its 18-mi line in 1987, and an extension under construction will add 2½ mi next year. San Jose opened a portion of the line in 1987 and completed the entire 21-mi route in 1992. Los Angeles opened the 22-mi Blue Line in 1990 and 15 mi of the Green Line in 1995.

For the purposes of this paper the San Francisco Municipal Railway (Muni) has been excluded. Although Muni shares some modern characteristics with the newer LRT systems, it is, by and large, still primarily a streetcar operation. Muni shares the same track gage with the modern systems and its 600 volt D.C. overhead with San Diego.

Elements of Standardization

A review of standardization could include virtually every aspect of light rail operations. The focus here will be on the six key issues of vehicles, fare collection, grade crossings, communications, accessibility, and organization. Vehicles are touched on because they represent one of the most visible and expensive components of a new light rail system. Fare collection is covered because it dictates to a great extent the range of possibilities in station design. Grade crossings, defined very broadly, are examined because they are often a new and controversial element in the urban landscape and require retraining on the part of motor vehicle operators and pedestrians. Communications will be covered in the context of the capabilities of each system because it is the range and requirements of communications that often dictate staffing decisions. The method of system access influences everything from vehicle design to station design, and once determined it is difficult to change. Finally, the organization of each property is explored because it often determines the visibility of light rail within the overall organization, the priority it receives, and the agency approach to problem solving.

Vehicles

All of the California properties standardized on a long, single articulated car. San Diego and Sacramento did so in order to purchase a service-proven design currently in production and operation. Both Los Angeles and San Jose specified an articulated car to take maximum advantage of one operator in a single car carrying a maximum number of passengers.

All properties standardized on a double-ended vehicle. In the case of San Diego, Los Angeles, and San Jose, the right-of-way available did not allow for a loop at both ends of the line or for short turn loops. In Sacramento use of a single-end car meant increased right-of-way costs that were not offset by the potential savings in vehicle costs.

While San Diego and Sacramento adopted knee to knee seating (essentially open compartments where four people sit facing each other), Los Angeles and San Jose chose the cab facing forward seating. While a conscious decision in Los Angeles and San Jose, the choice in the two Duewag properties was dictated by the buyer's off-the-shelf preference.

All systems initially prohibited advertising on the vehicles. San Diego chose a new image and red color, which clearly distinguished light rail from the existing bus operation. San Jose's vehicles were painted to match the buses. In Sacramento the vehicles received a paint scheme similar to the buses but significantly with no logo to identify light rail as a part of the regional transit system. Los Angeles adopted an elaborately detailed paint scheme completely different from that used by any Los Angeles County bus operators.

Fare Collection

San Diego pioneered the self-service fare collection system in California, and every property thereafter has fallen in line with this method. While all properties have standardized on self-service, each has its own method of enforcement. San Diego contracts with the regional transit organization to provide fare enforcement; Los Angeles uses sworn peace officers; and San Jose started with contracted officers to do fare inspection but now has in-house personnel. Sacramento uses in-house union personnel after opening with noncontract in-house personnel doing fare inspection. In all cases the system has worked well, with evasion rates at less than 3 percent for all properties.

All properties but Los Angeles include a prepaid ticket validator as part of the fare collection process. In Los Angeles the fare machines originally accepted only cash but have been reprogrammed to accept the new Los Angeles token. All other properties use tickets as their prepaid fare medium. No property has chosen to install fare vending equipment on board the rail car.

Grade Crossings

Grade crossings have been a focus of attention for all properties. Unlike in other parts of the country, *grade crossing* has been very loosely defined in California. Crossbucks exist where tracks occupy city streets on nonexclusive rights-of-way completely contrary to operating practice outside of California.

Standardization at grade crossings consists mostly of the use of standard signs. Audible warnings, as required by the state Public Utilities Commission (PUC), range from four blasts of a very loud air horn to the ringing of the vehicle's gong. In between these two extremes, San Jose uses an electronically generated horn and San Diego uses a buzzer type low-volume horn commonly called a quacker.

New grade crossings required a new alertness on the part of motorists and pedestrians. What was once a sleepy railroad freight line in San Diego became a busy urban rail system with grade crossing arms lowering frequently throughout the day. Light rail reappeared in the street in downtown San Diego and created new experiences for cross traffic accustomed only to looking for other motor vehicles. Sacramento also operated in the street but included grade crossings on a one-way street where the train ran contra-flow. San Jose's new experiences included significant median running where essentially left-turn "grade crossings" were created. Los Angeles incorporated all the unusual aspects of the existing light rail systems and added the challenge of operating in an active freight service corridor and around a long one-way loop with a combination of private reservation and shared right-of-way trackage.

The problems encountered by the various properties were diverse. San Jose had to deal with motorists ignoring red arrows and turning left in front of trains. Los Angeles dealt with motorists and pedestrians ignoring down crossing gates and flashing red lights in trying to race the train to a crossing.

As operating experience was gained, each property responded differently to situations that arose, leading even further away from standardization. In San Jose additional signage was added at intersections where left-turn collisions were a concern. Los Angeles began a test program with cameras at selected grade crossings to photograph grade crossing violators. San Diego and Sacramento installed "nearside" signals to minimize gate-down time at crossings where stations were just previous to the crossing.

Communications

Lack of standardization in California is probably best illustrated by each property's approach to what can be loosely termed "communications." While Los Angeles built a control center proudly nicknamed the "Starship Enterprise," Sacramento managed with a paper track schematic and magnets. San Jose installed a supervisory control and data acquisition (SCADA) system to monitor and control traction power and provide information on fare vending machines. San Diego began with a Sacramento-type system but gradually upgraded to provide a certain level of train location information. Some justification for these differences can be found in the number of trains operated (Los Angeles operates twice as many trains as Sacramento, for example), but significantly each property has determined that a different level of oversight and control is necessary.

All properties provide hand-held radios to train operators and supervisors. While San Diego and Sacramento opted for radio chargers in the rail cars, Los Angeles and San Jose had fixed radios mounted in each vehicle.

The complexity of communications led to a direct impact on staffing. Once communications were established, the onus was then on the property to provide monitoring. Hence, Los Angeles has an entire closed-circuit television monitoring staff and a control center staffing double that of any other property.

Accessibility

Each property took a completely different approach to accessibility. San Diego initially was not accessible except to people who could readily climb stairs. Sacramento had to deal with accessibility and wrestled with the difficult issue of high platforms on an urban pedestrian mall. San Jose, too, was concerned about access in its stations. Los Angeles, not having to deal with a pedestrian mall and having a downtown subway and elevated stations, had many alternatives from which to choose.

San Diego ultimately installed lifts on each rail car, balking at the cost of retrofitting numerous existing stations. Sacramento settled for what has become known as the *high block* (or mini-high) platform approach first pioneered in Buffalo. San Jose elected to go with a wayside lift activated by the train operator when necessary at each station. Los Angeles, in light of the significant investment planned in right-of-way structures and mindful of a downtown tunnel, opted for high platforms.

Organization

Organization is not normally considered a potential element of standardization, and clearly there was little in common in the way each California property chose to organize. San Diego set up an entirely new organization completely separate from the existing bus transit organization. Sacramento created a Light Rail Department but included several light–rail-related responsibilities (such as station cleaning and right-of-way fending maintenance) within an Operations Support Department, which also had bus-related responsibilities. San Jose created an entirely stand alone Light Rail Division. Los Angeles took all the rail functions and split them among existing bus departments.

Light rail was clearly a high priority and highly visible in San Diego. Completely separate from the existing bus agency, the light rail operation had an opportunity to establish its own image and reputation. As a separate department, light rail in Sacramento was accorded a level of priority, but as only one component of the chief operating officer's responsibility, it did not achieve the regional priority accorded light rail in San Diego.

In San Jose the light rail operation was clearly visible within the organization and received a high priority when resources were allocated. Because of the differing priorities between the *build* agency (Los Angeles County Transportation Commission) and the *operate* agency (Southern California Rapid Transit District), light rail was highly visible and received a high priority in the region. Within the operating agency, however, because of the fragmentation of the light rail responsibilities, preparing to operate the new rail line was a tedious challenge. The organization was set up among bus transit operating practices, and obvious interrelated areas such as vehicle maintenance and wayside came together only at a very high level and then in competition with bus-related priorities.

Lack of comparable organization structures led to much discussion, particularly in Los Angeles, when staffing decisions were being made. Because the other light rail properties were so differently organized, it was difficult to compare adequately Los Angeles's needs in relation to the other properties. Compounding this situation was the fact that Los Angeles had a level of technology far beyond what existed at any of the other properties.

Review of Standardization Issues and Impacts

Although a comprehensive review and analysis of standardization issues and impacts would be a major research paper, it is clear that standardization had had, and continues to have, an impact on the growth and development of light rail in California. Under the California Public Utilities Commission (PUC), certain issues are, in effect, standardized by state decree (General Order 143A as an example, covering everything from construction to operations and maintenance). However, the PUC has shown sensitivity to the needs of the individual properties and has accepted locally generated solutions to situations as long as the solutions met the requirements of the PUC's general orders.

It is clear that having a car with like components has been a benefit to both San Diego and Sacramento. Parts sharing has taken place, and personnel recruited from San Diego were able to reduce the learning curve in vehicle maintenance in Sacramento. Gearbox issues resulting from similarities in design, although not a deliberate attempt at standardization, in effect were concerns for three out of four properties. Although each property started with essentially "clean" image-based vehicles, Sacramento has now diverged from the standard by permitting exterior advertising.

Having a common fare collection system has benefited all properties. There is statewide unity when enforcement needs are discussed at a statewide level. Although only Los Angeles started with the platform as a paid area, San Diego has embraced the concept nearly systemwide. Just by having a similar system statewide, California has helped reduce the "don't understand the system" fare confusion that still exists among visitors to such cities as Buffalo and Baltimore. As to personnel, the trend has been toward union represented in-house staff for fare inspection. Both Sacramento and San Jose have gone this way after starting with noncontract and outside contracted personnel, respectively.

Grade crossings have become a big issue in Los Angeles, and the trend is somewhat away from standardization, althongh Los Angeles is now using the electronic horn, originally pioneered by San Jose, for grade crossing audible warnings. An effort to begin some sort of standardization move has started, prompted by the Los Angeles experience, within the California Traffic Control Devices group. While light rail is not subject to the Motor Vehicle Code, the code does cover such topics as motorist signage related to light rail. The nearside experiments in San Diego and Sacramento have been highly successful, and these efforts appear to be leading toward a standard in that area. Basically, the nearside system allows grade crossing gates to be delayed in coming down when there is a station stop between the normal call-on circuit and the actual grade crossing.

Little is changing in communications. Aside from San Diego looking into global positioning and some radio enhancements among the properties, most operators have remained with their basic initial designs.

As expected, accessibility has changed little. Once millions are invested in infrastructure, change comes only at a steep price. The biggest move, and this is one toward standardization, is taking place in San Jose. An alternative to the wayside lifts is being sought there because of dissatisfaction with the time required to use the lift and the resulting delay to service. Tentatively, a variation of the high block approach is planned.

Some of the greatest change both away from and toward standardization is in the area of organization. Los Angeles has taken bold steps toward the San Diego/Sacramento model, while San Jose has backed away and moved into the dispersed mode, with rail functions split among bus departments. Los Angeles has moved aggressively to consolidate rail-related responsibilities under a single regional manager. The merger of the formerly separate agencies and California's recession have encouraged the new MTA to examine closely the way business is conducted.

Standardization in the Future

The historic perspective on standardization is a mixed bag. On tbe basis of the traditional approach of equipment standardization, recent history does not bode well for the future. Taking a broader view of standardization, however, encompassing all the issues that affect light rail operation, there is more reason for optimism among standardization proponents. Agreement on an articulated car, proof-of-payment fare system, and rail-specific organization; the effect of PUC General Order 143A; and basic agreement on wayside issues, such as track and signals, encourage those that favor basic tenets of standardization.

Lacking a strong state role in light rail, as is planned in New Jersey, it is unlikely that any cost/benefit analysis will extend beyond the local level to consider the potential impact of standardization savings. The sheer geographic distances and distinctly local perceptions of rail transit work against interagency coordination. As the rail systems, their fleets, and equipment expand, there is less and less incentive to investigate standardization opportunities.

As time goes on the greatest forces for standardization are likely to be the outside influences of the California PUC and the financial consrraints of "going it alone." It can be said with certainty, however, as today's decisions become tomorrow's history and the issues of standardization are debated, the light rail renaissance will continue unabated in California.

Standardization: The Los Angeles Experience in Divergent Technologies

Neil Peterson, *Daniel, Mann, Johnson, and Mendenhall*

The reasons why different rail technologies (heavy, light, and commuter) were chosen for Los Angeles are explained. The attempts to standardize light rail vehicle technology in Los Angeles are reviewed, focusing on the Green Line car decisions. The meaning of standardization and how the Los Angeles experience might provide useful lessons are discussed.

The introduction of rail in Los Angeles after a 40-year absence was planned and is being implemented with the use of three different technologies.

Heavy Rail (Metro Red)

The Metro Red line utilizes traditional heavy-rail subway technology, with its initial operable segment running from Union Station in the east to Westlake/McArthur Park in the west, a distance of 4.4 mi. Like most heavyrail systems, tbe grades are not too severe. Given this, a rigid-body, two-truck vehicle approximately 75 ft long was the optimum solution. Breda supplied the vehicle. The first segment opened in January 1993. Segment 2, a 6.7-mi extension, will have a partial opening in 1996 and a full opening (to Hollywood and Vine) in 1998.

Commuter Rail (MetroLink)

MetroLink, the Southern California Regional Rail Authority's (SCRRA) commuter rail network, covers 400 mi of rail corridors, connecting San Bernardino, Los Angeles, Ventura, Riverside, Orange, and San Diego counties. In October 1990, the SCRRA and the Los Angeles County Transportation Commission (LACTC) reached agreement with the Southern Pacific Railroad to purchase 175 mi of right-of-way for the MetroLink system, which was followed by the purchase from the Sante Fe Railroad of an additional 240 mi of right of-way. The commuter rail cars are built by Bombardier. They are locomotive-haul push-pull design, in a multilevel configuration. They are easily accessible to the elderly and handicapped and have air conditioning and restrooms. They are pulled by state-of-the-art low-pollution diesel locomotives at speeds up to 90 mph.

Light Rail (Metro Blue and Metro Green)

The Metro Blue Line runs from Long Beach in the south up to downtown Los Angeles (Seventh and Flower St. Station). Unlike the Red Line, this line more closely resembles a light rail system, with a few exceptions. Although the cars are articulated, owing to tbe tight curve requirements, have an overhead current collection system, and are equipped for street running in mixed traffic (with automobiles), there are dedicated sections to track along the alignment as well. Moreover, unlike the traditional street-boarding light rail vehicles (LRVs), the Blue Line cars were designed for high-platform boarding only. Although this increased costs of station construction, it is more "user-friendly" to the ridership and allows for faster passenger loading and de-training. The Blue Line opened in July 1990, and ridership has grown steadily since. Current ridership for the 22-mi line is 40,000 passengers per day.

The Metro Green Line, expected to open in July 1995, will run from Norwalk in the east to El Segundo in the west, a distance of 20 mi, with an end-to-end travel time of only 35 min. The Green Line is unique in the metropolitan Los Angeles area in that it will be totally grade separated; in fact, the 16.5 mi stretch from Norwalk to Aviation Station will run down the center of the new Glenn Anderson (Century) freeway. After reaching Aviation Station, the line turns south for 3.5 mi (El Segundo segment) and ends at Marine Avenue in Redondo Beach, near the Pacific Coast. The fact that the line is totally grade separated has made it a candidate for several advanced transit concepts, including fully automated, driverless operation. The Green Line will also be the first recipient of the products output from the LACTC's Advanced Transit Products Development Program (ATPDP), discussed in detail later in this paper. The Green Line system design criteria call for a vehicle design similar to the Blue Line in many ways, but different in other important areas. Key differences are highlighted later in this paper.

Why Three Different Technologies?

Los Angeles chose the different technologies for several reasons.

- Different urban transportation needs. For example, heavy rail is designed to meet daily ridership demands of up to 300,000 riders in a highly congested, very densely populated part of the metropolitan area. Of the 400-mi rail system that is planned, only 24 mi will be dedicated to urban heavy rail. Service is planned to be run frequently with time between trains (headway) as short as 3 min. The trains will include four to six cars in order to carry the number of passengers projected.

Commuter rail was planned to meet the needs of long-distance travelers, from as far away as 80 mi, providing for the first time a rail connection for the 15 million residents of the six-county area of Southern California. Extending over 400 mi today, the commuter rail operation (MetroLink) carries up to 30,000 passengers per day, stopping at stations spaced an average of 5 mi apart, traveling at a maximum speed of 90 mph, pulled by locomotives. Most of the service is designed to meet the needs of commuters, and 80 percent of this service is provided in the a.m. and p.m. peak hours.

Light rail was planned to meet urban transport needs in corridors where maximum ridership is projected to be 50,000 to 80,000 riders per day, with station spacing 1 mi apart, and all-day service with headways of 5 min in the peak hours to 10 to 20 min in the off-peak hours.

- Belief that line-specific railcar technology was not as important as how the lines were integrated as a system. Greater importance was placed on the standardization of how the system interfaces with the public—for example, fare and transfer policies and prices, ticket machines, and station and on-board security.
- Institutions and timing. The first serious planning for rail in Los Angeles was conducted by the then Southern California Rapid Transit District (SCRTD) in the 1960s and 1970s. SCRTD was planning for only the Red Line as a rapid transit line. In the late 1970s and 1980s, another institution, LACTC, developed plans for rail for the rest of the county and the region. The rail planning, design, and construction were not merged until 1991 under LACTC, and the two institutions were merged in 1993.

But what about light rail technology? Why was the technology chosen for the Metro Green Line (MGL) different from that chosen for the Metro Blue Line (MBL)? This question is much more difficult to answer. The answer differs depending upon whether you are referring to the Los Angeles of the 1980s or to Los Angeles today.

In the 1980s, the elected officials in Los Angeles and their representatives serving on the LACTC chose to use a light rail technology for the MGL that was different from the MBL technology. The MGL was to be driverless, fully automated, light rail technology. It was selected for the following reasons:

- The MGL right-of-way was different from the MBL; it was totally grade separated.
- The MGL served the major employment centers of Los Angeles's aerospace industry, which at the time was a significant economic and political force.
- Certain system manufacturers had convinced certain key elected officials that the first driverless automated line in the United States was an important psychological and marketing symbol for the Los Angeles area.
- Certain elected officials believed that Los Angeles, because of its importance in the United States and the world, deserved a world class transportation system, and therefore should specifically not install an extremely simple and low-cost system like San Diego's.
- Some elected officials were convinced that in the long term, the operating savings of the line would more than pay for the increased up-front capital costs.

Sumitomo Decision

The approach to MGL technology changed in 1992 to what is being manufactured today—the LA Standard LRV. The reasons for the change in direction can be traced to the now infamous Sumitomo decision.

Sumitomo Corporation of Japan was recommended by LACTC staff to manufacture the proposed MGL car, a fully automated vehicle that would be a different technology than the MBL. The board agreed, and a firestorm of public criticism and outrage ensued. The decision became front-page news in New York, Washington, D.C., London, and Tokyo and was the lead item on the national network evening news shows in the United States.

Everything in life is timing, and this issue was no exception. During the same time period, two major events were taking place that dramatically affected the political climate surrounding the Sumitomo decision.

1. President Bush had recently returned from Japan on a trip designed to right the huge trade imbalance, but it was being viewed by all as singularly unsuccessful. It was the 50th anniversary of Pearl Harbor to boot, and the TV channels were clogged with videos of the surprise attack on Pearl Harbor. In short, America was not feeling pro-Japan.
2. The Southern California economy was in a significant recession, with property values dropping dramatically, aerospace jobs vanishing, and unemployment at an all-time high. What was worse was the psychological shock to Southern Californians, who thought that they were immune to national recessions.

In addition, the losing bidder, Morrison-Knudsen (MK), under the leadership of its them chief executive, William Agee, chose to exploit the situation by hiring public relations firms to create a "Buy America" frenzy and award the contract to MK.

The board rescinded its decision to award the car contract to Sumitomo. Additional reasons for this termination were as follows:

- The procurement did not guarantee sufficient local job generation in the eyes of some.
- The cost of automation exceeded the present Metro Green Line budget and could put other transit projects in jeopardy.
- The procurement of cars that were exclusively automated and driverless would create a fourth vehicle technology for the existing transit lines (heavy rail; manual light rail; automated, driverless light rail; and commuter rail).
- By purchasing only 41 unique transit cars, the Commission would not be able to realize the economies of scale in vehicle purchase.

LA Standard Car

During the next 6 months, the staff developed and the board adopted the concept of the Los Angeles (LA) Standard Car. In addition, to encourage local job generation, the Standard Car RFP required the following:

- Creation of the ATPDP, which required each proposer to the LA Standard Car Contract to team with a "high-tech" partner for the purpose of developing three advanced transit products. These products were to be tested and developed on the two prototype cars, which would then be used for ATPDP programs in future procurements. The commission has committed to fund this development up to a ceiling of $10 million. It was hoped, of course, that several of the high-tech partners would come from the local aerospace community, hit hard by both the recession and the reduction in defense funds. Much effort and evaluation went into the issue of why not encourage the aerospace firms to get back in the rail car manufacturing business. However, after discussion with the firms involved, it became obvious that the best opportunity for them was to help them develop products that would have a potential worldwide market, rather than get them involved in possibly manufacturing rail cars for Los Angeles with very little hope of being able to penetrate the already highly competitive market throughout the world. The viability of the three product ideas was scored in the proposal evaluation.
- Creation of a Domestic Business Development (DBD) program, in addition to requiring the FTA-mandated 60 percent domestic content. The DBD required each proposer to provide "new start businesses" as part of its proposal package. New businesses, or existing businesses never involved in the transit market, or existing transit suppliers interested in a new product line were eligible for consideration. In addition, the commission directed the creation of a *Product and Services Directory* of small Los Angeles firms that expressed an interest in exploring the transit market. This directory was published and forwarded to all holders of the RFP documents. DBD was included as a scored category in both the Standard Car and ATPDP portions of the proposals.
- As a final incentive to the creation of local job generation, the commission set a Small Minority Business Enterprise (SMBE) goal of 10 percent. In addition, "bonus points" were available up to 5 percent of the maximum possible proposal score for providing SMBE or MBE content up to an additional 10 percent over the base 10 percent goal.

What is the LA Standard Car? The Los Angeles move to standardization of its light rail vehicles incorporates

Vehicle Type

Standard:	Can be universally applied to all LA light rail lines
Modular:	Can be "upgraded" or "downgraded" in modular fashion in order to work with a variety of signal systems
Compatible:	Will work in train with existing Blue Line equipment
MU Operation:	Cars are capable of running in trains of up to three cars

Carbody Type

Six-Axle, Articulated LRV
High-Platform Loading
Four Bi-Parting Doorways per Side
LAHT Steel Construction

Key Dimensions

Height:	12 ft., 4 in.
Width:	8 ft., 8.75 in
Length:	Undefined, other than that length necessary to meet clearance restrictions, and that the car shell must accommodate at least 66 passengers seats

Service Performance Characteristics

Acceleration:	3.0 mph/s
Deceleration:	3.5 mph/s
Top Speed:	65 mph

Propulsion Characteristics

AC Propulsion
Two Bi Motor (End) Power Trucks
One (Center) Unpowered Truck
Auxiliary Inverter

Braking System Prioritization

Regenerative Braking
Resistive Braking
Air Friction Braking
Track Brake

Current Collection

750 VDC Nominal Catenary Line Voltage
Single Arm Pantograph

FIGURE 1 Technical description, Los Angeles standard light rail vehicle.

the concept that certain components of the car can be standardized, but certain other components need to be able to be upgraded as technology advances. A three-tier concept of standardization was developed (see Figure 1):

- Standard design component,
- Flexible design component, and
- Modular design component.

The standard design group would include those basic items that would remain identical, or very nearly so, from procurement to procurement, such as car body dimensions, structural design, truck design, equipment locations, and so forth. The flexible design group would include those items that may be upgraded for each new procurement in order to take advantage of advances in the state of the art and the competitive bidding process. This design group would include most subsystems, such as propulsion, auxiliaries, braking, air conditioning, door controls, and so forth. The final design group is the modular component, which would allow the commission two additional degrees of freedom:

- The ability to switch modules between cars, allowing, say, a Blue Line Standard LRV to become a Green Line or Pasadena car; and
- The ability to upgrade vehicles on a given line to more sophisticated levels of technology at some time in the future. The Metro Green Line cars would be the most obvious beneficiary of this concept.

Siemens Duewag was awarded the LA Standard Car contract in July 1994. The first car is scheduled to arrive in Los Angeles in June 1996.

Conclusion

The Los Angeles experience in divergent technologies is not one that others should copy; however, often in life lessons are learned and advances in thinking occur as a result of a crisis. Standardization became important over time in Los Angeles for the reasons outlined. What Los Angeles developed was a concept of standardization that allowed for

- The agency to receive the benefits of competitive bidding in the future;
- Certain components that could be upgraded in the future as technology advances; and
- An opportunity for the involvement of American industry in developing products that have a potential worldwide market.

Joint Use Corridors

Issues Associated with Light Rail Transit Use of Freight Railroad Right-of-Way

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During the 1980s and early 1990s, through railroad mergers and consolidations, many less profitable and redundant freight rail services were eliminated, making abandoned rail right-of-way available for other uses. During this period, light rail transit (LRT) experienced a resurgence in the United States, and LRT operators became interested in abandoned and active freight railroad properties as locations for investment. The joint use of right-of-way by LRT and freight railroads is an approach being considered for several new light rail projects. These include the New Jersey Waterfront project, Tampa LRT proposal, expansion of the New Orleans waterfront trolley, and extensions in Denver, Dallas, Sacramento, St. Louis, and elsewhere in the United States. Issues pertaining to LRT utilization of freight railroad right-of-way are discussed, and successful LRT/freight joint-use experience in Baltimore, Maryland, and San Diego, California, are described. Regulatory requirements and lessons learned from the transit agencies are reviewed. Observations and recommendations for further research and study are made.

Many significant changes took place throughout the railroad industry in the early 1970s, beginning with the collapse of the Penn Central and the formation of Consolidated Rail Corporation (Conrail) in 1976. Railroad mergers and consolidations became commonplace. During the 1980s and early 1990s, many less profitable and redundant freight rail services were eliminated, making abandoned rail right-of-way (ROW) available for other uses. During this period, light rail transit (LRT) experienced a resurgence in the United States, and rail transit operators became interested in abandoned and active freight railroad properties as locations for rail transit investment.

Joint use should not be viewed as a revolutionary concept. Indeed, joint use has a long tradition in the United States with many innovative and efficient approaches utilized over the last century. One good example is the shared use relationship enjoyed between railroads and the electric interurban services in many locations across the country.

From the transit operator's perspective, use of freight railroad ROW offers a number of actual and perceived benefits, including the following:

- Minimized environmental impacts: Noise, vibration, visnal, and neighborhood disruption impacts of LRT are less within an established rail corridor than in new LRT right-of-way.
- Minimized utility impacts: Utilities are already configured in a linear fashion.

• Fewer curves and flatter grades: Railroad ROW is generally relatively straight and flat, allowing higher LRT operating speeds than street ROW.

• Minimized and consolidated road crossings: At-grade railroad crossings are generally minimized, and major roadway crossings are concentrated at a limited number of grade-separated crossings.

There are four general approaches to LRT use of freight ROW:

1. Parallel an existing active freight railroad. This would place the LRT tracks adjacent to the freight trackways either in the same right-of-way or in a new one. Within the same right-of-way, clearance dimensions between centerlines are usually specified by the railroad. Clearances range from around 15 to 20 ft typically barrier-separated up to about 40 ft. Transit alignments in new right-of-way adjacent to a rail line are much less common. One of the key reasons is that the land use types normally found adjacent to rail corridors do not lend themselves well to acquisition of a 30- to 50 ft-wide strip for the LRT trackway.

2. Relocate an existing active freight railroad through consolidation with another railroad providing comparable service. This provides benefits both to the railroad in the form of faster operating speeds through the periphery of urban areas and to the general public with less impact to at-grade street crossings owing to slow-moving freight trains.

3. Joint LRT/freight use on the same tracks, typically accommodated by limiting LRT and freight operation to mutually exclusive times of day. This approach requires close coordination and cooperation between the two operating entities. Quite often, the freight operations are performed by a short line railroad under contract or owned by the transit agency. This provides the necessary control by the transit agency to ensure reliable passenger operations.

4. Petition the Interstate Commerce Commission (ICC) for abandonment of the railroad ROW. In this approach, the rail right-of-way has suffered years of nonuse and neglect, often with leases of the property or encroachments. This approach can sometimes require significant time but provides a clean operating environment.

Table 1 summarizes issues associated with each of these four utilization strategies. Of the four approaches

TABLE 1 Summary of Approaches to LRT Use of Freight Rail Right-of-Way

Approach	Issues
1. Parallel Operation	• To help protect itself from liability, freight operator may require horizontal separation of up to 40 feet and possible installation of a crash barrier. • Freight railroad may require LRT agency to assume total liability and/or to carry very high insurance coverage. • Freight railroad may require that proposed LRT at-grade crossings (especially pedestrian crossings near station platforms) be reconfigured to grade separated crossings. • Adjacent land owners accustomed to rail traffic. • At-grade rail crossings grouped together. • At-grade rail service to customers located on the side of the LRT corridor is problematic. • Railroad-oriented development potential of land adjacent to the LRT system may be compromised.
2. Relocate Freight	• Existing utilities, because many have been located along the railroad ROW as linear features, might easily be avoided. • Following construction of LRT, redevelopment along the corridor can proceed unimpeded by freight influences/impacts. • Negotiations with the railroad can be slow. • The costs associated with relocation of the freight railroad may not be justifiable.
3. LRT/Freight Joint-Use	• May be the only approach if ROW is limited and abandonment not possible. • Efficient use of track facilities. • Car design pertaining to buff impact loads must conform to Federal Railroad Administration (FRA) requirements if traffic intermingles without separation on different tracks or by time of day. • Extent of FRA regulation of transit operator is dependent upon segregation of LRT and freight operations and whether trackage is connected to the "general system of railroads" regulated by the FRA. • Track design and conflicts with system components such as catenary and passenger facilities such as station platforms, including horizontal and vertical clearance requirements, on sections utilized by freight must conform to FRA freight regulations. • FRA regulation may extend to elements of the transit system which affect freight operations, including signals, track and dispatch.
4. Freight Abandonment	• Affected railroad will be responsive once formal proceedings are submitted to the Interstate Commerce Commission. • If successful, the LRT can be constructed as under Approach 2, *Relocate Freight*. • Approval process can be slow. • On-line rail customers, existing and potential, may petition to maintain rail service.

SOURCE: William D. Burgel, unpublished paper presented at Institute of Transportation Engineers 1994 District 6 Meeting; Baltimore Mass Transit Administration; San Diego Metropolitan Development Board; BRW, Inc., 1994.

described in Table 1, LRT/freight joint use allows continued operation of LRT and freight with the least amount of new investment in trackage, crossing control, and other infrastructure.

Regulatory Issues

Two primary sources of regulation affect shared LRT/freight rail operations: the Federal Railroad Administration (FRA) and state public utility commissions. FRA regulations are contained in the *Code of Federal Regulations* (49 CFR 200.1–266.25). In some states, public utility commission regulations are promulgated as general orders. California is an example of a state that has developed general orders. By comparison, the Texas Railroad Commission enforces FRA regulations but does not promulgate its own.

Federal Railroad Administration regulatory issues pertaining to joint LRT/freight operation include the following:

- LRT/freight traffic intermingling: Under segregated LRT and freight operation (e.g., through time of day restrictions), FRA regulates only the portions of the transit-owned rail system affecting freight operations, which include signals and switching track. When freight and LRT traffic are intermingled, the system is typically subject to full regulation as a freight rail operator. A number of operating schemes, such as temporal mitigation, which assigns trackage use to specific portions of each day, can be used to address these regulations. Under such regulation, all transit employees would be considered railroad employees and therefore eligible for participation in the Railroad Retirement System, and the transit operator would be subject to the Federal Employer's Liability Act (FELA), which among other provisions removes the ceiling on employee injury and disability claims.
- Minimum buff impact loads: When freight and LRT traffic is intermingled, FRA requires that all rail vehicles, freight and LRT, meet minimum end (buff) impact standards. These standards relate to the end-to-end impact, which can be sustained without damage.
- Side clearance: FRA side clearance requirements for freight vehicles preclude the use of high level LRT platforms, which extend too far over the trackage.
- Vertical clearance: FRA vertical clearance requirements for freight cars and locomotives require significantly higher placement of overhead catenary than is typically required for LRT vehicles.
- Connectivity to the "general system": The single most important determinant of FRA regulation is whether the rail system connects to the general system of railroads. The basis for determination of connection is not clearly defined and can be somewhat subjective and subject to subtle distinctions.

LRT/Freight Joint Use Experience

Successful LRT/freight joint use arrangements in Baltimore, Maryland, and San Diego, California, are in existence and were studied for this paper. Key issues and recommendations gathered through interviews with transit and freight operations staff are presented below.

Baltimore: Mass Transit Administration of Maryland

The Mass Transit Administration of Maryland in Baltimore (MTA) has successfully shared LRT rail trackage on its Central Line with two freight railroads, Conrail and the Canton Company (a contract short line freight operator utilizing the former Baltimore & Annapolis Railroad ROW), for approximately 4 years. In 1988 the MTA initiated procedures to acquire right-of-way for the approximately 22.5 mile Central Line, a north–south LRT line bisecting the City of Baltimore and connecting the central city with outlying areas to the north and south. The line is depicted in Figure 1.

After approximately 3 years of planning and negotiation, MTA was successful in acquiring ownership rights to the right-of-way and establishing operating agreements with Conrail and Canton allowing LRT operation between 5:00 a.m. and 12:00 a.m. and freight operation between 12:00 a.m. and 5:00 a.m. ROW acquisition and the operating agreement were negotiated simultaneously.

The MTA is not currently regulated by the FRA, although the MTA and FRA are engaged in a debate over the question of connection to the general system of railroads and significance for future FRA regulatory involvement. The MTA currently utilizes FRA signal and track regulations as guidelines. MTA employees are not eligible for the Railroad Retirement System, and the MTA is not subject to FELA.

ROW Acquisition Issues

Key issues encountered in the acquisition of the freight rail ROW include the following:

- Establishment of clear title/identification of ownership rights: The trackage utilized by Conrail was established in 1823, and identification of the exact nature and extent of Conrail ownership rights required signif-

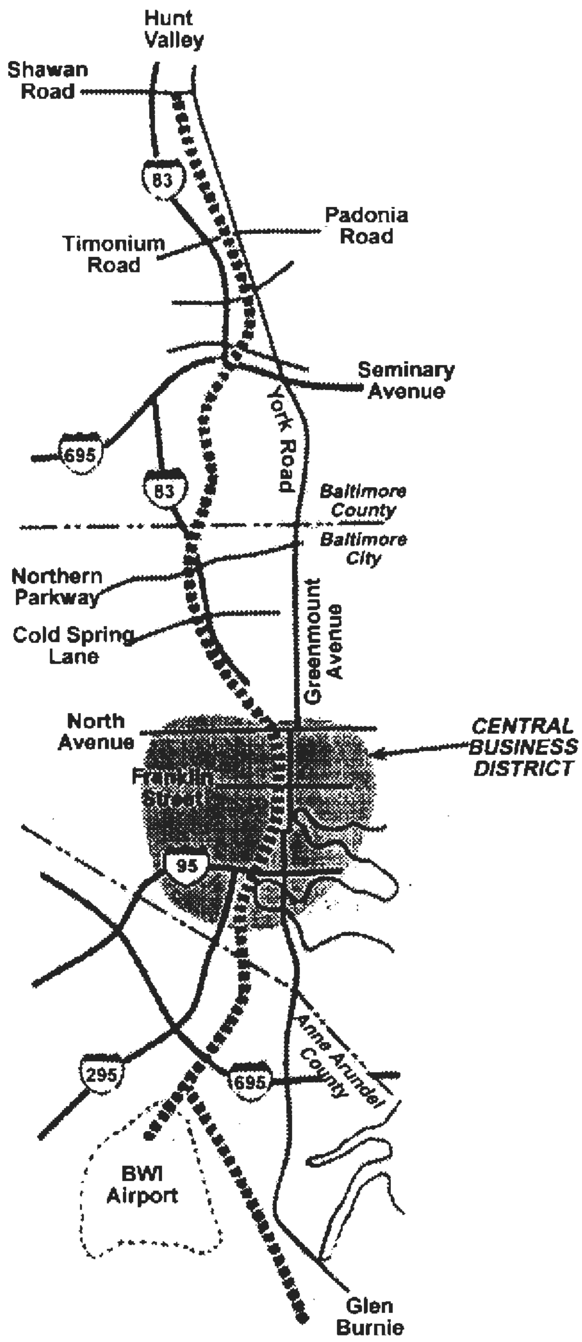

FIGURE 1 Baltimore's Central Rail Line, running along existing railroad corridors north and south of downtown.

icant research and was one of the first steps in negotiations.

- Dispatch rights: Dispatch rights describe the authority to schedule rail operations and were one of the most important issues for MTA. The MTA required dispatch rights in order to allow flexibility in scheduling special event LRT service, including baseball games at the new Camden Yards ballpark.
- Maintenance of freight service: Ensuring continued service to key freight customers was an important objective in negotiations. Success in maintaining service was due in part to the fact that the shipping needs of one of Conrail's major customers were not time-of-day sensitive and could be accommodated within the limited freight operating hours established in the agreement.
- Liability: Conrail's concern about liability for damages to LRT patrons and vehicles, along with design issues relating to LRT/freight compatibility, including FRA buff end loading standards, was an important reason why simultaneous LRT/freight operations were rejected as an option. Negotiation of liability was complicated by MTA's status as a state agency and its inability to indemnify.

Operational Issues

Critical operational issues encountered by the MTA include the following:

- Employee operating rules: Freight employees operating on transit system–owned trackage must be trained in both transit and freight operating rules. Effective integration and communication of these rules is critical. The MTA approach has been to provide freight employees with transit system operating rules supplemented with a list of exceptions applicable to freight operation.
- Freight operator compensation: Freight operator compensation to the transit operator for use of trackage can be negotiated into the initial ROW purchase price (as done with Conrail) or made on a percentage of gross revenue basis (as done in San Diego) or on a carload basis (as done with the Canton Company). When paying by the carload, it is to the advantage of the freight operator to maximize carloads. This incentive can affect freight car vehicle selection and the resulting rate of track wear and maintenance needs.
- Significance of "general system" connectivity: Connectivity to the "general system" of railroads is a key determinant in FRA regulation. When connection exists, the FRA may regulate a transit/freight operation. The determination of connectivity can be somewhat subjective, may hinge on subtle distinctions, and can change in response to relatively minor changes in freight connections. Obtaining a definitive and lasting determination by the FRA can be difficult.
- Station platform design: FRA side clearance requirements preclude the use of high-level LRT station platforms. The MTA approach to senior and disabled boardings uses Sacramento-type LRT vehicles and a high block bridge system featuring a small portion of ramped platform interfacing with an on-board ramp,

which is extended by the transit operator from the LRT vehicle.

Lessons Learned

Baltimore MTA staff offer the following conclusions and recommendations on the basis of their successful LRT/freight joint use experience:

- Get all that you pay for. Ownership consists of a bundle of rights, including ownership of the physical property and various operating privileges. An important point is that the price paid for ROW fairly reflects the degree of ownership and current and future control given by the transit operator. As operating rights and other privileges are granted to the freight operator, the value of the ROW to the transit operator is reduced.
- Transit operator control of dispatch can be critical. Special events, such as sporting events and conventions, and the flexibility to provide special transit service to these events require transit operator control of dispatch. In order to address FRA regulations such as the intermingling of traffic versus buff-strength requirements, separation of the two operations by time of day is practiced.
- Avoid track and ROW sharing if possible. Owing to the complications imposed by joint LRT/freight use, including employee work rules and ongoing susceptibility to full FRA regulation, separate LRT and freight facilities may be preferable. Obviously, reserved ROW for transit lines is preferred but not always possible considering costs and other considerations such as local impacts.
- Consider long-term transit vehicle needs. Consideration should be given to designing to freight vehicle standards even on portions of the LRT system that are never expected to be used by freight vehicles. This allows maximum flexibility in future transit vehicle use, which may involve vehicles with requirements similar to freight vehicles.
- Operating agreements should reflect long-range plans. When using time-of-day segregation of LRT and freight operations, long-range transit operating needs and the implications for freight operating and maintenance time windows should be considered in negotiating the initial operating agreement. If freight operator compensation is to be based on freight carloads, operating agreements should also limit the size and weight of freight vehicles.

San Diego Metropolitan Transit Development Board

The San Diego Metropolitan Transit Development Board (MTDB) purchased the 108-mi San Diego & Arizona Eastern Railway Company (SD&AE) from the Southern Pacific Railroad in 1979. Since 1981, MTDB (through its wholly owned subsidiary, San Diego Trolley, Inc.) has operated LRT service along a portion of the railroad trackage, and beginning in 1984 has shared a portion of that trackage with the San Diego & Imperial Valley (SD&IV) Railroad, a short-line freight operator. The MTDB agreement with SD&IV allows exclusive LRT operation from approximately 5:00 a.m. to 1:00 a.m. and exclusive freight use from approximately 1:00 a.m. to 5:00 a.m. The SD&IV pays MTDB a percentage of its revenues for use of the trackage. Figure 2 shows the South and East lines constructed within the railroad ROW.

San Diego Trolley is regulated by FRA for signals, trackage, and controlling (dispatch). San Diego Trolley is not classified by FRA as a freight railroad operator, however, and is not subject to FELA, and its employees are not eligible for participation in the Railroad Retirement System.

ROW Acquisition Issues

The greatest challenge faced by MTDB in acquiring the freight railroad ROW for LRT use was locating a freight contractor able to ensure the maintenance of freight service required by ICC.

The agreement reached between MTDB and the SD&IV was the culmination of a 5-year effort to establish a successful freight partnership. In 1978, before MTDB acquisition, ICC denied the Southern Pacific Railroad's request to abandon the SD&AE, ruling that freight service must be maintained. After purchasing the SD&AE in 1979, MTDB initially contracted with Kyle Railways to provide freight service. Unable to operate successfully under Federal Railroad Administration short-line freight regulations, Kyle Railways ended operations in San Diego in 1983. In 1984, MTDB signed an agreement with RailTex to provide freight service as the San Diego & Imperial Valley Railroad. Under the RailTex agreement, LRT and freight operations are segregated by time of day, a form of temporal mitigation.

Operational Issues

The following issues have been significant in MTDB's shared trolley/freight operations.

- Shrinking freight operating window/expanding LRT service: Since service began in 1981 LRT operating hours have expanded several times, shrinking the freight operating window. Since 1984 the demand for freight shipping has remained and even increased periodically, and periods of simultaneous operation of freight and LRT service have become more frequent, jeopardizing

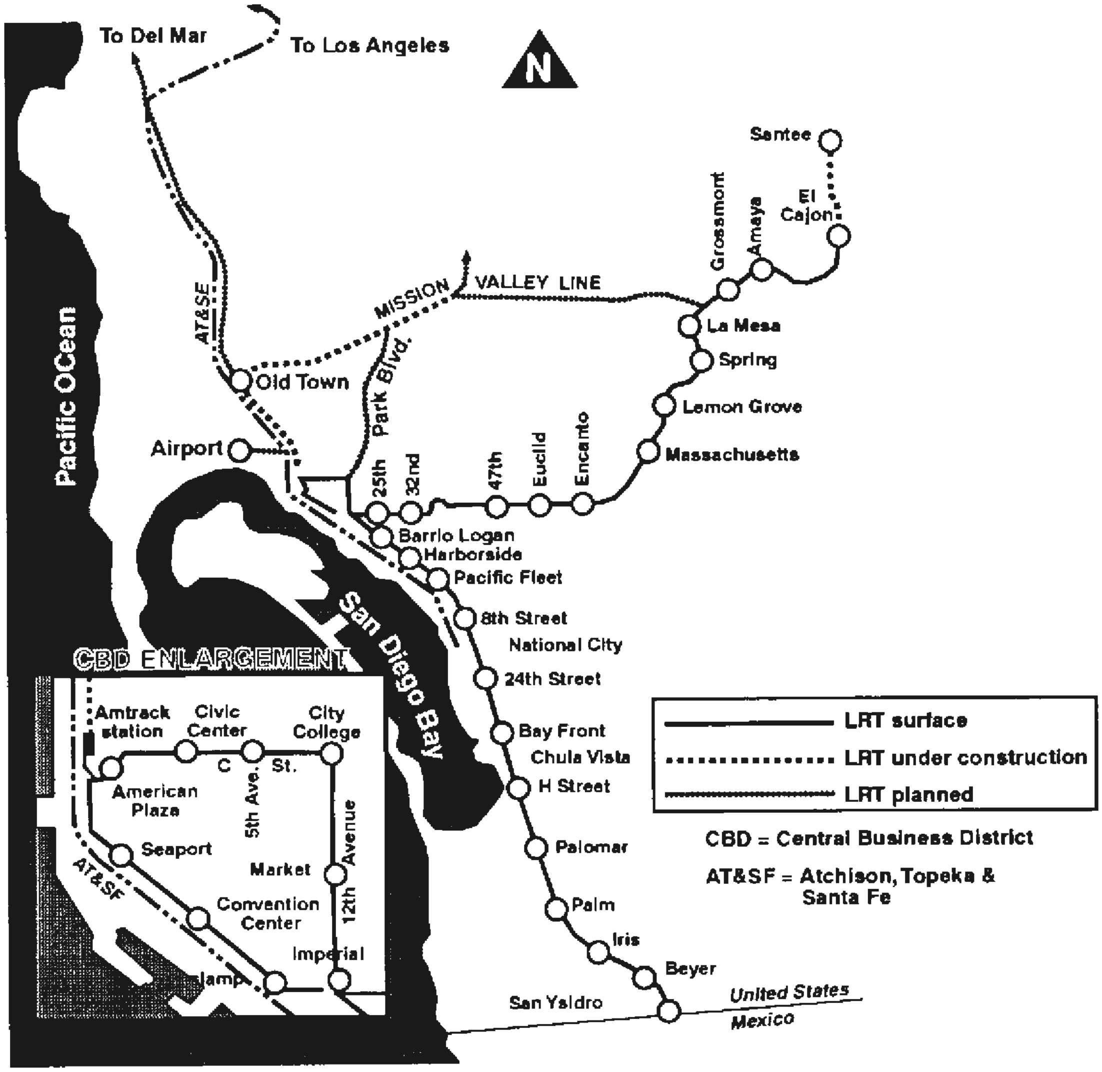

FIGURE 2 San Diego's South and East lines, within abandoned freight rail right-of-way.

exemption from full FRA regulation. As a result of FRA inquiries, MTDB is now formulating a new operating plan, which will more effectively restrict simultaneous LRT/freight operation.

- An approach to better deal with freight and transit vehicle interface mentioned by MTDB would be to undertake regulatory reform of the vehicle rules. Significant experience exists with recent transit/freight operations in the United States that could be used in the revision work. Similarly, substantial experience exists from European sources on buff end strength that could be applied.
- Station platform design: Because of California PUC and FRA side clearance requirements (8 ft 6 in.), no high-level LRT platforms have been used on the portion of LRT line shared with the SD&IV.
- Employee operating rules: In response to FRA requirements, the San Diego Trolley Rules and Instructions for Employees includes regulations for trolley and SD&IV employees.
- Vertical clearance: Because light rail and freight vehicles are used on the same track, LRT overhead catenary has been installed higher on share trackage than elsewhere in the LRT system in order to comply with PUC/FRA clearance requirements.
- Block signal issues: Timing of railway crossing signals on share trackage is based on the stopping distance and other requirements of freight vehicles, which are much greater and result in longer signal timings.
- Unionization: Freight operator union work rules can make coordination with LRT operations more difficult. Successful cooperation between the San Diego

Trolley and the SD&IV has required the sort of flexibility that sometimes does not exist under railroad union labor agreements.

Lessons Learned

San Diego Trolley and San Diego & Imperial Valley Railroad staff offer the following conclusions and recommendations on the basis of their successful LRT/freight joint use experience.

- Expect LRT operating hours to expand. If time of day LRT/freight segregation is used, plan on LRT operating hours to expand. Build into the operating agreement procedures that address contraction of the freight operating window and maintenance of freight service under such conditions. Transit operators should not assume that the demand for freight movement will decline over time or that LRT operating hours will not increase.
- Employee cross-training is important. Operating practices or equipment design issues relatively insignificant for LRT may significantly affect freight operations and vice versa. Successful cooperation between LRT and freight operations requires mutual understanding of the two operating environments throughout the planning, design, and operations phases. In some cases, the emphasis among rail transit planning and operations staff is on transit rather than rail, since many rail transit professionals come from a transit background. Conversely, many freight operators are unfamiliar with transit operations. Employees with transit and freight backgrounds are an asset for both operators.
- Expect the nature of freight operations to change and plan for it. The nature of the freight operation (e.g., material transported, length of trains, weight of cars, etc.) can significantly affect equipment and operating requirements. The LRT/freight operating agreement should address how changes in freight operations and requirements will be addressed.
- Avoid ROW sharing if possible. On the basis of difficulties in finding a successful freight partner and the ongoing and escalating complications generated by the need to accommodate equivalent or increasing freight operations within a shrinking operating window, MTDB's advice is to avoid shared LRT/freight operation if possible.

Observations and Recommendations

Significant experience has recently been gained in the joint use of freight rail trackage by transit services, particularly LRT lines. Two major properties in the United States that have operating experience with joint use have provided many lessons, several of which can be applied elsewhere or used to guide further research.

1. Avoid track and/or ROW sharing if possible. This subject was mentioned by both the Baltimore MTA and the San Diego MTDB as a preference from the transit agency's perspective. Reserved ROW is the preferred operating condition of all rail operators, both transit and freight railroads. However, shared ROW can be a cost-effective means to implement transit service earlier than would otherwise be possible. Although both agencies would prefer exclusive ROW and track, each readily agrees that the more important objective is to provide the transit service and to do so in a safe and cost-effective manner.
2. Plan for changes. Rail transit lines are built to last 50 to 100 years. Many will be around much longer, similar to the railroad lines they are replacing and joining. Because we cannot be certain of the future, we need to plan effectively for changes. Growth in ridership is often thought of in planning for transit, but planning for increases in freight service is also important in a shared use arrangement.
3. Vehicle compatibility remains a key constraint. The compatibility of freight rail cars and transit vehicles remains a major constraint to joint use operations. Because of significant differences between the two types of vehicles and the possibility of accidents between them, regulations have been promulgated that constrain joint operations. Two of the more important areas that directly affect LRT use and should be addressed in further research are clearances and buff end strength.

Low platforms are required for LRT along joint freight lines to accommodate lateral clearances. ADA accessibility requirements and other issues have caused transit agencies to look for solutions. Low-floor light rail vehicles (LRVs) may help, but these also introduce questions about buff end strength and telescoping as a result of nonuniform coupling heights. Issues such as these demand that more research be undertaken.

Significant experience exists with joint operations in this country and with additional studies on buff end strength in Europe, and regulatory reform of FRA standards for LRVs is appropriate. Additional review and research could be conducted to assist with reform of the regulations.

Joint Use of Track by Electric Railways and Railroads: Historic View

J. William Vigrass, *Hill International, Inc.*

Transit agencies are considering operating light rail or commuter railroad service on existing freight railroad tracks because of the high capital costs to construct new exclusive trackage for passenger service. A number of institutional, regulatory, and technical barriers, among them the buff strength of passenger carrying cars, must be overcome to allow joint use of railroad track. Case studies are examined: San Diego Trolley, Baltimore Central Light Rail Line, South Shore Line, and others. Historic cases will be examined to illustrate how joint operation was handled from 1900 to the 1950s. Also noted are examples of rulings as to what is a railroad. A number of Interstate Commerce Commission decisions turned on whether an electric railway was an interurban railway or a railroad that was "part of the general steam railroad system of the United States." In general, the proportion of railroad interchange freight revenue to passenger revenue was the deciding factor. The nature of freight service has been crucial to joint use. Whether it is line haul, local, slow, or fast governs how much time it will occupy the joint track. Axle loading may be important for design, construction, and maintenance of joint track. Frequency, the time of day, and the time sensitivity of the freight are important. Careful analysis of a railroad's needs has to be done and the plan developed to meet those needs; otherwise, the railroad company does not allow joint use. Only one vestige of joint use remains: the South Brooklyn Railway. Two new-start LRT lines, San Diego and Baltimore, have joint operation, separated temporally. Their example can provide guidance for present LRT planners. Can the several barriers to joint use in the United States be overcome to make LRT and other forms of rail transit more affordable, yet safe? History and current overseas experience indicate that they can.

There is substantial and increasing interest worldwide in operating electric railway services on the same track with railroad service. The reality of high capital costs to construct new exclusive trackage for electric railway transit service in a time when capital funding is severely restricted has forced agencies to consider, study, and in some cases use existing railroad track. In the most recent cases, the track itself has been replaced with new track of continuously welded rails.

Several recent light rail transit lines share track with railroad freight service. These will be examined. Some persons may believe that these few cases are innovative; in fact, there are numerous rail precedents, most of them abandoned years ago. Others fear that sharing a track with a freight railroad will bring burdensome railroad regulations upon a transit agency. Several instances will be cited from the present and the past showing electric railway transit services sharing track with a railroad without the transit operators falling under regulation as a railroad by the Interstate Commerce Commission (ICC).

Two examples of heavy rail transit sharing track with railroad carload freight service will be offered. The transit operators retain or retained their status as local transit systems that were not regulated as railroads.

In other cases, two operators of rapid transit-type service were classified as railroads. The reasons for this situation will be examined with the view of avoiding being classified as a railroad.

Even though there are successful examples, barriers of several kinds remain: institutional, regulatory, and technical; they will be described.

What Is a Railroad?

First it is important to define a railroad. The Interstate Commerce Act of 1887 (United States Code, Title 49, Subtitle IV) defines it as "part of the general steam railroad system of the United States." Every subsequent case has been adjudicated on its own merits, yet all have a common thread. If the rail line in question is part of the "general railroad system" ("steam" is no longer used), the company engages predominantly in interstate railroad freight or passenger traffic. Several measures have been applied. If a given company is not itself an interstate carrier, it can still be adjudged as engaging in interstate commerce, and under federal regulation, if it handles freight cars and/or passengers in interstate commerce. An intrastate short line railroad is engaged in interstate commerce if it handles a freight car (or passenger) traveling on an interstate waybill (or ticket).

There is a substantial body of case law in which the ICC classified companies as railroads or interurban electric railways on the basis of whether the freight traffic they handled was "predominant" or "incidental." There was no hard and fast rule. Each case was decided on its own merits. The measure was always whether the company was a railroad or not. Decisions did not revolve around the track itself. That is an important distinction.

Ex Parte 179 and Buff Strength

During 1953 and 1954 the ICC held hearings under a proceeding designated Ex Parte 179 and promulgated new regulations in CFR 49 Part 229.141 (D). This designated railroad multiple unit (MU) passenger carrying cars as locomotives, because they are self-propelled and subjected them to inspection standards and safety appliances that apply to locomotives. More importantly, buff strength standards for MU cars were also established. For trains weighing 600,000 lb tare (empty), buff strength per car of 400,000 lb was required. For a train of over 600,000 lb, buff strength of 800,000 lb was, and is, required. The regulation applies only to railroad MU cars.

A similar requirement had been previously imposed by contracts with the Post Office on any Railway Post Office (RPO) cars to protect the mail and railway mail clerks. In practice it established 800,000 lb for all railroad passenger trains cars. In most cases it is not possible for a railroad to predict train weights, hence they are designed to the higher standard.

At least two MU car fleets were designed to 400,000 lb. One was Port Authority Trans-Hudson (PATH), which was designated a railroad under another proceeding. Its K cars of 1958 and later PA cars were designed to 400,000 lb because an eight-car train of those 60,000-lb cars weighs less than 600,000 lb. Another example is the Staten Island Rapid Transit Railroad Operating Authority (SIRTOA), which acquired a small fleet of NYCTA R-44 subway-type cars in the early 1970s designed to the 400,000-lb standard. Its short trains were not supposed to exceed 600,000 lb tare.

The key point is that the buff strength regulation applies only to railroads. The ICC's safety and technical regulatory responsibilities are now carried out by the Federal Railroad Administration (FRA).

Rail transit is under the jurisdiction of the Federal Transit Administration, which has no regulatory authority. It is established transit industry practice to design heavy rail cars (i.e., high platform) to 200,000-lb buff. Light rail vehicles (LRVs) have been designed to about twice the weight of the car, but this is variable.

Significant to the transit industry is that Ex Parte 179 and CFR 49 part 229.141 (D) apply only to railroads.

Railroad Rapid Transit Line: The Hudson and Manhattan

A unique case is that of PATH Corporation, which earned the status of being a railroad in 1936, in its then status as the Hudson and Manhattan Railroad Company. The case was brought about by employees who wished to be under the Railroad Retirement Act. At that time there were few pension programs, and that of the railroads was deemed the most favorable to employees. In the days of the New Deal, with its strong support by organized labor, the employees were given due consideration.

The case was reported in an abstract from the *George Washington University Law Review 1938–1939* and is reproduced below because it is unique and has been cause for concern for certain present day interstate rail transit lines.

> In the Hudson and Manhattan proceeding, however, the Commission, on an apparently new principle, held that this subway railway was not an electric interurban within the meaning of section 1 of the Railway Labor

Act as amended. The following is a brief description of the Hudson and Manhattan: it is 20.3 miles long including sidings and yards but not including the 5.71 miles owned by the Pennsylvania Railroad and over which both operate joint trains. It has two branches, one from upper and one from lower New York City, running under the Hudson River through a tunnel and connecting on the New Jersey side of the Hudson River where there are railroad stations and bus and trolley terminals at Journal Square and Park Place, in Newark. Its tracks are similar to those used in New York subways, and there are numerous curves and no level straight sections on its line. The passenger cars are narrow. The revenues of the Hudson & Manhattan are derived 26.08% from non-railway operations and 8.13% from non-operating sources. Of the remainder of its income, local fares account for 77.03% and the interline business 22.97%.

The jointly operated section consists of 3.2 miles of Hudson and Manhattan track and 5.71 miles of track owned by the Pennsylvania. Expenses are borne in the ratio of 40-60%, about the same ratio as the track contributed. About 10% of the Hudson's employees are engaged in this joint service and when on the Pennsylvania section are subject to Pennsylvania rules and regulations. The Pennsylvania has a ticket office in the Hudson Terminal of the Hudson and Manhattan in New York where tickets to all Pennsylvania Railroad lines may be purchased. . . .

The Commission said: "In our opinion a carrier which participates in joint fares *and joint operations* with trunk line railroads to the extent this carrier does is not a mere interurban." Now the Hudson carries no freight, and outside of this joint operation with the Pennsylvania it engages in no operations similar to those of a steam railroad, and, as a matter of fact, because of its physical characteristics it cannot do so. Its operation, both in character and in extent, are interurban, that is, the carriage of passengers only for the short distance from New York under the Hudson River to Newark, the latter part of the line being that operated jointly. Therefore, in construing this railway to be more than an electric interurban the Commission proceeded on a principle not found in its previous decisions, for none of the operating characteristics found in those other cases are present here. There is nothing inconsistent with the nature of an interurban railway in the joint operations here conducted, that is, it is still engaging in operations germane to its character. If any explanation is needed it seems that it is the Pennsylvania which steps out of character, as it were, by engaging in a purely local movement of passengers. The principle of all the other determinations has been that if the interurban engages to a considerable extent in operations similar to those of a steam carrier it is not an interurban within these provisions. No case is found where the Commission has ruled in effect that if a steam railroad engages to some extent in local operations of a given interurban, then that interurban is no longer an interurban within the various sections of the Interstate Commerce Act or related acts. [216 ICC 745 (1936)]

The key item in the above Hudson and Manhattan case is that it was "a carrier which participates in joint fares *and joint operations*"; it is the joint operation that made the Hudson and Manhattan unique. Pennsylvania Railroad (PRR) employees and trains operated on the Hudson and Manhattan. Hudson and Manhattan trains operated on the PRR under PRR's control. That is what made the Hudson and Manhattan a "railroad," subject to railroad regulation.

A joint fare, by itself, does not affect the status of a carrier. There are numerous examples in history of railroad-steamship, railroad-bus, and even interurban-airline (Cleveland Southwestern Railway and Light Co./ Stout Airlines, Cleveland–Detroit in the 1920s), none of which affected the status of a carrier.

The small conjunction *and* was the key to the Hudson and Manhattan decision: "joint fares *and* joint operation."

During the 1960s, the Port Authority of New York and New Jersey (PANYNJ) took over the property of the Hudson and Manhattan Railroad Company and the segment of railroad between Journal Square, Jersey City, and Newark formerly owned by the PRR and operated under the joint service agreement. A new entity, Port Authority Trans-Hudson Corp., was created to operate the transit service and the PANYNJ began a major capital rehabilitation and modernization of its newly acquired property. The process continues.

Railroad trains were removed from what had been the joint track, except for an occasionally used crossover. Joint fares were abolished. PATH collects its own flat fare. The conditions that led to the ICC's classifying the Hudson and Manhattan as a railroad no longer exist, yet the PANYNJ has not applied to reclassify the transit line operated by PATH. They have given certain reasons why they believe there are certain advantages in remaining a railroad. Yet, PATH has applied for and has been granted waivers by the ICC and FRA from certain specific regulations.

This curious situation causes concern to certain other interstate rail transit lines that are not classified as a railroad. Their managements fear that their transit lines might be classified as railroads and become subject to the Hours of Service Law, the Locomotive Safety Appliance Act, the Locomotive Inspection Act and, most importantly, the Federal Employees Liability Act (FELA), whereby railroad employees sue their employers for injuries resulting from on-the-job injuries. Railroads are not subject to Workmen's Compensation.

Staten Island Rapid Transit Railroad Operating Authority

The only other rapid transit line that today is classified as a railroad is Staten Island Rapid Transit Railroad Operating Authority (SIRTOA). Its status is well founded in its history.

The Staten Island Railway was completed in 1860 to fill the needs of local passenger and minor freight traffic within Richmond Borough of New York City on Staten Island. Its connections to the outside world were by ferries. In 1880 the Staten Island Rapid Transit (SIRT) was formed to acquire by lease and extend the railway. In 1885 the Baltimore and Ohio (B&O) Railroad Co. acquired the SIRT and constructed a drawbridge across the Arthur Kill to New Jersey to create a connection with mainland railroads (*1*). The connection was completed in 1888. B&O developed SIRT as its freight terminal in New York, where car float terminals and piers were built. The SIRT was owned and operated as part of the B&O Railroad system. In the 1920s the B&O electrified the SIRT using technology based on that used by the Brooklyn-Manhattan Transit Corporation (BMT), looking forward to a connecting tunnel under The Narrows to allow through service to Manhattan over the BMT. The tunnel was not built. The SIRT remained an isolated passenger carrier yet fully integrated into the railroad freight network.

The B&O Railroad Co. losses on operating the service became untenable, and replacement of the 1925 vintage BMT-type rolling stock became necessary. Forced to deal with cessation of rail service, the city of New York acquired the SIRT from the B&O. SIRTOA was then incorporated as a railroad to operate freight and passenger service. In 1971 the city acquired the St. George-Tottenville mainline. Carload traffic declined and in due course was suspended. Nonetheless, SIRTOA remains a railroad.

In the 1970s new rolling stock of the NYCTA R-44 type was obtained for use by SIRTOA. These cars are designed to 400,000 lb buff strength required for railroad cars rather than the 200,000 lb customarily used for rapid transit cars.

In 1995 the conditions that caused SIRTOA to be deemed a railroad no longer exist, but its status is unchanged.

Port Authority Transit Corporation

Port Authority Transit Corporation (PATCO) is not a railroad, and purposely attained this status through carefully prepared plans by owner Delaware River Port Authority (DRPA) as follows.

The PRSL thereupon applied to abandon all service into Camden, but would retain service to 30th Street Station in Philadelphia via the Delair Bridge. Hearings were held in 1964 and 1965, and permission was received in November 1965. The final passenger train ran on January 15, 1966 over the Camden-Haddonfield segment of the route, ending railroad train service that had begun in 1854.

DRPA's legal counsel, in applying to the Interstate Commerce Commission for a "certificate of convenience and necessity" to construct the new rapid transit line, had carefully described the type of service that would be operated. It would be a frequent passenger service, not a part of the general railroad system of the United States; no interline train operation would be undertaken; no railroad freight cars would be handled in interchange service; no interline fares with railroads would be published. The presentation by DRPA was influenced by the fact that the Port Authority Trans-Hudson Corporation of the Port Authority of New York and New Jersey was in fact a "railroad" subject to ICC rules and regulations for railroads. Its predecessor, the Hudson & Manhattan Railroad, had been ruled a "railroad" in the mid-1930's on the basis of its interline operation with the Pennsylvania Railroad on that portion of the PRR between Journal Square, Jersey City, and Newark, N.J. The DRPA wanted no part of "railroad" regulation, and put its house in order before it made its presentation. It had applied for permission to build the new line and simultaneously submitted a motion to dismiss the case because the line to be built would not be a "railroad." They did the job well for under a service date of August 25, 1965 under Finance Docket No. 23694, the ICC stated:

> *We find*, That the railroad properties of applicant and the proposed extension constitute an interurban electric railway within the meaning of that term as used in section 1 (22) of the Interstate Commerce Act; that such properties are not and will not be operated as a part of a general steam railroad system of transportation; and that, accordingly, the Commission is without jurisdiction in the premises . . . and
> *It is ordered*, That applicant's petition to dismiss be, and it is hereby granted, and that the application and protestants' motions for consolidation with other proceedings be, and they are hereby, dismissed for lack of jurisdiction.

Section 1 (22) of the Interstate Commerce Act, as amended, provided:

> The authority of the Commission conferred by paragraphs (18) and (22), both inclusive, shall not extend to the construction of street, suburban or interurban electric railways, which are not operated as a part or parts of a general steam railroad system of transportation.

On November 23, 1965, the ICC further ruled that the new line would not be subject to the Safety Appliance Acts or the Locomotive Inspection Act (*2*).

The DRPA had clearly demonstrated how an interstate rail transit line could be ruled to be a nonrailroad. Because it engages in interstate commerce, PATCO was required to file its tariffs with the ICC, and did so. This caused some confusion within the ICC tariff bureau because of PATCO's unique status as an interurban electric railway. On several occasions, ICC file clerks phoned PATCO and asked what PATCO's motor carrier certificate was, judging that "transit" equated with "bus." It took some lengthy explanation to them that an interurban electric railway was neither a railroad nor a bus line.

Several other nonrailroads are engaged in interstate transportation of passengers: Washington Metropolitan Area Transportation Authority (WMATA), connecting Maryland and Virginia with the District of Columbia, and Bi-State Metro Link, connecting East St. Louis, Illinois, with St. Louis, Missouri. The latter crosses a freight railroad at-grade but shares no track. Both WMATA and Bi-State share right-of-way with a freight railroad, a fairly common practice.

In early plans, some gauntlet and/or joint operation with railroad freight was proposed. In preliminary engineering, that was eliminated in favor of separate track to remove complications to operations and to ensure that Bi-State Metro Link had no legal link to railroad freight. An interlocked diamond grade crossing provides access to a railroad industrial track on the opposite side of Metro Link's right-of-way.

Interurban Electric Railway Industry in the Midwest

Between 1895 and 1938 the interurban electric railway industry was created, developed, flourished, declined, and disappeared. During its classic period, 1910 to 1930, thousands of miles of interurban railways and street railways connected hundreds of municipalities and the intervening countryside in Ohio, Michigan, Illinois, and Indiana. Other states had extensive systems, but none were interconnected or so large. Interurbans began as mere extensions of street railway lines into the country or to the next town. They quickly grew to intercity lines competing to an extent with steam railroads for through city-to-city business, but they largely concentrated on local traffic. Steam railroad technology was ill suited to handling it, whereas single-car trains or short multiple-unit trains (two or three cars) were ideal.

In the period before widespread use of automobiles, they flourished. Most offered express service for parcels carried in passenger cars. Many offered less-than-carload (LCL) freight service in freight motors, which sometimes hauled freight trailers. Private sidings were rare. Nearly all freight was carried to and from freight houses by wagon (drays). Service was more frequent and direct than that offered by steam railroads. Electric interurban railways often dominated selected market segments. Freight was not a major factor in revenue before the 1920s (*3*).

During World War I steam railroad congestion became great, and this generated opportunities for interurbans to siphon LCL from railroads, often with the latter's silent blessing. Interurban freight grew rapidly in the 1920s, and its revenue offset declining passenger revenue as passengers became motorists.

Some interurbans interchanged LCL with railroads, but interurban rolling stock was not interchanged. It was designed for light track with sharp curves, and while standard gauge with knuckle couplers, it was not acceptable for railroad interchange because it was too lightly built. Most interurban freight trains had two trailers, with some having five or eight. Long trains were not possible. Most municipalities regulated train length by ordinance. In Cleveland streets, trains could not exceed three cars, including the motor car.

The entire interurban railway system was separate from "the general steam railroad system of the United States." It evolved its own work rules and technology, which were generally lighter and cheaper than railroads. Wages were generally much less and there were few employee benefits other than a pass.

A few interurbans were designed and built to handle "steam railroad" freight cars and did so from inception. Small trolley freight locomotives were used. They participated in joint rates and division of revenues with mainline railroads. When it became necessary to classify them as interurban or railroads, a body of case law evolved in which it was found that if railroad freight was "incidental," the railway was considered an interurban. If freight was significant, it became a railroad. A 50 percent of revenue rule came to be accepted as a measure of significance of freight (*4*).

During the 1920s and 30s as passenger and interurban freight declined in the face of improved highways, some interurbans that were able to do so began to handle railroad interchange freight. With the onset of new railroad regulation, more cases developed that furthered precedents already established, as described above. No less than 42 factors were considered in evaluating a case, but the primary measure was the percentage of revenue from railroad interchange freight.

Under the Railway Labor Act as amended June 21, 1934, the status of 15 electric railways was determined. Only one was found exempt, the Chicago North Shore and Milwaukee, but it was later found to be a railroad even though its railroad interline freight revenues were relatively small. The 14 electric railways that were found to be railroads in the 1930s are as follows: Texas Electric Railway, 208 ICC 193 (1935); Sacramento Northern Railway, 208 ICC 203 (1935); Waterloo, Cedar Falls & Northern Railway, 208 ICC 211 (1935); Piedmont & Northern Railway, 211 ICC 4 (1935); Ft. Dodge, Des Moines & Southern Railroad, 211 ICC 9 (1935); Chicago Tunnel Co. and Chicago Warehouse & Terminal Co., 214 ICC 81 (1936); Chicago, South Shore & South Bend Railroad, 214 ICC 167 (1936); Des Moines & Central Iowa Railroad, 214 ICC 353 (1936); Utah, Idaho Central Railroad, 214 ICC 707 (1936); Salt Lake & Utah Railroad, 214 ICC 717 (1936); Pacific Electric Railway, 215 ICC 414 (1936); Hudson & Manhattan Railroad, 216 ICC 745 (1936); Oklahoma Railway, 218 ICC 123 (1936); and New York, Westchester & Boston Railway, 218 ICC 253 (1936).

All but the Westchester had been built as interurban railways. The Westchester was built as an electrified railroad to haul commuters. It had a minuscule freight business but was wholly owned by the New York, New Haven and Hartford Railroad and was found to be a railroad for that and other reasons.

The context of these decisions must be kept in mind: it was during the 1930s when the Roosevelt administration strongly supported organized labor.

From the point of view of joint use of track, the principal asset of an interurban railway, examples can be found of a company providing local suburban passenger service, local and express interurban passenger service (i.e., between cities), local and interline interurban LCL package freight service, and railroad LCL and carload interchange freight. The three Chicago interurbans were perhaps the best examples: Chicago, Aurora & Elgin (CA&E); Chicago, North Shore & Milwaukee (CNS&M); and Chicago, South Shore & South Bend Railroad (CSS&SB).

Only the third remains in operation. It is a full fledged railroad, with heavy carload freight service. Track is shared with the Northern Indiana Commuter District, which operates electric commuter railroad service. South Shore's substantial freight business allowed it to survive as a company. Its two neighboring lines depended largely on passenger revenue, even though having been classified as railroads in the 1930s, and were abandoned in the late 1950s (CA&E) and 1963 (CNS&M). North Shore and South Shore were pioneer piggyback freight operators but their haul was too short (90 mi) to survive.

The inner segment of CA&E was shared with Chicago Rapid Transit Co. trains, which required high platforms for their cars that were 8 ft. 8 in. wide. To clear 10-ft.-wide railroad freight cars, the lip of the wooden platforms was hinged. It was folded up when a freight train passed. A trainman riding the deck of the locomotive reached ahead with a boat hook and flipped up the platform lip segments as the train slowly proceeded; another trainman in the caboose flipped them back.

The CNS&M used gauntlet track to allow 10-ft-wide freight trains to pass platforms sized for North Shore's passenger cars (8 ft. 8 in. wide) designed to operate on the Chicago Elevated (the L). Each had its own way. Both worked.

CSS&SB was built to railroad dimensions with 10-ft-wide passenger cars.

Carload Freight on Urban Rapid Transit Lines

There are two examples of successful operation of railroad carload freight on rapid transit tracks that did not cause the rapid transit line to be classified as a railroad.

Chicago Rapid Transit Company

Carload freight service was provided on the North Side Howard Street line of the Chicago Rapid Transit Company (CRT), later becoming the Chicago Transit Authority (CTA).

The Chicago L was built on structure ending at Wilson Avenue, about half way to the city limits at Howard Street. The Milwaukee Railroad owned a right-of-way from Wilson Avenue to Howard Street and leased the use of it to CRT Co. As part of the agreement, CRT provided delivery of carloads of freight to private sidings on the west side of the right-of-way. This was a four-tracked CRT line with the two center tracks local, and the two outside tracks express, used also by CNS&M trains. A lengthy gauntlet track provided clearance past rapid transit platforms.

The CRT did the switching during midnight hours for the Milwaukee Road and received a flat fee per car. The freight customer was billed by the railroad and paid the railroad; CRT was merely a contractor. When CTA took over CRT and assumed ownership of the railroad right-of-way, the process continued using the same two electric locomotives. Traffic was largely coal for home heating, with some refrigerator cars of foodstuffs. The market for home heating coal disappeared and other traffic took to trucks or to intermodal piggyback. Traffic declined to the point where CTA abandoned it. There was never a legal case on the status of CRT/CTA. It simply happened. (Conversation with George Krambles, CTA).

South Brooklyn Railway Co.

Common carrier railroad interchange freight operates on a short segment of the Brooklyn-Manhattan Transit Division of the New York City Transit Authority. A brief description follows (5):

> The South Brooklyn Railway (SBK) operates today as a common carrier whose president is, ex officio, the president of the NYCTA. The railroad has 1.5 mi. of track and two "road haul" locomotives. At one time the SBK was a much larger operation using electric freight motors. It served consignees along its own "mainline" between Coney Island and Bush Terminal and served sidings along other routes such as the Sea Beach Line. SBK trains operated on the surface beneath the Culver elevated from Coney Island to the Ninth Avenue Station of the Culver. From this point they operated through the lower (Culver) level of the station and then shared trackage with West End and Culver trains through the Culver Tunnel to Fourth Avenue, where they diverged and continued on their own route to Bush Terminal. Operation continues today, using diesel locomotives between Bush Terminal and Tenth Avenue. The NYCTA is the SBK's largest customer, however, some private consignees remain. The NYCTA maintains 24-hr passenger operation through the Culver Tunnel, hence movement of freight trains occurs over joint trackage in between passenger trains. Freight trains are short (less than six cars) and operate with a locomotive at each end when on joint trackage. The use of two locomotives provides protection against a loose car as well as improved tractive effort. Joint operation is currently being rediscovered ("Advance" 1971; Bergmann 1977) as a means of sharing the fixed plant costs of new transit services or as a necessary consequence of converting railroad rights-of-way to transit use; unfortunately, few contemporary studies on joint operation make note of the SBK operation.

The South Brooklyn Railway is a regulated common carrier hy railroad. It is part of "the general railroad system of the United States." It happens to operate on the same track as NYCTA rapid transit subway trains. Separation is enforced by the absolute block rule, by which only a SBK train or an NYCTA train may be on the jointly used track at one time. This has been an ongoing, if low volume, operation for about 100 years. Legal separation is maintained.

Texas Interurban Railway Co.

The Texas Interurban Railway Co. created a new interurban railway between Dallas and Denton, Texas, in 1924, a very late date to have built a new line. It was the result of an agreement between the City of Dallas and General Electric Co., owner of the Dallas Railway & Terminal Co. The city wanted two new lines, apparently to further business and commerce in Dallas. Denton was small, population 7,628, and intermediate territory contained only 1,200 persons per mile.

To serve this sparse territory as cheaply as possible, it was decided to electrify the existing Missouri-Kansas-Texas Railroad (M-K-T). The new line used 3½ mi of streetcar track in Dallas and a short distance on McKinney Avenue in Denton. The rest of the 38.66 mi was on the M-K-T.

Construction began in January 1924, and the line opened for operation October 1, 1924, in 9 months. Little new construction was needed. Simple catenary was hung above M-K-T's single track.

There were hourly interurban cars and two electric express (LCL) cars, plus two steam passengers and one steam freight train daily. Lightweight one-man interurban cars were used, but a porter was carried who could act as a flagman on that single-track unsignaled railroad. This provided customary railroad-type protection. Passenger trains, steam or electric, were first class, electric express second class, and steam freight third class. At sidings steam passenger trains were superior and held the mainline.

M-K-T dispatchers controlled the line. The dispatcher was in Dallas where the interurbans left the M-K-T, and the switches were normally set for the frequent interurhans. The dispatcher would throw the switches for steam trains, then realign them after the train passed. The low-roofed lightweight cars had a trolley stool on the roof so the pole could reach the railroad height (23 ft) catenary. Six lightweight passenger cars and one lightweight freight car were bought from American Car Co., with four GE 265 motors of 35 hp each. This equipment was generally good for 44 mph.

The Denton line was never a financial success and was foreclosed under bankruptcy in 1932. The cars were sold for $300 each to the Dallas Railway & Terminal Co., which modified them for city service by removing the lavatory, replacing the pilot (cowcatcher) with a wheelguard, and making other minor changes. They ran as city cars until 1953 (6).

The line was built quickly at low cost and evidently operated satisfactorily. It was never investigated by the ICC during the 1930s because it was abandoned. Its cars weighed about 30,000 lb and could not come close to meeting railroad strength requirements.

Texas Interurban Railway handled no railroad interchange freight itself so was not a railroad, even though it operated on railroad track.

Utica & Mohawk Valley Railway Company

Another electric railway that operated on "steam railroad" track was the Utica & Mohawk Valley Railway Company, which connected Rome, Utica, and Little Falls, New York (*7*). It operated on 3.17 mi of the West Shore Railroad between Frankfort and Herkimer, New York, in 1903. Simple catenary with bracket arms on poles on the outside of the double-tracked route was used. Operation was protected by "block signals of the standard New York Central type." Operation was by signal indication, making it unnecessary for the railroad dispatcher to issue train orders to scheduled trolleys or railroad trains.

On the basis of the successful installation described above, the interurban company also electrified railroad track between Utica and Syracuse known as the Oneida Line. Wire was 24 ft above the top of rail in accordance with the owning railroad's requirement. Much of the joint line used under running third rail. The West Shore's owner, New York Central, appeared to be cooperative with these specific electric railways.

The West Shore electrified lines were abandoned in the early 1930s, so were never subjects of adjudication to determine whether they were railroads or not. Their abandonment made their status moot.

Youngstown & Southern Railway Company

The Youngstown & Southern Railway (Y&S) was designed in 1903 as a third-rail electric railway to "steam road" standards to connect Youngstown with Columbiana, Ohio, 15 mi distant. It was built, not electrified, and operated by steam for 3 years. It was finally electrified with direct suspended overhead trolley in 1907 using two trolley wires, one for each direction, over single track. The wires simply spread at spring-switch-operated passing sidings. It operated large, heavy, single-end wooden interurban cars until the 1920s during which time six lightweight double-end trolley cars were obtained. Two weighed 28,520 lb, among the lightest ever built, and four weighed 33,000 lb, a more common weight. Business declined, and even though the lightweight cars lowered expenses, the Y&S faced abandonment.

In 1929 it was acquired by the Pittsburgh Coal Company (PCC), which had also bought the Pittsburgh Lisbon & Western (PL&W) to the south of Youngstown. Y&S built a line between Columbiana and Signal, Ohio, 6.45 mi (using PCC financial assistance) to connect Y&S with PL&W. The latter served some of they coal company's mines. PCC also built a private railroad from Negley, Ohio, to Smith's Ferry, Pennsylvania, with a barge/rail transfer terminal for its own coal traffic, thus providing a route from the Ohio River to Youngstown's steel mills. With its own rail route, PCC could charge itself less than the published railroad tariff rates then in force. Legal cases were brought by other railroads, primarily the Pennsylvania Railroad, but PCC prevailed because its coal was subject only to an intrastate railroad move, not to ICC regulation. The private railroad to Smith's Ferry, Pennsylvania, did not exist insofar as the ICC was concerned. This arrangement kept Y&S alive from the 1930s to the 1950s (*8*).

Steam locomotives would haul trains of standard railroad coal hoppers up to Signal, then on the electrified Y&S from Signal, to Columbiana, north to a long siding at North Lima, Ohio. There the steam train would meet a southbound train of empty hoppers hauled by two Y&S 40-ton box cab 400 hp Baldwin-Westinghouse electric locomotives. Locomotives and cabooses would be exchanged, and the Y&S electric locomotives would haul the coal train on to Youngstown to its interchange with the Lake Erie & Eastern, a switching line that was part of the NYC system. The steam train, with its empty hopper cars, would head back south to Negley. One round-trip a day was the usual freight train service. It always ran extra, not scheduled, carrying white flags. En route to Youngstown the electrically hauled freight train would meet one or two lightweight trolleys headed in the opposite direction.

The Y&S was an unsignaled single track railroad operating under timetable and train order rules. One-man trolley operators wrote out their own train orders, received by lineside telephone. There were no agent/operators in stations. All turnouts were hand thrown.

The Y&S, in various reorganizations the Youngstown & Suburban, was always a railroad and handled interchange freight. Yet until passenger service was abandoned in 1948, lightweight one-man-operated trolleys operated on the same track with electric- and steam-operated freight trains. Insofar as is known, there was no regulatory effort to cause such service to cease. Y&S's safety record was not perfect. A head-on collision of a trolley with a freight train occurred in the early 1930s, and two trolleys collided later causing one lightweight car to be scrapped. (It was not required for traffic anyway.) Regular peak service during World War II was provided by four of the five trolleys, with one spare. All-day base service required three trolleys.

The Y&S provided frequent (every 30 min) suburban service as a right-of-way very much like a modern light rail line. It operated on unsignaled single track at 44 mph on timetable and train order authority.

The Y&S still exists as a shortened switching line between Youngstown and Boardman, which was the end of frequent (30 min headway) suburban service. The line was converted to diesel power in the early 1950s and trolley wire was removed. The Y&S has remained when nearly all of its interurban contemporaries built in the first decade of the 20th century have been abandoned.

Keokuk Electric Railway

Another example of an electric railway electrifying and using a "steam" railroad was the Keokuk (Iowa) Electric Railway. It obtained trackage rights and electrified the bridge over the Mississippi River of the Keokuk-Hamilton Bridge Company, and thence to Warsaw, Illinois. These tracks were simultaneously used by the Toledo, Peoria & Western Railway and the Wabash Railway, which operated steam-powered freight trains. Scheduled passenger trolley operation was discontinued in 1928.

Here was an instance of an interstate trolley sharing an interstate railroad bridge with steam railroad trains. A tourist trolley operates across the bridge today.

Other Interstate Lines

The Indiana Railroad (IR) and its predecessor, Interstate Public Service Co., operated across the New York Central System's Big Four (Cleveland, Cincinnati, Chicago, and St. Louis) bridge between Jeffersonville, Indiana, and Louisville, Kentucky, from the early 20th century to the IR's abandonment in the late 1930s. The Big Four bridge was single track and unsignaled. A railroad flagman protected the bridge at each end of the bridge. For an interurban train to gain entry to the bridge, the flagman would telephone for clearance. Only after permission was granted was the interurban allowed to proceed onto the railroad track and across the bridge. This reflects use of the absolute block rule: only one train (of any kind) was allowed on the bridge at a time. This joint use lasted until the IR was abandoned in the late 1930s.

The Louisville and New Albany (L&NA) Interurban Railway connected Louisville, Kentucky, with New Albany, Indiana, immediately across the Ohio River. It used the Kentucky & Indiana Terminal (K&IT) Railroad Co. bridge. This was double tracked and was owned jointly by the B&O, Southern Railway, and Monon Railroad (Chicago, Indianapolis & Louisville). The L&NA used street railway type equipment: one-man–operated Peter Witt type motorcars supplemented in rush hours by a trailer with conductor. Approach to the K&IT bridge was controlled by railroad-type semaphore signals. A flagman boarded each L&NA train at the bridge approach with his railroad flagman's flag, lantern, fusees, and torpedoes. In case the L&NA train made an unscheduled stop, he would protect its rear under Railroad Rule 99 (flagging). L&NA cars carried full-sized railroad marker lamps at their rear (personal communication with Walter A. Zackon).

The L&NA was 5-ft-gauge, the same as Louisville Railway's streetcar system. Its rails were laid on the same ties as the standard (4 ft 8½ in.) gauge K&IT, but the four-rail gauntlet track gave each mode its own rails. The L&NA operated until shortly after World War II, at which time it was abandoned.

IR was an interurban; L&NA was a street railway. Neither was a railroad. Their rolling stock was built to interurban or street railway standards. None approached railroad standards. There is plenty of photographic evidence that the service existed.

Here again, interstate trolleys shared interstate railroad bridges with steam railroad trains successfully.

Two Contemporary Light Rail Lines Sharing Track with Railroad Freight Trains

San Diego Trolley Inc.

The first of the modern light rail lines in the United States was the San Diego Trolley, Inc., created by the San Diego Metropolitan Transit Development Board (MTDB).

The MTDB acquired the San Diego & Arizona Eastern (SD&AE) Railway, once a part of the Southern Pacific Railway. A major portion of the line in Mexico had been damaged by washouts and fires in its timber-lined tunnels. A short line operator provided freight service from points in Mexico, crossing the border at San Ysidro, to San Diego, where there was, and is, an interchange with the Santa Fe Railway. The freight service was important so had reason to be preserved.

The MTDB acquired the SD&AE railway and granted the railroad rights to operate over it. MTDB created subsidiary San Diego Trolley, Inc., to operate the trolley service and maintain the railway. San Diego Trolley is not "part of the general system of railroads of the United States." It provides only local passenger service.

SD&AE railroad provides international common carrier railroad carload freight service. Interline carload service via the Santa Fe to all rail points in North America is available. SD&AE is a railroad. San Diego Trolley is not. Both share the same track, largely owned by MTDB.

It was reported verbally that San Diego Trolley had explained to the FRA region in San Francisco that diesel-powered railroad freight trains would operate weeknights between midnight and 5:00 a.m. when there would be no trolley service. FRA did not object. There has been no formal hearing or decision.

Baltimore Central Light Rail Line

Baltimore's Central Light Rail Line of the Maryland Mass Transit Administration is the newest (1992) light rail line to share track with railroad freight service.

The MTA acquired a segment of the former Northern Central Railroad from Conrail under an agreement that granted Conrail trackage rights in perpetuity to provide common carrier railroad carload freight service. The Northern Central's remnant is identified as the Cockeysville Industrial Track of Conrail.

Hours and days of the week when freight trains may operate are stated. Generally it is midnight to 5:00 a.m., 3 days per week, according to Exhibit E of the Agreement of Sale, operating agreement between MTA and Conrail, March 29, 1990. A similar agreement with the Baltimore and Annapolis Railroad is in force on the southern end of the Baltimore Central Light Rail Line.

Both San Diego and Baltimore use low platforms that do not create a clearance problem for railroad freight trains. San Diego uses carborne lifts for ADA handicapped passengers, whereas Baltimore uses high block miniplatforms with bridge plates for ADA compliance. Both agreed to having freight trains operated by the former owners continue to provide carload freight services but at specified hours, midnight to 5:00 a.m. Interstate carload freight service was preserved. New light rail local passenger service was created. The light rail operators do not provide carload freight service, so both have retained their status as non-railroads. Legal and physical separation have been maintained. The public has benefited, and a precedent has been established that others may find useful to follow.

It is well to note that historic examples generally accommodated one freight move per day. In no case is a busy mainline freight railroad used jointly. Only lightly used freight lines can tolerate frequent transit service.

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Hudson-Bergen Light Rail Transit System Joint Occupancy–Joint Use

Richard F. Hernon, *New Jersey Transit*

Light rail systems share their rights-of-way with most other modes of ground transportation. The proposed Hudson-Bergen Light Rail Transit System and the planned and potential joint use and joint occupancies are described. Transportation systems and modes that will or could share the light rail transit route are freight railroads, commuter railroads, roadway vehicles, pedestrians, bicycles, and utilities. Methods of accommodating other kinds of transportation are also discussed.

Light rail transit (LRT) can share its operating alignment with most other forms of land-based transportation. Many, if not all, light rail systems in operation share their alignments with one or more forms of transportation. New Jersey's proposed Hudson-Bergen Light Rail Transit System (H-BLRTS) is being designed to share its right-of-way (ROW) with a number of other transportation systems. This paper discusses the proposed multimodal uses of the H-BLRTS right-of-way.

Proposed System

The H-BLRTS is a proposed 33-km light rail system composed of three branches that will radiate from the yard and shop site (Figure 1). The yard and shop site and one of the major park and ride lots will be located adjacent to the Exit 14C toll plaza on the New Jersey Turnpike Extension. This major junction is referred to as Gateway.

One branch will extend north from Gateway to the southern and eastern edges of downtown Jersey City for about 2.5 km. The branch will then continue 2 km through easements provided by three Waterfront developers to Hoboken. Upon leaving the easement area, the alignment will cross New Jersey (NJ) Transit's Hoboken rail yard into the city of Hoboken. In Hoboken the alignment will run 4.6 km on the east side along local roads. Most of the Hoboken alignment follows streets on the former Hoboken Shore Railroad, much of it on the west edge of the Hudson River.

North of Hoboken the alignment will follow the former Consolidated Rail Corporation (Conrail) River Line 4.0 km to and through the Weehawken Tunnel. After leaving the west portal of the tunnel, the light rail tracks will occupy the to-be-acquired Conrail Northern Branch for about 3.4 km to 83rd Street. From 83rd Street the LRT will occupy jointly with Conrail on the Northern Branch until the alignment reaches the New York Susquehanna & Western's Edgewater Branch. From there, it will turn west to run 1.2 km jointly along that branch, cross 0.2 km of wetlands and the New Jersey Turnpike Eastern Spur, and terminate at the Vince Lombardi park and ride. The total length of the Northern Branch of the LRT is 19.2 km.

A second branch will extend from Gateway south 9.6 km on the NJ Transit Bayonne Branch to the tip of the

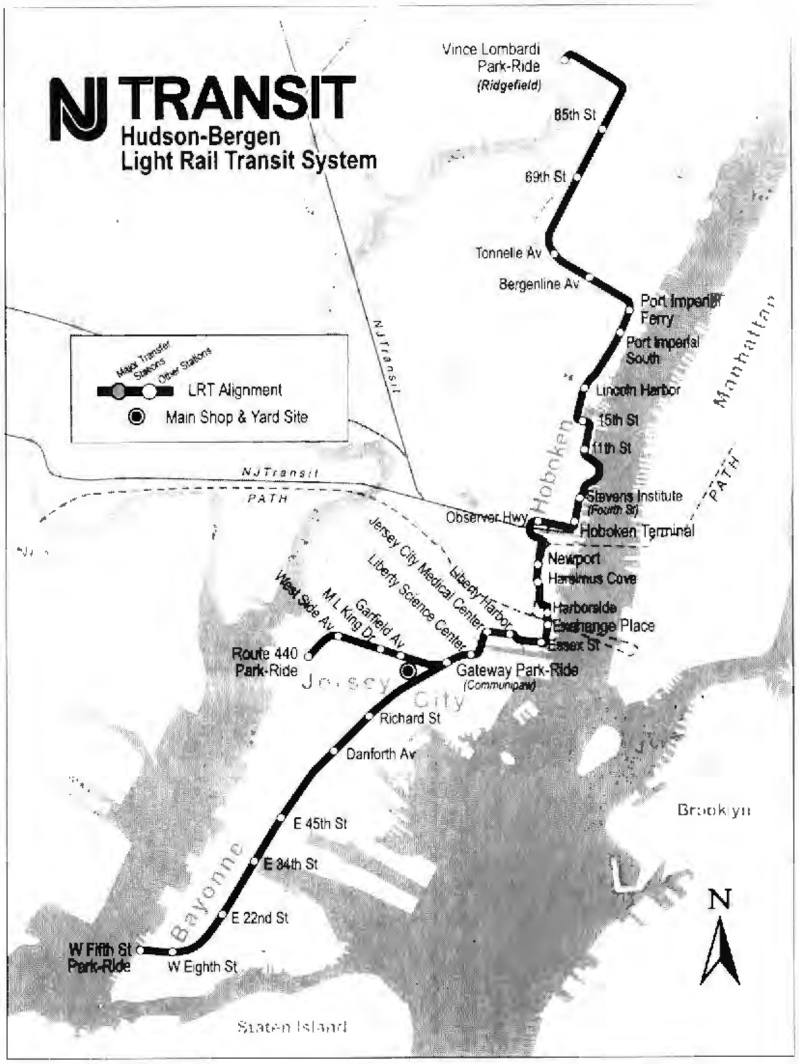

FIGURE 1 **Proposed Hudson-Bergen LRT system.**

city of Bayonne. This line would then extend west along the Conrail Avenue "A" Industrial Track to a terminus at a major (1,000 cars) park and ride.

The third branch would proceed west along the former West Side Industrial Track and then southwesterly on the former West Side Connector Track to a terminus at a moderate size park and ride. Length of this branch will be 3.6 km.

The total system will occupy 22.2 km of existing or former ROW—6.6 km of it running in or alongside city streets—and 4.2 km of easements through development properties.

Shared Facilities

The proposed H-BLRTS will have joint occupancy of rights-of-way with railroad freight, both mainline and local; roadway traffic on highways, arterials, and local streets; and pedestrian traffic both crossing and walking parallel to the system. There are plans for possible future joint occupancy with passengers trains. Potential exists to share a portion of the NJ Transit-owned ROW with a bike path.

At station locations the proposed system will interface with a number of transportation modes. Transfers to the Port Authority Trans-Hudson (PATH) system will occur at three locations (Hoboken, Pavonia, and Exchange Place). Transfers to commuter buses, transit buses, and taxis will be provided at a number of stations. Transfers to automobiles will be provided at 13 park and ride lots and via kiss-and-ride at a number of other stations. Transfers to commuter rail will be provided for at Hoboken and potentially to the proposed West Shore Railroad.

Sharing with Freight Railroads

Joint occupancy (separate tracks on the same right-of-way) use will occur on the southern branch and on the northern branch (Figure 2). Conrail will cross the LRT southern branch at-grade near the Jersey City/Bayonne border and have a single track on the east side of the two LRT tracks, to be installed on the Bayonne Branch. Near the point where the NJ Transit property joints the Conrail Avenue "A" Industrial Track, there is a Conrail yard served by the track running along the east side of the Bayonne Branch. The LRT will pass through the west side of the yard.

Conrail offered joint use (operation on the same track) of the Avenue "A" Industrial Track at the south end of Bayonne. However, review of its operations indicated that the easterly portion of their track is needed for use as a yard lead many hours a day. NJ Transit proposes to build a track parallel to the lead portion of the Conrail track and then connect into it for joint use past the lead. Conrail has been asked to consider providing operating windows so its track can be used to provide a two-track operation during the peak hours.

West of the Weehawken Tunnel the LRT will be located between Conrail's River Line and the New York, Susquehanna and Western (NYS&W) mainline, on the current Conrail Northern Branch. LRT use of the Northern Branch will be achieved by creating a connection between the River Line and the Northern Branch at 83rd Street in North Bergen. Such a connection will allow Conrail to shift its Northern Branch traffic onto its River Line and abandon the Northern Branch between 48th Street (Weehawken Tunnel) and 83rd Street for use by the LRT (Figure 3).

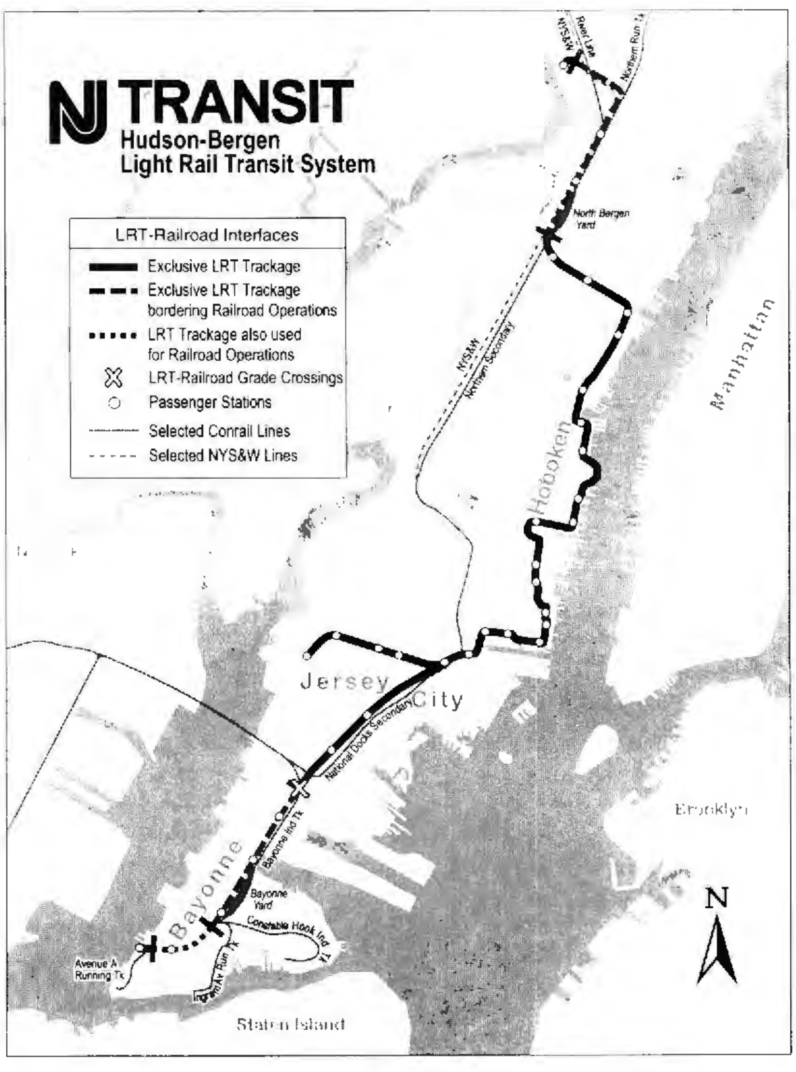

FIGURE 2 Railroad joint use and occupancy.

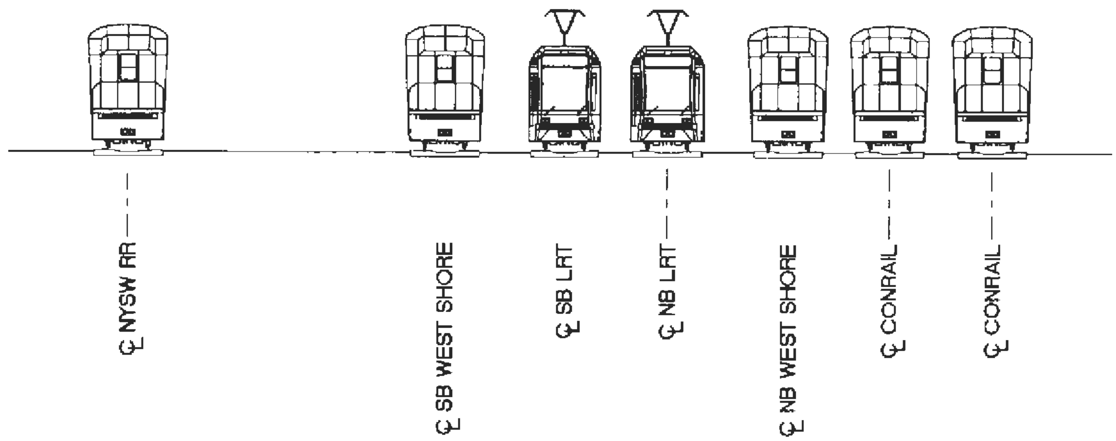

FIGURE 3 LRT in railroad corridor (looking north).

To accomplish this freeing up of the freight rail line for LRT use will involve an agreement for a capital investment in trade for the real estate.

North of 83rd Street the LRT will occupy the same ROW as the Conrail Northern Branch freight track. The tracks will run parallel for about 0.3 km. Additional rights-of-way will be acquired in order to provide sufficient room for two LRT tracks, a freight track, a siding track (for part of the distance), and a station platform (Figure 4).

The LRT will turn west and rise to occupy the NYS&W Edgewater Branch. The present single-track line will be developed into a three-track alignment for use by the LRT (two tracks) and freight (one track). The alignment will follow the Edgewater Branch for about 0.4 km until it veers away to cross wetlands and the New Jersey Turnpike Eastern Spur to the Vince Lombardi park and ride (Figure 5).

On joint occupancy properties (13.8 km), the clearance between the freight track and the nearest LRT track will be 5.2 m (17 ft) centerline-to-centerline, and between the centerlines a fence with intrusion alarms will be installed. In joint use track (1.0 km) the track would have operating windows for freight and LRT.

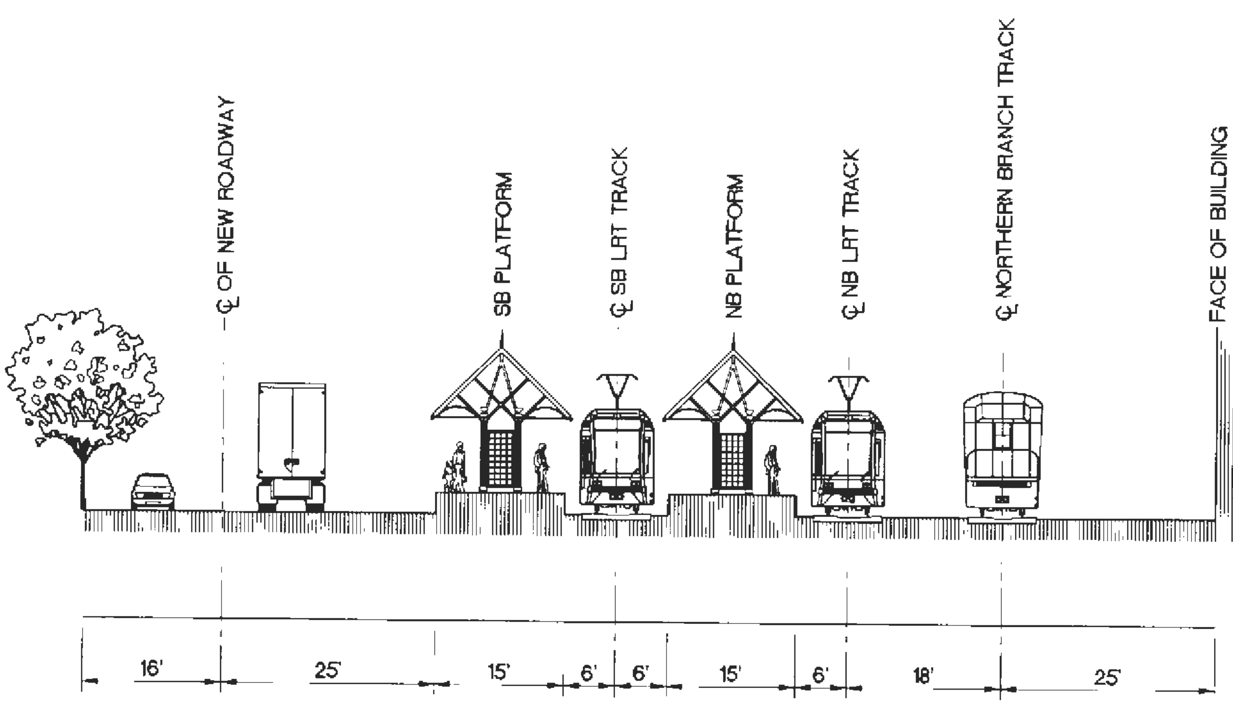

FIGURE 4 LRT adjacent to relocated northern branch (looking north).

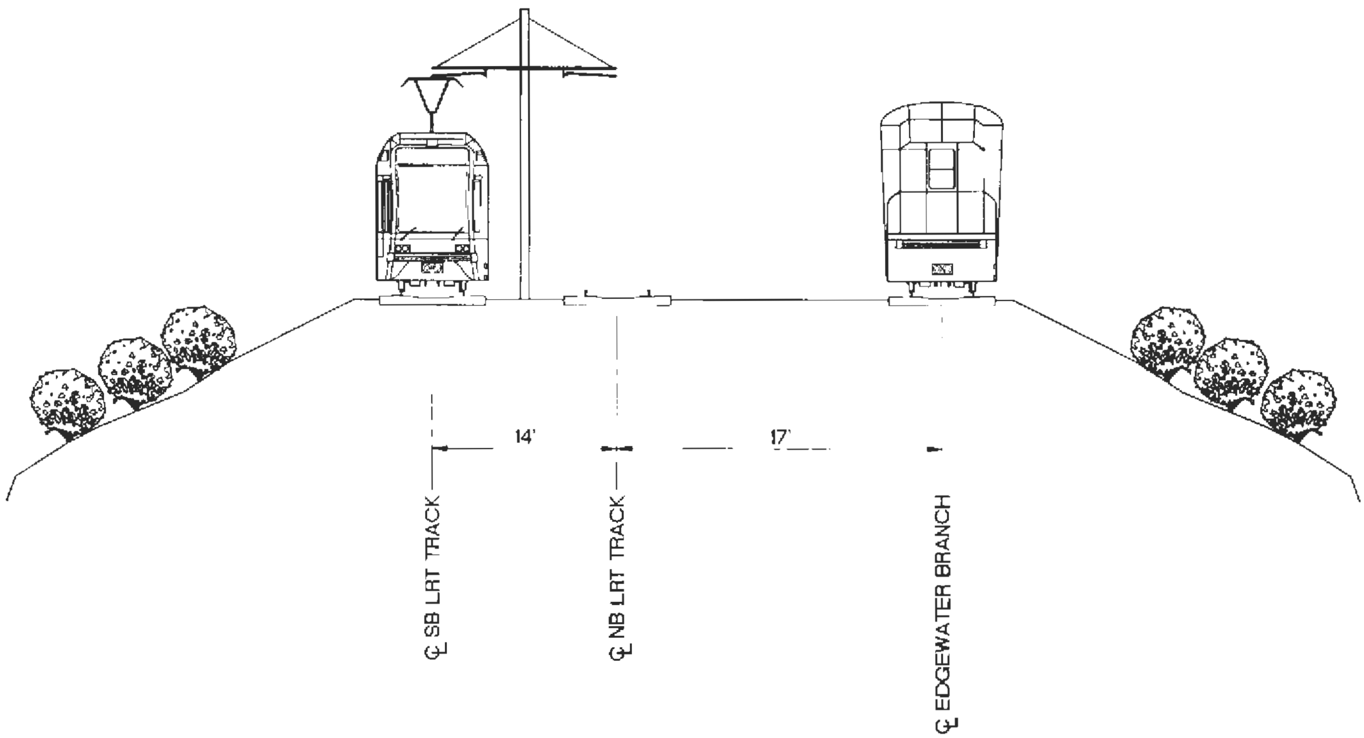

FIGURE 5 LRT on NYSW Edgewater branch.

Joint use track will be controlled by operating windows and by central control of the switches and track involved. Control of these track areas will be either by the Conrail dispatcher or by the LRT operation control center, depending on the location and the final agreement.

NJ Transit is fortunate that it has existing trackage rights agreement with Conrail. This agreement defines the relationship between the parties, particularly the major issues of liability and cost sharing. NJ Transit will include the joint occupancy/joint use areas in the existing trackage agreement. Such inclusion is possible because much of the joint occupancy area is owned by NJ Transit, and Conrail has trackage rights over the property.

Freight railroads are not interested in moving passengers and look upon such operations as being high risk and having the potential for interfering in their operations. Also, most existing trackage rights agreements use the speed-factored gross tonnage methodology to assign costs; freight railroads do not generally consider this a fair model. Therefore, agencies planning to operate over railroad-owned property in joint occupancy or joint use with a freight railroad must institute discussions with the railroad as soon as possible. Such negotiations could be long and difficult because a freight railroad is generally not inclined to accommodate a passenger operation on its property and generally cannot be forced to accept such joint occupancy or use.

A state or local agency dealing with a railroad for purchase or use of its ROW generally must develop a negotiated agreement with the rail line because the agency's power of eminent domain against a railroad is either very limited or nonexistent. This puts the railroad in a very strong bargaining position.

Issues important to the railroad will include liability, indemnification, facility separation (barrier and/or distance), control of the operations, maintenance responsibilities, capital costs, and operating costs.

Sharing with Commuter Railroads

The LRT will occupy the west end of the Hoboken Commuter Rail Yards. In addition the portion of the Conrail Northern Branch freed up by the connection of the Conrail River Line with its Northern Branch would provide for the LRT and two tracks of the originally proposed restoration of the West Shore Railroad route for commuter operations. Clearances between the LRT and the commuter rail would have been 4.4 m (14 ft 5 in.) centerline-to-centerline if this route were chosen. A joint-use passenger station could be developed at 69th Street in North Bergen.

Should NJ Transit decide to have its proposed West Shore and LRT share the same right-of-way, it is simply a policy decision. However, an agency charged with implementing an LRT on a commuter railroad and having no existing operating and trackage rights agreement will face basically the same issues as with a freight railroad. The agency may be more amenable to such occupancy and probably could be subject to some form of forced joint use or occupancy because it is state level or lower. Again risk and cost sharing would be the most significant issues.

Sharing with Roadway Rights-of-Way

Of the proposed system, 6.6 km will occupy road/street rights-of-way of existing or future streets. Most of the occupancies will be either in a median (0.5 km) or on the side of the road (5.7 km). A small amount of the occupancy (0.4 km) will involve street running with vehicular traffic.

Median occupancies will be separated from the adjacent travelways by curbing, landscaping, and other treatments (Figure 6). Side occupancies will involve the LRT being raised above the travelway and generally behind the public walkway. The LRT would be separated from the public walkway and the adjacent property by fencing and/or landscaping (Figure 7).

The LRT will share the travelway for about three blocks (0.4 km) and at existing future grade crossings. At most areas the LRT movement and that of the road traffic will be controlled by traffic control devices. Following current U.S. practice, the LRT will be controlled by white bar signals. The general design consultant, Parsons-Brinckerhoff, is now evaluating the need for signal preemptions or progression in downtown Jersey City and Hoboken.

In-street and generally at crossings, embedded girder rail, or standard rail with bolted-on strap guard, will be installed. At crossings other than city street intersections, normal preformed rail crossing material will be used.

Gates and other railroad-type warning devices will be used if they will not cause unacceptable delays to roadway traffic and if the higher LRV speed is allowed (35 mph).

Occupancy and use of local road rights-of-way will be established by easement agreements with the counties and municipalities involved. These agreements deal with defining property interest, allocating ability, establishing indemnification, providing mechanism for reimbursement of local force account costs, and defining responsibility of the parties for funding, inspection, and acceptance of construction.

Sharing with Buses

Transit buses will provide local feeder service to a number of station locations. Commuter buses will provide longer-distance service to major transfer points with the LRT (Port Imperial, Hoboken, Exchange Place, and Gateway).

Buses will loop at major transfer points. At Gateway the buses will circulate on internal park-and-ride roadways to platforms next to the LRT platforms. At Exchange Place the LRT will cross the base of the loop, and a traffic signal will control the bus and LRT moves. At Hoboken the LRT will cross through the middle of a bus loop. Because both the buses and the LRT will be operated by professional drivers, there is less need for protective devices, that is, traffic signals. The final level of protection at Hoboken has to be established. At Port Imperial the configuration still needs to be developed.

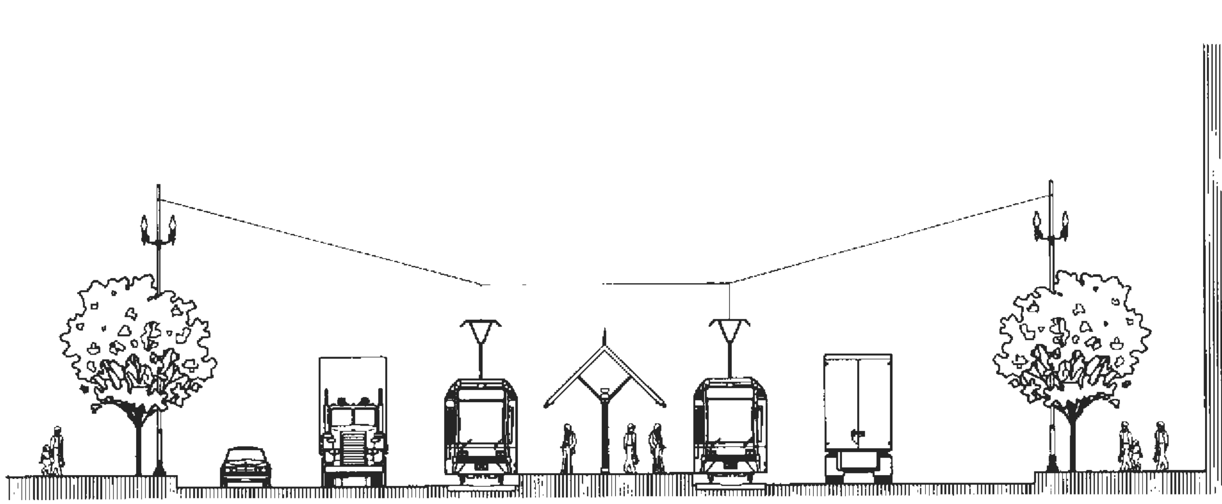

FIGURE 6 LRT in roadway median.

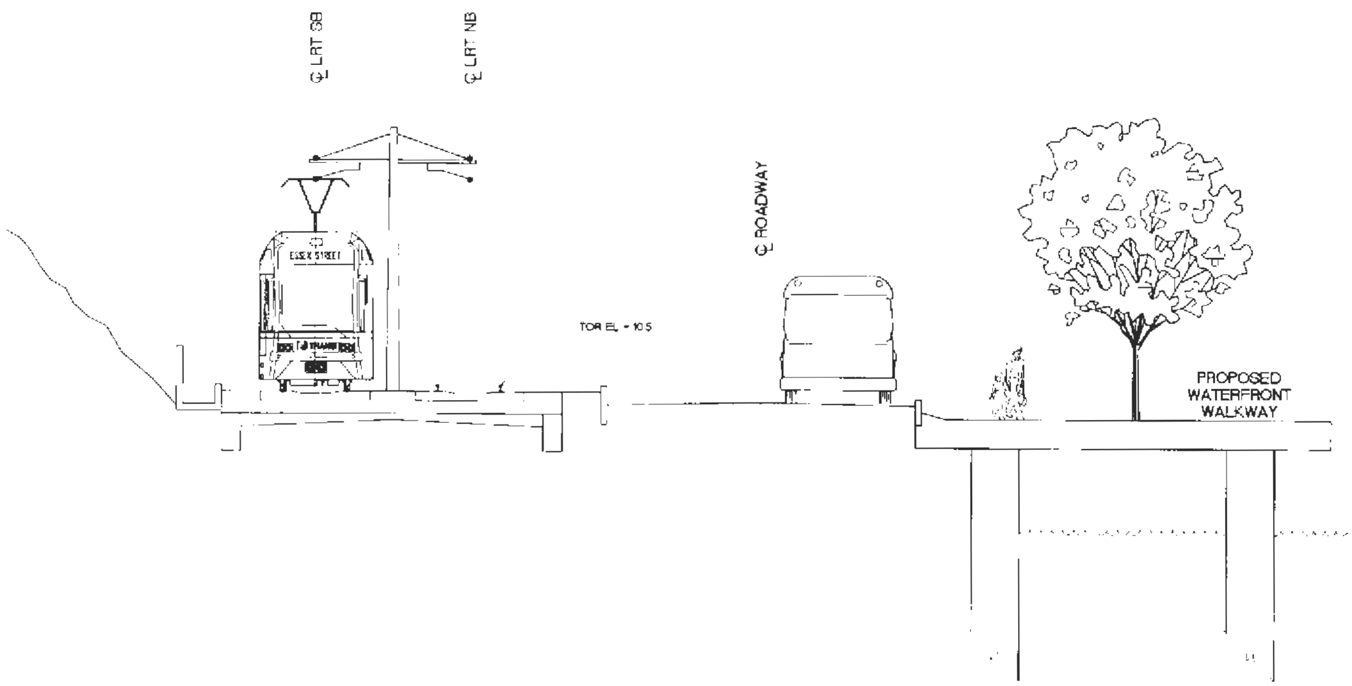

FIGURE 7 LRT alongside roadway.

Sharing with Pedestrians

The H-BLRTS, as with most systems, will share portions of its right-of-way with pedestrians. Primarily the pedestrian use of the ROW occurs where the system is in or along roadways and at stations.

In general the pedestrians' use of the right-of-way will be controlled by fencing, signage, pavement treatments, traffic signals, and other techniques. The needs for various control features are being evaluated in the design process. At the major transfer locations the volumes of pedestrians are so large (up to 3,600 pph) that the operation of station area/roadway intersections is being analyzed using several models. Models used will show on the computer monitor movements of pedestrian, roadway traffic, and LRTs through the intersection.

In some of the higher-speed LRT areas (55–90 kph) consideration is being given to providing walkways where there is a need for pedestrian moves parallel to the tracks. NJ Transit provides such walkways along its railroad where there are significant needs. For example, protected walkways along a track in one area provide a way for high school students to walk between their houses and school. Walkways along the LRT tracks could be as shown in Figure 8.

Providing walkways within the LRT right-of-way is a policy decision by the responsible agency. Risk and liability are probably going to be the primary factors in deciding to meet a possible need for such walkways.

As with walkways, the provision of bike paths along the LRT-owned ROW would be an agency policy decision weighing the public need against the potential risk and liability.

Sharing with Bicycles

Although there are no current plans to provide bikeways parallel to the LRT tracks, the opportunity exists to develop such facilities on the system ROW. New Jersey's Department of Environmental Protection is charged with developing a waterfront walkway to extend from the George Washington Bridge south to the tip of Bayonne. A substantial portion of the proposed LRT system is parallel to and near the proposed walkway and, as such, the system ROW could provide a supplement to the walkway, particularly for bikes. The western branch could provide a possible bike feeder route to the walkway and waterfront. A potential configuration on an at-grade profile is shown in Figure 9.

Sharing with Utilities

Railroads and LRT routes are natural locations for utilities. Most utilities are transportation systems for energy, communications, or other resources. Utility occupancies of the ROW can be beneficial because they can generate income and also serve as a resource to the LRT

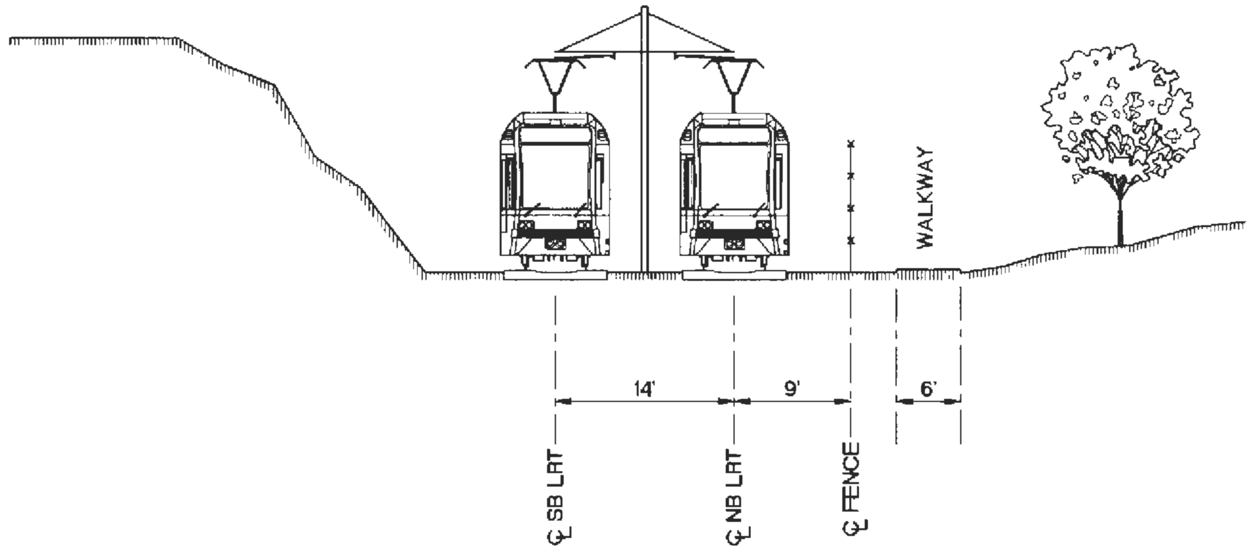

FIGURE 8 LRT shared with walkway.

system (i.e., use of part of a fiber optic occupancy for its communications). However, these shared uses can restrict the use of property, and a failure can disrupt operations.

Because NJ Transit has a railroad component, the use of the LRT real estate it now controls, or will control in the future, will be governed by "EP-2 Specifications for Pipeline Occupancy" and "EP-2 Specification for Aerial Occupancy." LRT real properties that were former railroads would have had past occupancies governed by similar standards. Use of such standards for ROW occupancies goes a long way in reducing the potential restriction of use by a proposed LRT system and possible disruption of LRT operations owing to a utility failure.

Obtaining copies of existing easements, licenses, and other property occupancy records is important in developing an LRT system. These property occupancies need to be located, and then ability to sustain LRT load-

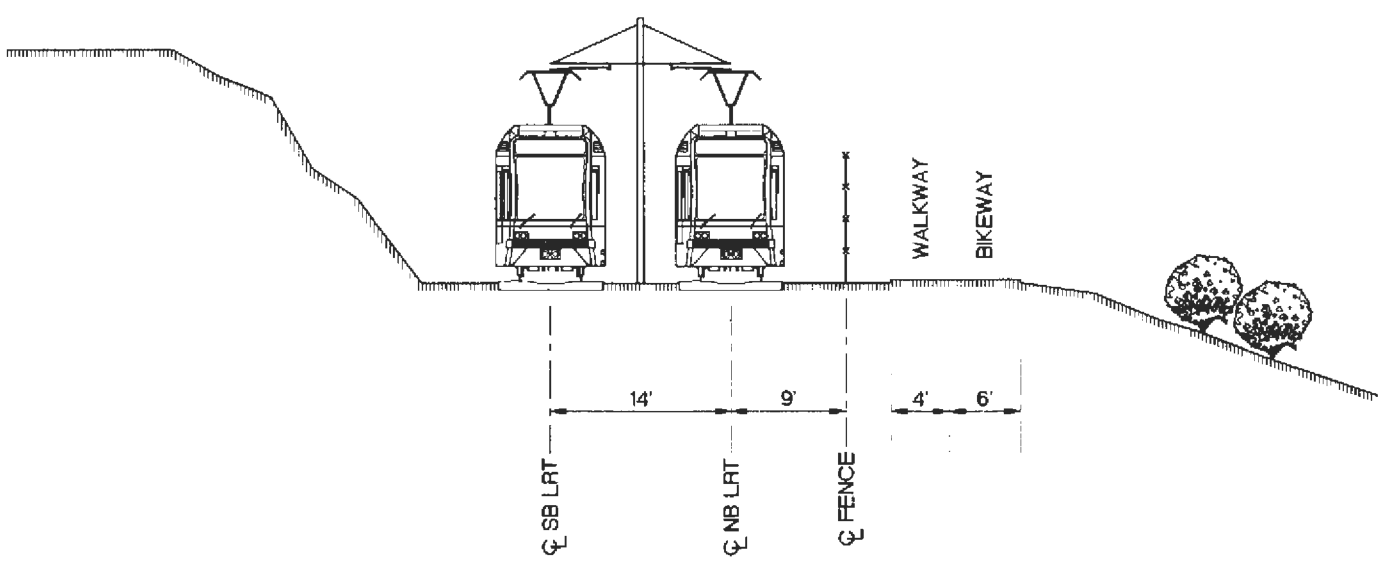

FIGURE 9 LRT shared with bikeway.

ings needs to be determined. Locating the occupancies will allow installation of an LRT system and facilities with the least amount of conflict and relocation. Evaluating the ability of a proposed utility to sustain loads will allow for necessary protection or relocation.

Property occupancies also lead to the need to evaluate stray current potential and the possible need for cathode protection to prevent long-term problems.

Utility use of an LRT right-of-way may result in an annual income (either formula or negotiated) or a lump sum negotiated one-time payment.

Conclusion

Light rail systems generally share their rights-of-way with many of the other ground transportation systems. The H-BLRTS will share its ROW, or route, with most other forms of ground transportation. Such shared uses are not only acceptable but should be encouraged. Successful sharing of a route with other forms of transportation requires careful planning, design, and property management to ensure that the joint occupancies can safely coexist.

PART 3
TECHNICAL ISSUES

Light Rail Vehicles

Introduction of Low-Floor Light Rail Vehicles to North America: History and Status of the Portland Type 2 Vehicle

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Modern low-floor light rail vehicles (LFLRVs) first entered revenue service in Europe during the mid-1980s, and since then, numerous transit agencies in Europe have ordered or are operating LFLRVs in various configurations. In 1991 Tri-County Metropolitan Transportation District of Oregon (Tri-Met), the transit operator in Portland, conducted an extensive study of accessibility to its existing and planned light rail lines and after much deliberation decided in 1992 to pursue the first LFLRV procurement in North America. Of particular concern to Tri-Met was whether LFLRVs could meet requirements for higher carbody strength and higher operating speeds than were common in European designs. After a competitive process, a contract was awarded to Siemens Duewag Corporation in June 1993 at a price of $86.6 million for 37 LFLRVs and associated equipment. Major features of the LFLRV are full compatibility with Tri-Met's existing high-floor light rail vehicles; a 70 percent low-floor section at a height of 14 in.; four doors per side, all in the low-floor section, with a bridgeplate in the center doors; an unpowered center truck with independently braked full-sized wheels on stub axles and with an articulation on each end of the truck; standard motor trucks; and a roof-mounted, microprocessor-controlled, AC propulsion system. Design of the LFLRV was substantially complete by the end of 1994, and proof-of-design tests for all major systems were completed or under way in mid-1995. Carbody strength tests were successfully conducted in March 1995. Assembly of the first vehicle began in May 1995, and it is estimated that the first vehicle will be delivered to Portland in December 1995.

Low-floor light rail vehicles (LFLRVs) were first introduced into Switzerland and France in the mid-1980s, and within a decade nearly three-fourths of all light rail vehicles on order or put into service in Western Europe have been LFLRVs. However, by the early 1990s no North American transit agency had placed an order for LFLRVs, and only a handful of studies and literature was even available about the subject. This paper describes the background, decision-making process, procurement process, technical characteristics, and current status of the first LFLRV to be introduced into North America.

Light Rail Transit in the Portland Area

In 1986 Tri-County Metropolitan Transportation District of Oregon (Tri-Met), the public transit authority in Portland, completed construction and opened for revenue service its first light rail line, known as the Banfield line. This new system represented a blend of European and North American transit practices, with low-platform stations, traditional high-floor light rail vehicles, self-service proof-of-payment fare collection, and a wide variety of right-of-way (ROW) conditions ranging from city streets to high-speed, grade-separated sections. Accessibility for mobility-impaired persons was provided by wayside lifts located at the far end of each platform.

The early success of the Banfield line rekindled interest in light rail transit throughout the Portland area. In 1988 Tri-Met began environmental and preliminary engineering studies associated with a major extension of the Banfield line to the western part of the Portland area, known at the Westside Light Rail Project. A Full Funding Grant Agreement, or contract between the Federal Transit Administration (FTA) and Tri-Met, was signed in 1992 for a Westside line approximately 11.4 mi long with 11 passenger stations. Construction started in mid-1993, and revenue service is planned to commence in 1998. In addition to the initial Westside Light Rail Project, funding approval for a further 6-mi extension of the Westside line to the community of Hillsboro was received in late 1994. Characteristics of the Westside-Hillsboro ROW are as varied as those on the Banfield line and also include a 3-mi-long twin bore tunnel with a deep underground station and extensive lengths of 5 percent and 6 percent grades. Planning is also actively under way for a 25-mi line, in a south/north orientation, in the Portland area.

Low-Floor Light Rail Vehicle Decision-Making Process

In 1991 Tri-Met was completing its environmental and preliminary engineering studies for the Westside Light Rail Project. During the local decision-making process on the project, community groups requested that Tri-Met consider "universal level boarding" for all passengers as an alternative to wayside lifts or "mini-high" platforms located at the ends of the normal station platform.

In summar 1991 Tri-Met conducted an internal study comparing the mini-high platform approach with LFLRVs. At that time it was concluded that, although LFLRVs were an emerging and attractive technology, their development was still too incipient and their costs likely too high to warrant incorporation into the project. No LFLRVs were on order or in service at that time in North America, and only the Massachusetts Bay Transportation Authority in Boston was known to be seriously investigating their implementation. Consequently Tri-Met recommended proceeding with mini-high platforms as a design basis for the Westside Light Rail Project and a moderate improvement in provision of accessibility over the wayside lifts on the Banfield line.

At about the same time that the initial report was released, the U.S. Department of Transportation issued its final regulations implementing the Americans with Disabilities Act (ADA), sweeping legislation passed by the U.S. Congress in 1990 that set standards and guidelines for accommodation of persons with disabilities. The ADA regulations thus focused attention on accessibility issues, and various community groups vociferously questioned Tri-Met's plan to proceed with mini-high platforms.

In fall 1991, in response to community concerns, Tri-Met decided to undertake a comprehensive study of accessibility to light rail vehicles and assembled a staff and consultant team to conduct the study. The charter was to investigate thoroughly all feasible means for providing accessibility to the existing and proposed light rail system for all persons, whether the general population or persons with disabilities. After some initial screening three main options were carried forward: mini-high platforms, full-length high platforms, and varying configurations of low-floor light rail vehicles. Vehicle considerations, station platform factors, other wayside elements, costs, urban impacts, service levels, and operations were all delineated.

North American transit properties in Sacramento, Los Angeles, Boston, and Calgary were visited to discuss their accessibility approaches and plans. A literature search of magazines and publications concerning LFLRVs was conducted. A study team visited several cities in six European countries, rode and inspected eight different LFLRVs, and met with several transit authorities and eight manufacturers to discuss LFLRV technology and operating experience. The study team included a wheelchair user, who was able to add an invaluable perspective on the extent of accessibility, or lack thereof, of European transit systems.

An important finding from the European trip was that LFLRVs were being introduced in most places in Europe to improve boarding for the general public but not necessarily for wheelchair users. Most European transit systems were still not accessible to wheelchair users after introduction of LFLRVs because the systems typically had wayside conditions (e.g., inaccessible platforms, street-level boarding, large vertical gaps, etc.) prohibitive for entry into even a low-floor vehicle. Some systems were incrementally raising or modifying their platforms and boarding areas to improve the situation.

The study team found that, at the time, only Grenoble, France, provided a truly accessible system because it was a completely new system constructed in the 1980s with wheelchair accessibility as a guideline. The

Grenoble system built all station platforms at approximately 10 in. above top of rail (TOR) and used bridgeplates on the FLRVs to bridge the remaining gaps between the vehicles and platform.

Progress of the accessibility study was closely monitored by an ad hoc committee chaired by Tri-Met's general manager and composed of representatives from various citizen interest groups, including the mobility-impaired community. This forum, and the commitment of Tri-Met's top management to an objective study, permitted a free exchange of opinions during the process and careful examination of the attributes of the options.

As the consultant team and Tri-Met learned of the extent to which LFLRV technology was permeating the European market, initial hesitations and technical uncertainties began to diminish. In effect, the team became converts. A report was published in early 1992, and the committee recommended that Tri-Met pursue an LFLRV procurement and develop the necessary specifications. This recommendation was approved by the Tri-Met board of directors, the agency's policy body, in April 1992.

The LFLRV approach was chosen in Portland for a number of reasons. In effect, LFLRVs offer the level boarding or near-level boarding capabilities of high-platform systems but do so with low station platforms more suitable for surface operations and cost-effective integration into compact urban environments. Accessibility for mobility-impaired persons and boarding for the general population are improved compared with traditional high-floor/low-platform systems, dwell times at stations are shorter, and schedule reliability is enhanced through elimination of wayside accessibility devices such as the lift in Portland. Wheelchair users can be mainstreamed or nearly mainstreamed into the system, and every LFLRV in a multiple-unit train will be accessible, not just the front end of the first car, as is currently the case in Portland.

A very important and much-debated set of considerations in deciding to proceed with LFLRVs involved the need for, the details of, and the impacts associated with bridgeplates on board the vehicles. Tri-Met's interpretation of pertinent regulations implementing the ADA was that the new vehicles had to be level-entry with the vertical gap between vehicle floor and platform surface within ⅝ in. or else some sort of bridging device would be necessary. Level entry could be achieved only if an air suspension system equipped with automatic leveling valves were incorporated into the LFLRV to guarantee a relatively constant floor height and if the platform height could match the vehicle floor height. The European experience in 1991 indicated that air suspension appeared to be anomalous but not impossible with LFLRVs. During the accessibility study the study team found one example of an LFLRV with air suspension—in Turino, Italy. But the real constraint in Tri-Met's system was permissible platform height. Because Tri-Met's existing Type 1 vehicles have swing plug doors, which extend over the platform edge, platform height was limited to 10 in. above TOR to provide clearance. Even if it had been practical to retrofit the Type 1 doors, raising the platform height from 8 in. above TOR to approximately 14 in. above TOR would have had major unworkable impacts throughout the existing Banfield line and also on the Westside-Hillsboro design and was dropped from consideration.

Thus, Tri-Met accepted that, to comply with ADA, in the Portland context a bridgeplate was required. The question then became one of details, in particular, whether the ADA requirements for ramp slope could be met without changing the existing 8-in. platforms. Obviously ramp slope had a direct relation with bridgeplate (transverse) width and impact on carbody structure. Discussions with vehicle manufacturers indicated that the cutout necessary in the underframe to accommodate a bridgeplate mechanism was significant and could not be tolerated on all doors without major impact on the carbody strength. Therefore, a compromise solution was accepted under which the four center doors (two per side) would have bridgeplates. After much investigation and some actual tests by wheelchair users of different ramp slopes, it was also determined that 10-in. platforms would become the design standard for Tri-Met, necessitating a platform retrofit program for the 48 existing 8-in. Banfield platforms.

Procurement Process

In July 1992 a request for proposal was issued to interested manufacturers. Tri-Met elected a competitive negotiation process, whereby technical proposal and price were evaluated separately, then combined into a single score for each proposal.

Proposals were received in November 1992. After evaluation of technical proposals and price a competitive range was established consisting of two proposers, Bombardier Corporation of Montreal, Canada, and Siemens Duewag Corporation (SDC) of Sacramento, California. Through negotiations with the manufacturers, Tri-Met was able to refine specification requirements, allowing a wider range of established components and manufacturing methods without reducing the reliability or safety of the vehicles. In February 1993 Tri-Met issued the request for best and final offer, and best and final offers were received at the end of March 1993. After evaluation, the contract was awarded in May 1993 to SDC for a total of $86.6 million for 37 LFLRVs, to be known as the Type 2 vehicles, including spare parts and system support. The contract also includes an escalation clause, which requires Tri-Met to compensate the contractor for cost increases due to inflation.

Since contract award, Tri-Met has exercised options for nine additional LFLRVs, and the contract as of mid-1995 is for 46 vehicles at a total cost of $107.2 million plus escalation.

Low-Floor Light Rail Vehicle Design

LFLRV development in Europe has progressed along two major paths: partial low-floor vehicles and 100 percent low-floor vehicles. At the time of Tri-Met's accessibility study, several cities in Europe had fleets of partial LFLRVs in revenue service, some for several years, but 100 percent LFLRVs were basically in the prototype stage or in operation in only a very limited fashion. Several concerns came to the fore during the study relating to the transfer of European LFLRV experience to a North American context in general, and a Portland context in particular.

General Arrangement

Three main technical challenges were identified, including a high buff strength (170,000 lbf) for the carbody structure compatible with Tri-Met's existing vehicles, a high-performance requirement with a maximum speed of 55 mph, and good ride quality and noise performance. The study team concluded that the most prudent course for introducing LFLRVs into the Tri-Met system would be to utilize a partial low-floor vehicle with standard powered trucks and a high-floor section at each end. Thus the general vehicle type that emerged was an articulated vehicle, approximately the size of the existing Banfield Type 1 vehicles, with a low-floor center section approximately two-thirds of the total floor area, a low-floor height of 14 in. above TOR, internal steps to the high-floor section (38 in. above TOR) at each end, and bridging plates in the center doorways similar to those in Grenoble to provide accessibility for all combinations of vertical and horizontal gaps with the station platform.

The new Type 2 LFLRV is 92 ft long and 8 ft 8 in. wide, with an empty vehicle weight estimated to be approximately 103,000 lb. There are three body sections: the two main sections (A and B) each approximately 40 ft long and a short center section (C) approximately 10 ft long. Approximately 70 percent of the passenger area is at a floor height of only 14 in. above TOR and all eight sliding plug doors (four per side) are in the low-floor area (see Figure 1). The four center doors are equipped with bridgeplates, which can be deployed by the driver or by passengers to allow smooth boarding of wheelchairs. Each vehicle has 72 seats and is capable of carrying 189 people at design load. At least four wheelchair spaces are provided.

The LFLRVs are fully bidirectional, with a driver's cab at each end, and are mechanically and electrically compatible with the Type 1 vehicles. Maximum speed is 55 mph, with service acceleration and braking rates of 3.0 mph/sec and an emergency brake rate of over 5.0 mph/sec. The vehicles are specified to climb grades of up to 7 percent and negotiate curves of 82-ft radius. Up to four vehicles can be coupled together, even though block lengths in downtown Portland restrict operation to two-vehicle trains. The new LFLRVs will couple with Tri-Met's existing high-floor vehicles, allowing operation of two-vehicle trains with at least one accessible low-floor vehicle in each train. Pursuant to successful performance of the new LFLRVs, Tri-Met intends to remove all wayside lifts from the Banfield line and provide accessibility exclusively with the LFLRVs.

The major structural elements, including the carbody shells and truck frames, are of welded steel construction and are designed and manufactured at Duewag's facility in Düsseldorf, Germany. The design of these elements, while unique to the Portland vehicle, generally derive from designs and practices found in other Duewag light rail vehicles.

Trucks

Most modern light rail vehicles in North America are articulated, and all such modern articulated vehicles have been single articulated with unpowered center trucks. The Portland low-floor center truck will also be unpowered but represents a significant departure from practices found in North America to date, owing to the requirement by Tri-Met that the low-floor section be continuous throughout the center of the vehicle. Basically, geometry precludes the use of typical wheels (26 to 28 in. in diameter) pressed on typical axles (6 to 8 in. in diameter) in a low-floor section with a 14-in. passenger floor height. Some low-floor truck designs have utilized small wheels (10 to 14 in. in diameter); the more common approach is to use independently mounted wheels without through axles. The Portland center truck is based on the latter approach. Individual, 26-in.-diameter wheels are mounted on bearings on stub axles connected to each other by two U-shaped drop axle pieces (see Figure 2). Thus the stub axles do not rotate during vehicle translation.

The center truck is mounted under a short intermediate body section, which in turn is connected by an articulation on each end to the two main body sections.

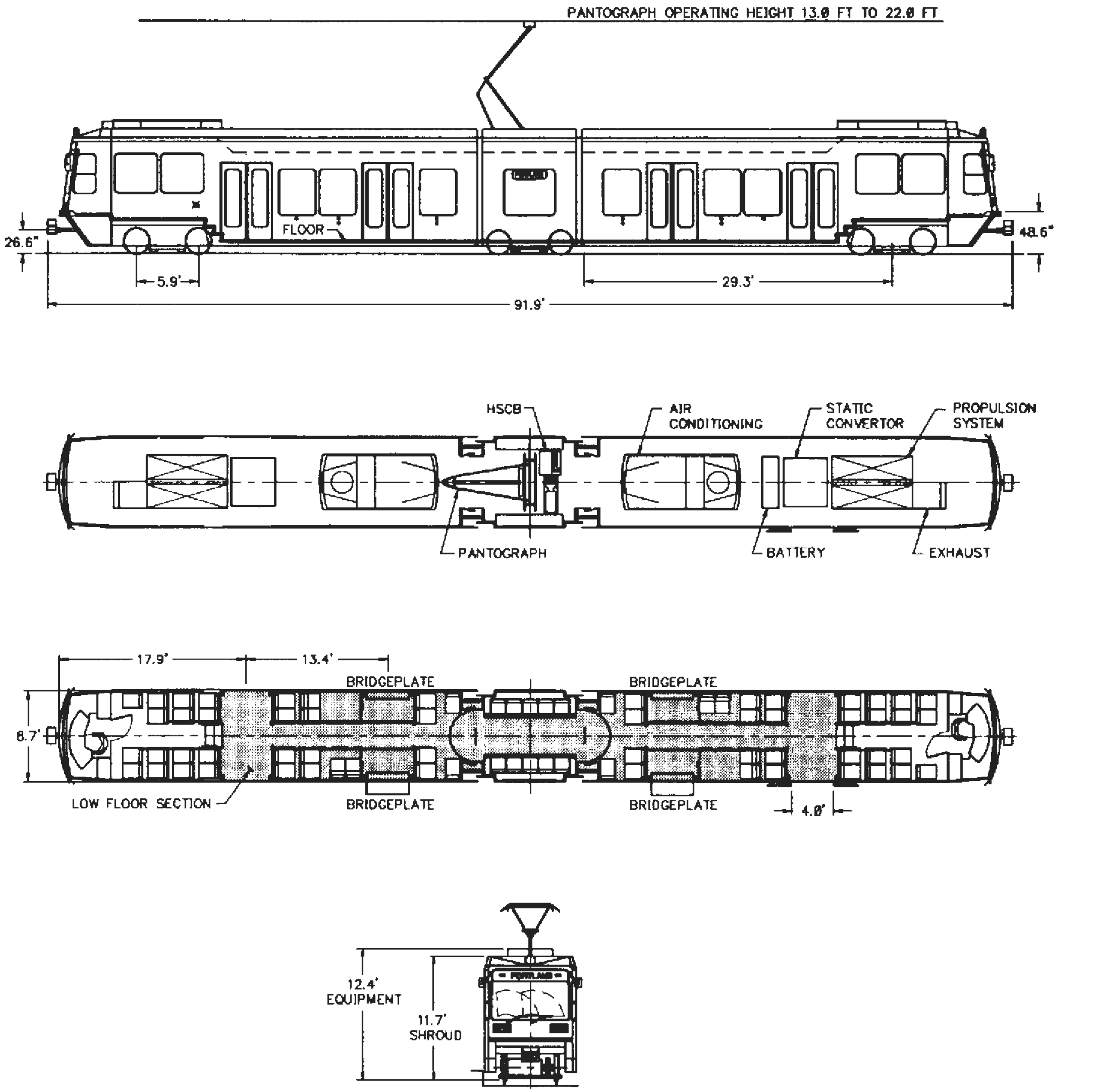

FIGURE 1 General arrangement.

Elastomeric elements will provide a primary suspension system, and coil springs are used for the secondary suspension. The design of the center truck and center body section not only permits the low floor to carry through the center of the vehicle but also permits longitudinal passenger seats in the center section and maintains a similar truck center dimension to that of the Type 1 vehicles and thus similar clearance geometry.

The powered trucks are of conventional Duewag design. Primary suspension is provided by chevrons, and secondary suspension by coil springs. Each end truck is powered by two self-ventilated, fully encapsulated six-pole AC induction motors, each rated at 140 kW. Motors will be truck frame mounted parallel to the axle, and a helical gear drive and flexible coupling transmit the torque to the wheels.

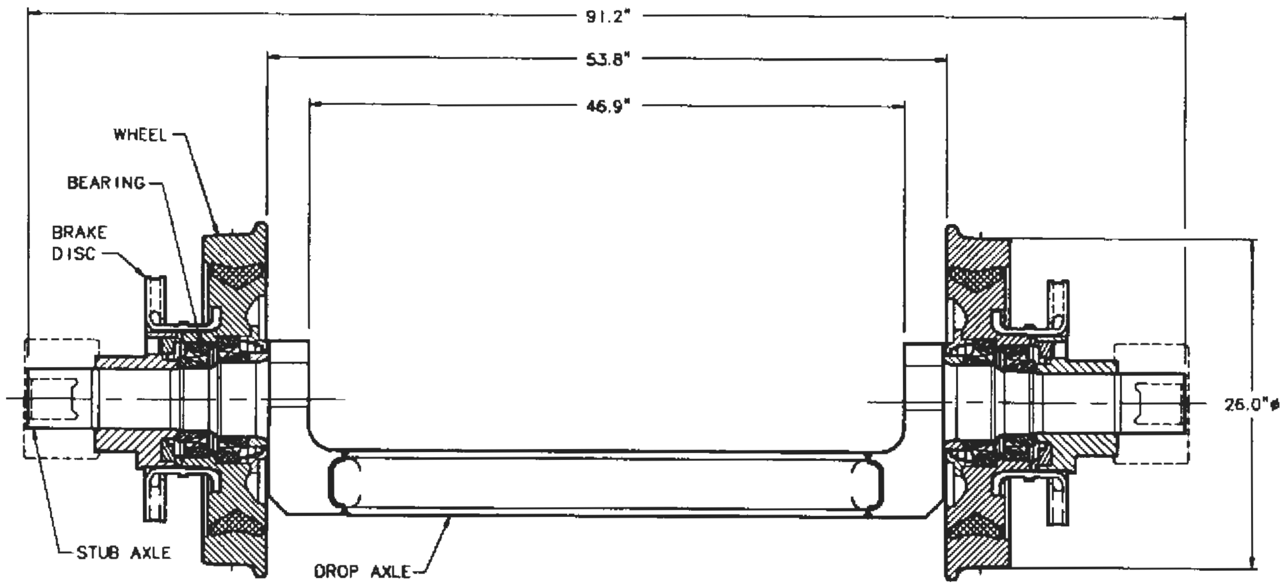

FIGURE 2 Trailer truck drop axle assembly.

Bridgeplate

As discussed above, Tri-Met determined that bridgeplates were necessary for ADA and platform reasons and elected to require them on the four center doors of the vehicle, similar to the arrangement in Grenoble. Since well less than 1 percent of the passenger boardings are forecast to be by wheelchair users requiring the bridgeplate, Tri-Met decided that, for reliability and speed-of-operation reasons, the bridgeplate should not be deployed with every door opening. Accordingly, bridgeplates will be deployed by the train operator or upon request by a passenger. Train operators will be trained to look for wheelchair passengers on the platforms and will then automatically deploy all bridgeplates as part of the normal door opening sequence. Similarly, bridgeplate request buttons inside the vehicle will allow passengers to request and train operators to initiate bridgeplate deployment only at requested doors as part of the normal door opening cycle. If there are no internal bridgeplate requests and the train operator does not see a wheelchair user on the platform, doors will be released or opened as normal without bridgeplate deployment. Should there be a subsequent (late arrival) external bridgeplate request and the door in question is already open, the train operator will close all doors and the requested bridgeplate/door will recycle and deploy.

The bridgeplate will be approximately 48 in. wide, the width of the doorway, and will generally be of a two-piece configuration (see Figure 3). Transverse width will total approximately 21 in. One piece, about 9 in. in transverse width, will be part of the passenger floor. The other piece, about 12 in. in transverse width, will be stored underneath the floor. When deploying, the undercar portion will extend outward from the vehicle to form a smooth surface with the floor portion, and the whole assembly will pivot or drop to contact the platform approximately 9 to 10 in. from platform edge. An electric motor will drive the bridgeplate kinematics, and the entire assembly will be made of stainless steel and aluminum components.

The bridgeplate assembly will undergo 250,000 cycles of testing prior to installation on the first vehicle. Reliability of the bridgeplate will be important to the successful implementation of the Type 2 concept and will be monitored closely through the acceptance test phase of the contract.

Propulsion and Braking

Traction power is controlled by two voltage source, pulse width modulated inverters, one per motor truck, which are mounted on the roof. The traction inverters employ insulated gate bipolar transistor (IGBT) technology, which allows higher switching frequencies and results in reduced power loss in the motors. The propulsion inverters are force ventilated, and the electronic control units are microprocessor based. Dynamic brake resistors are also force ventilated and mounted on the roof.

A fully blended braking system makes maximum use of regenerative/rheostatic braking, supported by hydraulically operated disc brakes on all axles of the pow-

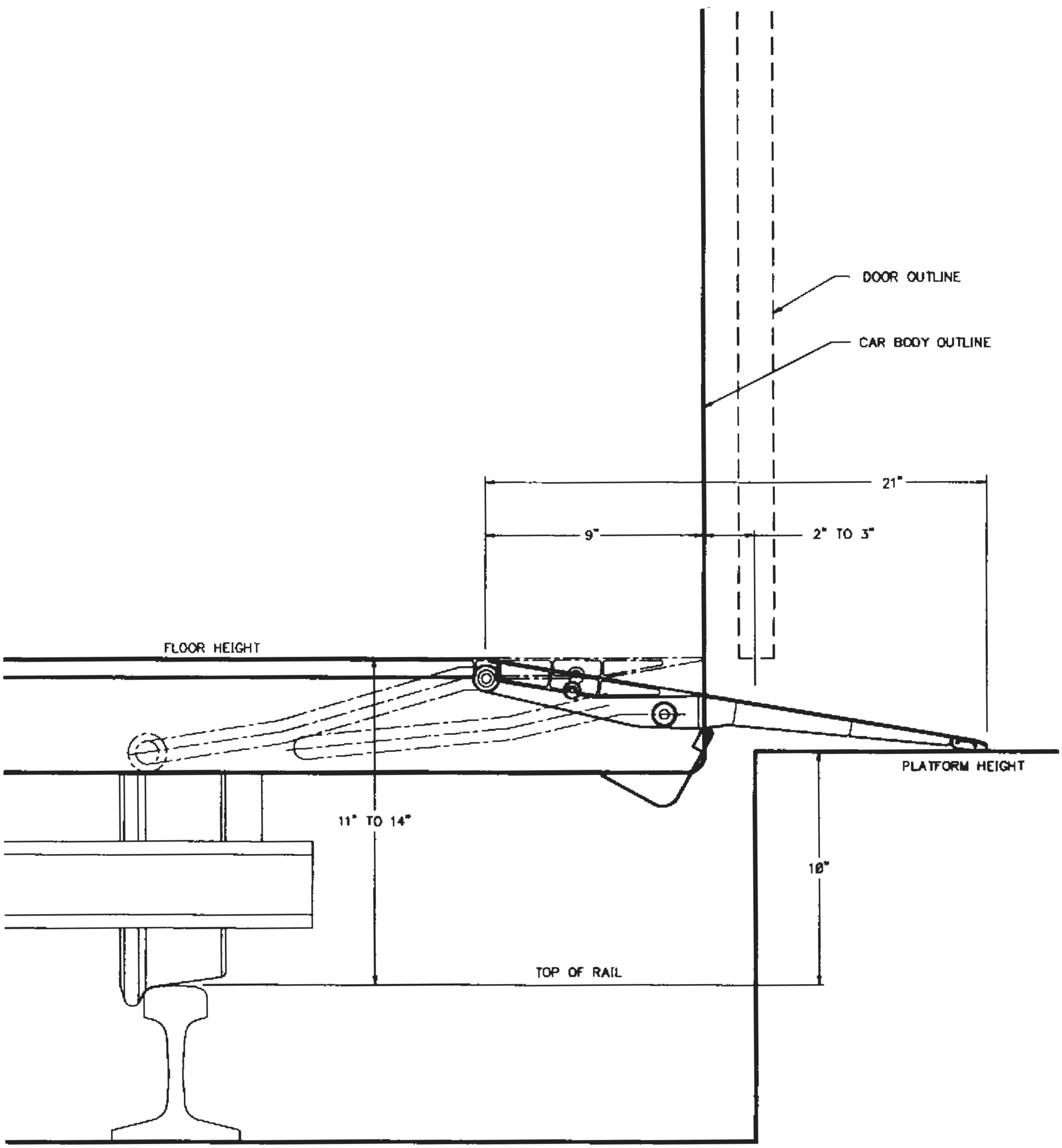

FIGURE 3 Bridgeplate assembly and platform interface.

ered trucks and on all wheels of the trailer truck. The brake control units are of a special design to fit into the minimal undercar space. Track brakes on all trucks provide additional safety and reduced stopping distances in case of emergency.

Carbody Strength and Crashworthiness Considerations

A fundamental concern of Tri-Met during the LFLRV deliberations of 1991 and 1992 was whether the

LFLRV carbody could meet Tri-Met's carbody strength and crashworthiness requirements. Unlike a new start transit system with no prior transit equipment constraints, Tri-Met had decided that the LFLRVs would be completely integrated into its existing operations and would entrain with the existing Type 1 vehicles. Thus it was determined that the LFLRVs would need to meet at least the same carbody compression strength, or buff load, requirements as the Type 1, that is, 170,000 lbf on the anticlimber and 100,000 lbf on the coupler pivot. The 170,000 lbf figure was an early "two-times-the-empty-weight" value, or "2 *g*" approximation, for the Type 1 vehicles and would prove to be a 1.65 *g* requirement for the (estimated) 103,000-lb Type 2 vehicles.

In contrast to a buff load requirement of 170,000 lbf, Tri-Met learned in 1991 that most European LFLRVs were designed to withstand buff loads of only 50,000 lbf to 90,000 lbf, roughly half or less than half that required. Apparently a parallel development with LFLRV technology in Europe during the 1980s and early 1990s was a trend toward vehicle weight reduction owing to the relatively high energy costs there. Compounding the concern of meeting higher buff loads was the particular geometry of the Tri-Met LFLRV, which required a relatively high anticlimber height to mate with the existing Type 1 anticlimber and thus demanded even greater structural integrity to provide successful transmission of force from the high-floor section to the low-floor section without failure. In addition, from a crashworthiness perspective, Tri-Met required progressive buckling of the carbody from the end of the car toward the center in the event of an impact in order to prevent telescoping of the body and catastrophic damage in the passenger sections.

The first finite element analysis by SDC indicated some high stresses in the area of the transition from high floor to low floor. Design modifications introduced some reinforcements in this transition area to ensure that progressive buckling, or deformation of the carbody structure on impact, would generally occur from the end of the car towards the center in order to protect the passenger area. Since demonstration of progressive buckling would be a destructive test, Tri-Met only required analysis of the crashworthiness of the vehicle.

An extensive carbody strength test was conducted on one of the first carbody shells at the Duewag facility in Düsseldorf in February and March 1995. In addition to various compressive loads applied to the ends of the carbody, the test included vertical loads to confirm door operation and torsional loads to simulate diagonal jacking or rerailing.

The carbody tested included the three complete but bare carshell sections (A, B, and C) with no flooring, no internal or external appurtenances or equipment, no paint, and dummy trucks for support (see Figure 4). For just the vertical load test, two complete door assemblies and one bridgeplate assembly were installed and required to operate under maximum load conditions. Approximately 270 strain gauges were mounted on the carbody in critical locations to monitor movement under load and translate readings to stress values in the various structural elements. All readings were recorded and analyzed electronically. In addition, physical deflections were measured using mechanical devices such as plumb bobs and specialized gauges. During the course of the tests, as required, various weights were added to the carbody to simulate actual conditions under passenger loads. Tri-Met's specifications generally required that no permanent deformation of metal occur, no failure of welds occur, and no stress readings exceed the yield strength of the material in question. By contract, SDC was allowed to conduct pretests to ascertain compliance prior to official tests, which would be formally witnessed and recorded.

Initial pretests by SDC of the end compressive load on the anticlimber (the buff load) in February 1995 resulted in a failure at about 70 percent of design load of the floor and roof areas of the center (C) section. SDC responded with the addition of various stiffener plates and gussets to improve weak areas. Similarly, diagonal jacking pretests revealed weak areas in the portals around the interface between the A and C and between the B and C sections, and SDC identified appropriate modifications. When official tests were conducted in March with structural modifications in place, specification requirements were met to Tri-Met's satisfaction.

In summary the carbody strength tests required approximately 3 weeks of setup and 5 weeks to complete in a successful manner. As a result of these tests, ap-

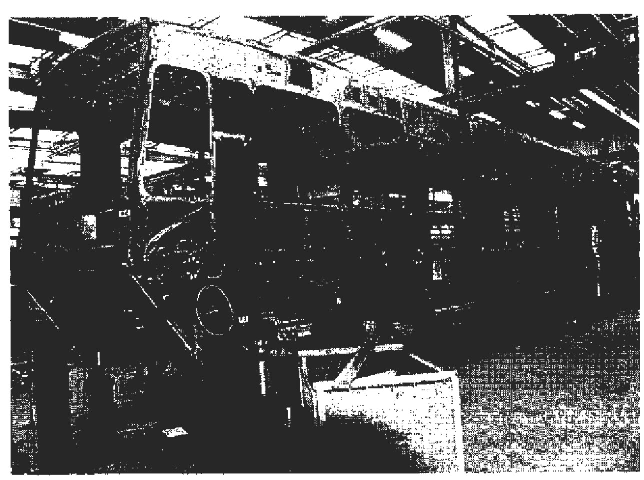

FIGURE 4 Carshell during compression test at Duewag AG plant in Germany.

proximately 120 pieces were added to the carbody structure, most being relatively small plates and gussets, for a total weight of approximately 500 lb, or roughly 2 percent of the three carshell sections and ½ percent of the total estimated car weight.

Schedule

Vehicle carbody construction and truck frame fabrication started at the Duewag plant in Germany in mid-1994. Fatigue tests of the motor truck frame, trailer truck ftame, trailer truck drop axle, and bolster were started in late 1994 and successfully completed in early 1995. As discussed above, the critical test of the carbody structure was completed in March 1995. Propulsion system tests, motor tests, braking system tests, low voltage power supply tests, and HVAC tests were all conducted from late 1994 to mid-1995. Extensive testing of the various systems and components has been and will be performed throughout the mannfacturing process to ensure a safe and reliable vehicle.

Final assembly of the first vehicle began at the SDC plant in Sacramento, California, in May 1995. The first vehicle is currently scheduled to arrive in Portland in December 1995 for operational and compatibility testing with the Type 1 vehicles. Production vehicles will be delivered beginning in early 1996, with the last of the 46 vehicles to be accepted for operation by fall 1997.

Conclusions

In 1991, as part of a major light rail extension project, Tri-Met began seriously studying LFLRVs in order to meet ADA requirements and to improve light rail operations and service. Initial concerns were the extent of technical risk and cost in adapting European designs and practices to Tri-Met's requirements and standards, particularly in the areas of carbody strength and high-speed ride quality and center truck stability. These concerns were balanced with perceived advantages of LFLRVs, and a decision was reached in 1992 to proceed with an LFLRV procurement. To minimize technical risks, Tri-Met specified a partial LFLRV with standard motor trucks and required an extensive proof-of-design test program.

Imposition of typical North American requirements for carbody strength has placed a difficult burden on Tri-Met's vehicle manufacturer; yet Tri-Met considered the requirements carefully and determined they were necessary for the natural progression of its system expansion. SDC has demonstrated that North American carbody strength requirements can be successfully met with LFLRVs. This capability, coupled with the stringent requiremenrs of the ADA, likely portend expanded consideration of the LFLRV in major transit capital investment decisions of the future. Demonstration of ability to meet Tri-Met's other technical concern, acceptable ride quality during high-speed operation, will be undertaken in Portland in 1996.

The decision to procure LFLRVs has created much interest locally in Portland. Although validation of this decision cannot be fully realized until completion of all necessary testing, placement of the vehicles into revenue service, and public acceptance, it is Tri-Met's opinion that LFLRVs are exactly the correct approach for the light rail expansion program in Portland and their deployment will likely become widespread in North America, as has been the case in Europe.

Applicability of Low-Floor Light Rail Vehicles in North America

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The state of the art in the development of low-floor light rail vehicles (LFLRVs) is investigated, and the applicability of LFLRVs for use in North America is assessed. LRV categories have been developed to facilitate understanding of the different types of vehicles and their applications. Forces driving the growing trend toward using low-floor vehicles are described, and an extensive compilation of data on LFLRVs and on North American LRT system characteristics is provided. An analytical perspective on the issues relevant to North American policy makers, managers, and engineers is presented, and sample applications are developed to demonstrate issues of cost-effectiveness, sources of risk, and trade-offs between use of low-floor and high-floor LRVs.

There is a growing trend toward the use of low-floor light rail vehicles (LFLRVs)—as of early 1994, more than 1,700 LFLRVs had been delivered to or ordered by transit system operators in Europe and North America. Since LFLRVs were introduced in Europe over 10 years ago, approximately 75 percent of new LRV orders in Europe have been for LFLRVs.

The same trend is now apparent in North America. Portland, the first North American city to adopt LFLRVs, will receive its new cars later this year. New-start projects including the Hudson Bergen LRT (New Jersey) and the Chicago Circulator have both embraced use of low-floor cars.

LFLRVs improve accessibility and are more easily integrated into the built environment than conventional LRVs. Low floors are typically 350 mm (13.8 in.) or less above the top of rail (TOR) compared with 910 mm (35.8 in.) or more for high floors. Only a single step is needed to board LFLRVs from curb level compared with three or four steps for conventional LRVs. Installing platforms, which might be something as simple as a raised curb, can provide level boarding of the LFLRV. In contrast, the platforms necessary to match high-floor vehicles extend high above the adjacent sidewalk.

Accessibility is becoming a much more important issue in North America. Transit agencies see the increasing need to provide barrier-free service. In the United States, the Americans with Disabilities Act of 1990 requires that rail transportation "be readily accessible to and usable by individuals with disabilities, including individuals who use wheelchairs."

There are problems with making conventional LRVs accessible. High platforms can be provided (mini or high platforms) to provide level boarding, but these take up considerable space and require a wider right of way. Carborne or wayside lifts can be used to raise wheelchairs from street level to the level of the car floor, but lifts are slow and not failproof. Whereas a person in a wheelchair can enter or exit a car during a normal station dwell time where level boarding is provided, it takes 2 to 4 min for this passenger to enter or to exit a vehicle when a lift is used. On systems with tight peak-period headways, one person in a wheelchair entering, then exiting, a car could cause delays so significant that a train could be lost from the peak-period schedule. Also, cars served by lifts or miniplatforms can usually accommodate only two wheelchairs per train. LFLRVs offer new solutions to these problems.

A remaining impediment to the adoption of LFLRVs was price. Recent data from North America and Europe indicate that the price difference between high-floor and low-floor LRVs has virtually disappeared and that an intelligently specified LFLRV can be procured for the same price as or less than a conventional high-floor car.

Accordingly, for all new-start projects, the most logical choice is a low-floor car. Only for systems requiring extensions or car replacements on systems with high platforms is the use of high-floor vehicles a serious option.

Classification of LFLRVs

A wide variety of LFLRVs are available, and many of them bear a great deal of similarity to each other. An extensive data base record of available vehicles is provided in Figure 1 and Table 1. Three categories have been developed to simplify discussion and understanding of LFLRVs:

1. Vehicles use conventional powered and trailing trucks. Vehicles are usually created by adding a body section, articulation, and an additional truck into a conventional LRV (Figure 2). The new body section contains the low-floor section (typically 9 to 15 percent of the floor area). The vehicles make extensive use of proven technology. Maintenance and operating costs are comparable to those for conventional high-floor vehicles.
2. Conventional motored trucks are used on Category 2 vehicles, so vehicle propulsion is not affected (Figure 3). To increase the amount of low-floor area in the vehicle (typically 50 to 70 percent of the floor area), modified trailer trucks are used. The trailing trucks might use smaller wheels, cranked axles, or independent wheels to accommodate the low-floor area above. The Portland vehicle is an example of a Category 2 vehicle. As do Category 1 vehicles, Category 2 vehicles make extensive use of proven technology. The modified trailer trucks have also proved to be very cost-effective and reliable, so vehicle operating and maintenance costs are comparable to those of conventional LRVs.
3. Innovative motored and trailing trucks and other novel technologies are used to create vehicles with a 100 percent low-floor area (Figure 4). Unlike conventional LRVs, standard modules are used to create vehicles with multiple articulations, and running gear and drive technologies are substantially different from those used on conventional vehicles. Designs vary widely, and the technology is still evolving rapidly. Category 3 vehicles have not been in service long enough to allow an assessment of long-term reliability, maintainability, or cost-effectiveness.

Comparison of Conventional and Low-Floor LRVs

The price of conventional LRVs ranges from $2 million to $2.2 million (1994 dollars) per car for orders of 30 or more cars on the basis of recent procurement information from San Francisco's Muni and Metro Dallas Area Rapid Transit. The premium cost for LFLRVs compared with a similar conventional vehicle is between 0 and 30 percent (Table 2). For the Portland Category 2 vehicle, the premium was approximately 10 percent. With the increasing number of low-floor vehicle orders, this premium is expected to disappear completely over the next 5 years.

Almost all experience with LFLRVs to date comes from Europe. European practices differ in some ways from those in North America, and the following issues warrant attention when adapting European vehicles:

- *Buff loads.* European LRVs are designed to withstand buff loads of 20 to 40 T, whereas North American vehicles are usually required to withstand loads equal to two times the car weight (Figure 5). The significant increase in longitudinal load-carrying capacity requires strengthening of European vehicles and will result in an increase to the vehicle's mass (Figure 6). In the case of mixed consist operation, particularly with conventional and Category 3 vehicles, this problem is exacerbated by the different floor heights of vehicles. The floor is one of the major structural components that must resist axial compression loads.
- *Coupling.* Category 1 and Category 2 vehicles use conventional power trucks, therefore coupling to conventional vehicles can be accommodated. Category 3 vehicles are often lengthened by adding a body section and articulation rather than by coupling to a second vehicle. Because of the different floor heights, coupling of Category 3 LFLRVs with Category 1 or 2 LFLRVs or other low- or high-floor vehicles would be problematic.
- *Operating speed.* Many European LFLRVs have top speeds of 70 km/hr (44 mph), which is substantially lower than some North American transit systems. With operation in city streets and close station spacing, common in Europe, higher top speeds are unimportant. Pro-

pulsion systems can be enhanced to provide vehicles that meet North American criteria.

- *Maintenance facilities.* With the reduced availability of space under the car to support equipment, LFLRVs use space above the roof of the car. As a result, less work is performed in pits, and more work is performed at the car roof level. Raised platforms are needed to support these efforts. Many LFLRVs are longer and have more body sections than conventional LRVs, too. Requirements for jacks, cranes, and pit and paint booth lengths may vary from those for existing fleets.
- *Fire resistance.* To reduce vehicle weights and improve energy consumption, European vehicles often use lightweight materials. Fire resistance of the car body and fire hardening of vehicle roofs are issues that need to be considered.

LFLRVs in the North American Context

There is a great deal of variety in the fleets operated by North American transit agencies and the accompanying right-of-way, systems, and station infrastructure. Depending on whether the agency is procuring vehicles, improving the accessibility of an existing line, building a line extension, or constructing a brand new line, the key issues to be addressed by the agency will vary. An

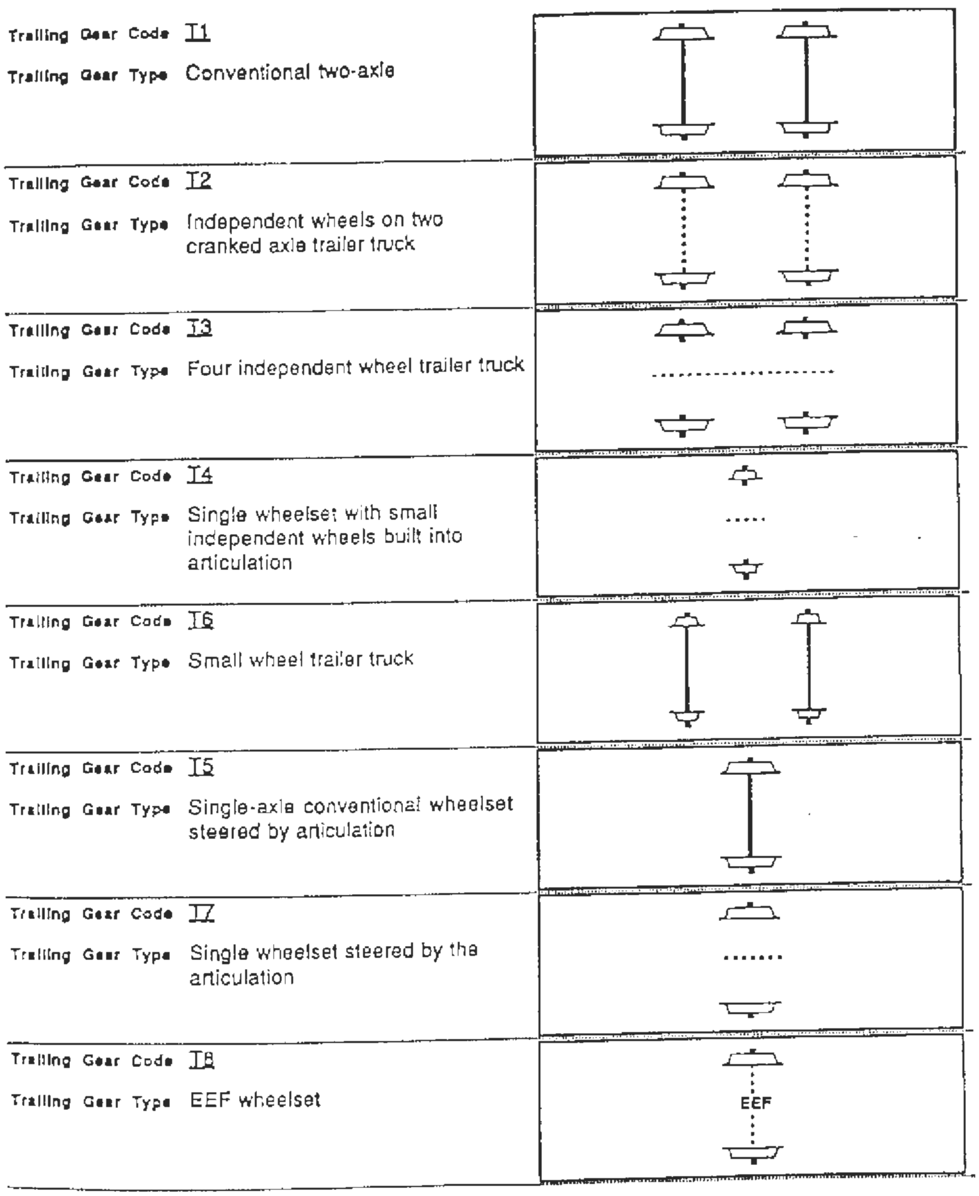
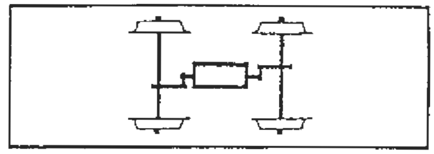


FIGURE 1 Conventional and LFLRV wheelset and drive arrangements.

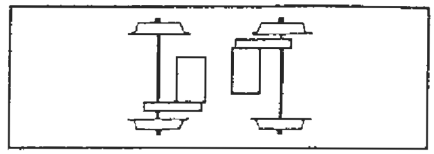
Power Gear Code M1

Power Gear Type Conventional monomotor



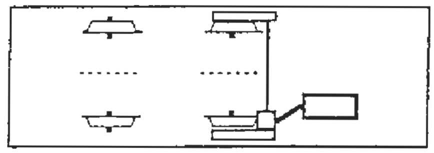
Power Gear Code M2

Power Gear Type Conventional bi-motor



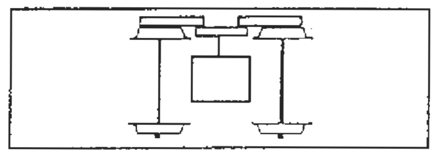
Power Gear Code M3

Power Gear Type Independent wheels, one pair driven, one pair free-wheeling



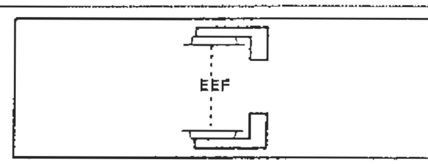
Power Gear Code M4

Power Gear Type Transverse-mounted motor drives both axles through parallel gears and cardan shaft



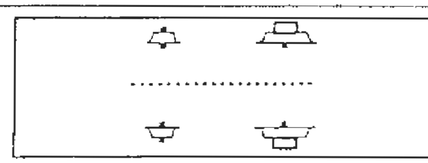
Power Gear Code M5

Power Gear Type Motored EEF self-steering wheelset



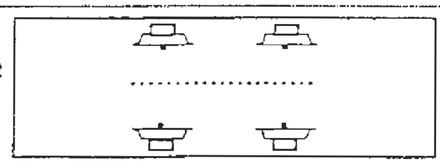
Power Gear Code M6

Power Gear Type Articulated truck frame, two large hub motor-driven wheels, two small guiding wheels



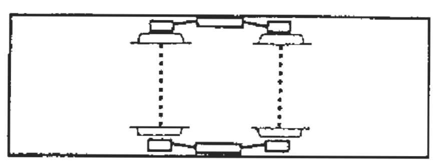
Power Gear Code M7

Power Gear Type Four hub motor-driven, independent wheels



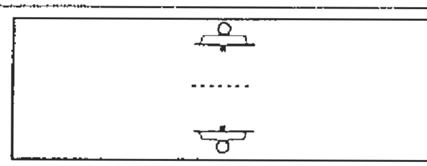
Power Gear Code M8

Power Gear Type Motor drives wheels on one side via cardan shafts



Power Gear Code M9

Power Gear Type Vertically mounted motors driving independent wheels built into articulation portal



Power Gear Code M10

Power Gear Type Independent wheels mounted on radial-arm axleboxes driven by motor via parallel gears

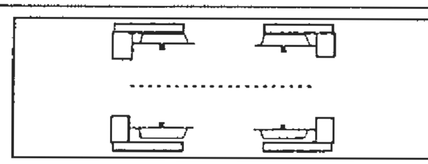


FIGURE 1 *Continued*

TABLE 1 Summary of Category 1, 2, and 3 LFLRVs

Category 1 Low Floor LRV's

City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m / *ft*)	Car Width (m / *ft*)	Floor Height Max (mm / *in*)	Floor Height Min (mm / *in*)	Weight (tonne / *lbs*)	Max Speed (km/h / *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Mannheim	Duewag		B'2'2'B'	23	9%	25.7 / *84.2*	2.2 / *7.2*	889 / *35*	353 / *13.9*	26 / *57,320*	60 / *37*	25 / *82*	M1	T1	1991
Amsterdam/ GVBA	Bombardier (BN)	11G & 12G	Bo'Bo'Bo'Bo'	45	9%	25.6 / *84.1*	2.4 / *7.7*	870 / *34.3*	280 / *11*	36.9 / *81,351*	70 / *44*	25 / *82*	M2		1989
Freiburg/ VAG	Duewag	GT 8C	B'B'B'B'	11	9%	32.8 / *107.7*	2.3 / *7.5*	910 / *35.8*	270 / *10.6*	38.5 / *84,878*	70 / *44*	25 / *82*	M1		1990
Nurnberg	AEG (MAN)	N82	B'2'2'B'	12	9%	26.1 / *85.8*	2.3 / *7.5*	880 / *34.6*	284 / *11.2*	32.8 / *72,312*	70 / *44*	25 / *82*	M1	T1	1992
Wurzburg	LHB	GT 8/8C	B'B'B'B'	14	10%	32.6 / *107*	2.4 / *7.9*	910 / *35.8*	310 / *12.2*	42.5 / *93,697*	70 / *44*	25 / *82*	M1		1989
Antwerp/ De Lijn	Bombardier (BN)		B'2'2'B'	10	10%	29.3 / *96.1*	2.3 / *7.5*	860 / *33.9*	350 / *13.8*	42 / *92,594*	80 / *50*		M1	T1	1993
Basle/ BVB	Schindler (SIG)	Be 4/4	B'2'2'B'	19	15%	25.4 / *83.3*	2.2 / *7.2*	855 / *33.7*	325 / *12.8*	31 / *68,343*	65 / *40*	12 / *39.4*	M1	T1	1987
Nantes/ SEMITAN	GEC Alsthom		B'2'2'B'	34	16%	39.2 / *128.4*	2.3 / *7.5*	873 / *34.4*	353 / *13.9*	51.9 / *114,420*	70 / *44*	25 / *82*	M1	T1	1992
Nantes/ SEMITAN	GEC Alsthom		B'2'2'B'	12	18%	39.2 / *128.4*	2.3 / *7.5*	850 / *33.5*	350 / *13.8*	51.6 / *113,759*	70 / *44*		M1	T1	1993
Sheffield/ SYST	Duewag	GT 8	B'B'B'B'	25	34%	34.8 / *114*	2.7 / *8.7*	880 / *34.6*	480 / *18.9*	46 / *101,413*	80 / *50*	25 / *82*	M1		1993
Freiburg	Duewag	GT8D-MNZ	Bo'Bo'Bo'Bo'	26	40%	33.1 / *108.6*	2.3 / *7.5*	560 / *22*	290 / *11.4*	38.5 / *84,878*	70 / *44*	19 / *62.3*	M2		1993
RBS	Schindler (SIG)	ABe4/8	Bo'2'2'Bo'	23	50%	39.3 / *128.9*	2.7 / *8.7*	830 / *32.7*	390 / *15.4*	51 / *112,436*	90 / *56*		M2	T1	1992

Sum of Category 1 Cars Ordered 254

Category 2 Low Floor LRV's

City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m / *ft*)	Car Width (m / *ft*)	Floor Height Max (mm / *in*)	Floor Height Min (mm / *in*)	Weight (tonne / *lbs*)	Max Speed (km/h / *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Trailing Gear: Independent wheels on two cranked axle trailer truck															
Portland	Duewag		Bo'2Bo'	46	66%	28.0 / *92*	2.7 / *8.7*	980 / *38.6*	355 / *14*	44 / *97,003*	88 / *55*	25 / *82*	M2	T2	1995
Grenoble/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	38	65%	29.4 / *96.5*	2.3 / *7.5*	875 / *34.4*	345 / *13.6*	43.9 / *96,783*	70 / *44*	25 / *82*	M1	T2	1987
Grenoble/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	7	65%	29.4 / *96.5*	2.3 / *7.5*	875 / *34.4*	345 / *13.6*	43.9 / *96,783*	70 / *44*	25 / *82*	M2	T2	1995
Paris/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	17	65%	29.4 / *96.5*	2.3 / *7.5*	875 / *34.4*	345 / *13.6*	43.9 / *96,783*	70 / *44*	25 / *82*	M1	T2	>1993
Rouen/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	28	65%	29.4 / *96.5*	2.3 / *7.5*	875 / *34.4*	345 / *13.6*	43.9 / *96,783*	70 / *44*	25 / *82*	M1	T2	1993
Val de Seine/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	17	65%	29.4 / *96.5*	2.3 / *7.5*	875 / *34.4*	345 / *13.6*	43.9 / *96,783*	70 / *44*	25 / *82*	M1	T2	>1993
Trailing Gear: Four independent wheel trailer truck															
Buenos Aires	Duewag		Bo'2Bo'	9	62%	23.8 / *78*	2.4 / *7.9*	560 / *22*	350 / *13.8*	29.7 / *65,477*	70 / *44*	25 / *82*	M2	T3	1994
Valencia	Duewag		Bo'2Bo'	24	62%	23.8 / *78*	2.4 / *7.9*	560 / *22*	350 / *13.8*	29.7 / *65,477*	65 / *40*	20 / *65.6*	M2	T3	1994
Turin/ ATM	Fiat (Firema)	5000	B'2'B	54	56%	22.2 / *72.8*	2.3 / *7.5*	870 / *34.3*	350 / *13.8*	30 / *66,139*	60 / *37*	16 / *52.5*	M1	T3	1989
Dresden	Duewag	6MGT	Bo'22Bo'	20	64%	40.5 / *132.9*	2.4 / *7.9*	600 / *23.6*	350 / *13.8*	42 / *92,594*	70 / *44*	15 / *49.2*	M2	T3	>1993
Mannheim	Duewag	6MGT	Bo'2Bo'	64	64%	29.9 / *98.1*	2.4 / *7.9*	600 / *23.6*	350 / *13.8*	33 / *72,753*	70 / *44*	15 / *49.2*	M2	T3	1994
Mannheim	Duewag	6MGT	Bo'22Bo'	5	64%	40.5 / *132.9*	2.4 / *7.9*	600 / *23.6*	350 / *13.8*	42 / *92,594*	70 / *44*	15 / *49.2*	M2	T3	1994
Mannheim	ABB Henschel	6NGT/ Variotram	N/A	2	70%	0.0 / *0*	0.0 / *0*	N/A / *0*	290 / *11.4*	N/A / *0*	N/A / *0*	N/A / *0*	M2	T3	1996
Karlsruhe	Duewag	70D/N	Bo'2Bo'	20	61%	28.8 / *94.6*	2.7 / *8.7*	580 / *22.8*	390 / *15.4*	34.5 / *76,060*	80 / *50*		M2	T3	1994
Brno City Transport	CKD Tatra	RT6-N1	Bo'2Bo'	12	63%	26.3 / *86.2*	2.4 / *8*	900 / *35.4*	350 / *13.8*	32 / *70,548*	80 / *50*	25 / *82*	M2	T3	>1993
Prototype	CKD Tatra	RT6-N1	Bo'2Bo'	1	63%	26.3 / *86.2*	2.4 / *8*	900 / *35.4*	350 / *13.8*	32 / *70,548*	80 / *50*	25 / *82*	M2	T3	1993
Rome/ ATAC	Socimi	T8000	Bo'2Bo'	34	54%	21.2 / *69.6*	2.3 / *7.5*	835 / *32.9*	350 / *13.8*	29.7 / *65,477*	70 / *44*	15 / *49.2*	M2	T3	1990
Trailing Gear: Single-axle conventional wheelset steered by articulation															
Cologne	Bombardier (Rotax)	T	Bo'1'1'Bo'	40	60%	26.8 / *87.9*	2.7 / *8.7*	530 / *20.9*	440 / *17.3*	34.7 / *76,500*	80 / *50*	20 / *65.6*	M2	T5	>1993
Vienna U-Bahn	Bombardier (Rotax)	T	Bo'1'1'Bo'	68	60%	26.8 / *87.9*	2.7 / *8.7*	530 / *20.9*	440 / *17.3*	34.7 / *76,500*	80 / *50*	20 / *65.6*	M2	T5	1992

Category 2 Low Floor LRV's City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Trailing Gear: Small wheel trailer truck															
Leipzig	Duewag	8NGT	Bo'2'2'Bo'	25	61%	27.8 *91.2*	2.2 *7.2*	560 *22*	300 *11.8*	32 *70,540*	70 *44*		M2	T6	1994
Swiss-Italian Railway/ FART	ACM Vevey	ABe4/6	Bo'2'Bo'	12	80%	30.3 *99.4*	2.7 *8.7*	900 *35.4*	530 *20.9*	42.5 *93,697*	80 *50*		M2	T6	1992
Geneva/ TPG	ACM Vevey	Be4/6	B'2'B'	46	60%	21.0 *68.9*	2.3 *7.5*	870 *34.3*	480 *18.9*	27 *59,525*	60 *37*	17.5 *57.4*	M1	T6	1984
St. Etienne/ STAS	GEC Alsthom	Be4/6	B'2'B'	25	59%	23.2 *76.2*	2.1 *6.9*	710 *28*	350 *13.8*	27.4 *60,407*	70 *44*	18 *59.1*	M1	T6	1991
Bern/ SVB	ACM Vevey	Be4/8	B'2'2'B'	12	73%	31.0 *101.7*	2.2 *7.2*	710 *28*	350 *13.8*	34 *74,957*	60 *37*	15 *49.2*	M1	T6	1989
Geneva	ACM Vevey	Be4/8 Intermediate	N/A	18	0%	0.0 *0*	0.0 *0*	N/A *0*	350 *13.8*	N/A *0*	N/A *0*	N/A *0*	M1	T6	1995
Magdeburg	LHB	NGT 8D	Bo'2'2'Bo'	120	60%	29.0 *95.1*	2.3 *7.5*	570 *22.4*	350 *13.8*	34 *74,957*	70 *44*		M2	T6	1995
Trailing Gear: EEF wheelset															
Rostock	Duewag	6NGTWDE	Bo'1'1'Bo'	50	50%	30.4 *99.7*	2.3 *7.5*	560 *22*	350 *13.8*	30.4 *67,021*	70 *44*	15 *49.2*	M2	T8	1994
Bogestra/ Bochum	Duewag	MGT6D	Bo'1'1'Bo'	43	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	1992
Brandenburg	Duewag	MGT6D	Bo'1'1'Bo'	4	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	>1993
Erfurt	Duewag	MGT6D	Bo'1'1'Bo'	4	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	>1993
Halle	Duewag	MGT6D	Bo'1'1'Bo'	14	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	1992
Heidelberg	Duewag	MGT6D	Bo'1'1'Bo'	12	63%	28.9 *94.9*	2.3 *7.5*	540 *21.3*	350 *13.8*	31.5 *69,446*	70 *44*	15 *49.2*	M2	T8	1994
Mulheim	Duewag	MGT6D	Bo'1'1'Bo'	4	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	>1993
Kassel/ KVG	Duewag	NGT6C	B'1'1'B'	25	70%	28.8 *94.3*	2.3 *7.5*	700 *27.6*	350 *13.8*	30.2 *66,580*	70 *44*	15 *49.2*	M1	T8	1990
Bonn	Duewag	NGT6D	Bo'1'1'Bo'	24	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	31.5 *69,446*	70 *44*	15 *49.2*	M2	T8	1994
Dusseldorf	Duewag	NGT6D	Bo'1'1'Bo'	10	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	31.5 *69,446*	70 *44*	15 *49.2*	M2	T8	>1993

Sum of Category 2 Cars Ordered 954

Category 3 Low Floor LRV's City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Power Gear: Unknown															
Prototype (Turin)	Firema	Prototype	Bo'2'Bo'	1	100%	22.2 *72.8*	2.3 *7.5*	350 *13.8*	350 *13.8*	24 *52,911*	90 *56*			T3	
Power Gear: Independent wheels mounted on radial-arm axleboxes driven by motor via parallel gears															
Prototype (Rome)	Socimi		BoBoBo	1	100%	22.0 *72.2*	2.4 *7.9*	350 *13.8*	350 *13.8*	25 *55,116*	60 *37*		M10		1992
Strasbourg	ABB (Socimi)	Eurotram	BoBoBo2	26	100%	32.5 *106.6*	2.4 *7.9*	350 *13.8*	350 *13.8*	29 *63,934*	60 *37*	25 *82*	M10	T3	1994
Prototype (Milan)	Socimi	S-350LRV	Bo'Bo'	1	100%	14.0 *45.9*	2.4 *7.9*	350 *13.8*	350 *13.8*	10.5 *23,149*	70 *44*	15 *49.2*	M10		1989
Power Gear: Independent wheels, one pair driven, one pair free-wheeling															
Augsburg	AEG (MAN)	GT6M	1A'A1'A1'	1	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	29.6 *65,257*	70 *44*	15 *49.2*	M3		1993
Berlin	AEG (MAN)	GT6N	1A'A1'A1'	120	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		1994
Braunschweig	AEG (MAN)	GT6N	1A'A1'A1'	11	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Bremen	AEG (MAN)	GT6N	1A'A1'A1'	18	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		1990
Frankfurt-an-der-Oder	AEG (MAN)	GT6N	1A'A1'A1'	13	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Halle	AEG (MAN)	GT6N	1A'A1'A1'	1	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Munich	AEG (MAN)	GT6N	1A'A1'A1'	70	100%	27.3 *89.6*	2.3 *7.5*	350 *13.8*	300 *11.8*	29.4 *64,816*	70 *44*	15 *49.2*	M3		1994
Zwickau	AEG (MAN)	GT6N	1A'A1'A1'	12	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Munich	AEG (MAN)	GT6N/ R1.1	1A'A1'A1'	3	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	29.5 *65,036*	70 *44*	15 *49.2*	M3		1990
Bremen	AEG (MAN)	GT8N	1A'1A'1A'1A'	61	100%	35.0 *114.8*	2.3 *7.5*	350 *13.8*	300 *11.8*	34 *74,957*	70 *44*	15 *49.2*	M3		1993
Jena	AEG (MAN)	GT8N	1A'1A'1A'1A'	10	100%	35.0 *114.8*	2.3 *7.5*	350 *13.8*	300 *11.8*	34 *74,957*	70 *44*	15 *49.2*	M3		>1993
Power Gear: Transverse-mounted motor drives both axles through parallel gears and cardan shaft															
Lille	Breda	VLC	B'1 1 1 B'	24	80%	29.9 *98.1*	2.4 *7.9*	950 *37.4*	350 *13.8*	40 *88,185*	70 *44*	25 *82*	M4	T4	1993
Prototype (Rome)	Breda	VLC	B'1 1 B'	1	75%	22.0 *72.2*	2.5 *8.2*	950 *37.4*	350 *13.8*	22 *48,502*	70 *44*	20 *65.6*	M4	T4	1990

(*continued on next page*)

TABLE 1 (*Continued*)

Category 3 Low Floor LRV's City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Power Gear: Motored EEF self-steering wheelset															
Mannheim/ MVG	German Consortium	dGTW-ER	A'A'A'1'	1	100%	26.7 *87.6*	2.3 *7.5*	350 *13.8*	290 *11.4*	23.98 *52,867*	70 *44*	15 *49.2*	M5	T8	1991
Dusseldorf/ RBG	German Consortium	GTW-ER	A'A'1'	1	100%	20.2 *66.2*	2.4 *7.9*	350 *13.8*	290 *11.4*	17.75 *39,132*	70 *44*	18 *59.1*	M5	T8	1991
Bonn/SWB	German Consortium	GTW-ZR	A'A'1'	1	100%	20.2 *66.2*	2.4 *7.9*	350 *13.8*	290 *11.4*	18.56 *40,918*	70 *44*	18 *59.1*	M5	T8	1991
Power Gear: Articulated truck frame, two large hub motor-driven wheels, two small guiding wheels															
Prototype	Bombardier (BN)	LRV2000	A'1'1'A'1'A'	1	100%	20.2 *66.3*	2.5 *8.1*	350 *13.8*	350 *13.8*	24 *52,911*	70 *44*		M6		1990
Brussels	Bombardier (BN)	TRAM2000	A'1'Bo1'A'	51	100%	22.8 *74.8*	2.3 *7.5*	350 *13.8*	350 *13.8*	31.9 *70,328*	70 *44*	17.5 *57.4*	M6		1994
Power Gear: Four hub motor-driven, independent wheels															
Chemnitz	ABB Henschel	6NGT/ Variotram	Bo'2'Bo'	53	100%	30.9 *101.4*	2.7 *8.7*	350 *13.8*	290 *11.4*	28.3 *62,391*	70 *44*	18 *59.1*	M7	T3	1993
Wurzburg	LHB	GTW	Bo'Bo'Bo'	20	100%	29.1 *95.5*	2.4 *7.9*	350 *13.8*	300 *11.8*	35 *77,162*	80 *50*		M7		>1993
Frankfurt am Main	Duewag	R3.1	Bo'2'Bo'	20	100%	27.2 *89.2*	2.4 *7.7*	350 *13.8*	300 *11.8*	33 *72,753*	70 *44*	18 *59.1*	M7	T3	1993
Power Gear: Motor drives wheels on one side via cardan shafts															
Prototype	Schindler (SIG)	Cobra 370	A'A'A'A'	1	100%	24.5 *80.4*	2.3 *7.5*	370 *14.6*	320 *12.6*	25 *55,116*	65 *40*	11.8 *38.7*	M8		1993
Power Gear: Vertically mounted motors driving independent wheels built into articulation portal															
Vienna "A"	SGP	ULF197-4	1A'A'A'1	100*	100%	23.6 *77.5*	2.4 *7.9*	197 *7.8*	197 *7.8*	23 *50,706*	70 *44*	18 *59.1*	M9	T7	1995
Vienna "A" Prototype	SGP	ULF197-4	1'A'A'A'1	1	100%	23.6 *77.5*	2.4 *7.9*	197 *7.8*	197 *7.8*	23 *50,706*	70 *44*	18 *59.1*	M9	T7	1994
Vienna "B"	SGP	ULF197-6	1'A'A'A'A'1'	50*	100%	34.9 *114.4*	2.4 *7.9*	197 *7.8*	197 *7.8*	32.5 *71,650*	70 *44*	18 *59.1*	M9	T7	1995
Vienna "B" Prototype	SGP	ULF197-6	1'A'A'A'A'1	1	100%	34.9 *114.4*	2.4 *7.9*	197 *7.8*	197 *7.8*	32.5 *71,650*	70 *44*	18 *59.1*	M9	T7	1994

Sum of Category 3 Cars Ordered 675

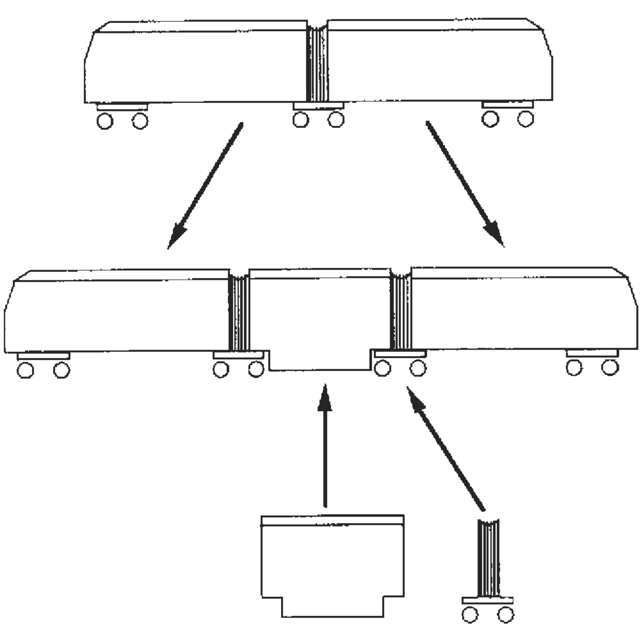


FIGURE 2 LFLRV achieved by converting conventional six-axle, single-articulation LRV into eight-axle, double-articulation LRV.

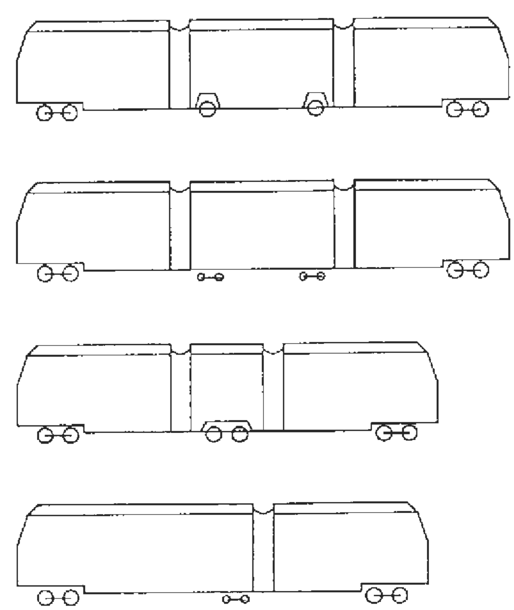


FIGURE 3 Various configurations of Category 2 LFLRVs with conventional motor trucks (not to scale).

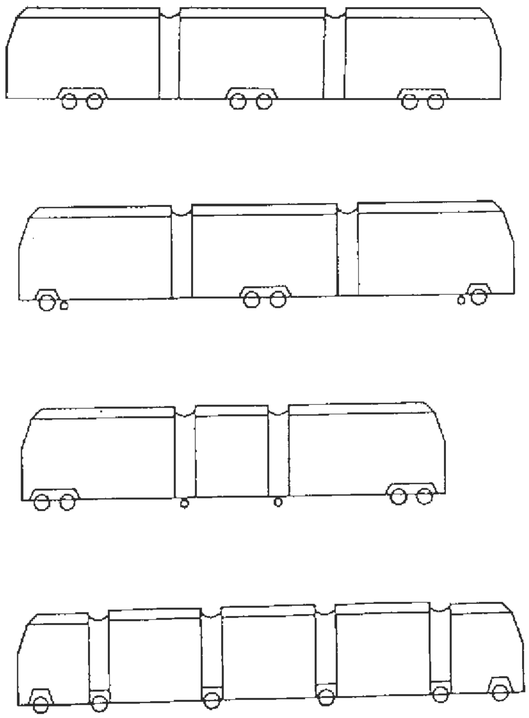


FIGURE 4 Typical configurations of Category 3 LFLRVs (not to scale).

applicability assessment strategy that can be used to evaluate the effectiveness of low-floor vehicles is described here and shown in Figure 7:

- *Define options.* The availability of LFLRV solutions provides a new range of options. They include mixed consist operation (conventional LRVs and LFLRVs) and the construction of low platforms to allow level boarding at the low-floor level. Other options relating to LFLRVs are similar to high-floor options.
- *Assess technological risk.* Category 1 and Category 2 LFLRVs use technology with a history of reliability and performance, but Category 3 LFLRVs incorporate many technological innovations never tried before. Agencies should select a vehicle consistent with the degree of risk that they are willing to accept.
- *Evaluate physical compatibility.* The compatibility of LFLRVs with the existing infrastructure must be assessed. If a new system is being constructed, the physical infrastructure and the vehicles can be designed to complement each other. If it is an existing system, the ability of cars to run in mixed consists and the potential need for retrofits of platforms, shops, right of way, and systems must be considered. Where the existing line has a number of existing high platforms to provide level boarding of conventional LRVs, using LFLRVs is most likely inappropriate.
- *Quantify operational impacts.* The operation and maintenance of a mixed fleet complicate work practices.

TABLE 2 Category 2 Vehicle Prices

CITY	BUILDER	LENGTH	WIDTH	YEAR OF DELIVERY	NUMBER OF VEHICLES	US $ EQUIVALENT
Paris[1]	GEC-Alsthom	29.4 m (96 ft 5.5 in)	2.3 m (7 ft 6 in)	1991	34	2,400,000
Geneva[1]	ACM Vevey	21.0 m (68 ft 11 in)	2.3 m (7 ft 6 in)	1990	46	2,350,000
Portland (Tri-Met)[1]	Siemens-Duewag Corp.	28.0 m (92 ft)	2.65 m (8 ft 8 in)	1995	46	2,319,000
Grenoble[2]	GEC-Alsthom	29.4 m (96 ft 5.5 in)	2.3 m (7 ft 6 in)	1987	38	2,363,000
Mannheim[2]	Duewag	29.9 m (98 ft 1 in)	2.4 m (7 ft 11 in)	1994	64	2,010,000
Dusseldorf[2]	Duewag	28.6 m (93 ft 8 in)	2.3 m (7 ft 6 in)	–	10	1,635,000
Boston[2]	Breda	22.68 m (75 ft)	2.64 m (8 ft 8 in)	1999	100	2,100,000

1 Information obtained through interviews
2 Information obtained from *Railway Gazette International Year Book,* Developing Metros 1994, "German Cities Dominate Deliveries of Novel Low and Middle-Floor Cars."

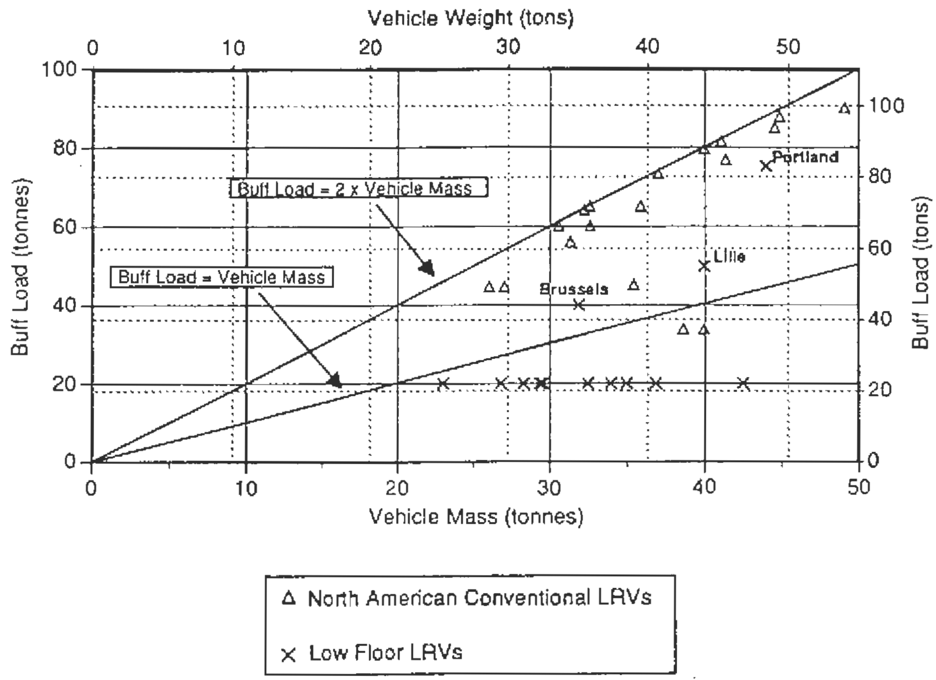


FIGURE 5 Comparison of buff load.

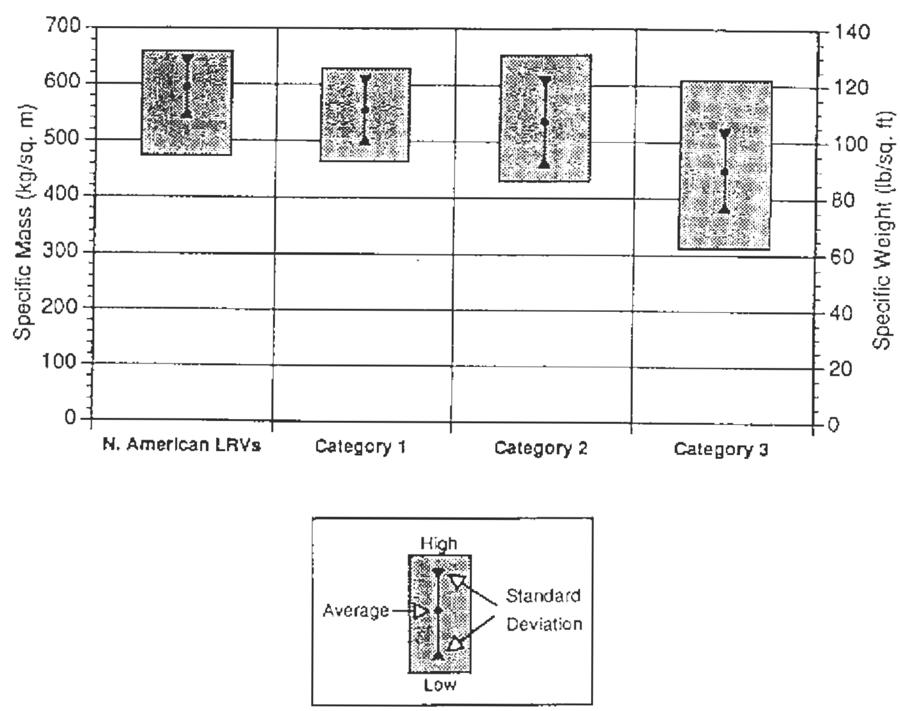


FIGURE 6 Comparison of specific mass for LFLRVs and conventional North American LRVs.

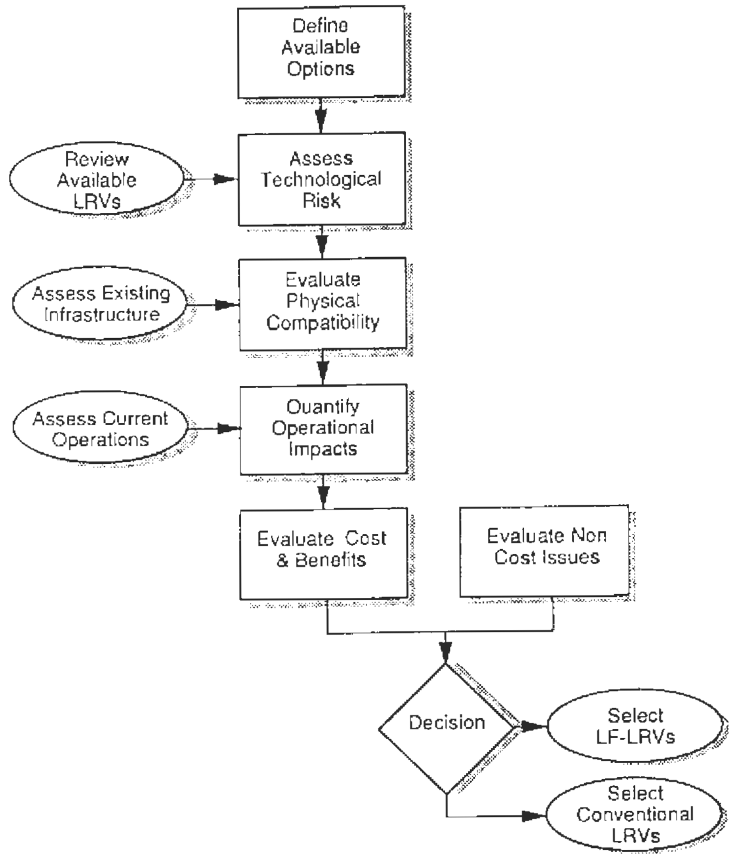


FIGURE 7 Applicability assessment model.

At the same time, LFLRVs offer many advantages. Improved accessibility is an important consideration. If level boarding of LFLRVs can be provided where level boarding of conventional LRVs cannot, a significant improvement in service reliability and reduction in round-trip time are possible. Reduced round-trip times may allow decreases in fleet requirements. For example, with wayside lift loading and unloading of two passengers, a system delay of 10 min or more is possible. Delays of 10 min per trip will manifest either as reduced service reliability or increased vehicle requirements to compensate for the delays. With 10-min headways, one additional train would be required. Level boarding of LFLRVs effectively removes boarding delays and the need for additional vehicles.

• *Evaluate costs and benefits.* LFLRVs currently cost up to 10 percent more than similar conventional vehicles. It is anticipated that the cost premium for LFLRVs will soon disappear. In addition, loading platforms can be constructed much more cheaply for LFLRVs, and operating efficiencies may result in fleet requirement savings.

• *Evaluate noncost issues.* Transit agencies should weigh a number of noncost considerations. The public increasingly expects barrier-free accessibility to public transportation. The degree of visibility and intrusion of system infrastructure into the built environment around an LRT line are directly affected by the type of vehicle used. LFLRVs provide superior solutions with respect to both concerns.

Summary

The Americans with Disabilities Act has been a great catalyst in the United States in the movement toward LFLRV solutions. Portland and more recently Boston have demonstrated that LFLRVs can be implemented in North America in a very cost-effective fashion.

As more LFLRV systems are installed, the premium cost of low-floor versus high-floor vehicles will continue to fall; it is expected that the gap in prices will disappear very soon. LFLRVs will become the norm for new-start LRT projects, and high-floor vehicles will be used only for vehicle replacement or line extensions on systems with high-platform stations.

Compression Loads for Light Rail Vehicles in the United States

Joe Lewalski, *D&D Engineering*

The requirements of the Americans with Disabilities Act for (LRVs), resulting in the emergence of lower floors and cutouts in the underframe for wheelchair lifts, will create new challenges for structural engineers. These challenges will make it necessary to reexamine the specified LRV design compression loads and to compare them with design compression loads on other types of vehicles. When a comparison takes into consideration the size of the trains and their operating speeds, a case can be made for lowering the compression load of 2 *g* at AWO (empty) vehicle weight currently prevailing in U.S. specifications. A crash index is introduced that indicates how much compression resistance is assigned to absorb and disperse a unit of a train's energy. It is concluded that the LRV crash index is approximately four times higher than that for mainline or rapid transit cars. Accordingly, LRV compression loads should be lowered to provide greater safety, lower weight, lower energy consumption, and more attractive general arrangements.

The compression load is a design load that engineers apply to the ends of a railcar to squeeze it longitudinally for either strength calculations or testing. The car must not change its shape permanently under the action of the specified compression load.

Specified Compression Loads for Light Rail Vehicles

Although federally mandated or unequivocally accepted compression load standards do not exist, the 2-*g* practice (i.e., specifying a compression load equal to two weights of the empty car) until recently appeared to be taking hold in the United States.

Some simple calculations indicated that these values for the compression load were high. The weights and operational speeds of various trains—mainline commuter, rapid transit, and light rail vehicle (LRV)—were compared, and it was found that in terms of the forces and dissipated energy that can occur in collisions, American LRVs are relatively much stronger than other types of rail vehicles.

The objectives of this paper are as follows:

- Identify the problem,
- Bring it to the attention of the professional community,
- Indicate some possible ways of handling it, and
- Generate the interest of the broader segments of the industry in attacking the issue.

The facts in hand are the two widely accepted design buff loads: 800,000 lb for mainline commuter passenger coaches and 200,000 lb for self-propelled mass transit vehicles. Many years of experience with such vehicles, and a statistically sufficient number of investigated collisions and passenger injuries, indicate that 800,000 lb for commuter cars and 200,000 lb for transit cars provide a good measure to be applied in the design and evaluation of passenger rail vehicles. The practice of operating railcars built to such a specification appears to be well recognized by the mass transit community as providing an acceptable compromise between the two main requirements for protecting passengers against injury: a car body structure that is sufficiently impact-resistant and, at the same time, sufficiently shock-absorbing (collapsible).

What is wrong with the fact that American LRVs are much stronger than other types of rail vehicles? What is wrong is that such LRVs might be too rigid, which may hurt people when, during a collision where there is no adequate cushioning effect provided by the collapsing structure, they are thrown violently against the elements of the vehicle interior.

It is true that more severe types of injuries (called primary injuries) occur when the car body shell opens or collapses under the forces of collision. However, statistics for heavy rail passenger operations show that although primary injuries are frequently fatal, the number of secondary injuries due to passenger impact against the car interior is much larger (*1*). For instance, within the statistical period of 1966 to 1973, there were 50 passenger fatalities in the United States due to primary injuries, and one fatality and 1,661 injuries due to the impact of passengers against the car interior. These statistics become even more telling when one realizes that out of 50 primary-injury fatalities, 45 occurred in a single accident. In addition, in this infamous collision (in Chicago) the problem was not the insufficient resistance to compression load, but the fact that one car overrode the other and penetrated the passenger compartment. Such collisions are unlikely on LRVs because of their lower masses and velocities.

Thus, a vehicle of optimal safety will be neither too weak nor too strong. A proper amount of structural vulnerability is beneficial in the sense that the collapsing structure provides cushioning between a passenger and the obstruction causing the collapse. A car structure should resist impact but also absorb the impact energy.

Finally, if LRV cars are made too strong they will be unnecessarily heavy, thus more expensive, and their design will impose limitations on such attractive arrangements as large windows and low floors. Heavier cars will also consume more energy and therefore cost more to operate.

Compression Loads for Other Railcars

One reason for the apparently excessive LRV car body stiffness is the fact that for LRVs, and only for LRVs, the compression load is not specified as an absolute force but as a fraction of car body weight. In American practice LRV specifications do not indicate that the compression load should be so many pounds. Instead, it should be twice (or some other multiple) its empty weight. And this creates a problem.

Begin the comparison with mainline and commuter cars. The specified compression load for these cars is 3356 kN (equal to 800,000 lb of force). This requirement remains constant irrespective of the number of cars in a train consist (Figure 1). Thus, whether there will be two cars, five, or ten in the train consist, a single car must resist the same 3356 kN (800,000 lb).

The same logic applies to rapid transit cars with their 889-kN (200,000-lb) compression load requirement (Figure 2). Whether for a single car, or a consist of two, four, or more cars, the strength requirement remains the same.

The predecessors to contemporary LRVs, the original President's Conference Committee (PCC) cars, had various weights, depending on their type and application. The weights of the early PCC cars are as follows (*2*, p. 190):

- Brooklyn 1001: 15 112 kg (33,360 lb),
- Chicago 4002: 16 489 kg (36,400 lb), and
- St. Louis 1500: 15 230 kg (33,620 lb).

Mystery of Original PCC Cars

Unfortunately, the compression load of the PCC cars has not been established. Nevertheless, for the sake

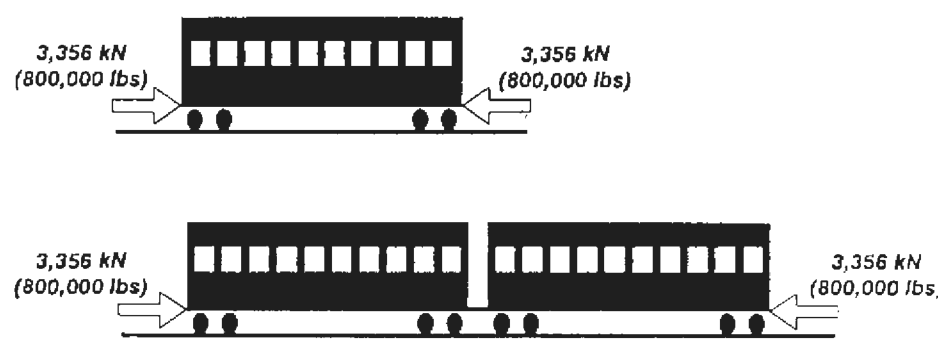


FIGURE 1 Compression load for mainline railcars.

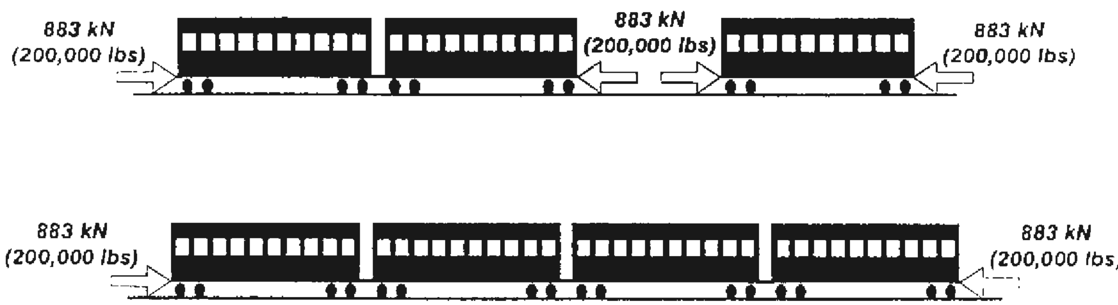


FIGURE 2 Compression load for rapid transit railcars.

of argument, assume that the PCC compression load indeed was equal to twice the weight of an empty car (2 *g*). Thus, the compression loads for the cars listed earlier presumably were as follows:

- Brooklyn: 279 kN (66,720 lb),
- Chicago: 324 kN (72,800 lb), and
- St. Louis: 299 kN (67,240 lb).

Therefore, assume that the compression load of the PCC cars averaged approximately 311 kN (70,000 lb). On occasion, these cars were coupled in pairs or in multiple-unit trains, as seen in the pictures in *The PCC Car: An American Original* (2, pp. 82, 105, 108, 110). There is no evidence that on these occasions transit authorities made massive structural modifications to multiply the compression load of these cars by the number of cars in a train consist. This was the same policy as described earlier in respect to mainline and mass transit cars (Figure 3).

This policy prevailed until the concept of articulation became popular for reasons of reduced operational cost. Then, suddenly, a unit that should have been considered as consisting of two car bodies was treated as a single car with the resulting extreme increase of design compression load (Figure 4).

Time for a Change

What is being challenged here is not any particular value for the compression load but the doubling of this value when a coupler joint between cars is replaced by an articulation joint. Adding more articulations in future designs for the U.S. market—two, three, or more—may lead to a further increase of compression load requirements.

It appears reasonable to abandon the convention of defining compression loads as a function of LRV weight. The author recommends that the LRV car body

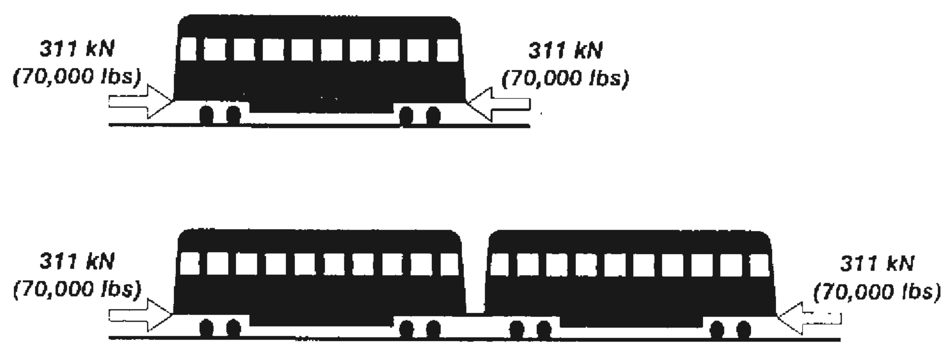


FIGURE 3 Presumed compression load on PCC cars.

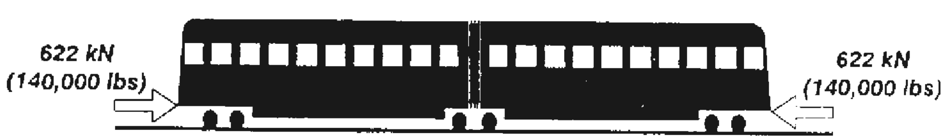


FIGURE 4 Compression load for present-day American LRVs.

TABLE 1 Compression Load for Present-Day American LRVs (kN) (1 kN = 224.94 lb)

Column (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Unit Weight							Compression	
	Car	Locomotive	Train Weight	Maximum Speed		Speed Square	Kinetic Energy	Load	Crash Index
	(kg)	(kg)	(kg)	(km/h)	(m/sec)	(m/sec)square	(kJoules)	(kNewtons)	
					(5) x 0.28	(6)x(6)	(4)x(7)/2000		(9)/(8)
4 LRVs	40,770	NA	163,080	80	22.22	493.73	4.03E+04	711	1.77E-02
10 Rapid Transit Cars	38,505	NA	385,050	120	33.33	1,110.89	2.14E+05	889	4.16E-03
10 Commuter Cars + 2 Locos	54,360	181,200	906,000	152	42.22	1,782.53	8.07E+05	3,356	4.16E-03

design squeeze force be specified in terms of an absolute load, similar to the requirements for rapid transit and commuter rail cars in the United States and for LRVs elsewhere in the world.

Suggested Specified Compression Load

To determine the best specified compression load, compare the kinetic energies of three of the heaviest train sets for each of the main rail vehicles—namely, LRV, rapid transit, and commuter cars—each train set running at the highest operational speed (Table 1). For each type of car these would be the most disastrous conditions in case of a collision. The specified compression loads will be divided by the calculated train energies [(Table 1, Column 8; kinetic energy = mass × velocity^2/ $2g$, and g = 9.81 m/sec^2 (32.2 ft/sec^2)]. The resulting values (Table 1, Column 10) will tell how much compression resistance is assigned to handle (i.e., to absorb and disperse) a unit of the train's energy.

The analysis shows (Figure 5) that the car bodies of LRVs in the United States are overbuilt when compared with mass transit and commuter cars. Dissipating one unit of energy uses 17.7 units of compression resistance in LRVs but only 4.16 units in mass transit and commuter cars.

Such a comparison will always be based on matters of judgment, and with different assumptions the results will differ somewhat in each case. For instance, the maximum speed of the commuter car can be assumed to be 160 rather than 152 km/hr (100 rather than 95 mph), the number of cars in the rapid transit train 12 rather than the 10 used here, or the cars loaded rather than empty. However, with a little attention to detail, and while maintaining some level of reasonableness, it will be seen that the differences identified among the types of cars investigated remain in roughly the same relation: the expected collision performance of rapid transit and commuter cars will be comparable; that of LRVs, quite different.

What would the LRV compression load be if the car were required to have the same crash index as rapid transit and commuter cars? This can be calculated as follows:

Since

Crash index = (compression load)/(kinetic energy)

then

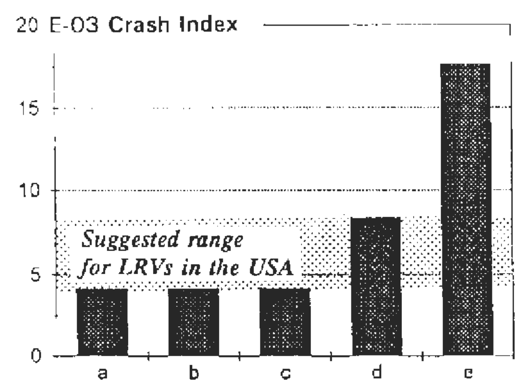
Compression load = (crash index) × (kinetic energy)

Thus, if the desired crash index for LRVs is to resemble those for mass transit and commuter cars (i.e., to be approximately 4.16×10^{-3}), the equivalent compression load for LRVs would be

$$\text{Compression load}_{LRV} = (4.16 \times 10^{-3}) \times (4.03 \times 10^4)\ \text{(kJ)}$$

$$= 168\ \text{kN}\ (37{,}800\ \text{lb})$$

(For energy value, see Table 1.)



	Crash Index	Compression (kN)
a. Commuter Car	4.16	3,356
b. Rapid Transit Car	4.16	883
c. Equivalent-crash-index LRV	4.16	168
d. Suggested max-compression LRV	8.33	336
e. 2g LRV	17.7	622

FIGURE 5 Suggested range for LRV crash indexes.

TABLE 2 Crash Indexes for Various Railcars

Baltimore	886
Boston, Kinki Sharyo	333
Boston, Low-Floor Spec	640
Buffalo	632
Chicago Low-Floor Spec	489
Calgary	591
Cleveland	333
Denver	720
Edmonton	591
Los Angeles Blue Line	836
Philadelphia City Transit	441
Philadelphia Red Arrow	441
Pittsburgh	782
Portland, Bombardier	756
Portland, Siemens/Duewag	756
Sacramento	711
San Diego SD 100	720
San Francisco, Boeing LRV	551
San Francisco, Breda LRV	445
Santa Clara	862
St. Louis	800
Toronto CLRV	445
Toronto ALRV	445
European Standard	200
Suggested for the USA	266-355

Similarly, the crash index for a car with the maximum suggested compression load of 336 kN (80,000 lb) (Table 2) would be

$$\text{Crash index}_{\text{LRV max}} = 336\ (\text{kN})/4.03 \times 10^4\ (\text{kJ})$$
$$= 8.33 \times 10^{-3}$$

Conclusions

The design compression load will most likely be decided every time a new car is ordered, in negotiations among the purchasing transit authority, the vehicle procurement consultant, and the car builder. More than the crash index will have to be considered. The most important will be the results of an examination of the injury statistics of past LRV collisions. However, even with a bias for having LRVs built relatively stronger than rapid transit and commuter cars, it would be difficult, in the author's opinion, to justify compression loads higher than half of what is specified today, or 267 to 336 kN (60,000 to 80,000 lb) (Table 2). This is certainly true for the LRV train set investigated here, consisting of four 38 000 to 41 000-kg (83,885- to 90,500-lb) cars and capable of speeds up to 88 km/hr (55 mph).

Those indicating that Europe can afford lower compression loads because their LRV consists are shorter and slower [with maximum speeds of 64 to 72 km/hr (40 to 45 mph)] might notice that the new compression loads suggested here for the United States would still be 1.3 to 1.8 times higher than those in Europe, currently specified at 200 kN (45,000 lb) (Table 2).

It should come as no surprise if LRVs ordered in the United States in the future are allowed to be built to load requirements lower than those used today.

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Innovative Approach to Light Rail Vehicle Design

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Passenger expectations, along with transit authority requirements, shape the design of modern-day transit equipment. Not only should today's light rail vehicles (LRVs) be perceived by passengers as user-friendly, comfortable, and environmentally sound, but they must also meet stringent criteria set by urban transportation planners and administrators. The design features of ABB's Variotram, a unique vehicle that employs modular design concepts for flexibility and a gearless hub motor as a solution to the need for low floors, are described. To achieve a totally flat low floor, the traditional LRV drive system has been redesigned. The Variotram LRV features an in-wheel hub motor that is fitted with direct drive for every wheel in a 100 percent low-floor LRV. This unique hub motor eliminates the need for wheel shafts and gear boxes, which, in turn, allows a low floor from end to end. The motor is a totally encapsulated unit, making it virtually maintenance-free and ensuring quiet operation. Transistorized technology allows for an extremely compact inverter unit that mounts on the roof above the truck section of the LRV. These technologies have made a 100 percent low-floor design possible and are revolutionizing the entire LRV concept. The Variotram is based on a set of five modules that can be built to different widths and for broad, standard, or meter gauge networks. Modules of different lengths are joined by articulation units and can be configured for either unidirectional or bidirectional operation. In addition to its adaptability, this modular LRV is designed for superior comfort with low floors, climate control, and larger windows—features that studies have shown greatly increase passenger acceptance. The Variotram has been in operation in Chemnitz, Germany, since June 1994.

Innovation is usually a product of need. Transit authorities today more than ever need to minimize capital and operating costs while providing upgraded service to their passengers. ABB's Variotram, the world's first low-floor light rail vehicle (LRV) equipped with in-wheel hub traction motors and designed entirely for modular flexibility, was a direct response to these needs. The Variotram prototype was delivered to the transit authority of Chemnitz, Germany, in December 1993. It has been in operation since June 1994, logging some 125 mi daily.

The Variotram is truly a unique LRV. Its design is a response to both passenger expectations and transit authority requirements.

Passenger Expectations

Pleasing passengers is not only an important public issue, but a critical element that shapes the design of an LRV. Passengers want to reach their destinations quickly and comfortably. They want frequent and reliable service, easy boarding, and sufficient capacity to ensure that seats will be available. While en route, they want "rider-friendly" destination information and the security of having the operator communicate wirh them. By meeting passenger expectations, a well-designed LRV enhances the chances of developing a profitable and loyal ridership.

Transit Authority Requirements

Another dimension of the design formula is having features that fulfill the requirements of transit authorities, needs that often appear to be at odds with the expectations of passengers.

For example, transit authorities worldwide are faced with the need to minimize costs—not only in buying equipment acquisition, but in operating their systems. Of course, this affects their choice of transit vehicle, as well as their operations and maintenance standards and procedures. Thus, transit authorities provide equipment manufacturers with many challenges. Their design requirements include those given the following sections.

Energy Savings

Energy costs must be minimized. One way of achieving this is through the use of lightweight, high-efficiency vehicles with regenerative dynamic brake systems.

Environmental Benefits

New vehicles must be environmentally friendly. Vehicles powered by electricity and employing operational systems that use nontoxic substances meet the environmental challenge.

Reduced Downtime

Vehicle downtime must be minimized in order to meet revenue goals. Easy accessibility and user-friendly modular subsystems, along with modern vehicle diagnostic and fault-monitoring systems, reduce both preventive and corrective maintenance time.

Compatibility with Existing Alignments

New vehicles must adapt to the existing gauge and curvatures to avoid or reduce costly infrastructure investment.

Compliance with Laws and Regulations

With new regulations challenging every transit operation, new vehicles must be designed to meet known and expected requirements.

Mixed Traffic Compatibility

During the transition period between old and new vehicles, the new vehicle must be capable of mixed operation.

Flexible Passenger Capacity

Vehicles should be adaptable to changing operational conditions. For example, a flexible vehicle length can be the answer to matching capacity with demand. The possibility of increasing a vehicle's length without costly modifications provides the operational flexibility needed by many transit authorities.

Right Combination of Features

The Variotram meets the requirements of both passengers and operators through its use of *modular* design. The design, is, in effect, a menu of modules that can be combined for different track gauges, vehicle width and length requirements, and the need to accommodate more passengers. The following elements provide the modular flexibility in the Variotram concept.

Track Gauge and Vehicle Width

Broad, standard, and meter gauges can be combined with vehicle widths ranging from 7 ft 2.6 in. to 8 ft 8.3 in. In Chemnitz, the Variotram operates on standard gauge track with a width of 8 ft 8.3 in.

Unidirectional or Bidirectional Operation

Only one module—the passenger module—is different for the two types of operation, no matter what vehicle combination is chosen. Options include one or two doors on one side for unidirectional operation or on both sides for bidirectional operation. In Chemnitz, the Variotram is a unidirectional vehicle for the implementation phase of the project.

Vehicle Length

With five basic car body modules, the Variotram concept allows the length of the vehicle units, and combinations thereof, to be varied at will—all with different capacities and relatively few wheels.

Vehicle Modules: Building Blocks of Total System

The various Variotram modules are illustrated in Figure 1. The *front end module* (Module 1 of Figure 1) is designed for both unidirectional and bidirectional vehicles. It incorporates a spacious, ergonomically designed driving cab with the control and display elements integrated into a free-standing console that can he individually designed to a customer's requirements. A control cubicle, which also serves as the partition wall at the back of the cab, contains most of the electrical and electronic components. An air-conditioning unit can be installed in the roof section of the cab. There is a wide door provided for passengers on the right side.

The *powered truck module* (Module 2) is equipped with the power electronics and appropriate controls to drive the four wheels of the truck. The forward module is connected to the front end module to form a single integrated front end unit, whereas the rear module is designed to form a single integrated unit with the rear end module for unidirectional vehicles. For bidirectional vehicles, a second front end module is added to the rear power truck module of the vehicle.

Passenger modules (Module 3) are available in various lengths, with a choice of one or two doors on one side for unidirectional vehicles or on both sides for bidirectional operation. Storage space or vestibules for wheelchairs, strollers, luggage, or bicycles can he created as necessary with flip-up seats.

The *trailer truck module* (Module 4) is mounted on running gear and placed between two passenger modules so articulation at both ends is required. The module supports the pantograph and accommodates the power supply circuitry and the auxiliary converter. The interior design of the nonpowered module is identical to that of the powered truck module.

The *rear end module* (Module 5) is used with unidirectional vehicles. With the exception of the access door on the opposite side, it is essentially identical to a front end module. The module is equipped with an auxiliary driver's console.

Figure 2 illustrates vehicle and train combinations using the basic vehicle modules.

Low Floor and Extended Vehicle Width To Increase Comfort

As Figure 3 shows, the articulated Variotram sections are designed to rotate around a point that moves from the centerline of the track to the outside of the curve. Unlike in conventional LRV designs, the full extent of the kinematic envelope can be used. In addition, as each front and rear end module is linked permanently to its respective power truck module, the overhang sections are brought toward the inside of the curve.

Thus, the Variotram travels through the route's kinematic envelope with greater vehicle width and a longer nose and trailing end, hut with no constraints on the exterior body profile. This means that there are virtually no restrictions placed on mixed operation with the operator's existing fleet. A wider vehicle means a more contented passenger: wider seats are simply more comfortable.

Passengers want to enter and exit from a vehicle easily, preferably without having to climb up and down steps. This is particularly true for elderly and physically challenged individuals. The floor height on the Variotram is less than 14 in. for the entire passenger area and can at access points be ramped to less than 11.5 in.

Figure 4 shows how the construction of a full-length low-floor vehicle is made possible by Variotram's space-saving and low-height truck. The innovative truck design is, despite its low height, equipped with full primary and secondary suspension using maintenance-free flexicoil springs to provide a highly satisfactory ride.

The low-floor area above the truck is made possible by eliminating conventional axles. By making the truck an integral part of the truck module (Figure 1), this design eliminates the space-consuming movements between truck and car body. Track guidance is provided in the torsionally flexible truck frame by having each wheel suspended in a wheel support frame. The entire wheel support frame pivots around a fixed point in the truck frame and is supported by primary springs and parallel vibration dampers. Wheel guide units above the wheel support frame can be designed to reduce the angle of attack for an improved ride.

Innovative Drive System

Limited space in low-floor LRVs have, until now, required extremely complicated mechanical power transmission systems between the traction motor and the wheels. This source of noise and high maintenance has been completely eliminated in the Variotram.

Figure 5 shows the Variotram fitted with gearless hub motors, which eliminate the need for axles between wheels. The wheel rim is shrunk directly onto the casing of the three-phase alternating current (AC) traction motor. The stator is mounted on the fixed axle of the wheel support frame, with the motor bearings designed to transmit the wheel loads and lateral forces between wheel and rail. In the trailer truck the wheel is fitted with two tapered roller bearings mounted directly onto the axles of the wheel support frame. Resilient wheels are also available for both the powered and nonpowered trucks.

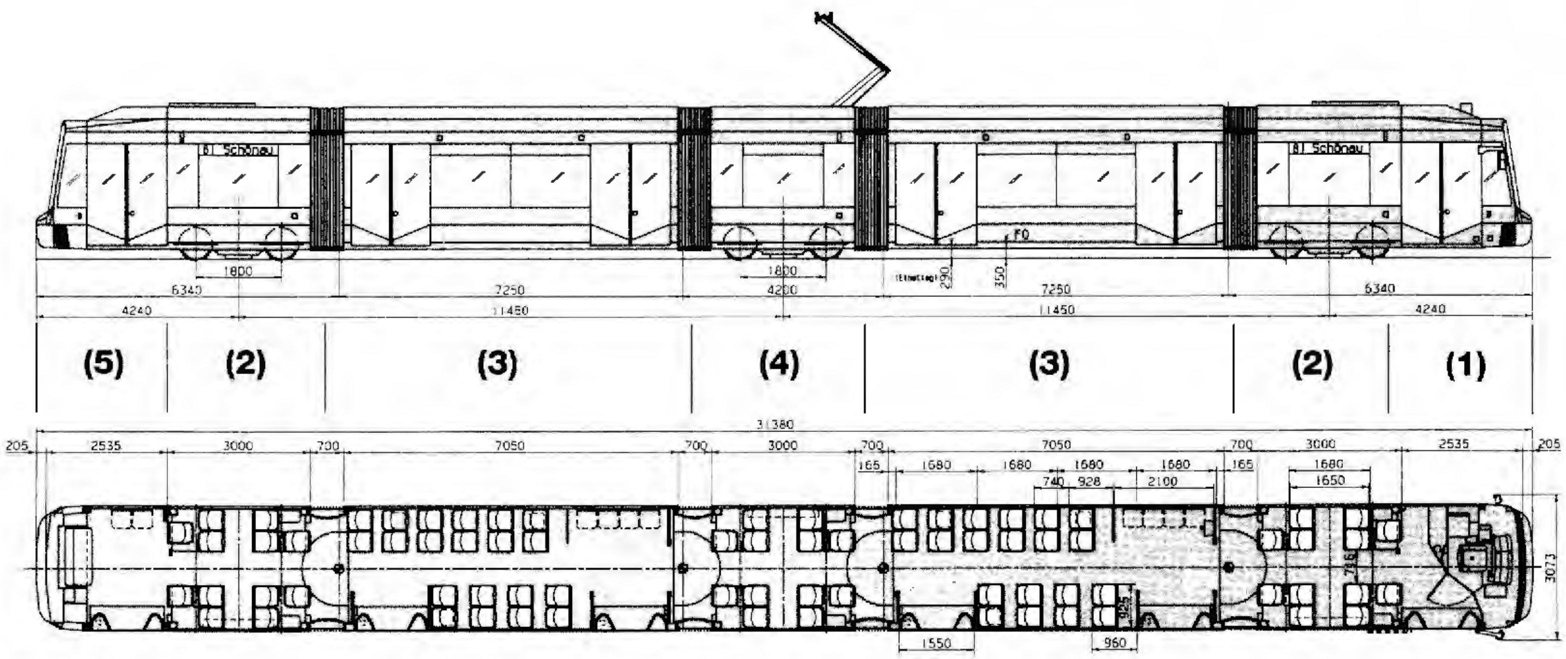

FIGURE 1 Variotram's set of five modules: front end (Module 1), powered truck (Module 2), passenger (Module 3), trailer truck (Module 4), and rear end (Module 5).

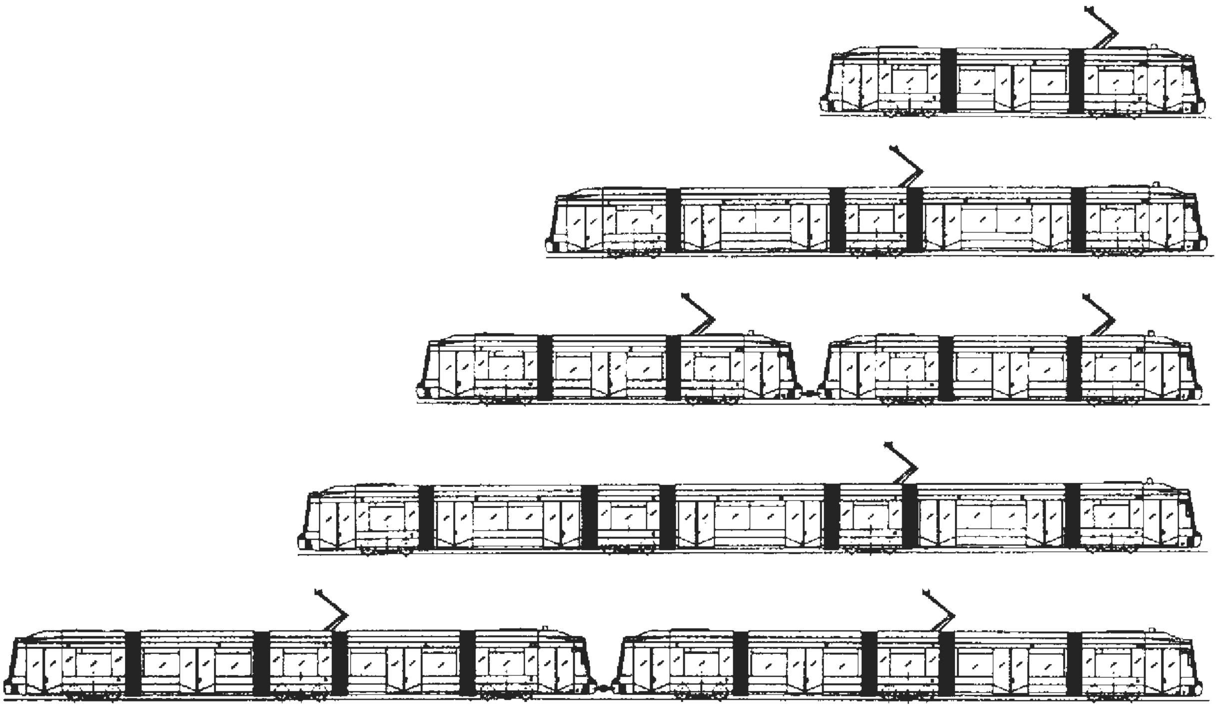

FIGURE 2 Five basic modules assembled and modified to create a variety of combinations.

The Variotram's totally encapsulated, water-cooled traction motors operate silently and require very little maintenance. The traction motor is designed as a three-phase induction motor with an external rotor to provide direct drive to the wheel. This "squirrel-cage" motor is the simplest type there is and, therefore, uniquely capable of dependable, trouble-free service. The stator's impact-resistant winding is inside the totally encapsulated motor, which protects it from contact with dirt and water to ensure a long, maintenance-free life. The two end plates of the hub motor accommodate the grease-lubricated cylindrical roller bearings. They are bolted to the ends of the casing tube.

The traction motor is cooled with ordinary tap water mixed with automotive antifreeze fluid. A pump circulates the water in the cooling circuit. The heat in the cooling water is removed via heat exchangers mounted on the roof. The energy can also be used to provide supplemental heat to the passenger compartment.

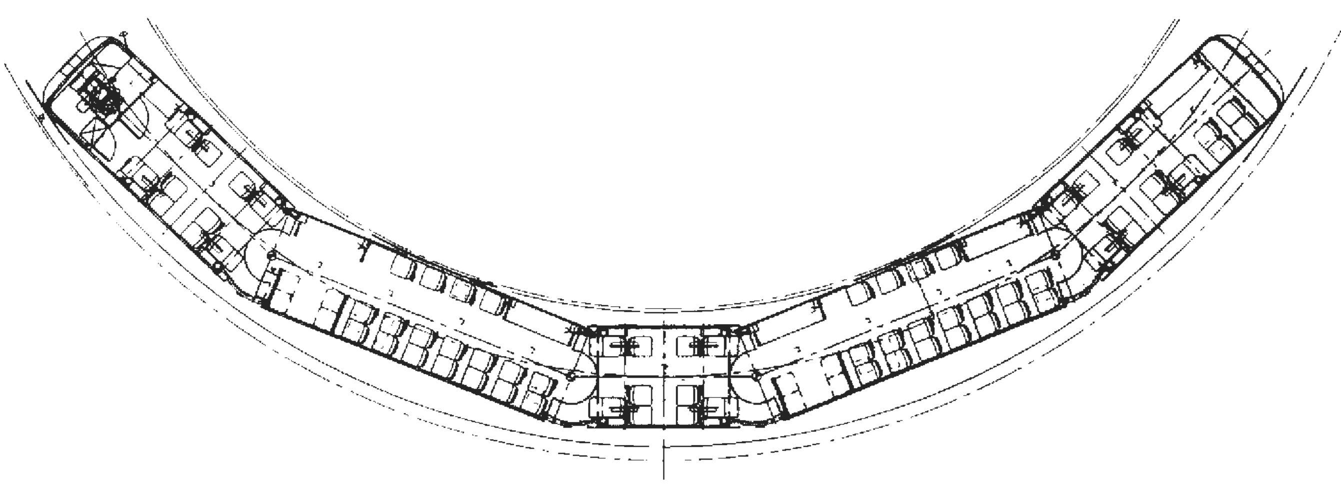

FIGURE 3 Articulated Variotram's use of kinematic envelope helps train negotiate curves.

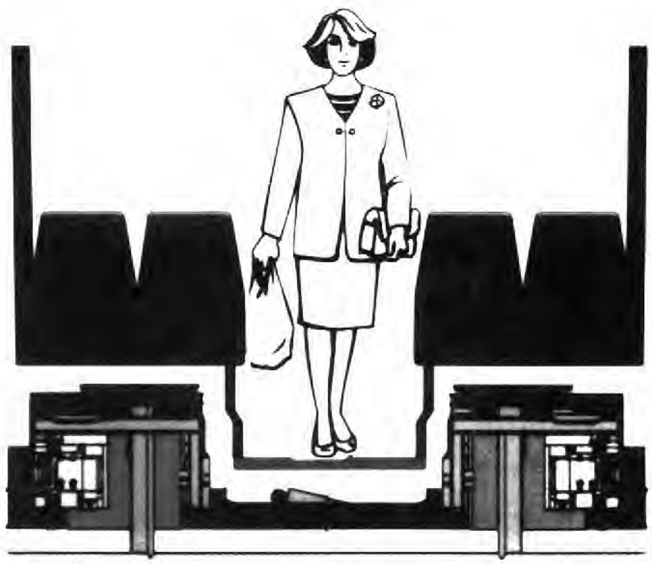

FIGURE 4 Low-height truck eliminates conventional axles to allow for end-to-end low-floor vehicle design.

Figure 6 illustrates yet another technology that has made the low-floor LRV possible: the compact and lightweight roof-mounted AC traction inverter unit. Each powered truck with its four traction motors is equipped with a traction inverter unit incorporating two transistor inverter modules, each of which is designed for parallel connection of two traction motors. The cooling system for the inverters, like that of the traction motors, uses tap water mixed with automotive antifreeze.

In dynamic braking, energy is fed back to the overhead line. If the network is not able to accept the energy, brake resistors are connected by a transistorized brake controller. For this purpose, each inverter is provided with its own brake controller.

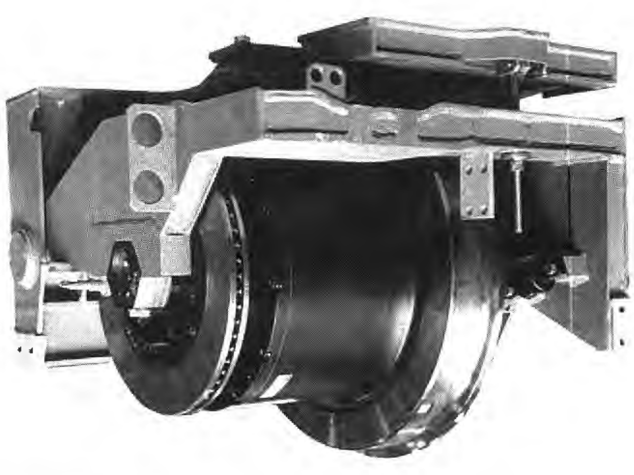

FIGURE 5 Gearless hub motor eliminates need for axles between wheels.

FIGURE 6 Compact and lightweight, roof-mounted AC traction inverter unit.

All auxiliary systems use three-phase motors fed from two independent static converters, all taking power directly from the overhead line.

Variotram's vehicle control and diagnostic system is based on MICAS-S, ABB's microprocessor-based traction control system. The hierarchical control structure combines drive control, module control with subsystems, and train control. At the drive control level, several connected vehicles can be controlled from one driver's desk via a single data bus line. The central processing units are located in the driver's cab, and the drive control units of the traction system are in the inverter units. The control system for the static converters is integrated into the relevant units. Extensive control cabling is eliminated by the use of an integrated vehicle data bus handling all communication within the MICAS-S system.

Variotram: Innovative Design Driven by Requirements

The lightweight, modular Variotram concept combines innovative ideas in technology and design with proven features to achieve the speed, punctuality, comfort, safety, and environmental benefits expected of today's advanced LRV. It gives transit operators a reliable, flexible vehicle with superior economic efficiency.

Three-phase AC drive technology, in conjunction with the hub motor design, was instrumental in making the Variotram low-floor concept a reality. The drive system's high level of efficiency and the benefits of regenerative braking combine to reduce energy consumption. As a result of its flexibility and combination of features, Variotram is the answer to the challenges facing the transit market today and in the future.

Transit Cooperative Research Program: Projects Under Way

Transit Cooperative Research Program Project A-8: Rail Transit Capacity

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Before the final report is completed in late 1995, the Transit Cooperative Research Program Project A-8, Rail Transit Capacity, is summarized with emphasis on the light rail content. The project investigated and quantified the variables that affect the maximum passenger carrying capacity of rail transit in four categories: rail rapid transit (heavy rail), light rail transit, commuter rail, and automated guideway transit in North America. Light rail work constituted 45 percent of the project. A survey of existing literature; a survey of rail transit operators in Canada, Mexico, and the United States; and field data surveys determined existing capacities and capacity constraints and accumulated extensive data. Quantitative analysis, narration, and calibration to real life resulted in procedures for estimating rail transit capacity under a variety of conditions, including realistic operating margins.

In the past several decades, many developments have directly affected North American rail transit performance, vehicles, operations, and systems technologies. These developments include the extension and modernization of rail rapid transit and commuter rail systems, the introduction of the proof-of-payment fare collection system, the requirements of the Americans with Disabilities Act (ADA), and the construction of new light rail, automated guideway transit (AGT), rail rapid transit, and commuter rail systems. Consequently, data and procedures related to estimating rail transit capacity need updating. Transit Cooperative Research Program (TCRP) Project A-8, Rail Transit Capacity, is intended to do this. Results to date are summarized here.

Factors affecting rail transit capacity need to be documented and identified, and data on current values of these factors must be collected in order to update and expand the range of applications for this information. The research must take into account vehicles, station designs, fare policies, train control technologies, and operating practices that better reflect North American rail transit experience. There is also a need for information and procedures for estimating capacity. Rail transit capacity, as defined for this project, includes both the number of people and the number of vehicles past a point per unit of time, and it relates to stations, routes, junctions, and other controlling transit system features.

Examples of applications for new rail transit capacity information include the following:

- Conducting project planning and operations analysis for new starts and extensions,
- Evaluating transit line performance,
- Establishing and updating service standards,
- Studying environmental impacts,
- Assessing the capacities of new train control technologies,
- Estimating changes in capacity and operations over time, and

• Assessing capacity impacts in land development studies where transit provides a significant access role.

Study Approach

The study has taken a structured and methodical approach that makes maximum use of previous work and existing data, including Federal Transit Administration (FTA) Section 15 reporting (*1*).

These data have been augmented by direct contacts with each rail operating agency to determine peak-point ridership, theoretical and actual minimum headways, limitations on headways, individual car loadings, location and frequencies of pass-ups, and other relevant factors.

The initial data collection was used as an input into an analytic framework containing the previous capacity-influencing factors with particular emphasis on achieving accurate real-life calibration for each factor.

Additional data needs were identified that concentrated on systems with heavily used rail lines. The only accurate way to determine the true maximum capacity of a car is when there are pass-ups—when passengers wait for the next train on a routine day-by-day basis. On only an estimated six locations in the United States and Canada do pass-ups occur on rail transit, and all of them were visited.

From the analytic framework and data collection, quantitative analysis was carried out and calibrated, with formulas and constants determined to provide a comprehensive method for determining rail transit capacity over a wide range of variants for each of the four rail modes. A practical method of using the data and determining capacity was developed in two categories. The first is a simple method containing basic parameters with constants for major variants that reflect *typical* or *average* conditions. The second category is more complete, adding further variants including capacity adjustments for grade and line voltage.

To assist in using the results of this research, a computer disk has been prepared that contains spreadsheets into which system variables can be inserted. The results are shown both numerically and graphically. The data base, main data tabulations, and a graphic simulation of a New York three-aspect signaling system interlocking are included on the disk. (The disk, in IBM 1.44 format only, is available from Transport Consulting Limited for a nominal duplication, handling, and postage charge of $10. Reference to the explanations and detail in the report is advised. Disk programs are Microsoft Excel 5.0 and Access 2.0. Microsoft Windows and these programs, or the ability to convert from them, are required.)

Rail Transit in North America

Rail transit plays a significant role in moving people in North American cities. In U.S. urbanized areas exceeding 200,000 in population, 35 percent of all transit trips in 1993 took place on one of the four rail modes; rail rapid transit alone accounted for 28 percent of these trips.

The four rail modes consist of AGT, commuter rail (CR), light rail transit (LRT), and rail rapid transit (RT). Each mode is described in more detail in this chapter. Table 1 gives a condensed look at key North American statistics for each mode, and Figures 1 and 2 show annual passenger trips and passenger kilometers for the four rail transit modes.

LRT started as a development of the streetcar to allow higher speeds. LRT is characterized by its versatility

TABLE 1 Comparison of Key Modal Statistics

Type	Routes	Average Line Length (km)	Total Length (km)	Average Station Spacing (km)	Average Line Speed (km/h)
AGT	3	6.3	19.0	0.70	24.3
CR	77	73.7	5672.1	5.71	52.7
LRT	51	13.9	708.5	0.83	22.1
RT	76	25.3	1868.6	1.47	36.2

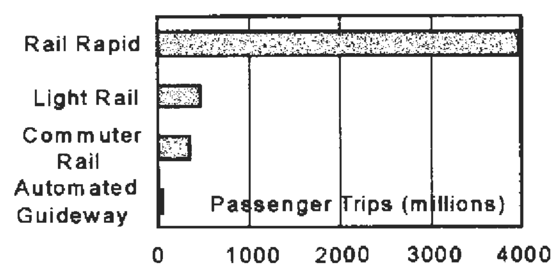


FIGURE 1 Annual passenger trips by rail transit mode.

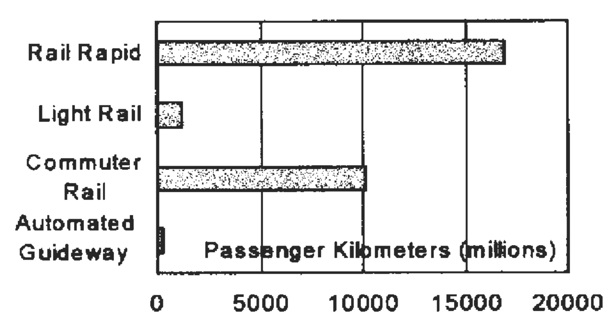


FIGURE 2 Annual passenger kilometers by rail transit mode.

of operation as it can operate separated from other traffic under the surface, at grade, on an elevated structure, or with road vehicles on the surface. Service can be operated with single cars or multiple-car trains. Electricity for traction power is taken from an overhead wire, thus eliminating the restrictions imposed by having a live third rail at ground level. (An exception is the Southeastern Pennsylvania Transit Authority's grade-separated Norristown high-speed line which uses third-rail current collection.) This flexibility helps to keep construction costs low and explains the popularity that this mode has experienced since 1978, when the first of the new North American LRT systems was opened in Edmonton.

These newer systems have adopted a much higher level of segregation from other traffic than earlier systems enjoyed. New Jersey Transit's Newark City Subway, opened in 1935, was ahead of its time in this respect, with a tunnel penetrating the downtown and few grade crossings. Segregation from motor traffic permits higher speeds, greater schedule reliability, and improved safety. Modern signal preemption and progression methods have also made on-street operation faster and more reliable.

Passenger loading can be accomplished at street level with steps on the cars or at car-floor level with high-level platforms. The lines in Calgary, Edmonton, and Los Angeles, for example, operate entirely with high-platform access. The San Francisco Municipal Railway uses movable steps on its cars to allow cars to use high-platform stations as well as simple street stops. Pittsburgh takes a different approach—it has two sets of doors on its light rail vehicles, one for high platforms and the other for low-level loading. Most other systems use low loading with steps. Low-floor cars, already popular in Europe, have been ordered for Portland and Boston to provide floor-level loading without the need for steps or high platforms. Wheelchair access also benefits since lifts are not required with low-floor cars.

There are 23 LRT systems in operation in North America (Table 2). This total includes the traditional streetcar lines in Toronto and New Orleans, because they are an integral part of their transit systems. Lines that are operated primarily for heritage and tourist purposes, such as those in Memphis and Seattle, were not included in this study.

The recent popularity of LRT is apparent in that 12 of the surveyed systems have opened since 1980. Older streetcar systems in Boston and Philadelphia survived the widespread replacement of streetcars with buses following the two world wars thanks to city-center tunnels that gave them rapid access to downtown. San Francisco's streetcars benefited from two tunnels that provide strategic routes under major hills in that city. Pittsburgh's streetcars survived for similar reasons. These

TABLE 2 North American LRT Systems

Abbreviation	Lines — km	System Name—(City)
Bi-State	1—31	Bi-State Development Agency (St. Louis)
CTS	2—31	Calgary Transit
Denv. RTD	1—8	Denver Regional Transportation District
ETS	1—14	Edmonton Transit
GCRTA	2—21	Greater Cleveland RTA
LACMTA	1—35	Los Angeles County MTA
MBTA	5—51	Massachusetts Bay Transportation Authority
Metrorrey	1—18	Metrorrey (Monterrey, Mexico)
MTA	1—36	Mass Transit Administration of Maryland
NFTA	1—10	Niagara Frontier TA (Buffalo)
NJT	1—8	New Jersey Transit Corporation
PAT	2—34	Port Authority of Allegheny County. (Pittsburgh)
RTA-NO	2—13	Regional Transit Authority - New Orleans
SCCTA	1—34	Santa Clara County Transportation Authority
SDT	2—56	San Diego Trolley Inc.
SDTEO	2—24	Sistema del Tren Electrica Urbana (Guadalajara)
SEPTA	8—95	Southeastern Pennsylvania Transp. Authority
SF Muni	5—62	San Francisco Municipal Railway
SRTD	1—27	Sacramento Regional Transit District
STC	1—17	Sistema de Transporte Colectiva (Mexico City)
STE	2—15	Servicio de Transportes Eléctricos del DF (Mex. C)
Tri-Met	1—24	Tri-County Metro. Transportation Oregon (Portland)
TTC	10—96	Toronto Transit Commission

older systems have been modernized with new cars and, in Pittsburgh and San Francisco, with tunnels penetrating the cities' downtowns.

Toronto is the last city to operate what is still largely a conventional streetcar network. Toronto's streetcars must share most their routes with vehicular traffic, a condition that leads to relatively slow service. Many of the other older streetcar systems with light rail characteristics must also operate with general traffic on substantial portions of their routes. Such is the case in San Francisco and Philadelphia, where tunnels bypass downtown traffic congestion and surface in outlying areas.

Ridership information collected by LRT systems is not as comprehensive as it is for other modes; many systems reported only the total number of passengers carried on an average weekday. Peak hour and peak 15-min flows were obtained for a number of systems, but these important data were not available for some of the major LRT systems, such as the San Diego Trolley. As a result, average weekday ridership for major routes is shown in Figure 3; available peak flows are shown in Figure 4. Data for the TTC's now atypical streetcar lines are not included. In some cases detailed ridership data may not be available because the system is not running near capacity, but this is not so with others, such as the busy San Francisco Muni Metro.

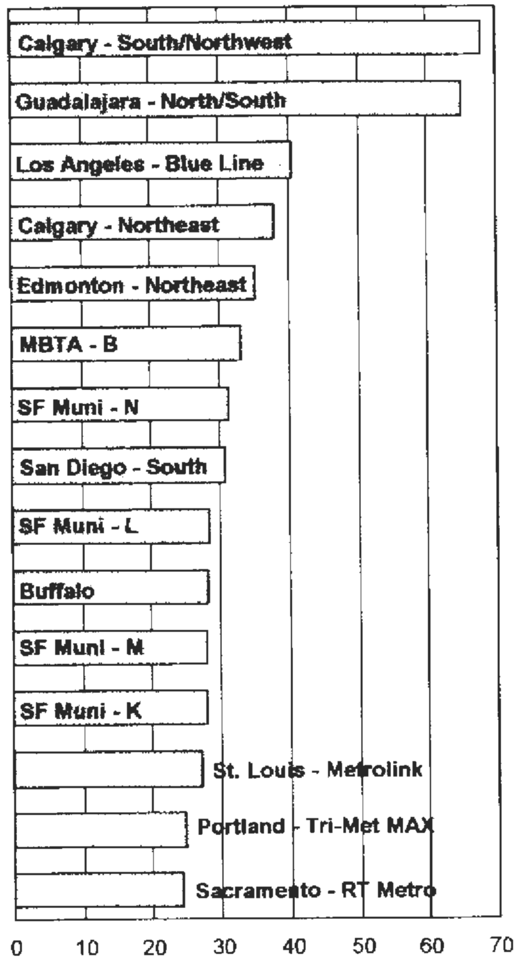


FIGURE 3 Weekday ridership for 15 busiest North American LRT lines.

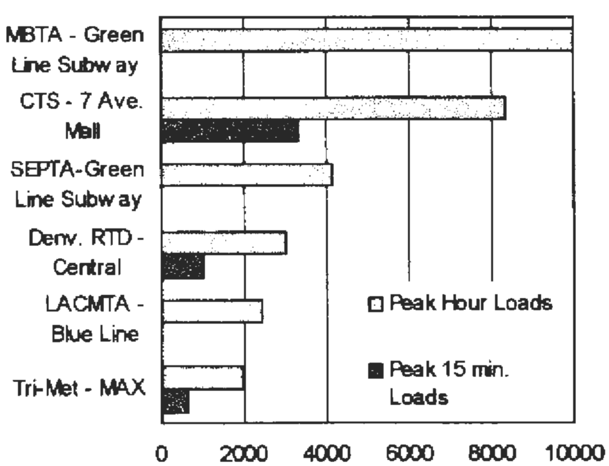


FIGURE 4 LRT peak hour and peak 15-min flows (these data were not available for many LRT systems).

It is worth noting that the first and fourth busiest LRT lines in North America—Calgary Transit's South (201) and Northeast (202) lines—operate mostly at grade; downtown operation is on a transit mall shared with buses.

Grouping

After the extensive literature review and data collection, it appears clear, for the purpose of capacity analysis, that the four modes of rail transit in this study should be grouped into specific like categories based on alignment, equipment, train control, and operating practices.

The first category is fully segregated, signaled, double-track right of way, operated by electrically propelled multiple-unit trains. This is the largest category encompassing all rail transit, all noninstitutional AGT, several light rail sections—for example, the Market Street Subway in San Francisco—and several commuter rail lines on the East Coast. The minor exceptions where there are grade crossings on rail rapid transit (CTA) will be discounted. Routes with more than two tracks will be discussed relative to express, local, and skip-stop service; capacity multipliers will be suggested for a range of situations. However, unique capacity calculations for multiple-track routes are not developed. (The Morgantown AGT, the only North American example of AGT with off-line stations, is not classed as a public operation by APTA.) This category is termed "grade-separated rail" and will have subcategories for variations such as low loading, commuter rail, and AGT with short trains.

The second category is light rail without fully segregated tracks, divided into on-street operations and right of way with grade crossings. Streetcar-only operations (Toronto and New Orleans) will fit as a subset of the on-street section.

The third category is commuter rail other than services in the first category. This in turn will be broken down according to track ownership and control.

The fourth category is automated guideway transit. Although most AGT is a subset of the main category grade-separated rail with very short trains, the use of off-line stations (on certain systems) is unique to this mode and requires separate examination.

Capacity Basics

Professor Richard Soberman in the *Canadian Transit Handbook* states: "The capacity of transit service is at best an elusive figure because of the large number of qualifications that must be attached to any measure of capacity that is adopted."

Most of the capacity calculations in the literature add constants, multipliers, reductive factors, or other methods to correlate theory with practice. In this paper, emphasis has been placed on reducing the number of qualifications and quantifying, describing, and explaining adjustments between theory and practice in determining rail transit capacity.

To avoid any confusion between supply and demand, and to avoid confusion with other work, the study uses two definitions of capacity:

- *Design/capacity*: The maximum number of passenger spaces past a single point in 1 hr in one direction on a single track.
- *Achievable capacity*: The maximum number of passengers that can be carried in 1 hr in one direction on a single track, allowing for the diversity of demand.

Design capacity is similar to, or the same as, maximum capacity, theoretical capacity, or theoretical maximum capacity—expressions used in other work. It makes no allowance for whether those spaces going by each hour will be used; they would be only if passengers uniformly filled the trains throughout the peak hour. This situation does not occur, though, and a more practical definition, sometimes referred to as practical capacity, is required. Achievable capacity takes into account that demand fluctuates over the peak hour and that not all trains—or all cars of a train—are equally and uniformly full of passengers.

Reference to single track is necessary as most trunk routes in New York, the Broad Street Subway in Philadelphia, and the North Side El in Chicago have four tracks, whereas certain other New York lines have sections with a third express track. (All New York three- or four-track trunks crossing the East and Harlem rivers merge into double-track tunnels or bridges.) The capacity of four-track lines is not a multiple of two single tracks and varies widely with operating practices, such as the merging and dividing of local and express services and the holding of trains at stations for local-express transfers. The result is that four tracks rarely increase capacity by more than 50 percent over a double-track line, and often less. A third express track does not necessarily increase capacity at all when restricted to the same station close-in limitations at stations with two platform faces.

Design capacity has two factors—line capacity and train capacity—and can be expressed as

Design capacity = line capacity × train capacity

where line capacity is the maximum throughput in trains per hour, and train capacity is the number of passenger spaces.

In turn, achievable capacity can be expressed as

Achievable capacity = design capacity
× peak-hour diversity factor

The basic capacity expression can be expanded as shown in Figure 5.

Line capacity = 3,600 ÷ (minimum train separation
+ controlling station dwell) (sec)

This expression determines the number of trains per hour (frequency) and is the inverse of the closest or minimum headway. The relevant minimum train separation in seconds is the minimum time to approach and leave a station (i.e., the time from when a train starts to leave a station until the following train can berth at that station). This is referred to as the "close-in" time.

In determining this minimum headway, the train separation is based on "line clear" close-in, with successive green signals governing the following train. Such a headway is called noninterference. The minimum line headway is determined by the critical line condition, usually the close-in at the maximum load point station. In the *Rail Transit Survey*, 9 out of 58 responding systems cited turnbacks as a constraint: two LRT, five rail transit, and two commuter rail operators. In comparison, 34 operators cited train control limitations as a capacity constraint.

From the previous expressions the framework can be expanded to include other variables. The flow chart in Figure 6 outlines the project.

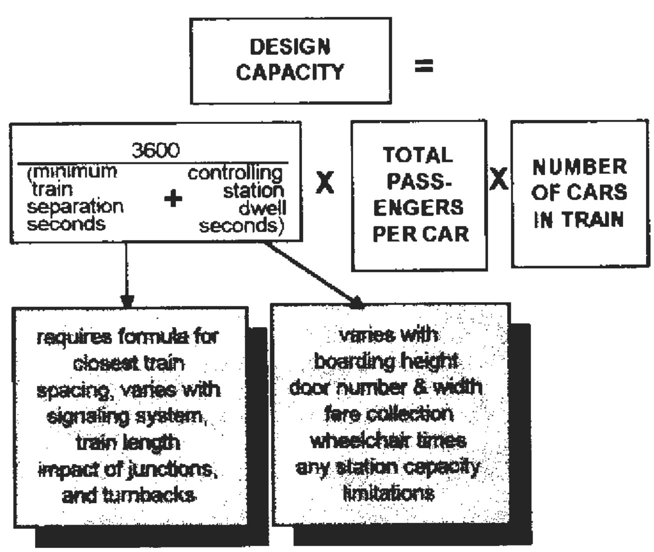


FIGURE 5 Expanded design capacity equation.

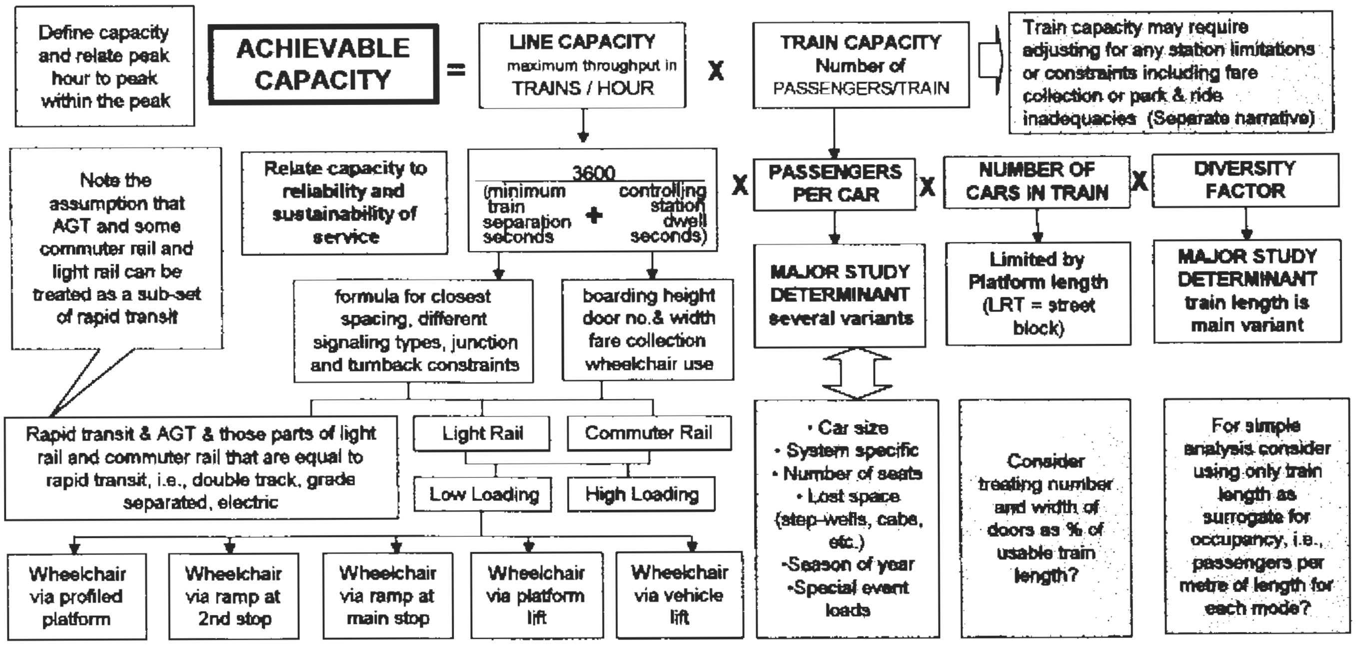


FIGURE 6 Project outline: analytic framework flow chart.

Dwell Times and Passenger Flow

The three constituents of headway are shown in Figure 7 and based on a heavy rail system at capacity operating 180-m-long trains with a three-aspect signaling system. The best achievable headway is 120 sec.

Dwell is the major component of headway at these close frequencies, and the operating margin is often consumed by the many small day-to-day irregularities as shown in Figure 8, where three trains have twice the average separation. This situation can worsen for light rail for which part of the operation is in mixed traffic, as shown in Figure 9 for Muni where five surface streetcar routes enter the Market Street Subway. This operation pushes the signaling system to its limits and is further hindered by the need to couple cars from individual routes into trains for operation through the subway, by constrictive turnback arrangements at Embarcadero, and by recalcitrant operating practices.

This situation is expected to improve when the new turn-back facilities are commissioned in 1998, in conjunction with a switch to a moving-block signaling system. The study found that a moving-block signaling system offers the highest throughput capabilities of all train control systems and can also provide the most sophisticated automatic train supervision.

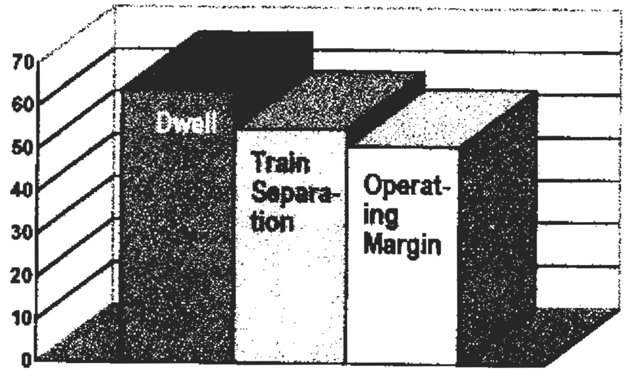


FIGURE 7 Typical headway components, in seconds.

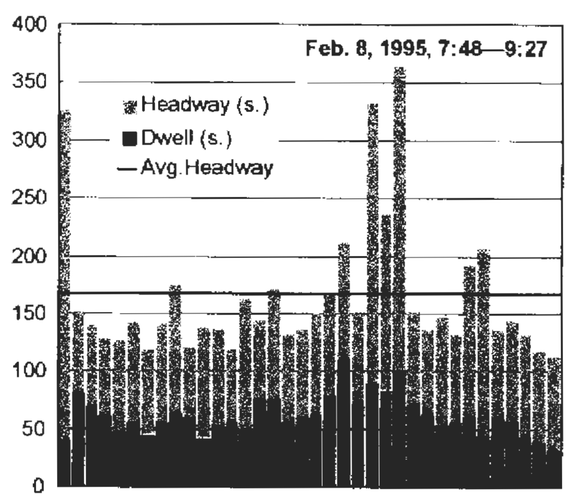


FIGURE 8 Headways, NYCT Grand Central Station.

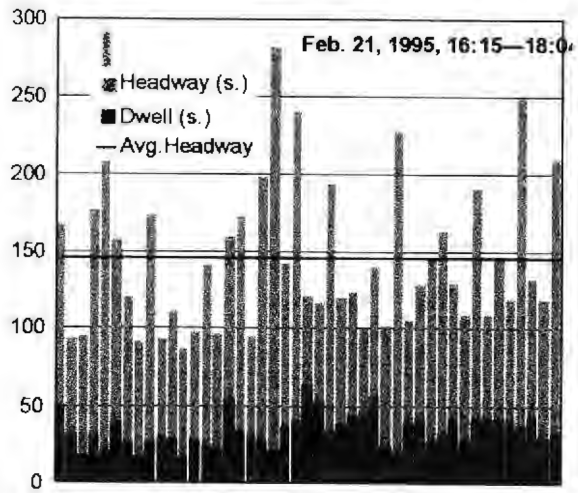


FIGURE 9 Headways with five surface lines interlaced into two multiple-car services (San Francisco Muni Metro).

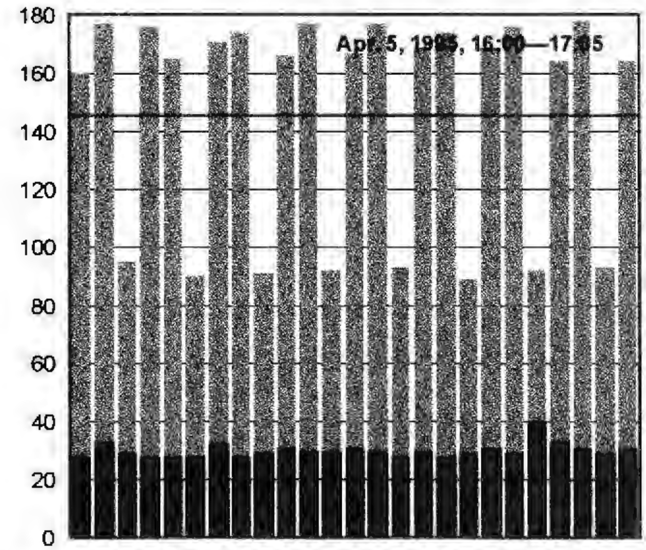


FIGURE 11 Headways with two interlaced services, BC Transit Broadway Station.

Calgary Transit, with the closest on-street headway of all U.S. and Canadian light rail systems, shows, in Figure 10, a similar smooth and regular interlacing of two services to those of BC Transit in Figure 11. This is all the more remarkable given the frequency of grade crossings on the system and the location: on-street along the downtown mall, shared with bus traffic.

The most even headways of a manually driveu system in the data collection survey—limited to two to four peak periods on systems operating at or close to their maximum capacity—were those of PATH, shown in Figure 12. An impressive performance was assisted by the multiple-track terminals in Manhattan.

Automatic driving should permit a train to run close to all civil speed limits and not commence braking until the last moment, reducing train separation by 5 to 15 percent, increasing capacity by a like amount, and improving regularity. There were insufficient data to confirm this, although Figure 11 shows BC Transit's regular operation with a short-turn service integrated into regular service at a very consistent 90-sec separation. Figures 13 and 14 show the components of dwell for the

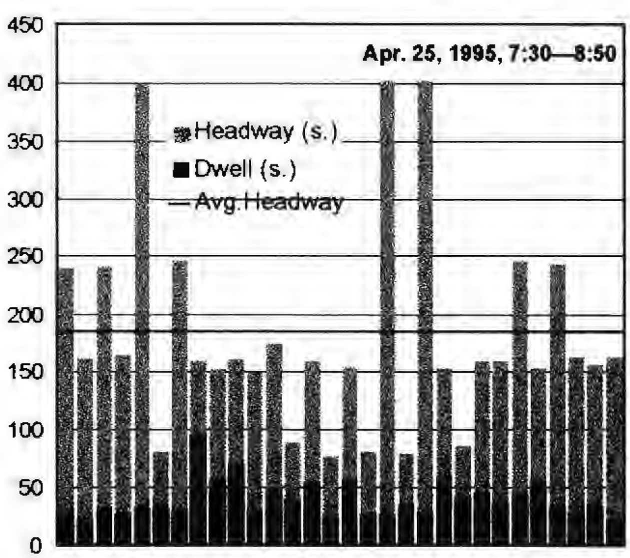


FIGURE 10 Headways, Calgary Light Rail Third Street S.W. eastbound (two services); note that headways are all multiples of 80-sec traffic light cycle.

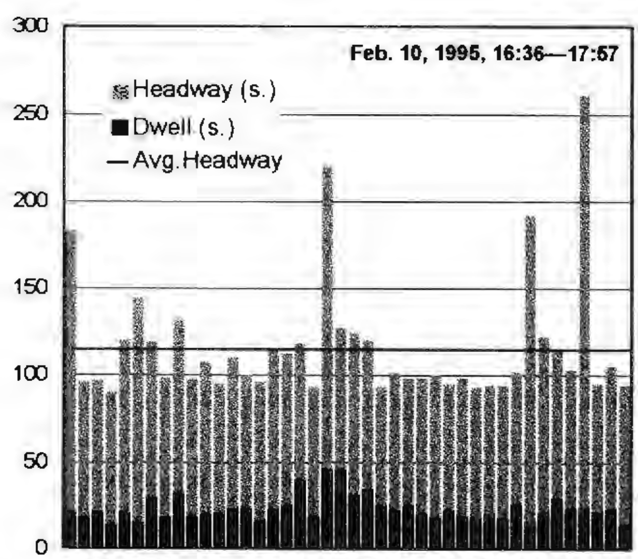
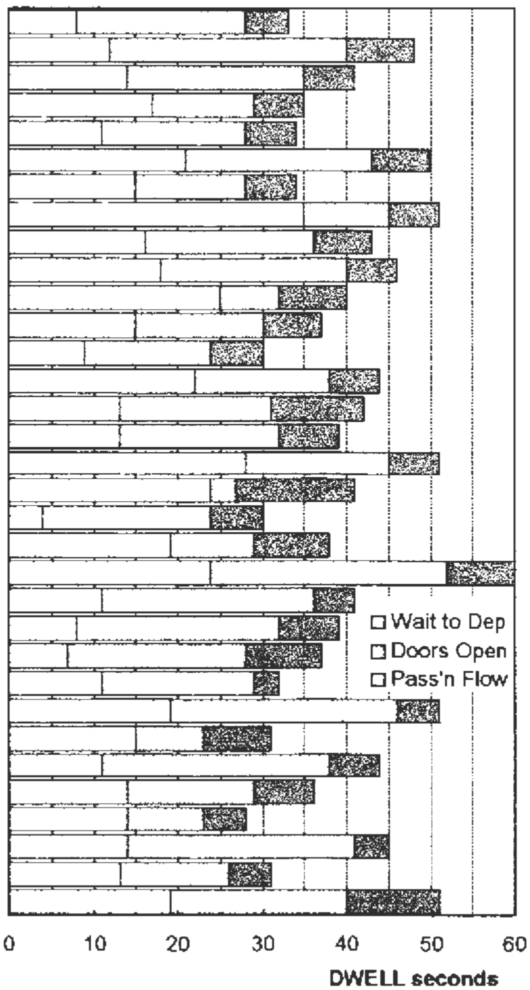
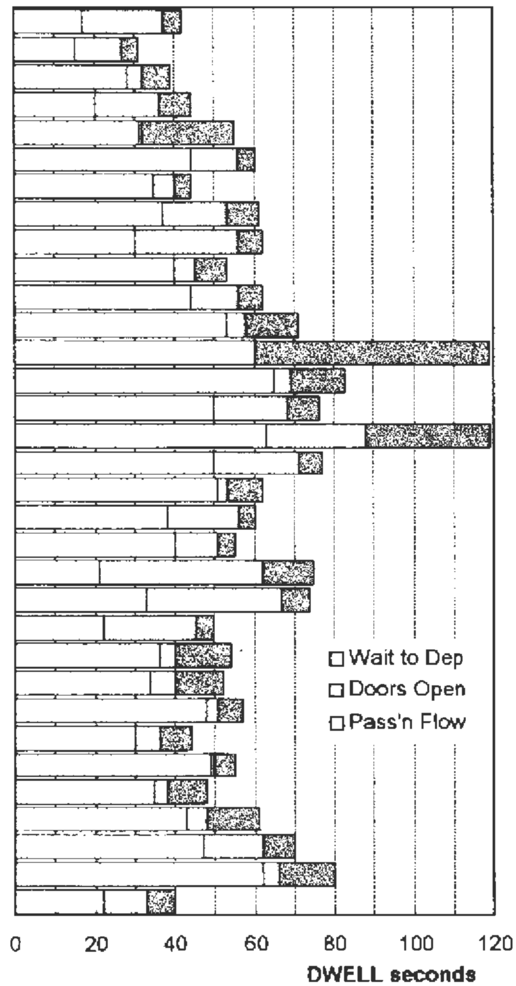


FIGURE 12 Headways, PATH Exchange Place westbound.



average headway — 153 seconds
number of passengers observed — 586
flow time averages 38% of total dwell

FIGURE 13 Dwell time components, BART Montgomery Station.



average headway — 160 seconds
number of passengers observed — 1,143
flow time averages 64% of total dwell

FIGURE 14 Dwell time components, NYCT Grand Central Station.

automatically driven BART versus the manually driven NYCT. On BART passenger flow times average 38 percent of the total dwell times; on NYCT passenger flow times average 64 percent of the total dwell time—almost double. Similar results were noted on other automatically driven systems. It appears that any operating gains from automatic driving are more than offset by lethargic station dwell practices.

Several light rail and heavy rail systems were notably slicker at station dwells than their counterparts, contributing to a faster, thus more economic and attractive, operation. Most automatically driven systems have sluggish station dwells in which expensive equipment and staff sit and wait long after all passenger movement has ended. Unfortunately, this torpor is extending to manually driven systems. TTC recently implemented a subway station departure delay for safety reasons. Whether this is well founded is uncertain. It dispenses with the once unsanctioned but common rail transit practice whereby the motorman would partially release the brakes, put the controller to full, and allow the door interlock circuit to initiate the departure from each station. Dwells of 8 sec were normal at quiet stations.

A companion TCRP project, Aids for Car Side Door Observation (A-3), addresses some of these issues but does not examine the overall safety of the door-platform interface or the wide differences in operating efficiency between various light and heavy rail systems. This sacred cow is one of the recommendations for future research from the A-8 project.

Given the importance of station dwells, the project examined the components of dwells shown in Figures

13 and 14. Passenger flow rates were measured under a wide variety of situations. A comprehensive statistical exercise attempted to relate the number of boarding and alighting passengers with the controlling dwell time—the longest dwell time during the peak within the peak (defined as a 15-min period) that establishes the minimum headway—and so the maximum system capacity. The process was only partly successful and is too lengthy for inclusion in this paper. A selection of the data are shown in Figure 15.

The most interesting component of these data is that passengers enter high-floor light rail vehicles faster from street level than they exit. This finding remained consistent through several full peak-period observations on different systems. Hypotheses include brisker movement going home than going to work, incentive to enter a warm dry car from wet slippy sidewalks, and easier balance ascending steps.

The A-3 report examines ways to increase capacity. These include the introduction of moving-block signaling systems and methods to reduce station dwells ranging from the design and location of platform exits to the interior design of rolling stock. JR East's Yamamoto Line in Tokyo is believed to be the world's highest-capacity two-track rail transit line. JR recently introduced high-capacity cars with longitudinal seats that are folded into the walls during the morning peak period, producing an all-standing car that is probably not appropriate for North America. Another Tokyo experiment with four stream doors is shown in Figure 16. Note the multistream line-up marks on the platform at each doorway. In combination with typical Japanese discipline, these reduce conflict between alighting and boarding passengers and help reduce the dwell time.

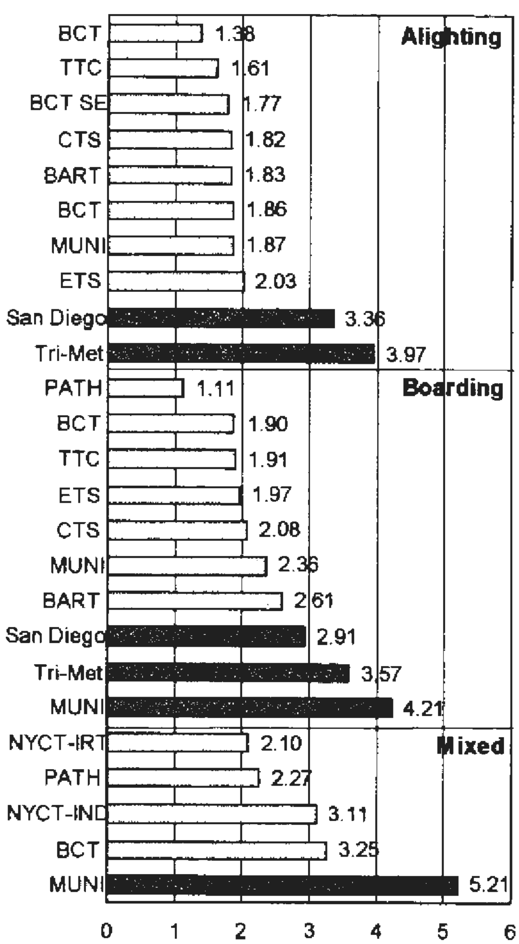


FIGURE 15 Selection of rail transit door flow rates (darker bars indicate low-level boarding with steps).

Americans with Disabilities Act

With dwell being one of the most important components of headway time, the impact of wheelchairs was studied. In addition to the modest number of field observations that could be timed, data were obtained from those few systems that have actual rather than anecdotal movement and delay times. The facts to date, though sparse, do tell a coherent story. Actual measured lift times are much shorter than many claim; they run 2 to 3 min and some are as low as 60 sec. Level wheelchair movements are generally faster than walking passengers except where the car or platform is crowded. One movement at a new San Francisco loading platform on the K Line was measured at 13 sec from doors fully opened to train moving. (This is, however, an arrangement in which the train must stop twice: once for the disabled passengers and again for the regular passengers.) An example of this loading arrangement is shown in Figure 17.

FIGURE 16 Experimental car with four-stream door, Tokyo.

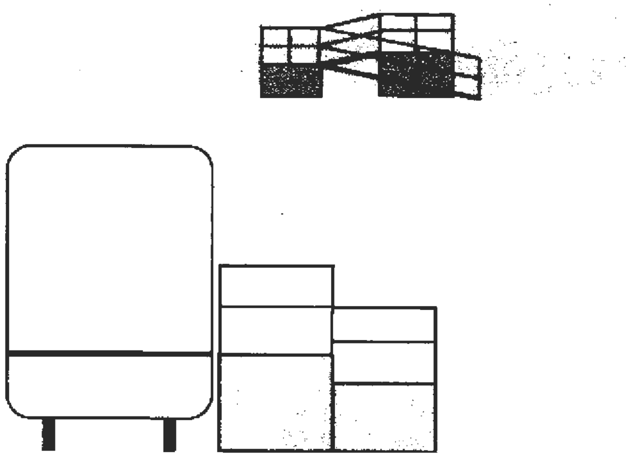


FIGURE 17 Wheelchair loading platform and ramp.

One consideration is the stratification in wheelchair use. ADA requires—and most systems already have—parallel services. The chronically disabled wheelchair user selects the parallel door-to-door paratransit service where an attendant assists with loading. This user is often unwilling or unable to negotiate curb cuts and ramps, or travel a substantial distance alone, to access a station.

Most rail transit wheelchair users are extremely agile. These are the people who want the mainstream option and use it. They appear to be particularly sensitive to not causing delays.

Tentative conclusions are that with full implementation of ADA, and no more lifts on close-headway rail systems, wheelchairs generally will have little or no impact on capacity, even allowing for the rare incident causing delay, such as the front wheels becoming stuck briefly in the platform-door gap. In the interim, wheelchair lift use may cause delays, but these delays generally are on systems with long headways (6 min and more), so they have minimal impact at these levels.

For maximum capacity, high-platform loading is preferred. Dwells are reduced, and no interior car capacity is lost to the stepwells or to interior steps—a feature of

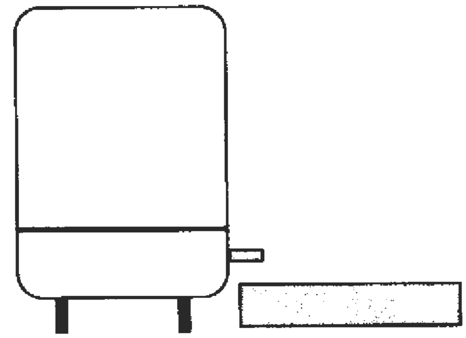


FIGURE 19 Profiled light rail platform showing slide-out or fold-down step that avoids internal steps.

high-floor cars with low-level boarding and some low-floor cars. Low-floor cars will offer much of the speed and easy access of high-platform loading. The first low-floor car to be introduced in the United States will be running in 1997 in Portland (Figure 18).

Level high-floor loading may be problematic in many systems. The options range from the interior folding steps used in San Francisco to the outboard folding steps used in San Diego combined with a Manchester-style profiled platform (Figures 19 and 20). Such a platform has an intermediate height and is profiled up to a short stretch that is level with one doorway for wheelchair use. Where the street arrangement permits, the profiled platform can be raised so that its midsection, taking up most of the length, is raised one step to provide a single-step entry to most doors.

Another option to meet the ADA requirements is the separate wheelchair ramps that are used in Baltimore, Sacramento, and San Francisco, among others. In this arrangement, shown in Figure 17, a car-floor-level platform, sized for one wheelchair, is accessed by a ramp at one end, preferably the front end of each light rail stop. These are less popular with members of the physically challenged community and present a greater physical and visual intrusion into the street scene. However, there are many examples, particularly in Sacramento, of carefully integrated and relatively unobtrusive ar-

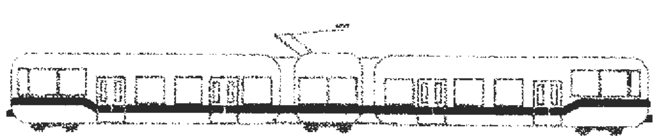


FIGURE 18 Siemens Duewag partial low-floor car, Tri-Met Portland.

FIGURE 20 Profiled light rail platform that provides two steps into all doors except the front, which is wheelchair-accessible. All slopes maximum of 8.5 degrees to meet ADA requirements; most of platform only slightly higher than sidewalk.

rangements. These minihigh platforms have advantages over car- or platform-mounted lifts in reducing delays. The platforms also save the need for maintenance and repair of mechanical lift equipment.

Capacity Calculations

The other two major components in determining the capacity of a rail transit system, besides passenger flow times and station dwells, are the train separation limitation of the signaling system and the passenger capacity of the vehicles. Each of these topics has an extensive section in the TCRP A-8 report in which methodologies are developed to calculate capacity under a variety of conditions. Only the results can be briefly shown in this paper.

The minimum separation of the train control systems can be expressed by

$$H(s) = \sqrt{\frac{2(L+D)}{a_s}} + \frac{L}{v_a} + \left(\frac{100}{K} + B\right)\left(\frac{v_a}{2d_s}\right) + \frac{a_s t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br} + t_d + t_{om} \quad (1)$$

where

$H_{(s)}$ = station headway (close-in) (sec);
L = length of longest train (m);
D = distance from front of stopped train to start of station exit block (m);
v_a = station approach speed (m/sec);
v_{max} = maximum line speed (m/sec);
K = braking safety factor (worst-case service braking is K percent of specified normal rate, typically 75 percent);
B = separation safety factor [equivalent to number of braking distances plus a margin (surrogate for blocks) that separates trains];
t_{os} = time for overspeed governor to operate on automatic systems (to be replaced with driver sighting and reaction times on manual systems);
t_{jl} = time lost to braking jerk limitation, typically 0.5 sec;
t_{br} = brake system reaction time (older air brake equipment only);
t_d = dwell time;
t_{om} = operating margin;
a_s = initial service acceleration rate (m/sec^2); and
d_s = service deceleration rate (msec^2).

(t_d and t_{om} may be combined as controlling dwell.) This equation approximates three types of train control systems:

1. Three-aspect signaling system (B = 2.4),
2. Multiple-command speed cab controls (B = 1.2), and
3. Moving block with variable safety distances (B = 1.0).

The passenger loading capacity of a railcar can be expressed as

$$V_c = \left[\frac{(L_c - 0.5L_a)W_c - 0.5D_nW_sD_w}{S_{sp}}\right] + N\left[\left(1 - \frac{S_a}{S_{sp}}\right)\left[\frac{L_c - L_a - D_n(D_w + 2S_b)}{S_w}\right]\right] \quad (2)$$

where

V_c = vehicle capacity (peak within the peak);
L_c = vehicle interior length;
L_a = articulation length for light rail;
W_s = stepwell width (certain light rail only);
W_c = vehicle interior width;
S_{sp} = space per standing passenger = 0.2 m^2 (2.15 ft^2) maximum, 0.3 m^2 (3.2 ft^2) reasonable, or 0.4 m^2 (4.3 ft^2) comfortable;
N = seating arrangement = 2 for longitudinal seating, 3 for 2 + 1 transverse seating, 4 for 2 + 2 transverse seating, or 5 for 2 + 3 transverse seating (2 + 3 seating available only on cars 3 m wide or more; not applicable to LRT or AGT);
S_a = area of single seat = 0.4 m^2 (4.3 ft^2) for transverse or 0.35 m^2 (3.8 ft^2) for longitudinal;
D_n = number of doorways;
D_w = doorway width;
S_b = single setback allowance = 0.2 m (0.67 ft) or less;
S_w = seat pitch = 0.69 m (2.25 ft) for transverse or 0.43 m (1.42 ft) for longitudinal; and
[. . .] = expression rounded down to nearest integer (whole number).

This equation can be worked in either meters or feet. An expanded version of Equation 2 is included on the computer disk that will be available with the A-8 report. The spreadsheet calculation automatically applies the seat pitch dimension (S_w) through an "if" statement acting on the seating arrangement factor (N) using the longitudinal dimension if N = 2. Light rail specifics are removed automatically if the articulation length is set to 0.

An alternative approach to car capacity is based on passengers per unit length; the light rail results are shown in Figure 21. As would be expected, the wider and longer Baltimore car has proportionately higher loadings per meter of length. The almost generic Sie-

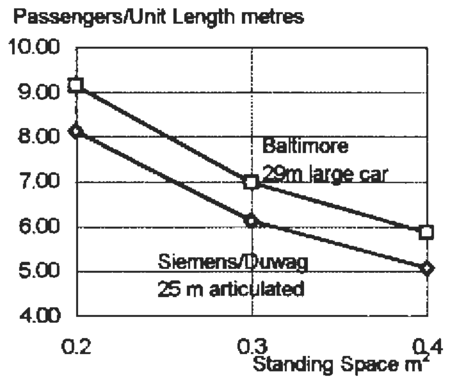


FIGURE 21 Linear passenger loading, articulated light rail vehicle.

mens Duewag car used in nine systems (with some dimensional changes) has a range of 5.0 to 8.0 passengers per meter of car length. The lower level of five passengers per meter length—with a standing space per passenger of 0.4 m^2—corresponds closely to the recommended quality loading of an average of 0.5 m^2 per passenger over the peak hour.

Equation 2 estimates vehicle capacity for the peak within the peak 15-min period. To convert to an hourly capacity, a peak-hour diversity factor must he used, expressed as

$$D_{ph} = \frac{R_{hour}}{4R_{15min}} \quad (3)$$

where

D_{ph} = diversity factor in peak hour,
R_{hour} = ridership in peak hour, and
R_{15min} = ridership in peak 15 min.

Typical values for this factor range from 0.75 to 0.90, with the upper end applicable to high-capacity heavy rail such as the NYCT Manhattan truck lines and the lower end to moderate-density light rail lines.

Light Rail Specifics

Light rail has a specific chapter in the report in which the factors limiting capacity are explored. System capacity is set by the weakest link in the chain:

- Signaled private right of way,
- On-street with regular traffic signals,
- On-street with partial preemption,
- On-street with full preemption,
- Other grade crossing restrictions,
- Single-track sections, and
- Train length limitations due to block length.

Most of the newer light rail systems surveyed have signalized sections of private right of way, usually with the signaling economically designed to support a minimum headway of 3 to 4 min. In all reported cases it is this signaling system that limits the train throughput, not the on-street operation or grade crossings, with or without differing forms of preemption. Obviously, on those systems with significant lengths of single-track operation, this becomes the constraint. Overall capacity is also limited where train length is restricted by short street blocks. Splitting trains before such sections or permitting occasional longer trains to briefly block a minor street are solutions that have been used in practice.

Space precludes further summary from this study. The final report will contain a glossary, appendixes with detailed summaries of 76 capacity-related reports, and comprehensive data tabulations. Publication of the final report, subject to the review panel and Transportation Research Board approval, is anticipated for early 1996.

REFERENCE

1. Section 15 of the Urban Mass Transportation Act of 1964, as amended. *Uniform System of Accounts and Records and Reporting System.* Federal Transit Administration, U.S. Department of Transportation.

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Americans with Disabilities Act Issues

Mass Transit: The Blind Person's Car

Steven Hastalis, *Chicago Transit Authority*

Vital to the quality of life in a large urban environment, mass transit takes on particular importance to blind people leading active, productive lives. Using practical, straightforward techniques, blind persons can travel safely, confidently, and competently on any mode. Blind transit riders can use sounds, feel, and other physical characteristics as excellent landmarks, especially on rail transit. Ongoing implementation of the Americans with Disabilities Act (ADA) has raised issues related to verbal and written communication with blind transit riders: Braille and raised print or audio/video signs and publications in alternative formats. ADA also has raised controversy among the blind about modifying the built environment, especially regarding raised, truncated-dome detectable warnings, ostensibly to alert blind persons approaching or walking along platform edges. Technological advances in the transit industry, such as automatic fare collection and passeuger-activated doors, highlight the need to work with blind people and resolve information access and travel issues. With imagination and a positive attitude about blindness, tbe industry can continue making mass transit the blind person's car.

The increasing awareness of and emphasis on disability issues lead to questions about the population percentage or number of people who might use related "accommodations"—services, programs, or facilities. The blind community makes up a very small portion of the population at large, as well as a small portion of the estimated population of more than 40 million people with disabilities. Federal population statistics estimate the number of blind people at two per thousand, or about 500,000 nationwide. This number, however, gives no indication of the percentage of blind people who ride transit.

At best, the transit industry has sketchy, incomplete data on possible numbers of blind riders. Since 1975 the Metropolitan Transportation Authority (MTA) in New York has issued 13,600 half-fare cards to blind riders, about 80 percent of these in New York City. MTA, however, has no count of blind persons who ride but have not applied for half-fare cards. Baruch College Computer Center for the Visually Impaired, which is producing a few system and line subway maps for MTA, estimates that about 5,000 blind people use the subway daily.

The Americans with Disabilities Act (ADA) Accessibility Guidelines (ADAAG) do not have a quantitative threshold, either in terms of population percentages or actual numbers, at which they become effective. This paper, therefore, will address transit issues pertinent to blind passengers from a qualitative rather than quantitative perspective. It is vital to the quality of life in a large urban environment, but mass transit takes on particular importance to blind people leading active, productive lives. Most notably, the National Federation of the Blind (NFB) has developed a decades-long history of advocacy, at the national, state, and local levels, for more and better transit service.

Methods and Techniques

Environmental Cues as Landmarks

Whether traveling with canes or dog guides, blind people use many practical, straightforward techniques and methods to ride rail transit safely and effectively. By listening, they ascertain the direction from which the train approaches, determine whether they board toward the front or rear, and locate the opening doors. Not seeing directional and informational signage, they maintain orientation by paying attention to compass directions, especially while walking through stations and riding trains as they round curves or switch tracks. The physical characteristics of the railway, sounds and feel, make excellent landmarks—for example, the echo and louder sound of subway tunnels; the vibration and slight rocking when riding through track switches; the crossing over from one track to another, as track switches guide the train along its route at terminal stations or junctions; the "clickety-clack" of jointed rail, with a rail joint usually about every 12 m (39 ft); the resonance of elevated structures and bridges; the smooth, quiet ride of welded rail (usually in sections of several hundred feet); and the quiet ride of ballasted track, with rails mounted on wooden or concrete ties set in crushed ballast rock.

Blind transit riders can note such landmarks along the way, just as sighted drivers note buildings or street names. Continuing this analogy, riding on the right-hand track of a two-track railroad compares with driving in the right-hand lane of a two-lane road. On a center platform station with two tracks, the passenger would face the desired direction and take the train on the right. Likewise, riding on the right-hand outside or inside track of a four-track operation corresponds to driving in the right-hand outside or inside lane of a four-lane road.

Canes

Blind people who use canes extend them to find the platform edge, walk straight, and keep a safe distance from it. Thus, they avoid the many fixtures and facilities typically installed toward the center of platforms: windbreaks on outdoor platforms, stairs, escalators, elevators, supervisor booths, trash cans, newspaper stands, benches, and advertising or informational signage or kiosks. Alternatively, some older subway stations have support pillars every few feet near platform edges. Blind people can locate these pillars with canes and walk a straight line just inside them. Canes also enable blind people to distinguish open doorways from the spaces between cars, as well as to negotiate the gap between platform edge and cars. This method works, regardless of whether trains have between-car barriers such as gates or springs.

Cane tips, especially metal ones, make an excellent sharp tapping sound on hard surfaces, the echo from which provides excellent auditory cues to blind people walking through stations. These auditory cues become especially useful on island platforms where other passengers insist on lining up and waiting along the edges, keeping blind persons from using them as a guide.

Dog Guides

Blind people who use dog guides avoid passengers and fixtures because dogs have received training to guide their users around obstacles. They also keep a safe distance from the platform edge because dogs respect the drop-off beyond it. When boarding trains, dogs guide their users away from spaces between cars and toward open doors.

Information Access

Publications in Alternative Formats

The Chicago Transit Authority (CTA) now produces and distributes several publications in such alternative formats as Braille, computer disk, large print, and audio cassette. CTA's *Rapid Transit Guide* covers all the rail routes, listing station name, street address coordinates, numbers of connecting CTA and Pace suburban bus routes, and information about connecting Metra commuter rail and other transportation services. CTA makes this guide available in Braille and computer disk, updating it as service changes.

Informational Announcements

Blind people have stressed the importance of bus operators' calling stops. Years before ADA, CTA's bus operator training and rules promoted the positive notion that announcing stops benefits all riders while providing more accessible service to blind people and others with disabilities. More than 1,300 buses that CTA received in the 1990s have public address systems.

All CTA railcars have had public address systems since the 1950s. All CTA cars in regular service also have outdoor speakers mounted near passenger doors to enable train personnel to make announcements directly to waiting passengers on the platform and, incidentally, focus their attention on the location of train car doors. Conductors or operators advise passengers about closing doors, standing clear of doors, priority seating, and no smoking or radio playing. They announce a train's run number, all station stops, transfer points to other rail lines, delays, reroutes, station closings, and major points of interest.

Audio/video station signs automatically announce the direction of train arrival and eventually may give delay information. In the winter and spring of 1995, CTA conducted a demonstration at the Merchandise Mart Station, using different male voices for southbound and northbound service.

Braille and Raised Print Signage

CTA will install Braille and raised print numbers in all buses, on the passenger side of the driver's barrier and on the panel behind the rear door, facing the stairs. These numbers will enable blind riders to identify buses when reporting incidents. The two new series, being delivered in 1995, have number plates, with white digits on a black background, mounted on stainless steel panels. CTA also will put these numbers on older buses, using stainless steel plates with no color contrast.

CTA train cars have their numbers written in raised print and Braille, 1.52 m (5 ft) from the floor on the panel to the right, as passengers leave the train. Riders may note the car number to report the condition of the car or activity on the train. The newest cars, in use on the Brown, Orange, and Yellow lines, have intercoms located toward the end of each car near the wheelchair positions and operators' cabs. Passengers may use these intercoms to communicate with the personnel operating the train. These intercom positions also have raised print and Braille instructions, as well as car numbers.

CTA planning, architectural, and engineering staff have explored messages, materials, and methods of installing Braille and raised print signs in rapid transit stations. Suggested locations include entrances; exits; points of level change; decision points, such as diverging paths toward side platforms; and boarding areas.

Truncated-Dome Detectable Warnings

Current ADAAGs require installation of raised, truncated-dome detectable warnings along the edges of train platforms at "key stations." These materials have heavy, bumpy texture—ostensibly to alert blind persons approaching or walking along platform edges. Some systems, including PATH and BART, already have installed these along all their station platforms. Others, such as New Jersey Transit, MARC/Mass Transit Administration in Maryland, Metra in the Chicago area, and Long Island Railroad, have installed these at many key station sites and may well install them in future construction projects.

Three completely rebuilt CTA stations have raised, truncated-dome detectable warnings along the entire length of their platform edges. Two other stations have demonstration projects, partial installations of raised, truncated domes made of various materials. Several other stations, new construction and reconstruction projects designed and funded before the effective dates of the ADAAG, do not have such materials, even though the work took place during the 1990s. As such, CTA staff have contemplated submitting a request for "equivalent facilitation" to the Federal Transit Administration (FTA) to retain existing edge treatments at these recently constructed outdoor sites. In 1992 CTA convened a task group to seek comment and suggestions from the blind community. Significantly, most task group members, blind and sighted alike, complained strongly that truncated domes endanger passengers, catching their cane tips and heels of shoes when they walk along platform edges or board trains.

NFB has long held that public entities, such as transit systems, could help blind persons more by allocating limited resources for general improvements than by wasting such dollars for unnecessary, expensive modifications of the built environment, which serve only to perpetuate negative myths about blindness. Blind persons have amply demonstrated that given proper training and opportunity, they can use public transportation and lead active, normal lives alongside their sighted colleagues. Recognizing this perspective and experience, skepticism and opposition to raised truncated domes have increased among government standard-setting bodies and operators of rail passenger service. In 1992 the American National Standards Institute removed the detectable warning requirement from its list of accessibility standards.

In July 1994 the Washington (D.C.) Metropolitan Area Transit Authority (WMATA) received an extension on the installation of truncated domes at key stations. Since then WMATA has analyzed this issue and has sought public participation. It installed two demonstration sites, one underground and the other outside, containing several detectable warning designs and materials, including truncated domes. The Battelle Memorial Institute conducted a platform edge study of a variety of detectable warning textures and materials 61 cm (24 in.) wide that concluded, in part, that "in terms of stopping distances for blind participants, no statistically reliable differences between warning surfaces were noted" (*1*). Battelle's second study concluded, in part, that "in terms of mean stopping distances from the platform edge, for participants who are blind or have low vision, no practical difference between 46-cm (18-in) and 61-cm (24-in) Flame Finish warning surfaces was noted" (*2*).

WMATA held public hearings on March 3 regarding its proposal to request equivalent facilitation for the current granite platform edge. Most testimony strongly supported this position. WMATA's news release proclaiming that the Federal Transit Administration (FTA) had decided in its favor began: "The [FTA] announced yesterday that [WMATA] would not be required to make any structural changes to the platform edges in its Metrorail system" (*3*).

On May 12, the Architectural and Transportation Barriers Compliance Board, or access board, considered NFB's petition to rescind the "raised, truncated dome" specification. CTA, WMATA, and the Southeastern Pennsylvania Transportation Authority, all of which operate extensive rail systems, submitted supporting petitions calling for the retention of existing platform edges instead.

James Gashel, NFB's Director of Governmental Affairs, reports that, in response to these petitions, the access board initiated a review process to consider whether to remove or modify this provision. It passed a resolution directing its communications subcommittee to develop a performance standard, reflecting the ultimate goal instead of the current descriptive standard requirement.

Observations and Recommendations

Fare Automation

The transit industry increasingly has turned toward automatic fare collection. New rapid transit systems of the late 1960s and 1970s have brought automatic fare card vending machines and ticket-activated fare gates into common use. Some older rail systems also have followed this trend. Metra Electric, formerly the commuter rail service of the Illinois Central, instituted a fare card system in the late 1960s. CTA is now developing a debit card system, planned for implementation in 1996. New York City Transit has an ongoing debit card demonstration project with specially equipped turnstiles in several stations. New light rail systems of the 1980s and 1990s commonly feature European-style barrier-free stations with inspectors riding trains and checking tickets. All these rail systems now have or will have automatic fare card vending machines.

How has the transit industry addressed information access for the blind passenger who previously asked a readily available fare-collecting employee the essential question, "What's the fare?" On a bus or streetcar with a farebox up front, the blind passenger, upon boarding, may ask questions of the operator about fares or transfers. On commuter trains with conductors who sell and collect tickets or handle cash fares, or at stations where agents handle currency and fare media, the blind person also may ask questions of personnel. Some rapid transit and commuter rail systems have station attendants; others have telephones at ticket or fare card vending machines. Either way, personnel can assist passengers, blind and sighted alike, with operating these machines and using the fare media.

A blind person purchasing a ticket at an unattended light rail station, with no Braille or speech on the vending machine and no telephone to call for assistance, can look for a passer-by or fellow passenger to help, or otherwise board the train without a ticket and try to convince the fare inspector or police officer of the circumstance. Moreover, a blind person riding a light rail train for the first time might not know about ticket vending machines and thus would anticipate buying a ticket from a conductor on board, as on a commuter train.

The transit industry cannot consider assistance from the sighted public to be the primary method of information access to blind passengers using automatic fare-collection equipment. In the interest of common sense, as well as ADA compliance, transit systems must give blind passengers a way to pay their fares independently. Some light rail and rapid transit systems have placed detailed Braille fare instructions on ticket or fare card vending machines. Writing these instructions on a panel of the machine poses the potential problem of giving outdated information unless the transit property updates the machines' hardware by physically changing out the material containing the Braille when fares change.

Depending on the variety of transactions that the fare structure offers, a blind person still may need assistance from a sighted person because, to date, these machines have had no synthetic speech. They give audible confirmation only by their mechanical operation, as they accept or reject currency and issue tickets. CTA's debit card program will include ticket vending machines with Braille instructions and speech on demand for a particular transaction, when a person presses the "audio" button. This compromise keeps the machine from announcing every fare transaction, an important security consideration for a passenger who may purchase a debit card with a large dollar amount, such as $20 or $40, at night in an inner-city station.

Light Rail Operation

Light rail offers a variety of service possibilities between traditional streetcar and rapid transit or commuter rail. Boarding light rail cars in "street running" resembles boarding buses, whereas boarding them on private right of way resembles boarding trains. In any event, all rail systems have certain common features: track, cars, and platforms (or at least car stops).

A primary difference between the older style of streetcar service and modern light rail is in boarding the car. The blind passenger, who usually boards the bus or streetcar on which the operator opens the front doors, as well as the rapid transit or commuter train on which all doors open, might be daunted at the prospect of locating buttons on the outside of cars to open doors. The transit system could alleviate this situation by having light rail train cabs equipped with door controls that the operator could use if a passenger, blind or sighted, has difficulty opening the doors from outside the car. When doors do not open, passengers obviously do not step off the car, and the boarding blind passenger does not have these sound cues. In this instance, a subtle auditory cue might assist blind people while benefiting other passengers as well. Perhaps the same circuit that enables passengers to press the button and open doors could activate a soft bell or tone located at the car door.

Alternatively, outdoor speakers mounted near doors similar to those on several systems' cars might serve a dual purpose. While alerting passengers to the location of doors, outdoor speakers can facilitate announcements of train direction and destination to waiting passengers at platforms where several routes stop or on outlying single-track sections on which trains travel in either direction.

Linear Path

In the context of accessible design, transit planners have expressed concern about incorporating clear, linear paths along platforms and through rail stations. A common-sense design and approach benefits all passengers, including blind people and others with disabilities. As such, primary travel paths should have as few turns as possible, allowing passengers to move efficiently and directly between essential elements of stations: entrances, fare controls, facilities of level change, and boarding areas. Whenever possible, these travel paths should run parallel with or perpendicular to major rights of way, streets or tracks, and platforms. For example, passengers can enter and exit stations and maintain their orientation more easily when fare controls, gates, and turnstiles face parallel with the direction of rail travel through stations. Clear, direct travel paths facilitate efficient passenger circulation across or perpendicular to the direction of travel in several situations: subway mezzanines, between entrances on or adjacent to sidewalks at street level and platform or platforms beneath the street, concourses serving several platforms at major terminals, and grade crossings at light rail stops or commuter train stations. The most efficient linear paths along platforms depend on station characteristics such as platform width as well as placement of support pillars, fixtures, and facilities of level change.

Transit Information

A telephone call to transit information, important to anyone needing directions, is even more important to blind passengers. When giving directions, transit information generally advises a sighted person to observe the signs. A blind person, therefore, may ask for more specific information about services and facilities: location of bus stops with relation to intersecting streets, location and layout of light rail stops, and location of entrances and platforms of elevated or subway stations. In many systems, transit information operators have extensive personal experience with their routes and service areas, along with detailed schedules and maps. In some systems transit information operators may refer blind callers to staff who can give such information. For example, the Travel Information Center in Chicago sometimes refers blind callers with detailed questions to CTA Customer Assistance. As part of a multifaceted travel-training program, WMATA proposes to establish a hotline for blind persons and others with disabilities who request detailed directions.

Conclusions

Blind people can provide the best solutions for their travel needs. The transit industry should take advantage of this valuable resource. With imagination and a positive attitude about blindness, light rail and other modes of transit can be made viable, safe, and effective for blind people. The author's experience is by no means unique. Thousands of blind persons throughout the country travel safely and confidently by mass transit every day. They are self-sufficient and independent and lead active, productive lives; they consider mass transit the blind person's car. Let's get in and go for a drive.

References

1. *The Impact of Transit Station Platform Edge Warning Surfaces on Persons with Visual Impairments and Persons with Mobility Impairments.* Battelle Memorial Institute, 1995.
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3. *Metro To Keep Existing Platform Edge: Federal Transit Administration Decides in Favor of WMATA Request.* News Release. Washington (D.C.) Metropolitan Area Transit Authority, April 26, 1995.

Making an Accessible Light Rail System More Accessible Under the Americans with Disabilities Act

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The Sacramento Regional Transit District (RT) light rail stations were built in 1987 to be accessible to persons with disabilities, but they do not necessarily include all of the features required by the Americans with Disabilities Act of 1990 (ADA). Accessibility to all trains via minihigh platforms has encouraged patronage by persons with disabilities; currently, wheelchair user boardings average 40 per weekday. State building code and then-current federal accessibility standards were followed in the design of the system, resulting in many user-friendly elements for passengers with disabilities. U.S. Department of Transportation ADA regulations require that transit systems retrofit "key" existing stations to meet the ADA guidelines. RT's key station plan to ensure compliance includes modifications to the following existing RT light rail station elements at nine key stations: detectable warning strips, signage, Braille or raised print information, parking, handrails, curb ramps, lighting, level track crossings, and elevator communications. In February 1995 RT entered a voluntary compliance agreement with the Federal Transit Administration to set deadlines for modifications that had not already been completed. Several questions remain as to what some of the final modifications will be, especially for detectable warnings. RT is also looking to the future with a study of whether the existing design should be continued when the system is expanded, or whether alternative vehicle (low-floor, revised seating, etc.) or station designs will be required to continue the high level of accessibility enjoyed by Sacramento light rail riders.

The Americans with Disabilities Act of 1990 (ADA) requires that new or altered rail transit stations be accessible to and usable by persons with disabilities, including wheelchair users. These stations must meet Architectural and Transportation Barriers Compliance Board (access board) guidelines contained in the U.S. Department of Transportation (DOT) regulation implementing the ADA. In addition, existing stations considered to be critical to the use of the system must be designated as "key" and modified to meet certain access board guidelines. Key stations that were built in compliance with federal accessibility standards in effect at the time of construction are not required to be completely retrofitted, except for ADA-mandated items not included in the earlier standards. (For example, detectable warnings were not required by the pre-ADA accessibility regulations and therefore must be added to all key stations.)

Sacramento Light Rail

The Sacramento Regional Transit District (RT) operates a 30-km (18-mi) light rail system with 30 stations.

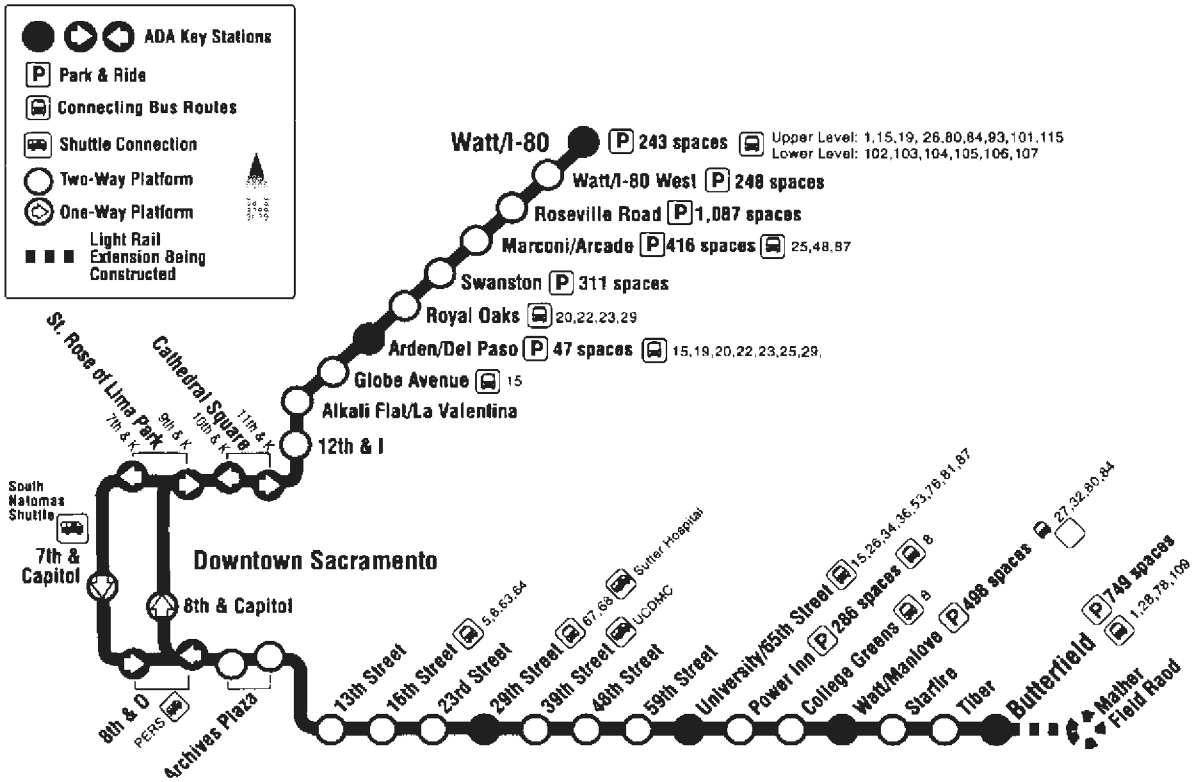

FIGURE 1 Sacramento Regional Transit light rail system.

Opened for service in 1987, the line serves two major travel corridors in the greater Sacramento area. The system operates on a combination of private and shared-street rights of way. Automated grade crossing signals and gates separate the operation from other vehicular traffic in all areas but the central business district, where it runs in streetcar fashion. Figure 1 contains a map of the RT light rail system. Timed-transfer connections to the RT bus system are available at nine stations. Park-and-ride lots accommodating between 40 and 1,100 cars are located at nine stations at the outer ends of the system. The light rail system is scheduled for a one-station (3.7-km/2.3-mi) extension in 1996 and possible extensions of 8 km (5 mi) and 14.5 km (9 mi) on the existing corridors when funding becomes available. Expansion into a new corridor (south area) has recently received approval for preliminary engineering and environmental work; implementation is contingent on future funding availability.

Stations on the light rail lines are of open-air design and feature automated fare vending machines (FVMs) that dispense tickets or passes used in an honor system for payment with random inspection. The stations were built to be accessible to persons with disabilities, including those using wheelchairs. The design and construction of the stations met state of California accessibility standards in effect at the time and were also carried out in close consultation with local persons and groups representing a cross section of disability interests.

The resulting stations feature minihigh platforms with ramps (Figure 2) or wayside lifts (Figure 3). The platforms combine with bridge plates on the rail cars that operators deploy manually to afford walk- or roll-

FIGURE 2 Minihigh platform with ramp.

FIGURE 3 Wayside lift.

on access to passengers with mobility restrictions (Figures 4 and 5). Color-contrasting resilient-overlay detectable warning strips of a truncated-dome design are installed at all platform and boarding area edges. The FVM's have been adapted for use by blind patrons with the addition of instructions in Braille. Other station accessibility features include parking for persons with disabilities, curb ramps, accessible paths to platforms and boarding areas, and elevators at a two-story station.

Two stations were added to the system in 1994. These stations were designed and built to meet ADA accessibility standards as well as California Building Code (Title 24) accessibility requirements. Improvements over older stations were as follows:

- Consistent ADA-standard detectable warning strips 61 cm (24 in.) deep on low boarding areas as well as minihigh platforms,
- Roof canopy structures and seating on minihigh platforms,
- Light rail vehicle (LRV) door locator texture behind detectable warning strips,
- FVMs with integrated Braille or raised print instructions,
- FVMs consistently placed in center of shelters,
- Directional surfaces leading to FVMs (experimental), and
- Detectable warning strips at tops of stairs (experimental).

Key Station Plans: ADA Standards Complicate Accessibility Compliance

The standards required at key stations are contained in the *ADA Accessibility Guidelines for Buildings and Facilities* (ADAAG, or access board guidelines). Two alternatives to complying with the full ADAAG standards are given in limited circumstances: the application of "grandfathering" items that met prior federal accessibility standards when originally built or installed, and the concept of equivalent facilitation.

FIGURE 4 Operator manually deploying bridge plate.

Grandfathering

For rail facilities already accessible before passage of the ADA, DOT allows items that met federal accessibility standards in effect at the time of construction or modification to be considered accessible under the ADA. To qualify for this grandfather clause, existing modifications must conform to the Uniform Federal Accessibility Standards (UFAS), which was a precursor to the ADAAG and was the standard to which all federally funded projects were subject before passage of the ADA.

However, this clause is limited to UFAS individual elements that were superseded by more stringent versions of the same standards in the ADA. New ADA

FIGURE 5 Bridge plate in position.

items that were not covered in UFAS must be retrofitted in existing key stations. For example, UFAS did not contain any standards for detectable warnings on walking surfaces or transit platforms. This means that even though the RT stations went beyond the UFAS in providing them, the existing platform detectable warnings, which do not meet ADA guidelines, could not be grandfathered.

Equivalent Facilitation

Departures from particular technical and scoping requirements of the ADAAG by using other designs and technologies are permitted when the alternatives will provide equivalent or greater access to and usability of the facility. The DOT regulation specifies a procedure for using alternative methods of compliance. This procedure includes making a request to the Federal Transit Administration (FTA) that states the reason for not complying with ADA, what the alternative method is, and how it provides equivalent accessibility; it also outlines public participation in the process.

RT Light Rail Compliance

The following are general descriptions of ADA-required items to the extent that they were applicable to the RT light rail system and were found to require significant changes. Applicable items were identified as to their compliance throughout the system. Site reviews were conducted to assess compliance at individual key stations, the results of which were included in a compliance plan for making the needed modifications.

Station Identification Signs

Signs identifying stations must meet minimum graphic standards and be visible on both sides of rail vehicles. Some RT stations had these signs on only one side. Signs on the other side were added at these locations, to the extent practicable. The graphic standards for character height and proportion, as well as finish and contrast, were met substantially by the existing signs. However, these signs were not as readable as they could have been, especially for low-vision patrons. Since the related destination signs were not compliant, RT decided to replace all of the station identification signs at the same time in a consistent graphic style. The ADAAG requirement for a totally nonglare eggshell finish was problematic because of the need to be able to remove graffiti. RT settled on a low-gloss paint combined with antigraffiti coating.

Station Information

Lists of stations, routes, or destinations served by the station must meet minimum graphic standards. At least one Braille and raised print sign identifying each station must be placed at uniform locations throughout the system. The RT destination signs ("To Butterfield," etc.) did not fully comply with the graphics standards and were targeted for replacement. Braille and raised print signs identifying each station had been planned and were already contained in a capital grant project intended to improve the existing Braille information on FVMs at each station.

The Braille and raised print signs posed some unique challenges to RT. First, the FVMs did not have enough space for both Braille and minimum 16-mm (5/8-in.) raised print information. And, in open-air stations, there are limited opportunities for consistent placement of signs to be easily located by patrons. This problem was exacerbated because RT stations varied greatly in their layout, including the location of shelters and FVMs. Ultimately, the railings of minihigh platforms were chosen as the best, most uniform location. Exposure to direct sunlight on Sacramento's 36°C (100°F) summer days precluded the metal signs that some other systems have developed as durable solutions—reading transit information is difficult when fingertips are being seared.

Searching for a tough yet cool material led RT to test signs made of Coryon, a high-density polymer that is sandblasted to create raised print characters. Braille is produced by sandblasting or by using inset beads (Figure 6). A prototype 6.4 mm (1/4 in.) thick was broken by vandals, which led to further testing of 12.7-mm (1/2-in.) material and the use of an aluminum frame. RT expects either of these versions to last several years in the field.

Fare Vending Machines

FVMs are required to be physically accessible, and instructions and information for use must be accessible to and independently usable by persons with vision impairments. RT's fare machines satisfy the requirements for maximum and minimum physical reach. However, the ADAAG does not specify standards for making instructions on fare machines (vis-a-vis the automated teller machine requirements) usable for those with vision impairments.

RT fare machines are equipped with a notice on the front of the machine in Braille, directing the user to a panel in Braille on the side of the machine explaining the front panel buttons and instructions. In addition to this inconvenient arrangement, the present Braille information is out of date and no longer accurate. RT had provided in its capital budget to replace the Braille information with a current version and add station identification, as part of the previously mentioned Braille sign project.

RT had the opportunity to test integral, "dedicated" Braille and raised print instructions on new FVMs purchased for the stations opened in 1994. With substantial input from blind advocates, including members of RT's disabled advisory committee, a successful prototype was developed for these machines that will also be the basis of machines replacing RT's original stock over the next few years. An interim retrofit of the existing machines was also developed in the form of a new faceplate incorporating integral Braille and raised print instructions. The existing mechanical and electrical components would require minimal modifications to accept the revised faceplate, and this approach may be used on some machines that are to be replaced late in the procurement cycle.

FIGURE 6 Destination sign with raised print and Braille (in white panel at bottom).

Detectable Warnings

Station platform edges must have color-contrasting detectible warning strips of a truncated-dome design at least 61 cm (24 in.) deep. This standard is duplicated by California Title 24, with the addition that it must have resiliency or sound-on-cane-contact difference in outdoor, as well as indoor (which ADAAG requires) applications. Title 24 also requires the color to be safety yellow. RT station platform edge warnings have the required design and yellow color, but they are generally 61 cm (24 in.) deep only on the minihigh platforms. The regular boarding areas have warning strips 30.5 or 45.7 cm (12 or 18 in.) deep.

RT was one of the first systems in the United States to install what later became ADA-standard detectable warning material. The original 1-ft^2 rubber overlay "tiles" were installed using construction-grade mastic. The combination of Sacramento's summer heat and the tendency of the material to stretch over time resulted in the closing of the original gaps between squares. The tiles then butted up against each other, causing some to pop up and curl (Figure 7). This created a tripping hazard for pedestrians, which resulted in a few injuries and in the need for RT to pull up curled tiles and replace them sooner than anticipated. On the other hand, RT has not had any major incidents or accidents in which visually impaired passengers or pedestrians have unknowingly walked in front of approachiug trains in station areas. Whether this would have been different if the detectable warnings were not in place is uncertain.

Several manufactured materials were tested by RT for installation characteristics, durability, and detectability by consumers during 1993 and 1994. The long-term experience with the rubber overlay material led RT to seek a more durable solution, preferably one that could be inset in a grout bed while still meeting desired detectability requirements. The city of Sacramento also had concerns about the aesthetic qualities of these materials on its revitalized downtown pedestrian mall. Failing to find an acceptable product offered by man-

FIGURE 7 Rubber overlay tiles with truncated-dome detectable warning material.

ufacturers, RT decided to develop a prototype specification and find a manufacturer willing to experiment with it. A few manufactured products that may be suitable began appearing in the spring of 1995, about the same time that RT began to develop its test specifications.

A new situation arose while the key station voluntary compliance agreement (VCA) was being negotiated with FTA in February 1995. RT had planned on the need for "hazardous vehicular area" detectable warnings 91.5 cm (36 in.) deep only at crosswalks for side streets crossing the downtown K Street pedestrian mall. Since the RT boarding platforms are all designed for boarding along their entire length, and no vehicles other than the rail cars themselves use them, the RT stations were considered platforms subject to the 61-cm (24-in.) warning depth requirement. This includes both downtown malls and most of the other key stations where the boarding area is flush and the pedestrian circulation area coincides or overlaps with the rail area.

The ADA requirement for 91.5-cm (36-in.) warnings applies only where pedestrian walkways cross or adjoin a vehicular way, without demarcation by curbs, railings, or other elements detectable by visually impaired pedestrians. This requirement was explained in detail in RT's key station plan, which was adopted using extensive public participation by interested advocates and consumers with disabilities.

Upon negotiating the VCA, FTA decided to delete the detectable warnings, as it was now considering RT's flush boarding areas to be "hazardous vehicular areas" (the minihigh platforms already had 61-cm warnings). The regulation for the 91.5-cm (36-in.) detectable warnings at hazardous vehicular areas was suspended by the access board pending further research and therefore could not be applied in the VCA. RT agreed to execute the agreement but also offered to help FTA reevaluate its new interpretation, which could result in confusion between pedestrian mall boarding areas and adjacent motor traffic. Consistency in the treatment of transit boarding areas, as couched in ADA mission statements, would be better served by keeping transit boarding areas differentiated from cross streets.

Illumination Levels

Lighting in areas where signage is located must be uniform and must minimize glare on signs. Lighting along pedestrian circulation routes must provide uniform illumination. The lighting at some RT stations was inadequate, especially on stairways and adjacent areas at the two-story Watt/I-80 station, and at several stations where the lights did not shine down directly on the station identification signs. A project to rectify lighting deficiencies should be completed by mid-1995.

Track Crossings

Where it is necessary to cross tracks to reach boarding platforms, the route surface must be level and flush with the rail top, except for a maximum 6.4-cm (2.5-in.) gap on the inner edge of each rail. Track crossings over what constitute hazardous vehicular ways must have detectable warnings as described earlier and must be 91.5 cm (36 in.) deep. The light rail tracks at RT stations were generally in compliance with this requirement. A few stations, however, feature pedestrian access over the tracks of a freight rail spur line. The infrequent use of these tracks by trains made it difficult to determine whether they constituted a hazard. Erring on the side of caution, RT decided to install the 91.5-cm (36-in.) warning strips on pedestrian approaches to the platforms that cross these tracks. This installation is now on hold because of the regulatory suspension by the access board described earlier. In addition, the pavement across the freight tracks was not level in some places and is being repaired.

Elevators

Elevators at stations must have glazed or transparent panels to allow an unobstructed view both into and out of the car; they must also meet standards for accessibility of signals, controls, and other operating features. The elevators at RT's Watt/I-80 station were built to comply with Title 24 of the California Building Code and complied with UFAS. Most of the features of the elevators also meet the ADA standards. The elevators have transparent panels that allow visibility into and out of the sides of the car. However, the design of the station includes a solid wall on the lower level that does not allow visibility to these clear elevator panels from the platform itself.

Since the elevators substantially conformed to UFAS at the time of construction, RT considered them to be grandfathered under the provisions of the DOT rule for the transparent panel requirement. Not eligible for grandfathering, however, was the requirement that the emergency intercommunication system not be dependent solely on voice communication. RT investigated the installation of an alternative device to augment the existing telephone/intercom system, but it may instead replace the elevator control system entirely to deal with this and continuing damage to the controls by vandals. If the new design is successful, the elevator cars will automatically move up or down to the other level when passengers enter, obviating passenger-operated selections. Sensors would alert RT personnel of any malfunctions, alleviating the need for intercoms or alarms.

Cost Estimates and Budget Impacts

The total estimated cost for required key station improvements, including new station identification and destination signs as well as Braille information at all (key and nonkey) stations was approximately $700,000. Another $630,000 would be required to upgrade the remaining nonkey stations to ADA standards. Both of these figures are likely to increase significantly if RT chooses an inset, as opposed to overlay, type of detectable warning material. The key station project was budgeted by RT using 80 percent federal capital funds. In the interest of systemwide consistency, nonkey stations will be completed over the next few years in stages, as funds become available.

RT annually budgets a separate amount for miscellaneous ADA accessibility facility and equipment upgrades (including bus system items), which will eventually cover the modifications to nonkey stations. These costs may appear modest when compared with those needed by older systems with center platforms and multilevel stations. However, they may be considered significant for a recently opened system that placed accessibility high among its original design criteria and that has attracted and served passengers with disabilities for several years without major problems.

A third item budgeted is the rebuilding of the only station in the system that does not provide disabled boarding in both directions. The tracks here are in a downtown roadway, and the inbound boarding area requires passengers to cross the outbound tracks. It will cost about $750,000 to move the tracks and sidewalk. This project is also contingent on taking several feet of private right of way, which will not be practical until the property is redeveloped. The city of Sacramento's rezoning for the proposed development requires the developer to contribute $250,000 toward the cost of moving the station.

Vehicle Loading and Ramps Versus Wayside Lifts for Access

RT's design using minihigh platforms has been almost universally hailed in the community as an unqualified success. An average of 40 patrons using mobility aids (wheelchairs, scooters, etc.) board light rail on weekdays, and approximately 250 passengers who do not use wheelchairs board using the minihigh platforms. These include people using canes or crutches, people whose condition makes it difficult to climb the vehicle steps, and patrons with baby strollers or shopping carts. The latter category was encouraged for inclusion by RT's disabled advisory committee after the system opened with usage restricted to passengers with disabilities only. The philosophy that accessibility improvements should benefit and be used by anyone who can use them was the basis of this decision. Mainstreaming, as later forwarded by the ADA, is not accomplished as readily when facilities or programs for customers with disabilities are kept exclusive.

The ease of use of RT's design has created a two-edged sword: the system is so popular that it is beginning to turn away disabled passengers because of overcrowding. The current average is five to seven "pass-bys" per month, or about 0.6 percent of all boardings by mobility aid users. There are two reasons for this. First, the three wheelchair positions are sometimes occupied, especially during peak periods, by mobility aid users. Second, passengers not using mobility aids sometimes refuse to move for disabled patrons. RT operators are trained to ask such passengers to vacate the positions when needed, but once patrons have taken a seat, it is sometimes hard to budge them. Single-track staging on the system makes prolonged dwells for supervisory intervention in these cases highly undesirable. Educating riders on this and other accessibility issues is a priority in RT's upcoming marketing program. System procedure for all pass-bys is to alert the next train (most on 15-min headways, equivalent to the most frequent bus services) to make sure the passenger is able to board. To deal with the crowding issue, RT is considering requiring that all baby strollers be folded upon boarding, which should alleviate crowding of the wheelchair positions as well as regular seating areas.

Most of the minihigh platforms are accessed by ramps with rises of 1 in 12, which meets the ADA standard. User acceptance of the ramps is high, partly because transit-riding mobility aid users tend to have powered wheelchairs or enough upper body strength to use ramps without problems. Three of RT's platforms (out of 60 one-way boarding areas) have wayside lifts, which are the source of problems for passengers with arm or hand movement limitations.

Unlike the wayside lifts on some other U.S. systems, Sacramento's were designed to be operated by the passenger without assistance from LRV operators (Figure 8; note passenger using foot to hold door open). Riders are required to be on the platform when the train arrives. Operators sometimes provide assistance if their schedules allow, but several users have complained about difficulty in opening the manually operated doors to the lift car or operating the control switches. RT plans to retrofit the controls with larger, paddle-type switches. Another possibility, for which technical solutions are not yet final, may be to convert the doors to open automatically and close when the up or down controls are activated.

The wayside lifts originally were used in places where platform or sidewalk clearance would not allow a ramp. RT's informal policy is to replace the wayside lifts if possible, depending on negotiations for space with the city and adjacent property owners. All new stations are designed to allow for ramps in conjunction with the minihigh platforms. New platform ramps are also designed with a rise of 1 in 14 where space is sufficient for the longer runs required.

FIGURE 8 Wayside lift operated by passenger.

Light Rail Accessibility Study

The loading problems result in part from the RT system having consistent 15-min headways throughout the day, including peak periods. Capacity for peak loads is provided through the use of three- and four-car consists. Only the leading car of multiple-car trains is accessible via the minihigh platforms. The ADA standard for a minimum of two wheelchair locations per car would result in the need for up to eight locations at each end of every car, since the cars are double-ended and are operated in both directions. The size of the Siemens LRVs, combined with space limitations on RT's right of way, preclude the use of turn-around loops for single-ended LRVs.

To gauge whether the existing system features will provide enough accessibility to disabled passengers and adequate boarding for all passengers when future system extensions are built, RT has initiated a study to determine which direction will best address Sacramento's needs. The study is being conducted by a consultant team consisting of several firms with experience in rail planning and accessibility issues. Currently under evaluation are five alternatives for improved accessibility:

1. Double-stop trains at minihigh platforms:
   - Time constraints would result from operator assistance required, and
   - City street traffic would be blocked at certain times and locations.
2. Switch to low-floor LRVs:
   - Entire fleet would have to be replaced, with mixing of modes necessary until changeover is completed;
   - Station boarding areas would have to be reconstructed with 25.4- to 30.5-cm (10- to 12-in.) raised platforms, which would harm usability and aesthetics of downtown pedestrian mall; and
   - Minihigh platforms would be removed (after phase in is completed).
3. Lengthen each LRV with a low-floor middle section:
   - Stations would require raised platforms similar to full low-floor alternative,
   - Fleet capacity could be increased without adding new LRVs, and
   - Wheelchair access would be restricted to center sections of cars only or could be augmented by

leaving existing minihigh platform access for leading cars

4. Increase number of wheelchair spaces in a car:
   - –Modifying existing cars could be the lowest-cost option,
   - –Would not require new LRVs or station modifications,
   - –Existing method of seating at both ends would significantly reduce overall seating, and
   - –Single-ended cars would limit operational flexibility in assembling trains.
5. Implement high-level loading at all stations:
   - –Would increase service speed with decreased boarding times;
   - –Would require major rebuilding of all stations at significant, unplanned expense;
   - –Would also require significant modification of existing LRV doors, steps, and suspension; and
   - –High platforms on downtown pedestrian malls face strong opposition from community.

Organizational Issues

The various projects have involved the significant expense of time and effort by many of RT's operational, planning, and management departments:

- Chief Operating Officer,
- Civil and Track Design,
- Customer Relations (marketing and graphic design),
- Facilities Maintenance,
- Finance,
- General Manager,
- Legal,
- Light Rail,
- Planning,
- Program Control and Procurement,
- Safety,
- Systems Design, and
- Systems Development Director.

General planning and coordination of involvement by these departments in rail accessibility issues are handled by RT's accessible services staff. Operating under the assistant to the general manager, this function is staffed by a full-time administrator, a student intern, and a part-time secretary. The accessible services staff are also responsible for RT's bus service and facility accessibility, paratransit planning and contract management, and support to the Disabled and Elderly Committee for Accessible Transportation. Rail accessibility is a regular item on the advisory committee's monthly agenda, which has resulted in good communication between disabled customers and advocates, and the RT staff and board of directors.

Conclusions

The public transportation system in Sacramento affords a very high level of accessibility to passengers with disabilities. The fully accessible light rail system coordinates with a bus system equipped with wheelchair lifts on 97 percent of all trips and a paratransit system providing more than 1,000 trips per average weekday. The RT system had a head start on meeting the requirements of the ADA by being designed to forward-looking state guidelines for disabled accessibility. Most of the improvements mandated for retrofitting will result in better access and usability by disabled, as well as nondisabled, patrons of the RT system. However, since the system was essentially already accessible, it is doubtful that these minor improvements will cause patronage by disabled people to rise perceptibly. Some doubt remains about how certain items required by the ADA, such as detectable warnings, can best be accommodated. Future system design to allow for ueeded accessibility is also not fully determined, with some of the more "pure" solutions posing issues of cost or streetscape disruption. The ultimate decisions in dealing with these concerns will inevitably build on Sacramento RT's strong history of accessibility as well as continued dialogue with disabled transit riders and advocates.

Technology To Help Compliance with Americans with Disabilities Act in Public Transit

Elizabeth Eva Lewalski, *Transit Performance Engineering*

The introduction of the Americans with Disabilities Act (ADA) placed new responsibilities on public transit authorities in the United States. The readiness of technology to respond to the challenges of the ADA is addressed. Onboard devices to assist people with impaired mobility, devices outside the vehicle, and combinations of the two are examined. It is concluded that the greatest benefits will most likely be derived from lowering the floors of passenger compartments closer to street level.

The introduction of the Americans with Disabilities Act (ADA) placed new responsibilities on public transit authorities in the United States. The readiness of technology to respond to the challenges of the ADA is addressed. On-board devices to assist people with impaired mobility, devices outside the vehicle, and combinations of the two are examined. It is concluded that the greatest benefits will most likely be derived from lowering the floors of passenger compartments closer to street level.

High-Level Platforms

Historically, the first effective attempt by public transit to serve people with impaired mobility was demonstrated in underground transit systems. High-level platforms that matched vehicle floors provided a solution for select systems. The drawback to this solution has always been the high capital cost of the high-level platforms. In addition, when high platforms are installed in the streets for light rail vehicles (LRVs), they are frequently considered to be an eyesore.

Critics also complain that the gap between the platform and the vehicle, usually 3 in., and variations between the station level and the car's floor, sometimes exceeding 2 in., make it impossible for a disabled person in a wheelchair to negotiate the entrance without assistance. Still, several cities—such as Calgary and Edmonton in Canada, Pittsburgh, St. Louis, and Los Angeles in the United States, and Stuttgart in Germany—chose this solution for their light rail transit (LRT) systems. With assistance given where needed, a person in a wheelchair can be taken into or out of a car in a matter of seconds.

Minihigh-Level Platforms

A variation of the solution just described occurs when LRVs with high floors and low entrances are matched with minihigh-level platforms at the front end of the station. This arrangement must be supplemented with an on-board bridge plate, manually deployed above the vehicle's stairwells by the car's operator to bridge the gap between the car and the high platform. This method has been adopted, for instance, by LRV operators in Sacramento (Figure 1), Baltimore, and Denver. Such a system works fairly well, allowing for the transfer of a wheelchair within 30 sec, but it causes longer delays when a car's operator initially fails to stop the car in the right place against the short high-level platform.

Another unfortunate aspect of this arrangement is that the two doors (one on each side of the car) next to the active operator's cab are dedicated solely to serving people with impaired mobility, thus potentially increasing the time required for the exchange of able-bodied patrons.

Mechanical Wayside Lifts

Stationary mechanical wayside lifts were adopted by LRV operators in Portland, Oregon, and Santa Clara, California. They are being contemplated for use with the new San Francisco LRV being supplied by Breda. However, even with readily deployable lifts (Figure 2) such as these, transferring a wheelchair causes delays of approximately 3 min because of difficulties in matching the car's entrance with the lift location at the station. The author has been told that in Santa Clara, where the lifts are neatly packaged for architectural effect, the average transfer may cause delays of up to 5 min.

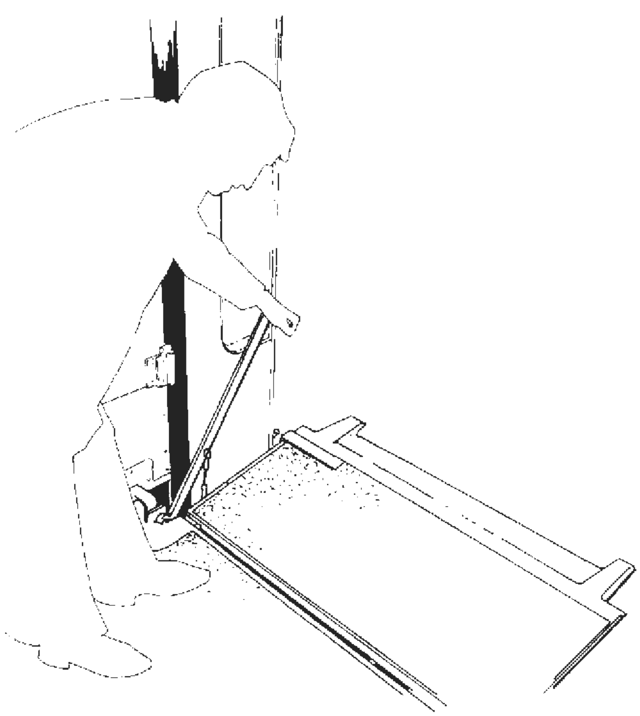

FIGURE 1 Manually deployed ramp on Sacramento LRVs by Duewag.

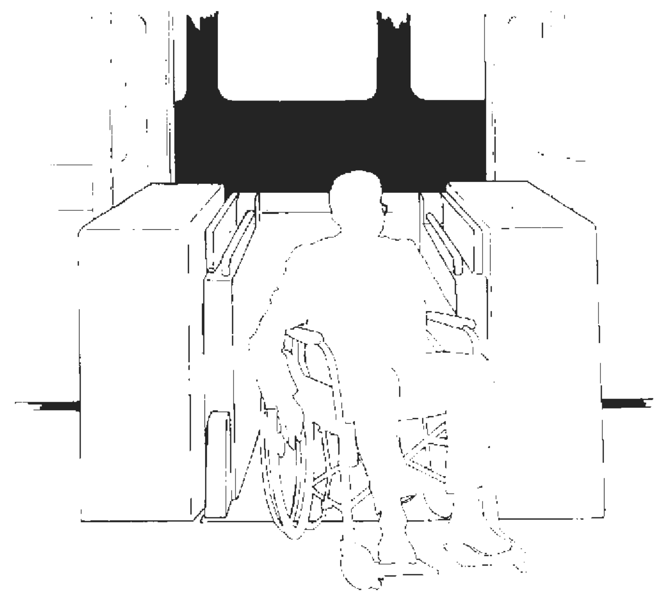

FIGURE 2 Wayside lift by Lift-U, Inc.

Movable Mechanical Wayside Lifts

The action of wayside lifts can be improved if they can be moved to match the lift platform with the entrance of the car. Such a lift serves the super-fast French intercity train, the TGV, in Grenoble.

Mechanical Folding On-Board Lifts

A distinct group of accessibility devices are the mechanically powered on-board lifts. The folding on-board lifts are especially popular for use with the small vans of paratransit operations (Figure 3). Similarly to the wayside mechanical lifts, these are not well suited for a fixed-route service because their slow action results in operational delays. In addition, they occupy the entire door entrance, as on the San Diego LRV (Figure 4). To avoid this inconvenience, Japanese car builder Nippon Sharyo locates its folding lift in a special opening in the side of the car. However, this solution affects the seating and standing capacity of the car.

Rotary Lifts

Some portion of the door entrance can he better used for foot passengers when a rotary on-board lift is used.

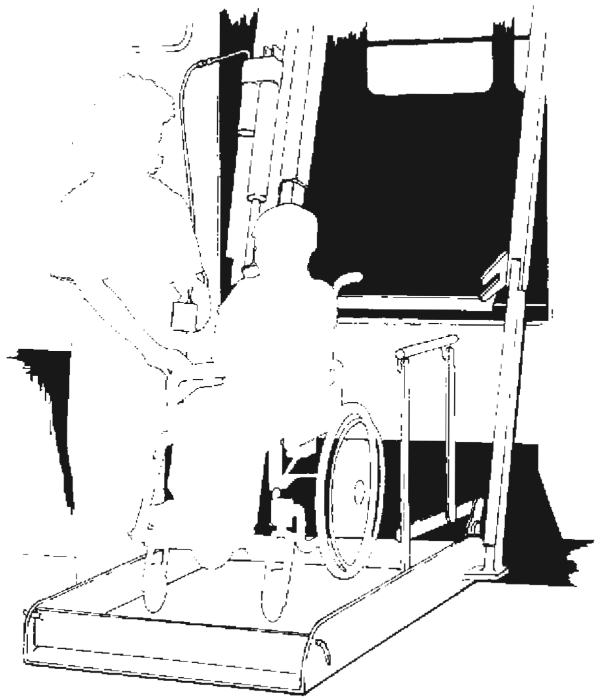

FIGURE 3 Folding lift by Ricon on San Diego LRVs by Duewag. Lift (seen here in folded position) occupies entire entrance.

The lift is stored next to the door post, transversely to the centerline of the car. After a complex set of movements, it unloads the passenger in the lift parallel to the side wall of the vehicle (Figure 5). These lifts are used on paratransit passenger vans, and one is being considered for the new double-deck intercity railcar of the California Department of Transportation.

Lifts in Entrance Steps

Another version of the on-board lift is the lift in the entrance steps. When folded, it forms the steps of the car. These lifts are popular in buses but are avoided in railcars since railcars have much higher structural strength requirements. A lift in the entrance steps needs a large cutout in the underframe, thus making it less resistant to the specified construction loads.

Low-Floor Vehicles

A breakthrough in serving the public occurred with the introduction of low-floor vehicles, both buses and railcars. In buses and LRVs the low floors are approximately 1 ft above (most typically 14 in. above) the road, 2 ft lower than in earlier designs. This includes vehicles with low floors along their entire length or partially low-floor arrangements, typically 70 percent low floors.

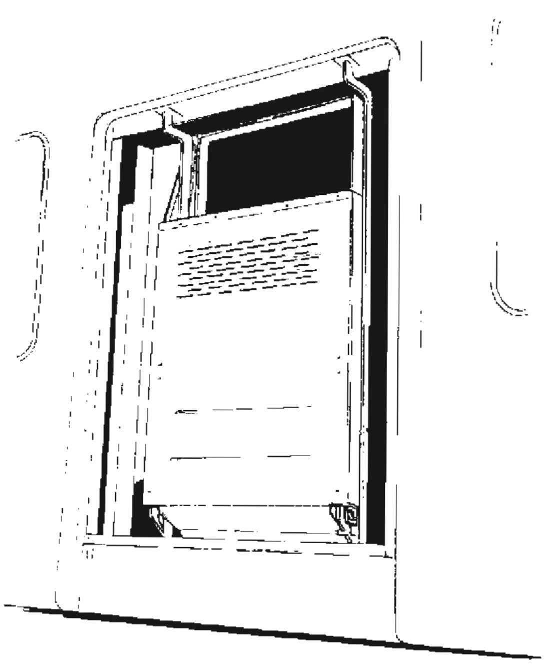

FIGURE 4 Folding lift by Braun Corporation.

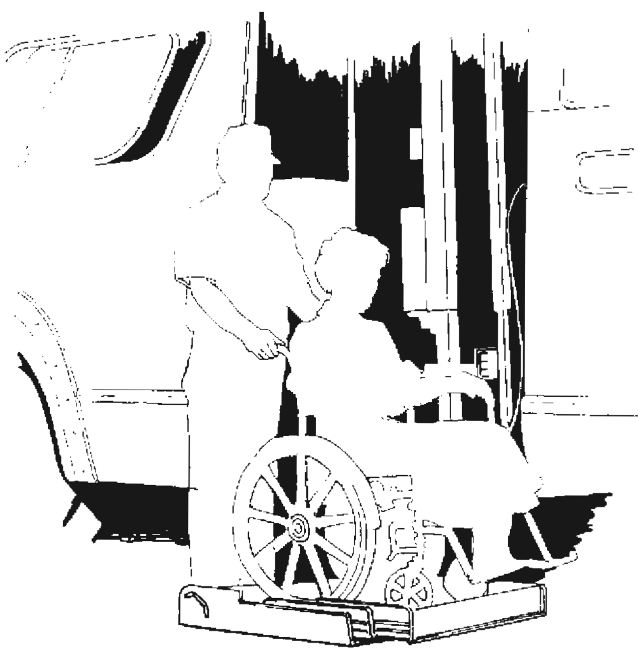

FIGURE 5 Rotary lift by Braun Corporation. After a sequence of linear and rotary motions of lift, a passenger in a wheelchair reaches ground with side to vehicle.

In mainline commuter and intercity railcars, the low-floor level is at 2 ft as opposed to the earlier height, typically 4 ft. Although a low floor does not mean a street-level floor, the described vehicles, when combined with adequately elevated station platforms, greatly facilitate the movement of passengers through their doors, even without supplementary ramps or lifts.

Low-Floor Vehicles with Supplementary Lifts

A low-floor vehicle with a supplementary lift exists in Munich on a 100 percent low-floor LRV manufactured by AEG (Figure 6). The lift, supplied by Messerschmidt-Boelkow-Blohm GmbH, drops part of the entrance floor to the ground and allows a wheelchair to be picked up even from rail level. In Munich 120 buses are also fitted with these lifts. However, this complex mechanism is relatively expensive.

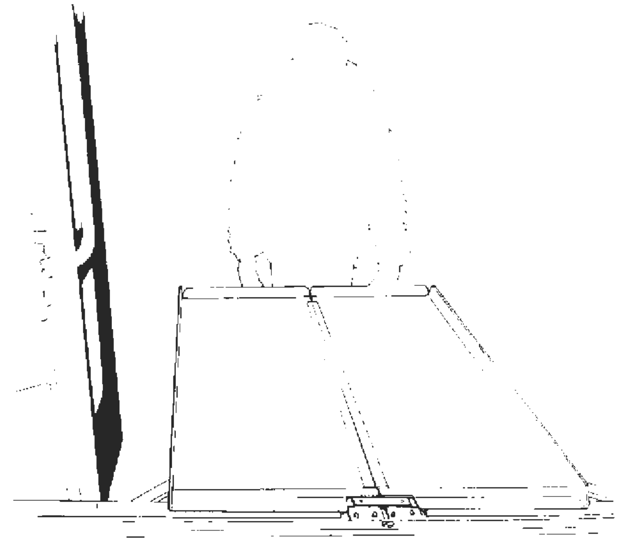

FIGURE 7 Manually unfolded ramp by Bombardier on Los Angeles Metro Link bilevel commuter cars.

Manually Deployed Ramps

At the opposite end of the price and complexity range is a manually deployed ramp manufactured by the Canadian company Bomdardier for its Los Angeles Metro Link commuter cars (Figure 7). This simple ramp, constructed of aluminum extrusions and honeycomb sandwich panels with fiberglass skins, weighs only 30 lb and can be provided at a fraction of the cost of the Messerschmidt ramp. Because of its relatively longer time of deployment, this ramp is considered more appropriate for use on railroads than on light rail systems with their tight travel schedules.

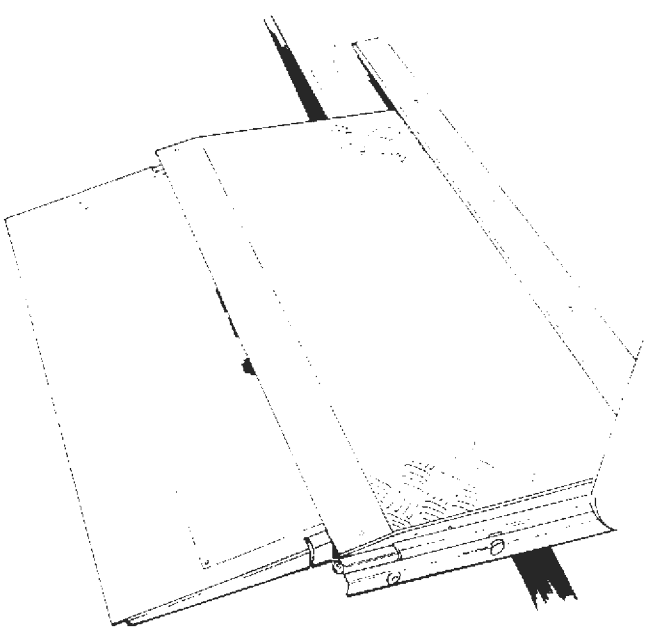

FIGURE 6 Lift by Messerschmidt-Boelkow-Blohm GmbH on low-floor AEG LRVs in Munich, Germany.

Motorized Ramps

Motorized ramps are installed on some MAN kneeling buses. The driver first lets the air out of the air-bag suspension on the curb side of the bus, lowering the low-floor from its normal 12 in. down to 7 in. Then the driver remotely deploys from a slot in the underframe a thin blade-like ramp, some 3 ft long, that bridges the door and the wayside pavement. A similar ramp is in service on the Duewag low-floor Frankfurt LRVs, deployed of course without a kneeling action of the vehicle. The deployment of the ramp appears to take some 5 sec or so.

Short Ramps Mounted in Threshold

The French car builder GEC Alsthom provides on its Grenoble low-floor LRV cars with a short, wide ramp incorporated into the side-door threshold and deployed when needed within seconds (Figure 8). This ramp, covering the gap between the car and the station, has the flexibility to accommodate variations in the height of station platforms. The entire ramp mechanism is a module that can be quickly removed for service or replace-

FIGURE 8 Powered ramp on GEC Alsthom low-floor LRVs in Nantes, France. Ramp is deployed within a fraction of a second, together with opening door.

ment when damaged. Since the ramp is short and engages the station platform only across a couple of inches, its sudden and aggressive emergence from the door threshold does not startle passengers waiting at the stop.

Nantes LRV Ramps: Deployed at Every Stop

The action of similar ramps was observed on the newer Nantes low-floor LRVs, also by GEC Alsthom. Here, the ramps are deployed automatically every time the side doors are opened. This relieves the driver from making decisions about the ramp and invites all patrons to enjoy this convenience. Mothers with children in strollers, elderly people with canes, and people with shopping carts enter and leave the cars naturally and without thinking much about it, something that cannot be said for other accessibility arrangements. However, some operators prefer the type of ramp deployed only on demand, citing the lesser cost of maintenance if the ramps are used selectively.

Conclusions

The introduction of the steam engine, almost 200 years ago, changed the aspect of speed in transportation. Electricity has made transportation efficient and continually raised its level of comfort over the past 100 years. Today the general arrangements of passenger rail vehicles are being rethought in an effort to make them widely accessible to all segments of the public. In this respect it appears that the greatest benefits will be derived from lowering passenger compartments closer to street level. As has been true in the past with similar challenges, the role of technology will be decisive in ensuring accessibility to public means of transportation.

Providing Platform/Vehicle Access To Satisfy the Americans with Disabilities Act: Santa Clara County Solution

Willard D. Weiss, *Morrison Knudsen Corporation*
Robert E. Murphy, *ICF Kaiser/Santa Clara County Transportation Agency*
Paul S. McCauley, *Parsons Brinckerhoff Quade & Douglas, Inc.*

As part of the Tasman Corridor Project light rail transit (LRT) extension, the Santa Clara County (California) Transportation Agency is designing new passenger stations and light rail vehicles to satisfy requirements of the Americans with Disabilities Act. Following an exhaustive evaluation of alternatives, the agency initially decided to implement level boarding using high platforms with high-floor vehicles. Existing Guadalupe Corridor street-level platform passenger stations were to be rebuilt as high-platform stations. Existing light rail vehicles would be modified to cover stepwells and replace doors. A combination of budget concerns and opposition to high platforms in the downtown San Jose transit mall resulted in a subsequent proposal to defer the purchase of new vehicles and redesign station platforms to accommodate low-floor light rail vehicles that would be procured at some future date. Temporary minihigh platforms and modified existing vehicles will be used until then. The alternatives evaluated, the rationale for selecting the high-platform alternative, and the circumstances that led to the current plan are described.

The initial segment of Santa Clara County's (California) 33-km (20-mi) Guadalupe Corridor light rail transit (LRT) line opened for revenue service in December 1987; the south segment of the line opened in April 1991.

The 50 Guadalupe Corridor light rail vehicles (LRVs) are high-floor [990 mm (39 in.) above top of rail] articulated vehicles with four bifolding doors on each side and a stepwell at each door. The 33 Guadalupe Corridor passenger stations have street-level platforms 140 mm ($5\frac{1}{2}$ in.) above top of rail [except in the San Jose transit mall, where they are 100 mm (4 in.)]. The system is designed for operation with trains of up to three vehicles in length. Access for mobility-impaired passengers is provided by wayside mechanical wheelchair lifts operated by the train operator. Every vehicle has two wheelchair positions at each end, but only the positions at the head of a train are adjacent to the wayside lift. Passengers in wheelchairs must use the lifts to board or exit the train through the first door of the lead vehicle, and the train operator must exit the cab to deploy, operate, and secure the lift each time it is used.

The Santa Clara County Transportation Agency (TA) is now completing design of the Tasman Corridor Project, the first of a series of planned extensions to the light rail system. The east-west Tasman Line will be a 20-km (12-mi) extension to the primarily north-south Guadalupe Line, connecting at the Guadalupe Line's northerly terminus. Figure 1 indicates the relationship between the existing rail corridors and the planned extensions to the system. The Guadalupe Corridor, Tasman Corridor, and subsequent extensions are planned to operate as a single system; that is, trains will be through-routed from one corridor to another.

As part of the Tasman Project, the TA has taken a fresh look at its approach to vehicle accessibility. The reexamination is partially a result of the 1990 Americans with Disabilities Act (ADA) and the associated U.S. Department of Transportation rules. Even without the ADA, however, the TA was determined to improve its approach to LRV accessibility. The operating department sought ways to reduce or eliminate the delays inherent in the use of staff-operated lifts, and the mobility-impaired community has expressed concern about the attention received by wheelchair users when using the lifts.

This paper summarizes the TA's analysis of the ADA requirements, the range of methods available for providing access to LRVs for patrons in wheelchairs, and the accessibility approach to be implemented on the Tasman Corridor and retrofitted in the Guadalupe Corridor.

ADA Requirements

The ADA and the associated Code of Federal Regulations (CFR) set forth new requirements for "accessibility" including those that must be met by transportation facilities such as the Santa Clara County light rail system. The basic ADA requirements for *system* accessibility stem from Title 49 CFR Part 37, *Transportation Services for Individuals with Disabilities (ADA)*. These requirements address the construction of new facilities such as the Tasman Corridor Project stations, modifications to existing stations, and the acquisition of LRVs. Requirements for accessible *vehicles* are addressed in

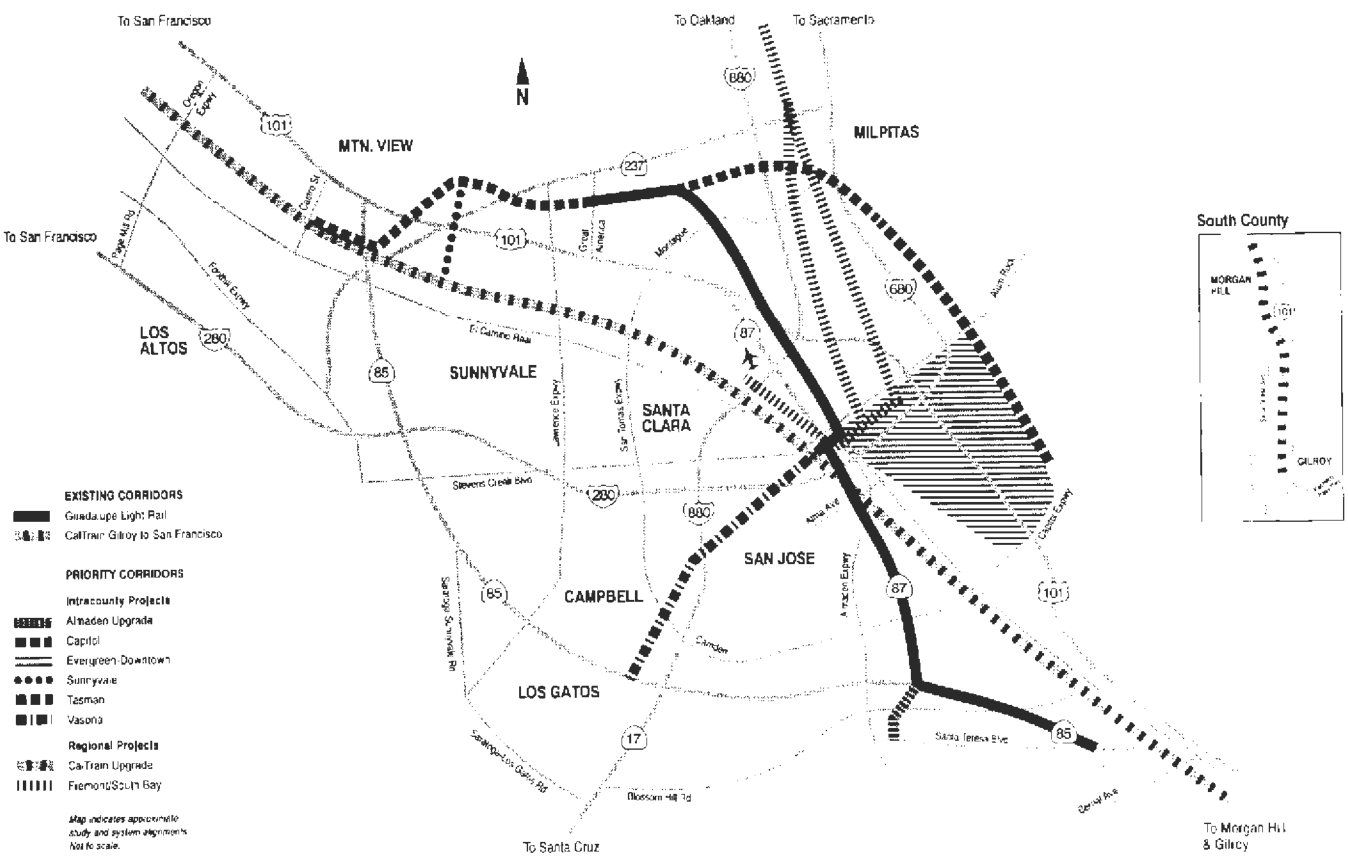

FIGURE 1 Rail master plan.

Title 49 CFR Part 38, *Accessibility Specifications for Transportation Vehicles*.

In interpreting the CFR rules, the implications of the ADA requirements as they pertain to the Santa Clara County light rail system are considered to be as follows:

- The Tasman Corridor must be fully accessible. That is, every new vehicle at a new station must be accessible, and at least one old vehicle per multicar train must be accessible.
- On the existing Guadalupe Corridor, at least one car per multicar train must be accessible. (This accessibility is currently provided by use of the wayside lifts.)
- Where level boarding is not practicable, level-change mechanisms such as wayside or carborne lifts, minihigh platforms, or similar means of access must be provided.
- With single-door accessibility (lifts or minihigh platforms), double/multiple stopping is required when all available wheelchair positions in the first car are occupied, additional wheelchair space is needed, and there are other accessible cars on the train. If wheelchair space is available on the first car, it is not required that the wheelchair user be given a choice of cars.
- The extent to which *new* cars must be accessible when operating on the Guadalupe Corridor line is made questionable by the one-car-per-train rule, which suggests that not all cars in a train need to be accessible on an existing system. However, the problem of coordinating boardings and deboardings of mobility-impaired riders on trains running between the Tasman and Guadalupe corridors requires that there must be a compatible method of vehicle access on the Tasman and Guadalupe corridors for the success of interline train operation.

Alternatives Considered

A range of vehicle accessibility alternatives were identified by the TA for evaluation; these alternatives are described in the sections that follow and summarized in Table 1. As noted, there are two categories of vehicle access: level-change boarding and level boarding.

Level-Change Boarding

Level-change boarding provides access to and from vehicles by using lifts or ramps to assist a mobility-impaired rider in making the transition between the platform at one level and the vehicle floor at another. This type of boarding is compliant with the ADA requirements when it is deemed to be impracticable to achieve level boarding. Alternatives in this group employ conventional (high-floor) LRVs and street-level platforms, with either vehicle-mounted lifts or wayside lifts or ramps. The alternatives in this group typically

TABLE 1 Alternative Station Platform and Vehicle Configurations

Alternative No.	Ref	Mobility Impaired Access	Platform	Vehicle	Comments
LEVEL-CHANGE BOARDING:					
1	WSL	Wayside lift at single door	Street level	High floor, fixed steps	Guadalupe Corridor system
2	LOV	Lift on veh. at single door	Street level	High floor, fixed steps w/lift	San Diego system, but four lifts/car
3	MHP	Mini-high platform at single door	Street level	High floor, fixed or movable steps	Sacramento system
LEVEL BOARDING:					
4	HPMS	Level boarding, all doors	High (990 mm (39") above top of rail); [not all platforms need to be high]	High floor, movable steps	SF Muni, Buffalo
5	HPNS	Level boarding, all doors	High (990 mm (39") above top of rail)	High floor, no steps	LA, St. Louis Calgary
6	LFV30	Level boarding, center doors	Low (355 mm (14") above top of rail)	Low floor, center w/2nd articulation	European (interior steps in vehicles)
7	LFV30	Level boarding, all doors	Low (355 mm (14") above top of rail)	Low floor, between (conventional) trucks	Portland (interior steps in vehicle)
8	LFV100	Level boarding, all doors	Low (355 mm (14") above top of rail)	Low floor, 100% low	Unproven technology

provide boarding at only a single door of each accessible vehicle, and all add some time to the normal station dwell time.

Wayside Lifts

Figure 2 shows the existing wayside lift (WSL) on the Guadalupe Corridor. Pertinent accessibility elements include

- Street-level platform,
- High-floor (conventional) LRVs,
- Single-door mobility-impaired access,
- Other doors with step access, and
- All doors usable if wayside lift not used.

The accessible door (usually the front door nearest the train operator) must be aligned with the wayside lifting device. Once aligned, the operator deploys the lift, the wheelchair passenger moves onto the lift, and the lift is raised to car-floor level. A bridge plate is extended from the lift to cross over the stepwell area on the car. The entire operation takes from 2 to 5 min. If the wayside lift is not used, the train is stopped just short of the lift so that all doors are usable by mobile passengers.

Lifts on Vehicle

Figure 3 shows the lifts on vehicles (LOV) on the San Diego light rail system. Pertinent accessibility elements include

- Street-level platform;
- High-floor (conventional) LRVs;
- Front-door mobility-impaired access; not usable by other patrons; and

FIGURE 2 **Wayside lift.**

FIGURE 3 **Lift on vehicle.**

- Other doors with step access.

This alternative includes vehicles with special lifting devices installed in the front door. Current systems that use such lifts require dedicated doors for the lifts because of their placement when stored. The train operator positions the lift and assists the mobility-impaired rider onto the train. The operation takes approximately 3 min. (It may be possible, though unproven, to design an automatic lift that would not require a dedicated door.) For maximum flexibility in consist makeup, all four end doors require lifts; however, lifts on only one end (two lifts) may be used if the vehicles are always oriented with these lifts at the head of the train.

Minihigh Platforms

Figure 4 shows the minihigh platform on the Sacramento light rail system. This setup was considered the original basis for design of the Tasman Corridor Project. Pertinent accessibility elements include

- Street-level platform,
- High-floor (conventional) LRVs,
- High-level miniplatforms at single door location, and
- Other doors with step access.

At one location along the station platform, normally at the front door of the first car, a raised platform is built level with the car floor. (Space limitations normally prevent more than one minihigh platform on each platform). The train is always stopped with the front door at the minihigh platform. Access to the minihigh platform is via a ramp or a lift, independent of train op-

FIGURE 4 Minihigh platform.

eration. The train operator positions the accessible door adjacent to the minihigh platform and extends a bridge plate (from the car or from the platform) to span over the stepwell. The boarding operation takes approximately $1\frac{1}{2}$ min.

Level Boarding

With level boarding, the vehicle floor height matches the platform height so that passengers can move directly in and out of the vehicles without changing their level—no steps, ramps, or lifts. Two groups of alternatives were considered that provide level boarding: one that employs conventional LRV design and high-level platforms [990 mm (39 in.) above top of rail], and one that uses a low-floor LRV design and platforms that would match [about 355 mm (14 in.) above top of rail]. Ramps are commonly used to reach the platform from an adjacent sidewalk.

High Platforms

High-Floor, Movable-Step Vehicles Figures 5 and 6 show the high-platform, movable steps (HPMS) on the San Francisco MUNI light rail system, in the raised and lowered positions. Pertinent accessibility elements include

- Full-length, high-level [990-mm (39-in.)] platform where practical,
- Street-level platforms where required, and
- High-floor (conventional) LRVs with movable steps.

With a movable step, the step can be placed in the raised position as an extension of the floor when stops are at high-level platforms and in the lowered or step position (for use with wayside lifts) when the stops are at street-level platforms.

High-Floor, No-Step Vehicles Figure 7 shows the high-platform, no-step (HPNS) vehicle on the Los Angeles light rail system. Pertinent accessibility elements include

- High-level [990 mm (39-in)] platforms, and
- High-floor (conventional) LRVs.

The car door design, track alignment, and load-leveling capabilities allow only a small gap between the car and the platform [76 mm (3 in.) horizontal, 15.9 mm ($\frac{5}{8}$ in.) vertical]. This design permits wheelchairs to roll on or off the vehicle without using a bridge plate.

Low Platforms

As mentioned, low-floor vehicles have floor levels that are about 355 mm (14 in.) above the top of rail. These

FIGURE 5 High platform, movable steps; steps in raised position.

FIGURE 6 High platform, movable steps; steps in lowered position.

FIGURE 7 High platform, no steps.

vehicles can be manufactured in three alternative configurations:

- LFV30: Separation of a conventional, single-articulated high-floor vehicle and addition of a special low-floor section and a conventional truck, resulting in a double-articulated vehicle with up to 30 percent of the vehicle having a low-level floor;
- LFV70: Design of the nonpowered center truck so that the center portion of the car between end trucks can be lowered, resulting in up to 70 percent of the vehicle having a low-level floor; and
- LFV100: Design of the center and end trucks so that the entire interior floor area is at a low level.

Figure 8 shows a side view of these three types of vehicles. All three configurations have been employed in various locations in Europe, and Portland and Boston have ordered LFV70-type vehicles.

Vehicles with Low Floor at Center Pertinent accessibility elements for LFV30 vehicles include

- Low [355-mm (14-in.)] platform,
- Vehicles with low-floor center sections (up to 30 percent) of floor space),
- Level boarding at center doors, and
- Steps between center section and end sections.

The LFV30 alternative allows the option of raising only a portion of the platform adjacent to the center doors.

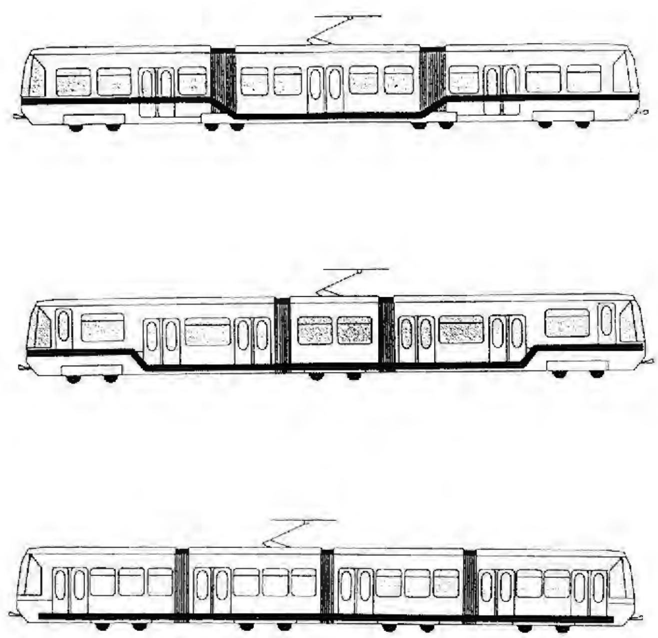

FIGURE 8 Three types of low-floor LRVs: *top*, LFV30; *middle*, LFV70; *bottom*, LFV100.

Low-Floor, Conventional-End-Truck Vehicles
Pertinent accessibility elements for LFV70 vehicles include

- Low [355-mm (14-in.)] platform,
- Vehicles with low floors between end trucks (70 percent low floor),
- Level boarding through all doors, and
- Interior steps at each end of each car.

The LFV70 alternative provides level boarding at all doors using a low floor between high-floor end trucks, which are accessed via interior steps.

Completely Low-Floor Vehicles Pertinent accessibility elements for LFV100 vehicles include

- Low [355-mm (14-in.)] platform,
- Vehicles with low floors end to end (100 percent low floor), and
- Level boarding at all doors.

The LFV100 alternative provides level hoarding at all doors.

Evaluation of Alternatives

Evaluation Criteria

TA considered a number of factors in evaluating the alternatives. These factors were consolidated into five criteria:

1. Compliance with ADA,
2. Impacts on Guadalupe Corridor and future extensions,
3. Costs,
4. Community impact, and
5. Potential risks.

Compliance with ADA

All the alternatives comply with ADA requirements for vehicle accessibility and vehicle/station interface, but some provide easier access than others.

The number of accessible doors varies for each alternative. If wayside lifts or minihigh platforms are incorporated, the vehicle must be aligned with the lift or platform to allow a single door to be accessible. Multiple stopping or multiple lifts/minihigh platforms would be required to access other doors or other vehicles. The vehicle-lift alternative would provide access to the front door of each vehicle at each stop; however, the operator would have to leave the train to operate the lift on other than the first vehicle. The full-length high-platform alternative and two low-floor-vehicle alternatives enable every door on the vehicle to be accessible. LFV30 vehicles have only center doors accessible.

As developed for this evaluation, the LFV70 and LFV100 alternatives would result in a mixed fleet of vehicle types (existing high-floor and new low-floor). The existing type of vehicle would not be accessible by the mobility-impaired. Furthermore, enough new vehicles must be purchased to have at least one new vehicle on every train. This requires more new vehicles than would otherwise be needed to fill out the fleet requirements.

Double/multiple stopping is an undesirable means for complying with the ADA. It involves stopping each vehicle in the train at the station's single boarding device (e.g., wayside lift or minihigh platform). As with the vehicle-lift alternative, the operator would have to leave the cab in order to operate the boarding device at the second and third vehicles, which would result in substantial delays. In addition, double/multiple stopping would not be feasible at many intersections because the first vehicle would block cross traffic.

The ADA requires each level-change accessible vehicle to have at least two wheelchair positions. There has been some debate on whether installing four or six wheelchair positions in the first vehicle of a two- or three-vehicle train would meet ADA requirements without making it necessary to double/multiple stop. However, one interpretation is that limiting riders in wheelchairs to the front vehicle of a train would constitute segregation, which is prohibited. In any event, further research by the TA has indicated that it is not feasible to modify the existing vehicles to accommodate four or six wheelchair positions, since it would remove at least 12 seats per vehicle and would allow little room in the vehicle for maneuvering.

Impacts on Guadalupe Corridor and Future Extensions

Interface

Compatibility with the existing Guadalupe Corridor Line is a major factor in evaluating vehicle accessibility for the Tasman Corridor Project. Most of the existing platforms are 140 mm (5½ in.) above top of rail. All of the alternatives would allow vehicles to serve passenger stations on both lines, except for HPNS vehicles, which would not be compatible.

Operating with separate fleets and separate lines is considered unacceptable by the TA because of the loss of flexibility in both operations and maintenance. Consequently, the HPNS vehicle alternative would require converting the existing Guadalupe Corridor stations as well. And even though the low-floor vehicle alternatives would allow level boarding at the Tasman Corridor stations with level-change boarding at the Guadalupe Corridor stations (like the HPMS alternative), it has been assumed that the Guadalupe Corridor station platforms would be raised to 355 mm (14 in.) to provide level boarding on both lines.

Operations

A significant disadvantage of the wayside or vehicle lifts is the time it takes for wheelchair passengers to board and deboard the train: 2 to 5 min for either operation. This can severely affect headway and make it difficult to maintain schedules. Apart from mobility-impaired boarding, ordinary passenger boarding and deboarding times are approximately three times longer for step-entry vehicles than for level boarding. As a result, any level boarding alternative would improve service for the entire riding public.

The alternatives also vary in how much they would affect operations due to possible restrictions in the makeup of train consists. Currently, any Guadalupe vehicle can be coupled with any other vehicle to form a revenue service train of up to three cars. The LFV70 and LFV100 alternatives would result in a fleet with two different types of vehicles. The LFV30 alternative would result in a basic vehicle unit that is 50 percent larger than the existing vehicles, which would be oversized for off-peak operations when it is desirable to operate the minimum capacity to reduce energy costs.

Wayside clearance requirements are of concern because a portion of the Tasman Corridor Line and future extensions will be shared with freight trains. All the level-boarding platform configurations encroach on the required freight train clearance envelope. To allow shared light rail and freight operations, the track arrangement must be configured to allow greater clearance for the freight operation (e.g., addition of a gauntlet track).

Use of Existing Fleet

The LFV70 and LFV100 alternatives assume that the existing Guadalupe Corridor vehicles could operate on the Tasman Corridor Line even though they would not be accessible to mobility-impaired riders. In these alternatives, multiple-car trains could include both new low-floor vehicles and existing Guadalupe Corridor vehicles, but the existing vehicles could not be operated individually. The LFV30 alternative would involve modification of the existing fleet to create fully accessible vehicles.

For the high-platform alternatives, the existing vehicles would be made compatible with high platforms by covering the stepwells or adding movable steps and by converting to sliding doors. For the LOV alternative, lifts would be added to give the existing fleet the same accessibility as new vehicles. The WSL alternative would not require any modifications to the existing fleet.

Costs

The capital cost elements unique to implementing each alternative have been estimated, including both platform and vehicle costs, plus any related costs that differ for any alternative (e.g., maintenance facility modifications for LFV30). Table 2 gives costs for each alternative.

Operations and maintenance costs will also vary with each alternative because of costs associated with requirements such as lift maintenance, added maintenance of low-floor vehicles, and additional train operations (required if run times are increased). However, with respect to the overall light rail operations and maintenance budget, the variations in operations and maintenance costs among alternatives would not be significant.

TABLE 2 Summary of Capital Costs by Alternative

		Costs ($ Millions)		
Ref.	Alternative	Tasman Corridor	Guadalupe Corridor	Total
WSL	Wayside Lifts	67	0	67
LOV	Lifts on Vehicles	70	0	70
MHP	Mini-High Platforms	69	0	69
HPMS	High Platforms, Movable Steps	89	0	89
HPNS	High Platforms, No Steps	77	19	96
LFV30	Low-Floor Vehicles (30% Low)	91	12	103
LFV70	Low-Floor Vehicles (70% Low)	119	12	131
LFV100	Low-Floor Vehicles (100% Low)	140	12	152

Community Impact

Although wayside lifts, minihigh platforms, and low platforms for low-floor vehicles would all have some aesthetic effect, the high-platform alternatives would have the most significant impact. The LOV alternative, by eliminating the need for wayside lifts, would be the least obtrusive of all alternatives.

Impacts associated with the construction were considered to be limited to the station modifications required on the Guadalupe Corridor for the level-boarding alternatives. A variety of methods are available for performing the construction under revenue service, most of them involving operation of "bus bridges" around stations being modified. It was assumed that the effect of any additional construction required on the Tasman Corridor Project would be insignificant considering the other construction work required to complete the new line.

On light rail systems with minihigh platforms, some congestion problems have occurred at accessible doors. The single vehicle door is used not only by wheelchair passengers, but also by people with strollers and other mobility-impaired riders. A similar problem could arise with the LFV30 alternative where a single door is available for level boarding.

Risks

Risks and uncertainties in each alternative could threaten the goal of completing the Tasman Corridor Project on schedule and within budget. The risks associated with wayside and vehicle lifts, minihigh platforms, and high platforms are more user-related (as opposed to technical and procurement issues) and can be summarized as follows:

- Would user advocates accept wayside or vehicle lifts or minihigh platforms?
- Could wayside lifts or minihigh platforms be implemented without requiring double/multiple stopping? If not, is there a way to eliminate or minimize the operational and safety effects of double/multiple stopping?
- Could full-length high-platform stations be implemented without strong public opposition?

Reliability is an additional concern with level-change devices and in particular with automatic vehicle-mounted lifts. If the lift should fail during operation, the vehicle would be out of service.

Risks associated with the partial low-floor-vehicle alternatives are related to technology, procurement, and liability and could ultimately affect cost and schedule. The development of 100 percent low-floor vehicles is preliminary in nature and may therefore pose risks that cannot be known at this time. Partial low-floor vehicles are common in Europe, are being considered in Chicago and New Jersey, and have been ordered for Portland and Boston.

There is also a risk of limited competition among car builders for the initial procurement. Also, since no standard low-floor vehicle has emerged, there will be the associated future risk of limited competition when future, compatible vehicles are to be purchased.

A liability risk may also be introduced with partial low-floor vehicles, related to the interior steps at each end of the low-floor section leading to high-level end compartments. Any interior steps pose a potential hazard to passengers, especially when the vehicle is accelerating or decelerating.

Alternative Selected

Initial Evaluation

In initiating the final design for the Tasman Corridor Project, the TA evaluated the aforementioned factors with a view to selecting the most suitable alternative for implementation. Of the eight alternatives investigated, only three were considered possible candidates:

1. High platform with a full high-floor vehicle (HPNS),
2. Low platform with a 30 percent low-floor vehicle (LFV30), and
3. Low platform with a 70 percent low-floor vehicle (LFV70).

Table 3 presents a detailed comparison of the three candidates; the rationale for disqualifying the other candidates is given in Table 4.

After considering all the technical, operational, and cost factors, the TA selected the HPNS alternative as the best solution. The advantages that were considered especially important are as follows:

- Uses proven technology already in use in other North American cities;
- Meets all ADA requirements without qualification and provides universal level boarding, which would speed the boarding of all passengers;
- Costs the least of the three alternatives;
- Provides the shortest station dwell times and therefore the fastest run times;
- Reduces the need for new cars and permits flexibility in equipment assignments by modifying the 50 existing cars to the required configuration; and

TABLE 3 Comparison of Top Alternatives

Alt.	Cost* ($M)	ADA Compliance	Impact on Guadalupe and Extensions	Urban Impact	Risks
High Platform, No Steps	96	Full	Rebuild Guad($19M), marginally higher extension costs	Negative	Urban impact; Constructibility
30% Low Floor	103	Full	Rebuild Guad($12M), marginally higher extension costs	Improved	Vehicle reconstruction
70% Low	131	Issue with existing cars	Rebuild Guad($12M), marginally higher extension costs	Improved	Vehicle development

*Includes costs of modifying Guadalupe Corridor stations, shown in fourth column.

- Requires no additional modifications to the maintenance facility.

This alternative assumes that the Guadalupe Corridor stations would also be modified to include high platforms at an estimated cost of $19 million. This modification is complex and would take considerable time.

The low-floor vehicle configurations were not recommended. While feasible, any decision to adopt low-floor vehicles was not considered a risk-free or impact-free solution.

The LFV30 alternative would meet ADA mobility-impaired access requirements without qualification and would also provide speedier boarding of mobility-impaired passengers at some of the doors. However, its disadvantages were considered to be as follows:

- Costs more than the recommended configuration;
- Requires modifying vehicles, making them more difficult to maintain;
- Results in 50 percent larger vehicles, which are inefficient in off-peak periods;
- Has no present market for three-section articulated vehicles;
- Requires maintenance shop modifications to accommodate longer cars;
- Forces inconsistent passenger interface between different vehicle types; and
- Poses potential falling hazard due to steps within the vehicle aisle.

The 70 percent low-floor vehicle uses conventional running gear, but the articulation area poses a special technical challenge to achieve necessary stability and load-leveling functionality. The LFV70 alternative was considered to have the following disadvantages:

- Costs much more than the recommended configuration;
- Requires development of workable designs to meet U.S. standards for crashworthiness and flammability of materials;
- Requires additional vehicles to operate mixed train consists;

TABLE 4 Basis of Alternative Elimination

Alternative	Rationale for Elimination
Wayside Lifts (WSL)	Causes delays, general ridership does not benefit, requirement for multiple stopping to meet ADA is unacceptable.
Lifts on Vehicles (LOV)	Causes delays, general ridership does not benefit, operator assistance in use of lift undesirable, four doors on each car dedicated to lifts.
Mini-High Platforms(MHP)	General ridership does not benefit, requirements for multiple stopping to meet ADA is unacceptable.
High Platforms, Movable Steps (HPMS)	Provides inconsistent access on Tasman (level boarding) and Guadalupe (lifts), potential delays on Guadalupe, significant coordination of boarding on interline trains Tasman to Guadalupe.
100% Low-Floor Vehicles (LFV100)	Highest cost, highest technical risk, may not allow use of existing cars on Tasman.

- Provides level boarding only on the low-floor vehicles when operating a Guadalupe vehicle; and
- Poses potential falling hazard due to steps within the vehicle aisle.

Final Alternative Selection

In the process of final design of the Tasman Corridor Project, efforts to provide full compliance with the ADA requirements have continued. In February 1994 the TA staff recommended adoption of the HPNS alternative. Given the circumstances at the time, the high-platform recommendation was supported by the local Ad Hoc Committee on Transportation for the Mobility Impaired, the cities being served along the Tasman Corridor, and the Tasman Corridor Policy Oversight Committee. This support was given with the caveat that acceptable solutions be found to provide vehicle access in the downtown San Jose transit mall.

Several interrelated issues have recently prompted the TA staff to develop an alternative scope for the Tasman Corridor Project:

- The addition of financing costs to the project budget, which has increased the project cost to more than $600 million;
- The indication by the Federal Transit Administration (FTA) that less stringent requirements apply to the accessibility of existing vehicles on new lines;
- Continued opposition to the construction of high platforms in the San Jose transit mall; and
- The opportunity to defer the purchase of new LRVs, allowing time to evaluate in-service, low-floor vehicle technology in North America, particularly in Portland, Oregon.

Minimum-Cost Alternative

In response to these developments, a minimum-cost alternative was developed that provides a solution to both the budget and vehicle accessibility issues. This alternative best suits the existing budget, FTA guidance on ADA requirements, long-term accessibility goals, and concerns of the partner cities. It is summarized as follows:

- The Tasman Corridor stations would use 355-mm (14-in.) platforms to allow level boarding of future low-floor LRVs.
- No new vehicles would be purchased until subsequent system expansions.
- Temporary minihigh platforms would be included at all new Tasman stations to provide mobility-impaired access to the existing vehicles.
- The 50 existing vehicles would be modified so that the door operation does not conflict with the higher platforms, and movable stepwell covers would be added to allow access to the minihigh platforms.
- All platform modifications on the Guadalupe Corridor would be deferred until low-floor vehicles are purchased. At that time all Guadalupe Corridor platforms, including those in the San Jose transit mall, would be raised to 355 mm (14 in.).

The effects of the decision to adopt the minimum-cost alternative are summarized as follows:

- *Transit mall.* The San Jose transit mall is the area most sensitive to the impacts of station platform modifications. No changes are anticipated in the short term, but when new vehicles are placed in service, the boarding platform must be raised to 355 mm (14 in.) along with those in the other Guadalupe Corridor stations.
- *Mobility-impaired access.* In the short term, mobility-impaired access will be provided to the front door of the first vehicle on each train through the use of minihigh platforms on the new Tasman stations and the existing wayside lifts on the Guadalupe stations. When the new low-floor vehicles are purchased, these devices will be removed, and the Guadalupe stations will be raised to the 355-mm (14-in.) height.
- *Operations.* Planned Tasman/Guadalupe service levels will be somewhat reduced with the minimum-cost alternative. Several possible operating plans, supportable with the existing 50-vehicle fleet, have been identified, some of them involving shuttle service on some links, with transfers between the Guadalupe and Tasman corridors.

What Is Next?

In March 1995 the Santa Clara County Transportation Agency Board of Directors approved the minimum-cost alternative, and low-platform station design is proceeding on that basis. Final design is nearly completed, but local construction funding for the Tasman Project is still dependent on a forthcoming ruling by the state Supreme Court, which court is currently considering the validity of Measure A, a half-cent local sales tax passed by a majority (54 percent) of Santa Clara County voters in November 1992.

Passenger Security

Crime on Maryland Mass Transit Administration Light Rail Line: Myth or Reality?

Bernard Foster and Ronald Freeland, *Maryland Mass Transit Administration*

In 1992 the Maryland Mass Transit Administration (MTA) introduced a barrier-free light rail system that traveled through a variety of neighborhoods. Many of these neighborhoods are located just outside Baltimore City, but they were isolated and had not experienced the urban crime problems that are part of everyday life in the city. Soon after the Central Light Rail Line (CLRL) became operational, these isolated neighborhoods began to experience an increase in crime. It appeared inevitable that the CLRL would be blamed for the increase in crime, since the CLRL was the only significant change in decades for several of these neighborhoods. The crime situation grew worse, and community residents moved into action. At this point, there was only sketchy and incomplete evidence to support the notion that CLRL was transporting crime to the suburbs, but the public perceived that the crime existed, so for all intents and purposes, the increase in crime did exist. The MTA moved quickly to rescue the CLRL and to convince the public that it was a safe and efficient mode of transportation. The MTA used a variety of techniques to regain the public confidence, including public relations, increased policy enforcement, and a creative community outreach program. The MTA restored public confidence, the communities along the CLRL have been supportive, and ridership on the CLRL continues to grow.

Former Maryland Governor William Donald Schaefer had a dream. He envisioned a modern, state-of-the-art, well-equipped light rail system that would stimulate economic development in central Maryland and enhance the revitalization of the Baltimore metropolitan area. Governor Schaefer's vision began to take shape when mass transit planners designed a light rail system that linked Baltimore City with nearby Baltimore and Anne Arundel counties.

The final project design and construction of Phase 1 of the Mass Transit Administration's (MTA's) Central Light Rail Line (CLRL) produced a 22.5-mi, 24-station rail system that originates in northern Baltimore County, traverses the historic Jones Fall River mill area, cuts through the heart of the Baltimore City central business district, and continues in a southerly direction into densely populated, moderately commercial and industrial areas of Anne Arundel County. The $364 million CLRL, which was completely funded by the state of Maryland, opened in two sections. The first section opened in April 1992 and provided light rail service from Timonium in northern Baltimore County to Camden Yards, the home of the Baltimore Orioles, located in downtown Baltimore. The southern leg of Phase 1 of CLRL opened in June 1993; it extends south to Glen Burnie in Anne Arundel County.

After investigating operating models in other cities with light rail systems, MTA officials decided that CLRL would be a barrier-free, proof-of-payment system. In effect, CLRL was designed to be an honor system; frequent inspections would enforce the payment of fares. The honor system would later become a source of controversy, since many observers believed that a number of passengers were riding the system for free.

When it became fully operational, Phase 1 of the CLRL served a variety of diverse communities, some rich, others poor, and still others that were in the middle tier of the social and economic fabric of Baltimore metro area. Many citizens who lived in upscale communities believed that the new CLRL would hurt their property values, bring strange and unwelcome people to their neighborhoods, and deliver urban crime to their doorsteps. Some citizens did not believe that the CLRL met their transportation needs and, in several cases, strong and unified community organizations prevented light rail stations from being constructed in their neighborhoods.

Early Experience with CLRL

Despite the early public criticism of the CLRL, the project's understated budget, and the lack of widespread community support, early experiences with CLRL were encouraging. Ridership along the CLRL developed very rapidly. In fact, by autumn 1994, a comprehensive survey revealed that approximately 20,000 passengers a day were using the system. Moreover, CLRL had already proved that it was an ideal mode of transportation for delivering large numbers of patrons to downtown events such as Baltimore Orioles' major league baseball games, art festivals, and concerts. For example, a three-car train with one operator could carry as many as 600 people to and from an Orioles game. Indeed, the CLRL proved to be a very efficient way of moving large numbers of people.

Notwithstanding the efficiency of CLRL and its early popularity, signs of trouble were beginning to appear. Given the fact that the CLRL connected communities and citizens that otherwise did not come into contact with one another, it was predictable that some social, economic, and ethnic tensions would arise. Indeed, there were early signs of discomfort in certain communities along the CLRL when citizens of these communities came to realize that CLRL provided easy access to unfamiliar people.

In the opinion of most observers, the early success of the CLRL far outweighed the less onerous trade-offs of unfamiliar faces and infrequent incidents of shoplifting in stores near light rail stations. All was well with CLRL, and the future looked bright.

Buildup

Almost as if it were on some planned course of its own, crime, or the perception of crime, began to arise along the CLRL. By March 1994, CLRL patrons, community leaders, merchants, and MTA officials were concerned about the CLRL service's being linked to criminal misconduct. Much of the concern centered on complaints from the business community adjacent to the CLRL service.

MTA officials sounded an internal alert. Few merchants increased the level of security at their establishments, but they demanded more protection from local and MTA police. Some community organizations moved into high gear; these organizations held public meetings and formed committees to study the problem and make recommendations. Politicians with constituents along the CLRL monitored the events and planned their 1994 campaign strategies. Thus, the stage was set for a public debate over the perception of crime along the CLRL.

Evidence of Criminals Along System

By early spring 1994, there was evidence to suggest that the criminal element might be riding the rails in search of new markets. Merchants routinely reported that shoplifting was increasing at an alarming rate; in fact, shoplifting reportedly increased by 237 percent in one shopping center in northern Baltimore County, according to county police.

Citizens in certain communities began to report the disappearance of personal property such as bicycles and lawn equipment. One citizen proclaimed, "I've had things stolen off my front porch."

Citizens in these communities expressed outrage, because they were not accustomed to locking up their personal property. These citizens believed that their neighborhoods were free of crime, so they did not see a need to secure their personal belongings.

In late April 1994, a watershed event occurred on the CLRL. At approximately 10:00 one Saturday morning, a 24-year-old woman was stabbed in the chest as she waited for a light rail train. The woman was not fatally injured, but this event, combined with the recent reports from community groups, left the impression that crime was escalating. Emotions were running high. It no longer mattered whether crime along the CLRL was a myth or reality. People believed that crime was rampant, and various citizens groups were calling for swift corrective action.

Public and Community Reaction

Fearful of the potential hazard to their loved ones and their property, certain groups began to weigh in on the issues of crime and violence. Indeed, many people believed the Baltimore metro area was experiencing a mini-crime wave along the CLRL. These citizens decided it was time to act.

Communities affected by the increase in crime began to hold regular public meetings. Moreover, community associations began to develop plans designed to reduce the level of crime in their neighborhoods. At least two community associations recommended closing the CLRL stations in their communities. One community formed its own neighborhood watch team. Other suggestions included adding conductors to trains, eliminating the CLRL honor system, increasing the presence of police, fencing the system, and caning the culprits.

The cauldron was boiling. Efforts to deal with the perceived crime problem were fragmented, the personal security of citizens and their property was at stake, and a $364 million investment in CLRL was at risk. These conditions called for the MTA to assume the leadership in coordinating efforts to reduce crime and in dispelling the notion that it was dangerous to ride the CLRL.

Role of Media

The media chronicled with great interest the public debate over crime on the CLRL. Sensational and eye-catching headlines were the order of the day. An August 15, 1994, *U.S. News & World Report* dateline read "Lock the House, Here Comes the Train." On May 22, 1994, a Baltimore newspaper, *The Sun*, carried the headline "Light Rail Carries the Public's Worries."

During the period between March and July 1994, no fewer than 60 newspaper articles and editorials referred to crime on the CLRL. There were also many television and radio reports during this period.

MTA Response

The MTA began to move into action at the first signs of trouble along the CLRL. Even in the midst of emotional outcries from the communities and the intense media coverage, MTA management calmly and objectively went about the business of defining the problem and designing a solution.

MTA management knew that actual crime, or the perception of crime, along the CLRL could hurt ridership; worse yet, the issue of crime threatened the very future of the CLRL. Whether crime was occurring in communities along the CLRL no longer mattered; the important thing was that the public perceived crime to be a major problem.

During internal meetings, the management team decided to adopt a proactive approach to combatting crime on the CLRL. The MTA police were appointed to be the lead agency, and the chief of police, Bernard Foster, was designated as the lead spokesperson for MTA. The Offices of Transit Communications and Customer Services mounted a positive and straightforward campaign to convince the public that MTA cared and would take every means necessary to fight crime on the CLRL. In short, the MTA management team attended community meetings, talked to the media, discussed the problem with patrons, and did everything possible to assure the public that CLRL was not a dangerous, crime-ridden system.

In a March 21, 1994, editorial in the evening edition of *The Sun*, MTA Administrator John A. Agro, Jr., informed the public that customer safety was the highest MTA priority. Mr. Agro also laid out a four-part program designed to increase security on the CLRL. The program consisted of increased police presence, an undercover initiative, improved visibility of security devices already built into the CLRL system, and a community outreach program.

As part of the program, the MTA police increased its presence on the CLRL. The MTA police also attended community meetings in an effort to help citizens understand actions that MTA had taken to combat crime on the CLRL. At one such meeting, when he was asked about crime on CLRL, Chief Foster said, "Light rail is being used by people with bad intentions just like they use taxis and other forms of transportation."

In addition to increasing its presence on CLRL and attending community association meetings, the MTA police department also started a hotline and offered a cash reward of up to $1,000 for information leading to the arrest of persons who had committed crime along the CLRL. The hotline was intended to demonstrate MTA's commitment to this issue and to involve the general public in the apprehension, arrest, and conviction of criminals.

Cooperation with Other Police Departments

Chief Foster recognized that he could not maintain indefinitely the increased presence of MTA officers on the CLRL, because the MTA police were also responsible for providing security for the buses, subway, and commuter rail systems operated by MTA. Chief Foster, however, was convinced that the increased presence of uniformed police officers would help to deter crime on CLRL. Since he was not able to maintain this presence with his own police staffing, he negotiated agreements and created a task force with four other police departments that permitted officers of these departments to patrol CLRL stops and ride trains. These police departments had an interest in helping MTA, since they shared the responsibility of patrolling the jurisdictions where the reported increased crime was occurring.

The agreements with the other police departments proved to be very successful, which reassured CLRL communities and patrons and allowed Chief Foster to deploy his officers to ride trains and perform fare inspections. When Chief Foster's program was fully operational, uniformed officers were assigned to almost every CLRL station, and officers were riding every train. The result: after an initial flurry of police activity and arrests, fewer crimes were reported by community residents and CLRL patrons.

Unique Community Outreach Program

The "Together Project" was a unique community outreach program the MTA used in the fight against CLRL crime. The project identified youths who lived in one or more of the 18 communities along the CLRL; it brought these young people together to perform various jobs on the CLRL, such as helping customers, planting flowers, and cutting grass. The Together Project encouraged this diverse group of youths to learn to work with one another and to be tolerant of differences in other people. This project was immensely successful and had the added benefit of bringing together the parents from the various communities served by CLRL.

Conclusion

Today, incidents of reported crime are down by 93 percent throughout the entire CLRL system. Although this fact is undisputed, some communities are still having difficulty adjusting to the cultural diversity brought by a system such as CLRL.

The police task force concept has been the main force behind the reduced crime and general acceptance of the CLRL system by community residents and businesses, where opposition previously existed. The strong uniformed presence of task force participants sent a clear message that the MTA would not allow the CLRL system to be used as a conduit for criminal misconduct.

Another benefit of the task force has been the internal growth of the MTA police force to eventually assume the positions and duties of the task force members. Likewise, cameras at CLRL stations and on every CLRL car are being installed to provide greater coverage of the system while continuing the search for ways to place security personnel in more proactive roles.

Finally, reported crime figures before and after the formulation of the community outreach program, security task force, and regularly scheduled community meetings show a sharp contrast. Obviously, increased criminal activity in residential and business communities adjacent to the CLRL was a reality.

Historically, there have always been those who are not timid about availing themselves of the fruits of someone else's labor. In the MTA's case, the same type of individuals used the CLRL service to reach locations that had been inaccessible heretofore.

It was inevitable that once all the concerned groups organized and began to work together, the problem of increased criminal activity would be systematically eliminated.

Security Assessment of San Diego Light Rail Transit Service

Jeffrey Martin, *San Diego Association of Governments*

Comments from citizen groups and recent media attention describing crimes at or near light rail stations spurred the San Diego Metropolitan Transit Development Board (MTDB) to request that the San Diego Association of Governments (SANDAG) investigate the impact of introducing light rail service on crime activity in the community. SANDAG was also asked to evaluate the perceptions of trolley safety of both trolley riders and nonriders. In Phase 1 of the crime analysis, SANDAG reviewed crime data provided by local police and the San Diego County Sheriff's Department. The study area is located in the east suburban portion of San Diego County. Changes in property and violent crime rates were compared over a 5-year period for the communities surrounding light rail stations, for the study area as a whole, and for the San Diego region. Phase 2 of this study focused on crimes within a radius of 1/8, 1/4, and 1/2 mi of station loading platforms. Crime rates were evaluated before and after the service extension in 1989. The violent crime rate increased less in communities surrounding trolley stations than in the study area as a whole. The overall property crime rate decreased more than in the study area. However, Phase 2 identified a dramatic increase in crime within a 1/8-mi radius of trolley loading platforms. Property crimes, most notably car theft, increased the most. (Since most stations were built on vacant land, any type of development would be expected to increase the number of crimes occurring there.) Two surveys, one of trolley riders and the other of MTDB area residents, were also conducted by SANDAG and provide insight into the perceptions of safety and security of trolley users and of the general public. Crime stands out as a major concern for San Diego residents.

Crime is the primary problem facing the San Diego region, according to a recent survey of San Diego residents conducted by the San Diego Association of Governments (SANDAG) on behalf of the San Diego Metropolitan Transit Development Board (MTDB) and San Diego Trolley, Inc. (SDTI). It is no coincidence that safety and security issues have become important topics when discussing proposed light rail transit (LRT) service with community groups. Comments center on whether the extension of light rail service will bring crime into the community and whether the trolley is safe to use. On the basis of these comments and recent media attention describing crimes at or near light rail stations, MTDB requested that SANDAG investigate the impact of introducing light rail service on crime activity in that community. SANDAG was also asked to evaluate the perceptions of trolley safety of trolley riders and nonriders.

Many areas throughout the country are experiencing similar problems, with community groups and elected officials voicing concern over potential impacts of light rail service on their communities. This paper documents efforts to quantify the incidence of crime occurring at or near light rail stations and how riders and nonriders perceive personal safety at light rail stations and on board the trolley. Also discussed is how these efforts led to actions by MTDB and SDTI to improve both security and perceptions of security.

This report presents a compilation of the results from the three separate studies conducted by SANDAG. SANDAG serves as the Metropolitan Planning Organization for the San Diego region and, as such, provides technical support to local transit agencies through the Assistance to Transit Operators (ATO) work program. Funding for this program comes primarily from Section 9 planning funds.

To evaluate the impact on crime of the introduction of LRT service into a community, SANDAG—in Phase 1—reviewed crime data provided by local police and the San Diego County Sheriff's Department. The study area is located in the east suburban portion of San Diego County. The changes in property and violent crime rates were compared over a 5-year period for communities surrounding light rail stations, for the study area as a whole, and for the San Diego region. Phase 2 of this study focused on crimes within a radius of 1/8, 1/4, and 1/2 mi of station loading platforms. Crime rates were evaluated both before and after the service extension in 1989. The results of this analysis are discussed.

Also given are the findings from a survey SANDAG conducted on board the trolley to solicit opinions of the relative safety of trolley service. This survey of 1,247 trolley riders was conducted in November 1992.

The following year SANDAG conducted a telephone survey of 2,574 MTDB area residents, including riders and nonriders, to collect information on the public's use, awareness, and perceptions of public transit service. Included in the survey were questions about perceptions of safety on board the trolley and at trolley stations. Also investigated was how these safety perceptions were formed. A discussion of the results is included.

Conclusions from these studies and a summary of some of the actions taken by MTDB and San Diego Trolley, Inc., in response to study results are presented.

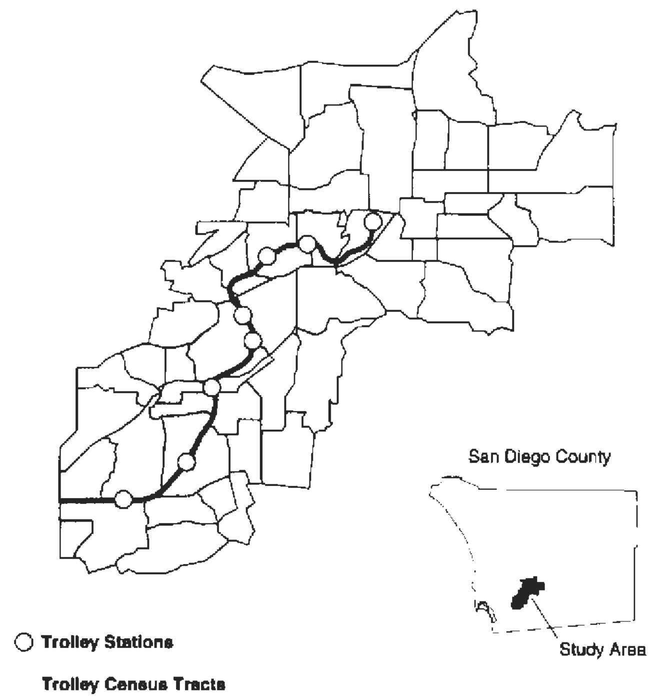

FIGURE 1 Study area and census tracts identified as near a trolley station.

Analysis of Crime Trends

This preliminary study assesses changes in crime over the period from 1987 to 1991 and provides comparisons between the region overall, a defined study area, and the communities surrounding trolley stations located in the study area. The study area is located in the east suburban part of San Diego County (Figure 1) and was chosen because of the recent trolley extension there and the availability of crime data from the Automated Regional Justice Information System (ARJIS) both before and after the extension. ARJIS includes crimes reported to nine municipal police departments and the San Diego County Sheriff's Department.

The study however, focuses primarily on FBI index crimes, which tend to be more serious offenses and likely to be reported to police. FBI index crimes include violent offenses (homicide, rape, robbery, and aggravated assault) and property crimes (burglary, larceny theft, and motor vehicle theft). Two other types of crime (malicious mischief and simple assault) were also included to measure other types of activity that may be of concern in areas surrounding trolley stops. Malicious mischief crimes include vandalism and trespassing. Simple assault is defined as an assault without the use of weapons and with no aggravated or serious injury to the victim.

This study is divided into two phases. The first phase looks at FBI index crimes at the census tract level, including property and violent crimes for the three geographic areas. The changes in crime rates per 1,000 residents were evaluated over a 5-year period, from 1987 to 1991, with a comparison between the region, the study area, and census tracts near trolley stations within the study area. Figure 1 shows the location of trolley stations within the study area and the census tracts identified as being near a trolley station.

The second phase of the study addresses the change over 5 years in the number of crimes within specified distances from trolley station loading platforms in the study area, up to 1/2 mi. Because accurate population estimates are not available within the specified distances from trolley stations, the change in the number of crimes was analyzed rather than the crime rate. The level of crime was evaluated at distances of 1/8 mi, 1/8 to 1/4 mi, and 1/4 to 1/2 mi from the station loading platform.

Study Results

In 1987 trolley stations did not exist in the study area. Therefore, part of this analysis is comparing crime activity before and after those trolley stations were built in 1989. The trolley has introduced a great deal of activity into the study area. On an average weekday in 1991 more than 7,000 persons were boarding the trolley in the study area. Just under 1,700 parking spaces were created, with more than half of them occupied at any given time on an average weekday. As a result, the numbers of potential victims and crime targets, such as motor vehicles, have increased in these areas. In general, the data show that the impact of the trolley has been primarily on crimes occurring within 1/8 mi of the trolley stations. The change in the level of crime within that radius may be related, in part, to introduction of the trolley, but it also may be associated with changes in land use patterns surrounding the trolley stations, such as shopping, restaurants, and theaters.

Phase 1 Data Summary

- From 1987 to 1991, the rate of violent crimes increased in the region (32.9 percent), while the property crime rate decreased (−7.9 percent).
- Census tracts near trolley stations in the study area had higher violent and property crime rates in each of the 5 years from 1987 to 1991 than the study area as a whole, but lower rates than the region.
- Violent crime rates in census tracts near trolley stations increased less than in the region and the study area.
- Property crime rates in census tracts near trolley stations declined more than in the study area, but somewhat less than in the entire region.

Phase 2 Data Summary

- Within a 1/2-mi radius of trolley stations, property crimes and simple assault increased at a higher rate than in the study area.
- Within a 1/2-mi radius of trolley stations, the reported number of violent crimes increased at a rate comparable with that of the study area.
- Within a 1/2-mi radius of trolley stations, reported malicious mischief offenses increased at a lesser rate than in the study area and the region.
- The largest increases in crime activity occurred within 1/8 mi of trolley stations, including violent crimes, property crimes, simple assaults, and malicious mischief. The 78.3 percent increase in property crimes in this area was due, in part, to a significant rise in the number of motor vehicle thefts.
- With the exception of simple assault, all types of crime show less growth more than 1/8 mi from trolley stations.

Conclusions

Results of this preliminary study suggest that the focus of enforcement and security should be within 1/8 mi of the stations. Owing to data limitations, this study does not address a number of related issues, such as the extent to which suspects from outside the area are committing crimes at trolley stations or the impact of changes in sociodemographic and land use patterns at specific stations.

Trolley Passenger Opinion Survey, 1992

SANDAG conducted a survey of trolley passengers to evaluate their opinions as to security and other trolley service issues. To gain a broader perspective of trolley service issues, trolley passengers were asked to provide their opinions of several regional issues. They were also asked to indicate how "safe" they feel at a variety of public places. A questionnaire was distributed to passengers on board the trolley. The questionnaire was printed in English and Spanish.

Passengers on the South Trolley Line and the East Trolley Line were surveyed. Trips were randomly selected for both weekdays and Saturdays. All times of the day were sampled. Surveys were completed by 1,247 trolley riders: 577 on the South Line and 670 on the East Line. Data were collected from November 5 through November 13, 1992. Questionnaires were distributed to passengers after they were seated and were collected by surveyors before the passengers' departure.

Survey Results

Fifty-nine percent of persons responding to the survey use the trolley 4 or more days per week. Twenty-two percent ride between 1 and 3 days per week, with the remaining 19 percent using the service less than once per week.

The economy was ranked as the most important issue facing the San Diego region by 48 percent of trolley passengers surveyed; crime was ranked first by 33 percent. The next highest issue was traffic congestion, with only eight percent of respondents ranking it as first.

Passengers were asked their opinion of various characteristics of trolley service. Operating characteristics such as frequency and hours of service were rated either good or average by well over 90 percent of surveyed passengers. Safety on board the trolley was rated by 89 percent as either good or average. Security at stations and security in station parking lots are rated the lowest, with 78 and 77 percent rating those characteristics either good or average, respectively. South Line and East Line passengers rated service characteristics and station cleanliness similarly. East Line riders rated trolley security somewhat lower than did South Line riders.

Passengers also were asked how additional transit funding should be spent, if it became available. This question required passengers to rank several service improvements in order of need. Construction of new trolley lines was listed by 48 percent of survey respondents as the first project to be funded. Hiring additional security personnel was ranked as first by 25 percent, and providing more frequent trolley service was ranked as first by 17 percent of those surveyed. Overall, increasing trolley service either by building new lines or by increasing the frequency on existing service was identified as the most needed project by 65 percent of passengers surveyed.

The questionnaire was also designed to find out whether passengers believed that service or conditions, either on board the trolley or at trolley stations, had changed over the last 2 years. Fifty-two percent of passengers surveyed had been riding the trolley for more than 2 years. Of those, 57 percent indicated that service had changed during that period. These passengers were then asked to describe how service had changed. Of those responding (270 passengers), 50 percent indicated that service has improved, 21 percent stated that there is more security now, and 12 percent stated that the service is less safe or secure now than 2 years ago. The feeling that trolleys are more crowded now was expressed by 4 percent of responding passengers.

To evaluate trolley security and safety in a broader context, passengers were asked to indicate how safe they feel at five different public locations. Eighty percent of surveyed riders said they felt safe on board the trolley. Trolley stations and shopping center parking lots were considered to be safe by 63 percent of passengers surveyed. Fifty-four percent indicated they felt safe at ATM machines, and fewer than half (47 percent) of the trolley passengers surveyed responded that they felt safe in downtown San Diego.

The questionnaire also requested that passengers write down any additional comments they wanted to provide. Thirty-four percent of respondents made comments. Of these, 30 percent were complimentary of trolley service, 26 percent requested more security and fare inspector personnel, and 22 percent requested more service.

Conclusions

Survey results show that service characteristics such as frequency and hours of service and safety on board the trolley were rated high by trolley passengers. Security at stations and in station parking lots were not rated as high. Data suggest that although there is some criticism of security at trolley stations, this concern may be more a reflection of the general public's overall concern related to crime and safety issues rather than criticism directed solely at the trolley. One-third of survey respondents indicated that crime was the most important issue facing the San Diego region out of a list that included the economy, traffic congestion, population growth, and air pollution. This concern about crime is consistent with a recent survey of San Diego County residents, sponsored by SANDAG, that identified crime as the primary problem facing the San Diego region. Despite the concern expressed about security at trolley stations, passengers feel at least as safe using the trolley as they do at other public places.

MTDB Area Public Opinion Survey

In September 1993, SANDAG contracted with a private consulting firm to conduct a telephone survey of 2,574 MTDB area residents. The purpose was to collect information on the public's use, awareness, and perceptions of public transit service. Respondents to the survey were randomly selected residents of the MTDB service area. A minimum of 500 responses was required from each of five subareas. Five percent of the surveys were conducted in Spanish.

The survey covered a wide variety of topics including respondent demographics, security perceptions, media questions, use of public transit, and opinions of public information services and demand response services. This section focuses primarily on questions related to trolley security.

Of all respondents 44.9 percent had used public transit in the last year, 70.7 percent had used public transit within the last 5 years, and 31.8 percent had used the trolley in the last year. The most common reason for using the trolley was recreation or visiting friends.

To better understand the public's relative level of concern regarding crime in general, the survey asked all respondents to rank in order of importance five selected issues facing the San Diego region. Sixty percent of survey respondents rated crime as the most important issue facing the region, with 26 percent rating the economy as most important. Population growth, air pollution, and traffic congestion were rated as the most important issue hy 6, 5, and 4 percent of respondents, respectively. The Trolley Passenger Opinion Survey showed that trolley riders rated the economy as the most important issue, with crime second.

Respondents were asked their perception of safety in several types of puhlic areas. Of those locations listed, shopping center parking lots were considered to be the most safe, followed by on board the bus or trolley, ATMs, bus stop or trolley stations, and downtown San Diego.

These results can be compared with the results of an identical question contained in the 1992 Trolley On-Board Survey. Trolley riders' perception of safety on board and at trolley stations is higher than that of the general public. This indicates an opportunity to improve the general public's perception of trolley safety. Respondents who have used public transit in the last year are much more likely to rate on board the trolley as safe (75 percent of users versus 48.1 percent of nonusers). Users also rate bus stops or trolley stations as safe more than nonusers (55.8 percent for users versus 38.7 percent of nonusers).

The majority (55 percent) of survey respondents believe the trolley and trolley stations to be safe, whereas 32 percent believe them to be unsafe and 13 percent do not know. Of those who believe the trolley or trolley stations to be unsafe, 47 percent base their opinion on news reports, 37 percent base it on their personal experience, and 25 percent base it on the experience of others they know. This illustrates the prominent role the news media play in shaping opinions of trolley safety. Respondents who have used public transit in the last year are more likely than nonusers to rate the trolley as safe (63 percent versus 49 percent).

When asked if they had heard or seen news reports about bus or trolley service, 55 percent indicated they had. Of those who remember media accounts of bus or trolley service, more say the accounts had a negative impact (38 percent) or no impact (33 percent) than say the accounts had a positive impact (28 percent).

A general preference for driving and the longer transit travel time stand out as the most common reasons cited by respondents for not using transit. If ranked in order of how frequently each reason was said to apply, concern for safety would be 9th out of the 12 reasons listed on the questionnaire.

To get some perspective on how security issues compare with other trolley service issues, a question was included that asked those respondents who have used trolley service in the past year to rate different aspects of trolley service. Safety at trolley stations was rated lowest of all trolley service characteristics followed by safety on board the trolley. However, the majority of riders rate safety as excellent or good. This result is consistent with the Trolley Passenger Opinion Survey.

Conclusions

The analysis of crime trends around trolley stations was designed to identify a relationship between the implementation of trolley service and an increase in either crime rates or the number of crimes within the affected communities. The violent crime rate increased less in communities surrounding trolley stations than in the study area as a whole. The overall property crime rate decreased more in these communities than in the study area. This does not support the expressed belief of some citizen groups that trolley service has hrought criminals into their communities and resulted in an increase in crime.

However, Phase 2 identified a dramatic increase in crime within ⅛ mi of trolley loading platforms. Property crimes, most notably car theft, increased the most. (Most stations were built on vacant land, and any type of development would be expected to increase the number of crimes occurring there.) One possible reason why crime increased at trolley stations and the immediate surroundings while overall community crime rates did not is that the trolley station, with all its activity, attracted crimes that would have occurred elsewhere if the trolley line had not been built.

Since this study was conducted, the number of trolley security personnel has been increased substantially, and coordination with local police agencies and the Sheriff's Department has been strengthened. Local police have been requested to use trolley station parking lots when they need to stop to fill out paperwork, thereby increasing their visibility at stations. A demonstration project was undertaken using video cameras at selected stations to monitor conditions. These and other efforts have been made to improve security and make security personnel more visible. Data from this study have been nsed in presentations to community groups to reduce concern over the trolley bringing crime into their community.

The two surveys, one of trolley riders and the other of MTDB area residents, provide insight into the perceptions of safety and security of trolley users and of the general public. Trolley riders expressed less concern about crime than did the general public. Trolley riders rated the economy as the regional issue of most concern, with crime second. The general public by far felt crime to be the most significant issue facing the region, with the economy second. Crime stands out as a major concern for San Diego residents, and that overall concern could have affected perceptions of security at trolley stations as well as other public places.

Trolley riders identified security at stations as their biggest concern, ahead of other service characteristics such as service frequency and hours of service. However, when asked how additional funding should be spent, 65 percent listed either trolley construction or more frequent service first. Additional security was listed first by 25 percent of respondents.

Crime is considered the most serious issue facing the region by MTDB area residents and is reflected in their perceptions of safety at various public places. Their perceptions of safety are markedly lower than those of transit users, especially at trolley stations. The biggest factor influencing the public's unsafe perceptions of the trolley is the news media, followed by personal experience.

Since these surveys have been conducted, MTDB has taken a more proactive approach toward the news media. They have met with the editorial staffs of various news media, including print and television and radio, to ensure that coverage is balanced. To make passengers more aware, and improve perceptions of safety, MTDB now regularly provides them with information on security improvements, along with other system changes.

Transit Security: Keeping Perceptions in Perspective

William B. Rumford, *Golden Gate Bridge Highway and Transportation District*

The bombings at the New York Trade Center and in Oklahoma have served notice to transit security administrators that terrorism in the United States is a reality. Many transit commuters may argue that they currently experience "domestic terrorism" in the form of antisocial behavior demonstrated on our transit systems. Transit police/security administrators recognize that various social problems are brought into the transit environment from the community. A workshop on transit security was held in Oakland, California, in 1992. Participants included transit police/security administrators, representatives of social agencies involved in community problems, and academics who provided information regarding the social problems. The four major topics were transit effectiveness in addressing intergenerational, ethnic, and cultural conflicts; in working with the larger community to maintain safe and drug-free environments; in alleviating the problem of homelessness; and, finally, how order and cleanliness contribute to a safe and civil transit environment. Many of the problems occurring on transit are not crimes but may be considered infractions, which result in a police/security action being taken. Therefore, the perception of crime on transit may appear to be greater than it actually is. The definition of transit crime continues to be debated among transit police/security administrators. Some argue that a crime is a crime regardless of where it occurs and others rationalize that a crime on transit is unique because of the confined environment. Regardless of the definition, the victims and commuters who use the system are directly affected by their perception of the transit environment. The problem facing transit police/security administrators is how to provide the public with a commuter quality environment. The approach to reducing criminal and social problems on transit must include the community where these problems originate. Law enforcement alone cannot abate the problems.

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The definition of transit crime continues to be debated among transit police/security administrators ("transit security" in this presentation is used interchangeably with "transit police"). Some argue that a crime is a crime regardless of where it occurs, while others rationalize that a criminal offense on transit is unique because of the confined environment, thereby justifying the term transit crime. Regardless of the definition, commuters who use the system, or those who may want to use the system, are directly affected by the perception of security on the transit system. Webster's dictionary defines perception as "an awareness of the elements of an environment through physical sensation;

or physical sensation that is interpreted in light of the experience." For our purposes in transit, it simply means what an individual experiences, witnesses, or is told.

Perceptions

Transit management, commuters, and employees all have security perceptions of the system. Ridership is directly affected by negative perceptions of social behavior. Marketing the transit system is extremely difficult if the image to the commuter is that of personal danger. Transit employees are ofteu the target of antisocial conduct, thus reaffirming the commuter's fears. The media respond with images of potential criminal attacks and lack of security on the system. But are these perceptions valid or are they distorted? Security reports tend to provide factual data, but the media may include infractions and misdemeanors along with major criminal incidents, thus giving the appearance that crime is out of control on the transit system. Graffiti, loud radios, boisterous behavior, and bad language are disturbing elements to most commuters but are not considered major criminal activity by transit security administrators. Yet, the perception of commuters, often supported by the media, is that the transit system is unsafe to ride.

If we include felonies, misdemeanors, and infractions under transit crime, it is easy to see why a perception of lack of security on a system may prevail. Is it a transit crime when a woman's purse is snatched at a bus stop? Or when a commuter heading for a bus stop or train platform is assaulted 300 ft from the boarding area? The commuter does not need a definition of transit crime. The fact that one believes he or she may be assaulted while approaching the boarding area is sufficient reason to avoid riding the transit system.

Management must be sure that reporting of antisocial behavior on the transit system is accurate and does not give the perception that crime is rampant. The Federal Transit Administration (FTA) has developed a new security reporting element for the National Transit Database (Section 15) Report, which has been incorporated into the safety element of that report. Examples of major crimes are arson, aggravated assault, burglary, robbery, grand theft, rape, and homicide. Other offenses include vandalism, loitering, drunkenness, disorderly conduct, fare evasion, and trespassing. This will help eliminate discrepancies in reporting and wrong perceptions of crime on transit.

A Commuter Quality Environment

Whatever the perception of security of the transit system is, the commuter is entitled to a quality environment. That means being free of antisocial behavior that is unacceptable to the commuters. To arrive at a commuter quality environment, it must be understood that the origin of antisocial behavior is within the community and that the transit system is only a vehicle for transporting this behavior.

Commuters are in a contained environment when they enter the system, and they expect the transit management to provide them with a commute that is free of nonthreatening activity. This is not an unreasonable expectation, although on some systems commuters realize they may have to chance unwanted encounters.

The problem facing transit managers is how to provide the public with a commuter quality environment. Administrators have recognized for several years that many of the antisocial behavior problems being experienced on transit are just an extension of problems originating in the community.

Management and the community must recognize that a joint effort is necessary to develop a commuter quality environment. Commuters look to law enforcement and social agencies to assist in keeping the community free of antisocial behavior; however, the transit system lacks the resources that are traditionally found in the community.

Managing Social Problems on Transit: The Workshop

Transit security chiefs have long recognized that antisocial problems have a direct effect on transit security perceptions. The FTA's Academic Security Committee, composed of several transit police–security chiefs from throughout the country, held a workshop in 1992 that included transit management, social welfare practitioners, educators, and community representatives. The workshop, Transit Security: Exploring New Concepts in Managing Social Problems, was funded by the Federal Transit Administration.

A major workshop theme was that there is no such thing as a transit crime or a transit social problem. These are problems that are emanating from the community and into the transit environment. If transit wants to prevent antisocial incidents from occurring on the system it must be proactive, and that means becoming involved with the communities it serves.

The following workshop modules were offered to the participants, and the recommendations of each are summarized.

Can the Transit System Be More Effective in Addressing Intergenerational, Ethnic, and Cultural Conflicts?

Facilitators were Michael O'Conner, Chief, New York City Transit Authority Police, New York; and Donald

Neuwirth, Conservation Corps Planning Consultant, San Francisco, California.

The Transit System and the Younger User

Preteenagers and teenagers are heavy users of transit systems and often do not realize that boisterous behavior, which is acceptable to their peers, may be unacceptable and even frightening to other transit users, especially senior citizens. Young people need to be educated about appropriate transit behavior, and this education should be reinforced by the school system, parents, and other community institutions. Participants in the workshop discussed whether and how the transit system can undertake this kind of education.

School/public transit partnerships are most likely to succeed if transit officials educate school system decision makers about the inconvenience and possible danger to other passengers of inappropriate behavior by young people on the transit system. School policy makers are also unaware of the high cost of these behaviors, and they do not realize that these costs are borne by the entire community through higher transit fares. It was pointed out that parents are often unaware that boisterous behavior, fare evasion, graffiti, and vandalism are problems on transit systems.

Participants suggested that one approach to working with young people is to develop peer-led programs that have teenagers explain to their peers and to younger children why it is important to maintain behavior standards on public transit. Senior citizens can also be recruited to educate students about how much senior citizens rely on transit and how important it is to them to have a peaceful ride. Participants in the workshop said that it was important to teach teenagers to see old people on the bus as "a lot like their grandmother" instead of "that slow old lady."

Several transit systems represented at the workshop have established outreach programs for the schools. The most successful of these programs have targeted schools where students have been heavily involved in problems on transit. The programs range from presentations in the schools by transit employees who are from the same community to distributing coloring books explaining why the transit system is a community resource and must be treated with respect.

Workshop participants stressed that occasional informal presentations in classrooms will not have a significant effect on the behavior of young people on the transit system. Coordinated and ongoing efforts with multiple points of contact with the decision makers, teachers, parents, and students are required to make a substantial difference in the behavior of young people on transit systems.

Recommendations

In addition to the programs and strategies that can be undertaken by local transit systems, the workshop participants recommended activities that could best be undertaken regionally or nationally to help transit systems address intergenerational, ethnic, and cultural conflicts. Research was a major interest.

Participants recommended collecting and disseminating information about programs that work. This could best be achieved by surveying transit systems for innovative approaches and inviting representatives of these programs to share their experiences with other transit officials. Participants strongly favored small, interactive, problem-solving sessions over presentations, lectures, large group sessions, written materials, or videos.

Because participants agreed that part of the problem is *perceptual*, they recommended a national marketing campaign focusing on the safety and convenience of public transit. A national campaign would be less expensive than multiple local efforts, and public service announcements could be tagged with local phone numbers where people could get more information about their local transit options.

Participants had a final recommendation that was only somewhat related to the subject of the workshop, but which they thought was important. They wanted to know what the likelihood is of being injured in a car accident compared with being the victim of a crime on public transit. It was recommended that if these statistics were not available, they should be gathered, and if they were available, they should be disseminated.

Can the Transit System and the Larger Community Work as Partners in Maintaining Safe and Drug-Free Environments?

Facilitators were Thomas C. Lambert, Chief of Transit Police, Metropolitan Transit Authority, Houston, Texas; and Michael Parker, Manager, Long Beach Neighborhood Services Bureau, City of Long Beach, California. No more than sixty percent of crime is ever reported, and transit systems have difficulty in convincing passengers to report what they have seen during an incident on the system. Part of the problem is building community trust. Workshop leaders encouraged participants to begin involving themselves in neighborhoods in new ways. Transit employees are often invited to attend PTA meetings or to visit Rotary Clubs, settings wherein there is a tradition of community leadership and participation. However, the communities that really need help and can most help the transit system are poorer, less organized, more culturally diverse, and harder to reach than middle-class communities.

Consensus Building in the Community

Participants discussed the fact that a single transit system typically operates in a number of communities and that it is usually not feasible to develop community-relations efforts in each. They recommended that consensus-building efforts be focused in the community where most of the system's patrons reside.

Consensus building begins by identifying the most trusted and respected members of the community. An initial approach would be to meet with all transit employees who are from the target community or who are members of the dominant ethnic and cultural groups in that community. These employees would be asked to identify important individuals and institutions in the community and to volunteer for outreach activities.

The process continues by bringing together community leaders to identify the most urgent community problems. Participants agreed that in their experience, community leaders identify the same problems that the transit system experiences: drug abuse, graffiti, personal safety, and so on. Community leaders, however, see these problems from a community perspective, and they want the transit system's help in dealing with the issues as community problems.

One participant pointed out that community leaders do not expect the transit system to solve all of the community's problems. What they appreciate is sincerity, a good faith effort, and listening. One of the benefits of close community involvement is educating the community about the budgetary limitations of the transit system.

It was stressed that consensus building would be slow. There is a history of neglect in many communities that has led to feelings of resentment and suspicion toward what is seen as "the establishment," which the transit system represents. There are also diverse cultures in most of these communities, and people will need time to learn about each other's communication styles and cultural customs.

Transit systems cannot solve security problems without addressing the fact that there is no such thing as transit crime; there is only community crime that occurs on the transit system. As the transit system becomes a partner with the community, positive results will benefit both.

Consensus Building in the Transit Agency

Community consensus building requires consensus building in the transit agency before building community-transit partnerships. Working effectively with the community requires an organizationwide commitment to transform the organizational culture from reactive to proactive. The transit agency must develop creative methods with new vision.

Although resources are needed for this transition, it can also be initiated through resource reallocation. What is needed most is a change in attitude, but these changes must be made throughout the organization, beginning at the top.

Recommendations

Workshop participants were concerned about the perception that exists in many communities that increased transit also increases the incidence of crime. Many participants questioned the validity of this belief and suggested that a research project to investigate this perception would be useful.

Participants also believed that many executive directors and general managers of transit systems do not understand how social problems in the larger community influence the long-term economic viability of the transit system, nor do they understand the advantages of becoming proactive in their service areas. There was strong agreement that executive directors and general managers should be better informed about these issues.

The participants strongly supported initiating research to determine whether potential transit users, especially commuters, avoid transit because of unfounded fears about the risks of so-called transit crime. If research supports this premise, aggressive marketing campaigns should be implemented to counteract these beliefs.

What Can the Transit System Do To Alleviate the Problem of Homelessness on the System?

Facilitators were Charles O. Lacy, Transit Security Administrator, Metropolitan Transit Development Board, San Diego, California; and Rita Schwartz, Supervisor of Government and Community Affairs, Port Authority of New York and New Jersey. Some participants argued that transit should not be involved with homelessness. They took the position that the transit systems are not in the business of providing food, shelter, or counseling. Further, they argued that transit systems whose budgets are already stretched beyond their limits must find ways to comply with the requirements of the Clean Air Act and the Americans with Disabilities Act before they consider allocating resources to social problems such as homelessness. However, the majority of participants favored transit involvement and countered by saying that the homeless living in transit facilities affects ridership, employee morale, relationships with vendors, and the communities that rely on the system. The homeless in transit facilities damage the infrastructure, impose on the commuters, make cleaning difficult, and are a danger to themselves and others. Because social service budgets are not adequate to address the problem, transit officials have no choice but to become involved. Although the homeless affect transit systems in many ways—living along the right-of-way, panhandling outside turnstiles, and sleeping on the system—the workshop focused almost exclusively on the problem of those who live in the transit facilities. Participants from the major metropolitan areas urged participants from smaller systems to address the problem early, before "you have to do what we have had to in New York, take back your facility, and it cost us $600,000 a year."

Who Are the Transit Homeless?

The homeless range from middle class families where the wage earners have lost their employment to seriously ill people with multiple medical and mental health problems. People who live in transit facilities usually fall into the latter category.

Some participants argued that homeless people like transit facilities because they are safer than shelters. Transit facilities are open and homeless persons can come and go at will. Transit facilities also provide good opportunities for panhandling and the anonymity of crowds.

New York Experiment

New York City sponsors a program called Operation Alternative, which, according to a workshop leader, has had the involvement of "everyone from the executive director to the washroom attendant." It includes drop-in centers near the transit facility where the homeless are provided assistance and referrals to other agencies, reserved beds in local shelters, and a system of outreach and cooperation with the social service system.

When homeless people violate transit rules, which are carefully defined and strictly enforced, they are given an alternative of going to an appropriate social service agency (detoxification, mental health), going to a shelter, or immediately leaving the facility. Although there are recurring problems and difficult cases, the program is an overall success. The facility environment has dramatically improved; staff and ridership are regaining trust in the system. At the time of the workshop, robberies and larcenies were down by 50 percent.

Undertaking a project similar to the New York program is not feasible for many transit systems. The political and social service environment in New York, which includes a "right to shelter" law, provides an array of social services that are not available in many other communities. The New York program is also expensive; however, there may be elements of it that could be successfully duplicated by other transit agencies.

Lobby for Resources

Participants in the workshop expressed concern over declining budgets and increasing regulatory demands that are creating fiscal hardships for transit agencies. Participants focused on practical low-cost approaches to the problem of homelessness.

One strategy that received strong workshop support was to lobby for additional resources. A number of approaches were suggested, and some overall guidelines for successful lobbying were proposed:

- Visual presentations are far more effective than oral ones. Slide shows, videos, and photographs of a situation on the transit system and in the community powerfully demonstrate the need for attention to the problem.
- In addition to presenting the problem, give viable solutions.
- Focus on the economic impact of homelessness. Find out how much it is costing the system and the community. Use a cost/benefit analysis.
- Join others in the community to lobby for social service spending. Be sure someone from the transit agency is present when social service budgets are considered. The transit agency can be a powerful voice because transit represents the economic viability of the entire community.
- Educate the transit board, management, and the union about the costs of homelessness. Treat this as a full-time, all-day, all-week, every-year problem.

Form Partnerships

- Take the lead in helping the community understand that homelessness is everyone's responsibility. Meet with other organizations that are involved with, or affected, by homelessness.
- Meet with other public agencies in your community—the police, city and county welfare agencies, health and mental health departments—to find out what they are doing.

Recommendations

Participants recommended training for transit officials in effectively presenting the problem of homelessness to other community institutions. There was also great interest in training for transit managers in how to build community partnerships to address homelessness.

How Do Order and Cleanliness Contribute to a Safe and Civil Transit Environment?

Facilitators were John Sullivan, Deputy Sheriff, Los Angeles County Sheriff's Department, Los Angeles, California; William T. Hathaway, Research and Special Programs Administration, John A. Volpe National Transportation Systems Center, Cambridge, Massachusetts; and George Kelling, Fellow, Kennedy School of Government, Harvard University, Cambridge, Massachusetts. Order and cleanliness encourage respect. Broken windows in neighborhood buildings are a sign that nobody cares. If there are indications that nobody cares, criminals feel free to violate the neighborhood. Thus, disorder is a precursor to serious crime. Workshop participants agreed that this phenomenon is also true in transit facilities. If they are dirty, noisy, run down, and full of graffiti, and if the system tolerates minor rule infractions, the perception is that nobody cares, and serious crime is more likely to occur.

Establishing order and cleanliness requires enforcement of, and community education about, quality of life rules, including prohibitions against smoking, drinking, and eating. It also requires community support for enforcing rules against such infractions as disorderly conduct, loitering, graffiti, and fare evasion.

The transit environment is a system composed of people, procedures, equipment and facilities, and the environment. In each element of the system, actions can be taken that will contribute to order and cleanliness and to the perception that commuters and employees care about the system. Security personnel cannot keep order on a system without support from management, operators, transit employees and commuters. Everyone must send the same message: misbehavior will not be tolerated.

Management

Participants suggested a number of actions that management can take to support a clean and orderly environment. One of the most important is for managers to know what is happening on the system. One general manager said that she asks each of her managers to ride the system at least once a week. She recommended this strategy as one of the most effective ways to get management's attention about the importance of cleanliness and order.

Other participants recommended surveying operators to get their ideas about how to discourage rule infractions and having management and the union work together to implement suggestions. Management often does not understand how serious the issues of cleanliness and disorder are for employee morale.

Participants said that management sometimes resists hearing about and admitting problems because of fear that the reputation of the system will be damaged. Rather than publicly focusing on specific problems, however, management can adopt comprehensive strategies that together send the message that "commuters have rights." Regular meetings can be held with all major departments in the system (planning, marketing, security, operations, purchasing, etc.) to discuss strategies for sending a coordinated message to the public and employees that supports "passengers' rights."

Operators

System operators are in a difficult position. Asking them to handle minor infractions is, as one participant said, "like asking the airline pilot to serve the food." Others said that an attitude of "All I do is drive this bus" actually encourages disorder, because passengers quickly sense that the operator will not take action to stop rule violations or to support the passengers who object to rule-breaking. The need for effective training in "dealing with difficult people," especially training conducted by other operators (peer to peer), figured in the discussion.

Operators need a quick and reliable backup when incidents occur, and they need to feel that management cares about preventing problems rather than reacting to them after the fact. One participant stated, "Security is not just giving citations; it is problem solving. It must be comprehensive; a fragmented approach doesn't work."

Commuters

There is a consensus about minimum standards of civility that cuts across races and cultures. Asking commuters what they find annoying or disturbing is a useful strategy for improving the system environment and gaining support from the riders.

Procedures

Quick removal of graffiti is one of the most important strategies for increasing the perception of order in the transit system and discouraging regular graffiti offenders.

Decentralizing routine station maintenance gives the employees a sense of ownership and improves their morale.

Equipment and Facilities

Participanrs were more interested in discussing low-cost solutions that could be implemented in existing systems than in recommending expensive design modifications or technological innovations for equipment and facilities.

Other Agencies

It is essential to involve the court system in the importance of prosecuting persistent rule hreakers. Strategies need to be found for educating judges about how much graffiti costs taxpayers. In one community, transit officials were able to get a misdemeanor ordinance passed that holds parents directly responsible for any damage their children do to transit facilities.

It is important to work with law enforcement agencies to be sure that laws are clarified, so that terms like "obstructing" have clear definitions. Security people need to be able to cite for specific violations. Arresting and booking procedures for disorder infractions can also be streamlined.

Community Outreach

Workshop participants identified several messages that need to be carried to the larger community. The most important of these are as follows:

- Transit is a community resource; the community is only as healthy as its transit system.
- Passengers have a right to be indignant when they are disturbed by disorderly behavior, fare evasion, graffiti, and other seemingly minor rule infractions.
- The rule infractions are not minor. They contribute to higher fares and reduced service.

Recommendations

Participants suggested involving operators more effectively in efforts to address rule infractions. Research with operators, focus groups, and surveys were recommended to determine how operators view rule infractions and their suggestions for dealing with them.

Participants expressed interest in training for transit officials in how to put cleanliness and civility on the agenda for their transit systems and their communities. They were interested in how to huild support for civility in the transit sysrem among other agencies, the larger community, major employers, and the media. They were also interested in giving training to new employees that emphasizes problem-solving as well as how to issue citations.

Closing Session of Workshop

The strongest recommendation from participants in the final session was that a similar workshop be conducted for general managers and executive directors. Many participants said the ideas presented in the workshop cannot be fully implemented without the support of the top managers who are, in general, not aware of many of the possible innovations in dealing with social problems on transit systems.

Participants, especially those from smaller transit systems, recommended that sessions be held to discuss how transit systems can develop partnerships with their local law enforcement agencies. There was also interest in learning how the concepts of community policing can he applied to the transit system. There was interest in "preventive security," efforts to work with the community to stop problems before they start.

Participants in the workshop concluded that there was a widespread lack of knowledge of the high costs of antisocial problems on the transit system. It is possible that transit management may not realize the impact of antisocial behavior on employee morale and commuters' attitudes, or the high costs associated with these problems. In addition, the community does not understand how it relies on transit for economic and social well-being and that social problems on transit contribute to higher fares and reduced service. A major educational program is needed within the transit industry and the community.

Policy makers—transit boards, school boards, city and county officials, and business and community leaders—need to understand that it is necessary for transit and the community to become partners in finding solutions to shared problems.

Research can support transit's efforts to become more proactive in addressing social problems. Information on effective programs can be disseminated. The prohlems that vehicle operators confront in their work environment can be identified and solutions found through a viable research program. Information gathered may also be used to lobby the federal government for funding transit system and community partnership programs. Research on transit antisocial behavior can also aid in marketing the system.

The workshop participants believed that a proactive image was necessary at every level of the transit organization. Management must develop new approaches of ways to work with the community without new funds through the reallocation of current resources.

Transit systems and the community need to refocus their attention on the rights of the commuter to a safe and quality environment by sending the message "Antisocial behavior will not be tolerated."

Conclusion

It is time that transit administrators took a proactive, rather than a reactive, approach to these problems. This is not to imply that we are not responding to transit security problems, because several transit systems throughout the country have instituted proactive programs. Rather, we are in an excellent position to take a leadership role in bringing social problem solvers together.

Technology in public transit is making tremendous progress, but our human concerns continue to lag. Many of the social problems we experience on transit, criminal and civil, are the result of the community's inability to resolve these problems. Transit administrators need to take a leadership role by bringing social welfare practitioners, academicians, community leaders, and transit managers together to seek new and alternative solutions to the problems we are currently facing.

It is well known that transit policing has never been the highest priority in transit districts; with the economy showing little or no sign of substantially turning around in the near future, even less money is expected for policing needs. We should basically look for resources outside the transit environment to help with these problems. It is the nontraditional methods that require more thought and research at this time, rather than an application of traditional methods.

The perception of transit security may be kept in true perspective if transit managers and the community move in more creative directions.

PART 4
LRT OPERATIONS

Traffic Engineering and Safety

Transportation Management Plan for the Chicago Central Area Circulator

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The economic well-being and quality of the Chicago Central Area is a function of many different factors, one of which is the transportation system. The ability to move people and goods to, from, and within the Central Area is important to its survival. The transportation system must be regularly improved to maintain this relationship. As one of the public transit elements of the transportation system, the Central Area Circulator is a vital part of the needed improvements. The Circulator will provide distributor and circulator service within the Central Area. To perform this function, it needs to access all of the significant land use areas. To do this, the Circulator will make use of existing street right-of-way. This requires close coordination with the other users of these streets. It is these relationships that the Traffic Management Plan (TMP) addresses. The TMP contains three primary elements: description of the principles for managing the transportation system for the Central Area, definition of the strategies and operating policies to uphold the principles, and development of the management actions to integrate the Central Area Circulator into the Central Area transportation system.

The economic well-being and quality of the Chicago Central Area is a function of many different factors. One of these is the transportation system.

The vision for the Chicago Central Area is one of significant growth and improvement. It will continue to enhance its role as a world-class commercial and cultural center. Such activities will increase transportation demand. The regional and Central Area transportation system will need to be improved both in capacity and in quality to serve these needs.

As one of the public transit elements of the transportation system, the Central Area Circulator is a vital part of the needed improvements. It will increase capacity and provide high-quality service. The Circulator will use light rail transit (LRT) technology, operating on rails and powered by overhead wires. Principal features will be

- Thirty-two stations located at about three-block intervals;
- "Proof of payment" fare collection process for fast and efficient boarding;
- LRT vehicles with low floors to provide full accessibility, multiple doors for convenient access, and other amenities to promote a positive transit image;
- Urban design and streetscape features along streets with LRT tracks and at stations;
- Service throughout the day to late evening, with headways of 6 to 7.5 min; and
- A fleet of 30 to 40 LRT cars.

The system will service about 12.9 km (8 mi) of corridor within the Central Area. This will provide access to the commuter rail terminals in the West Loop, the core of the Loop, the North Michigan Avenue area, Navy Pier, Lakefront, and McCormick Place.

The specific improvements will be coordinated with other transit services, and will be located within the public street right-of-way to be compatible with the other users of the street system. It is these latter relationships that the Traffic Management Plan (TMP) addresses; that is, how to incorporate the Circulator into the street system while maintaining other needed street functions. This plan contains the strategies and actions necessary to develop and operate the transportation system to meet the stated goals, objectives, and principles.

The TMP has two primary characteristics. First, it is an ongoing management structure that will be used to address traffic needs and operations on a daily basis. Second, the TMP contains specific operating recommendations that are subject to review and modification as the Circulator project proceeds.

The TMP for the Central Area Circulator has evolved from a three-step process:

- Describe the principles for managing the transportation system for the Central Area;
- Define the strategies and operating policies to uphold the principles; and
- Develop the management actions to integrate the Central Area Circulator into the Central Area transportation system.

Framework for the Traffic Management Plan

The TMP concerns the use of the system of public street rights-of-way. The focus is on the street and alley system as it is used by general traffic, trucks, taxis, buses, and the Circulator. The overall purpose of the plan is to coordinate these modes to achieve needed transportation services.

Perspective

The street and alley system provides for the movement of vehicles and pedestrians and for access to land uses. The right-of-way is largely a fixed asset, although some large development projects can add right-of-way to the system. For this asset to be used effectively and provide the greatest benefit, a concept for management is required.

As the Central Area continues to grow, use of the fixed asset (i.e., right-of-way) will change, or there will be a demand for change. A significant change to the right-of-way will be created by the Circulator. This will affect the function of the street, the allocation of space between general traffic and transit, and revisions to various utility and service activities. The presence of this mode needs to be reflected in the modifications in management of the street system.

The importance of interagency coordination (City of Chicago Departments of Transportation, Streets and Sanitation, Planning and Development, the Police and Fire departments, and the Chicago Transit Authority, Metra, and others) suggests that the implementation, monitoring, and ongoing management of the TMP will require an operational structure. Endorsement and implementation of the plan by this group would be essential.

Purpose and Principles

The purpose of the surface transportation system is to provide the safe and efficient movement of people and goods within and through the Central Area. It must serve several modes of transportation and provide appropriate service to all sectors of the Central Area. It must respect the physical environment and the activities of the land uses.

On the basis of this goal, a series of principles has been defined that will serve to guide the operation of the Circulator within the TMP:

- Transit: (*a*) Transit and pedestrian movements shall have priority over automobile movements; (*b*) light rail vehicles shall operate in exclusive lanes; and (*c*) light rail vehicle movements shall have traffic signal priority over other vehicle movements, except for emergency vehicles.
- Automobiles: (*a*) Vehicle movement shall have priority over vehicle parking, loading, and drop-off; (*b*) automobile trips with Central Area destinations shall have priority over automobile trips traveling through the Central Area; and (*c*) street traffic flow will be maintained at reasonable levels of service for local access and circulation.
- System: (*a*) A functional classification of Central Area streets reflecting these principles shall be established and appropriately implemented and (*b*) the Central Area transport system shall be actively managed, controlled, and enforced.

System Concepts

To translate these principles into a specific traffic management plan for the portions of the Central Area affected by the Circulator, certain system concepts have been considered. The intention is to use these concepts to create an overall context or framework for the street-specific elements of the TMP. The system concepts are categorized in terms of their setting, organizational considerations, functional classifications, and management strategies. Together, they establish the framework for the TMP.

Setting

Certain key facts about the Central Area transportation system influence the TMP.

1. Regional highway and major street access capacity to and from the Central Area can be expanded only marginally. No new major regional or citywide routes are likely in the future.
2. Regional transit lines still have the ability to increase their line-haul capacity for travel to the Central Area.
3. Air quality standards demand that mobile source (most vehicle traffic) air pollution be reduced. Current trends in national environmental policy development will probably reinforce or enhance the need for better air quality performance for the transportation system in the Chicago region.
4. Within the Central Area, the principal physical resource for the transportation system is the network of public street rights-of-way. Because of the extent of existing and committed development and the value of these land uses, the right-of-way network is largely a fixed resource. It is crucial to use this fixed asset in the optimal manner to achieve the Central Area transportation goals.
5. The street system has a grid configuration. This provides significant flexibility for the user in that multiple paths are available for most trips. Rather than depending on single streets, access and circulation needs can be served by several streets operating in combination.

Organizational Considerations

The concept of traffic management will be implemented taking into consideration the following organizational features:

1. The use of a street is guided by regulatory means, such as restrictions on the use of the curb lane, one-way flow, and turning movements at intersections.
2. The volume of traffic on a given street can be maintained in reasonable balance with available capacity. This can be achieved by controlling the amount of traffic entering the street. Ways of controlling input flow include introducing discontinuity, restricting access to streets by constraining turn movements, and adjusting traffic signal phasing.
3. Access to property by driveways or alleys should be located in such a way as to be safe and consistent with street function.
4. The organization of allowable movements should define circulation paths (e.g., around-the-block circulation) that achieve reasonable access to landuse sectors.
5. The hierarchy of streets needs to reflect logical connections and linkages within the system. These functions change only at intersections or interchanges.
6. The presence of very high concentrations of pedestrians needs to be recognized in the operating strategies.
7. Time management concepts should be used to obtain maximum productivity from the street system.

Functional Classifications

Streets in downtown Chicago serve a number of functions that are determined by such factors as street capacity, traffic demand, and connections to major arteries and public transit routes. The basic street system is defined in terms of three functional classes of streets: primary arterials, major collectors, and local streets (see Figures 1 through 4).

The functional classification of the existing street system will undergo minor revisions with the introduction of the Circulator. The existing classifications serve the city very well. The geographical distribution of arterials, collectors, and local streets provides the necessary through traffic requirements, distribution to and from the expressways, and access to individual land uses. The Circulator alignment and coordinated traffic management concepts attempt to preserve these system characteristics.

Management Plan

Strategies represent operating concepts that are recommended for application to the Central Area street system. These strategies are described in two sets of concepts. The first are broader in scope, defining the means to achieve positive overall system relationships. The second set describes specific actions for the TMP.

System Strategies

System strategies focus on a series of essential relationships that coordinate regional access, area circulation, and land use access. These strategies will be followed in conjunction with three primary system operations: dedicated lanes for the Circulator, a transit priority traf-

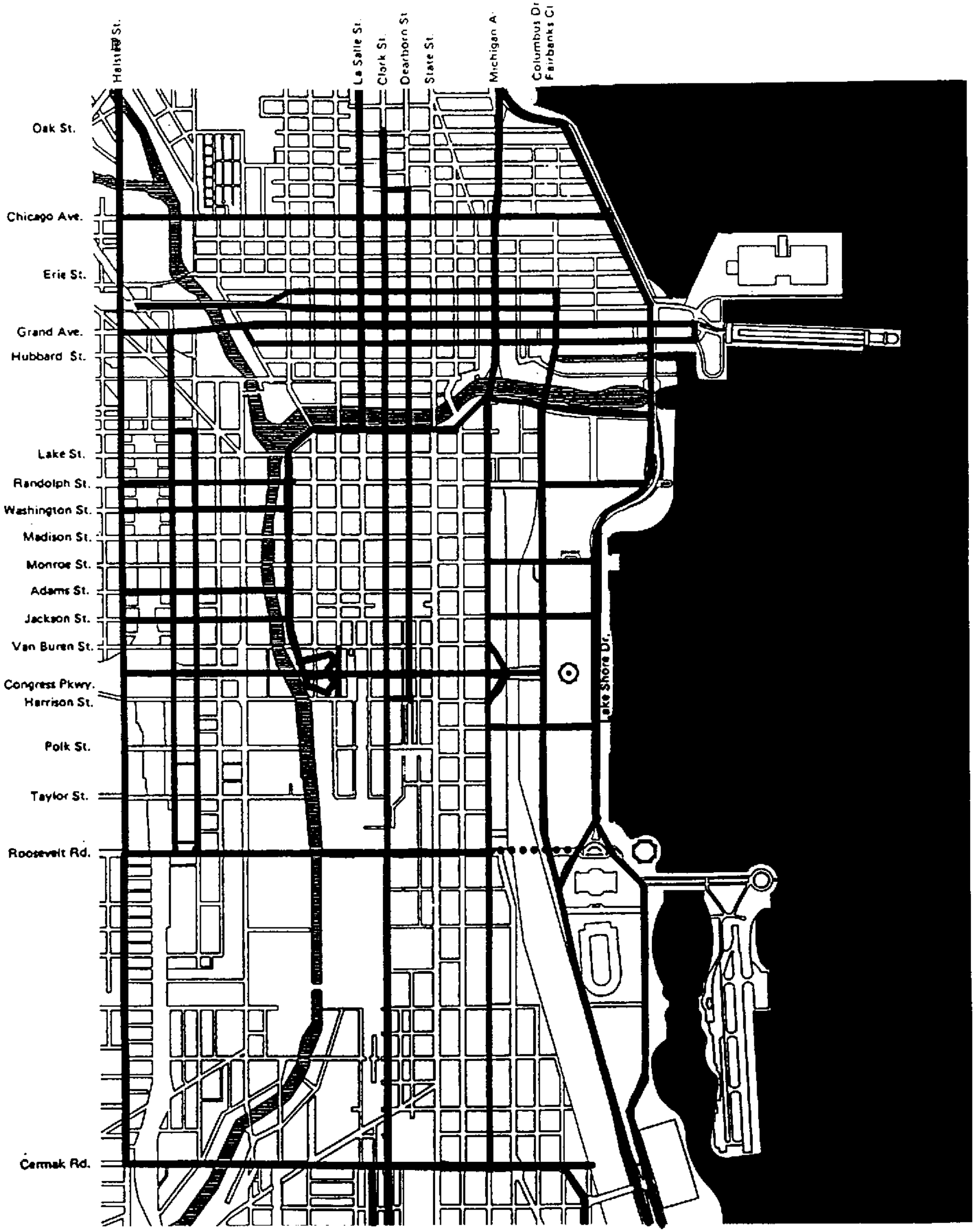

FIGURE 1 Primary arterials.

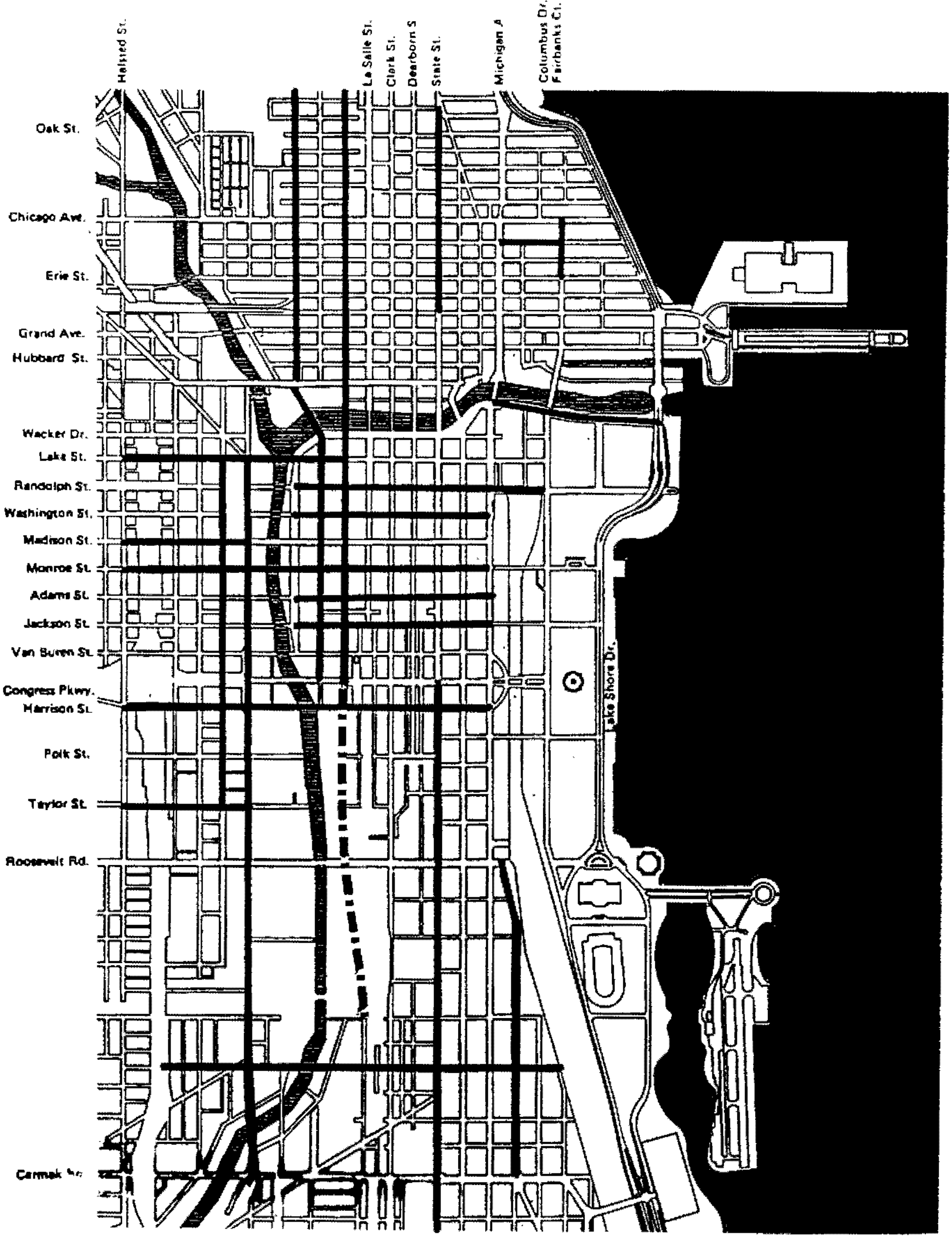

FIGURE 2 Collector streets.

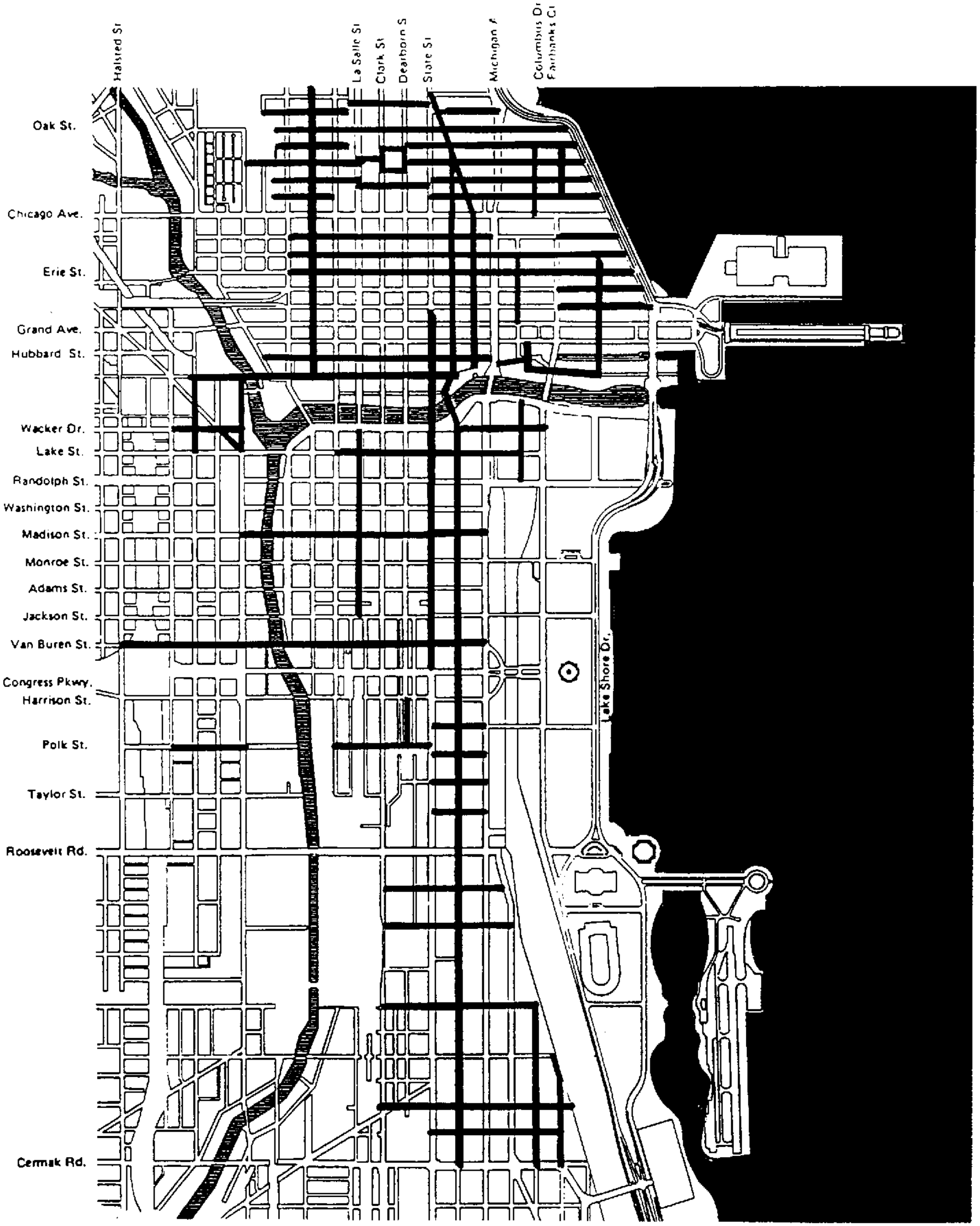

FIGURE 3 Local streets.

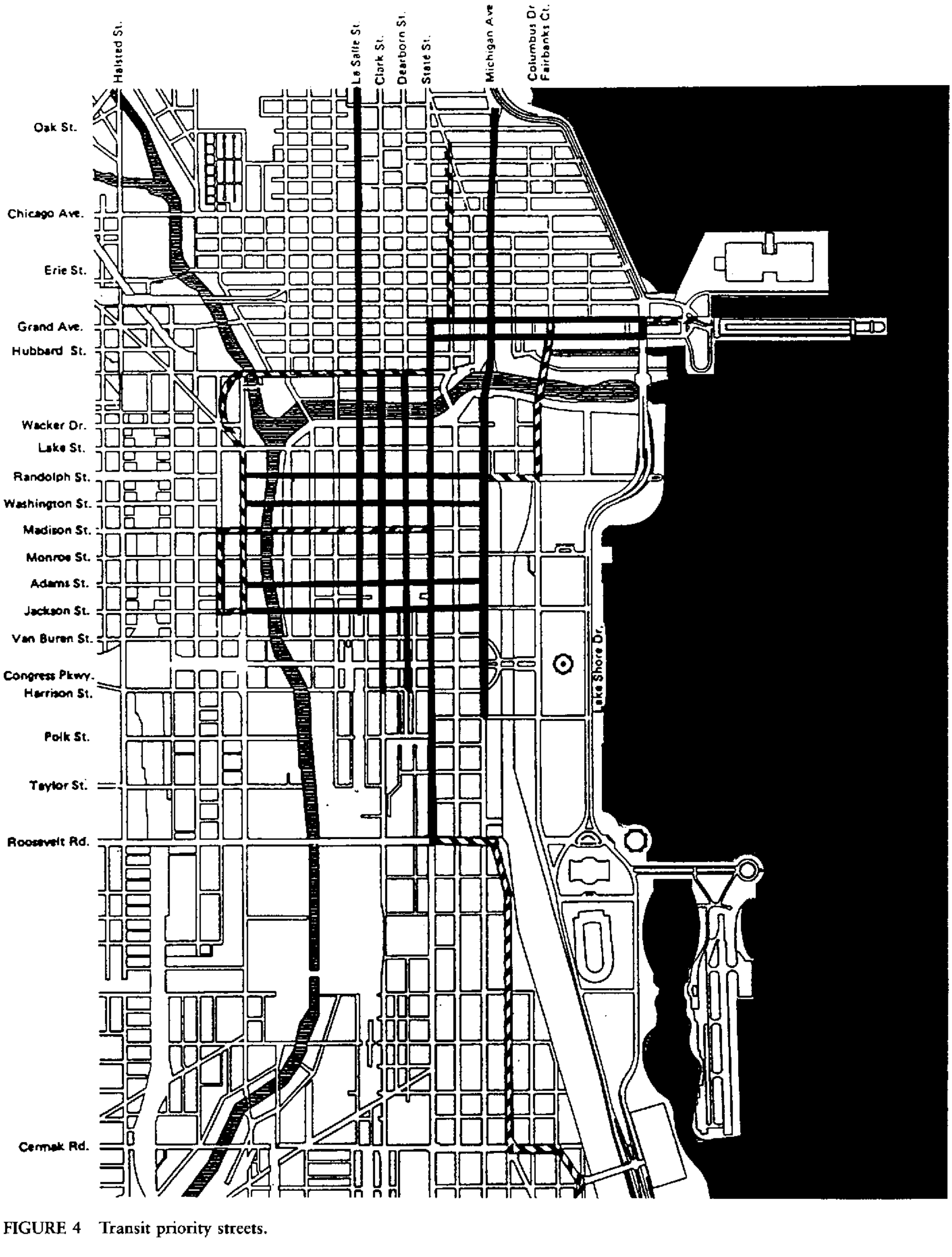

FIGURE 4 Transit priority streets.

fic signal system, and using built-in street capacity by converting parking spaces to traffic lanes. Specific aspects of these operations are as follows:

1. Dedicated LRT lanes are provided for the operation of the light rail vehicles (LRVs). The dedication of these lanes to LRVs will increase the person-carrying capability of the street. A dedicated transit lane can carry up to 11,200 persons per hour. An automobile lane in downtown Chicago can carry nearly 650 to 900 people per hour. A bus lane can carry up to 7,500 people per hour.
2. LRT priority traffic signals are to be provided along the Circulator alignment. The traffic signal system will give priority to LRVs while maintaining safe crossing times for pedestrians and minimizing delays to cross street and parallel traffic. This signal system will support the movement of the greatest number of people through the Central Area with minimal delay. These signals will be coordinated with the rest of the traffic signals in the Central Area.
3. A significant number of Central Area streets devote two curb lanes to parking. Because most of these streets have four-lane-wide pavements, 50 percent of the potential traffic movement capacity is not being used (25 percent for streets with one curb lane of parking). This built-in capacity will be utilized as curb lanes are converted to traffic movement. There has been expansion in the off-street parking system in most sectors of the Central Area to compensate for spaces to be removed from on-street use.

Specific Actions

The TMP comprises a series of features that reflect operating policies and actions. The TMP's specific features are traffic operations (i.e., traffic lanes and traffic controls), pedestrian movement areas, special operations for other vehicles (trucks, emergency vehicles, buses), property access, enforcement of the traffic management system, and safety.

Traffic Operations

The key features of traffic operations will be as follows:

1. Trackway alignments do not close any existing streets to vehicular traffic use.
2. The desired widths of all travel lanes is 3.4 m (11 ft) on city-maintained streets and 3.6 m (12 ft) on state-maintained streets. In many circumstances, given the need to maintain sidewalk widths for pedestrians, travel lanes 3 m (10 ft) in width are used.

At a few intersections where the pavement will be striped to provide a 2.7-m (9-ft) turning lane and an adjacent 2.7-m (9-ft) through lane, travel speeds through the intersection will decrease. However, these intersection approaches will be able to serve a higher demand with two 2.7-m (9-ft) lanes than with a single 5.5-m (18-ft) lane.

In instances where there is a single travel lane 4.9 to 5.5 m (16 to 18 ft) wide, pavement markings will be provided to effectively define a 3.7-m (12-ft) travelway. This will be done to discourage vehicles from driving next to one another in narrow travel lanes over long street segments. These pavement markings will allow stopping vehicles to pull out of the travel lane and not stop through traffic. Where lanes are not wide enough to allow stopped vehicles to pull out of through traffic, stopping shall be prohibited. Stopping shall be further discouraged through the use of urban design techniques.

3. Pavement markings will be placed in the LRV lanes to inform motorists that automobile traffic is prohibited in those lanes. The elongated white diamond and solid white striping will be used. Single wide vehicle travel lanes will also be marked as described above to channel traffic into the appropriate area. The travel paths of turning LRT trains at junctions will also be indicated.
4. Parking is prohibited on Circulator streets. The TMP seeks to prioritize pavement space for traffic movement. The street system has much built-in capacity that is not now being used. This potential capacity can be used to accommodate more transit service while maintaining reasonable operations for other traffic. This would be consistent with the Clean Air Act requirements.
5. Circulation with in the Central Area will remain much the same as at present. The Circulator alignment will not close any blocks to automobile traffic. Certain turning movements will be prohibited to ensure the flow of through traffic.
6. Signalized intersection operations will be managed locally rather than by a central control system; this will provide the needed flexibility to deal with localized variables that may affect intersection operations. This is a system separate from, yet linked to, the Loop traffic control system. The latter is operated by CDOT utilizing a central controller concept. Most of the street intersections that the Circulator will cross will be signalized. Local intersection traffic signal controllers will regulate the allocation of green time to LRV, car, and pedestrian movements.

The allocation of green time will depend on receiving and processing information transmitted from the LRVs and the need to serve all pedestrian movements in a cycle. LRVs will receive priority treatment with respect to allocating green time to LRVs as soon as possible through the truncation or reduction of green time for conflicting traffic movements. To the extent possible, LRVs will move concurrently with automobile and pedestrian traffic to minimize overall person delay. However, the traffic signal controllers will be capable of providing exclusive green time to specific LRV movements to enhance intersection safety. This is necessary at locations where parallel turning movements of automobiles across the tracks are permitted. The turning movements will require a separate phase and will not be provided during the LRT phase.

An important consideration of the signal timing will be minimization of added delay for streets intersecting the Circulator streets. This is especially significant for streets used by CTA bus routes. Because of the short amount of time needed to serve LRV movements, the use of concurrent (with LRV movement) traffic signal phases, and the provision of safe pedestrian clearance time to cross the Circulator streets, the amount of signal green time for the intersecting streets will not change substantially.

To facilitate overall traffic management operations, the controllers will have the capability of being integrated into the proposed Loop traffic signal system to provide operational status information, and they will be capable of accepting and responding to local commands for vehicle queue clearance. The controller functions will also provide flexibility so as not to preclude integration with future CTA bus priority operations.

The traffic signal controllers will provide timing functions to accommodate eight LRV phases in addition to the normal vehicular and pedestrian phases. The traffic signal controllers will provide separate outputs to illuminate LRV, vehicular, and pedestrian signals. LRVs will receive signal head displays that are distinct from those displayed for vehicular and pedestrian movements.

7. The phasing sequence for the LRV signals varies by location. The first difference is between concurrent and nonconcurrent intersections. Concurrent intersections are where the LRV can move with parallel traffic. This occurs where no turning movements are allowed across the tracks or where a separate turn lane exists so that turning movements can be separated from through traffic. Nonconcurrent intersections are where the LRV requires a separate transit phase and all automobiles must stop. The transit phases will be called as needed. They will be supplied when the signal cycle allows them to be serviced. Limitations in the time available in the cycle length may postpone processing a call until the next cycle.

8. The length of the signal cycle is dictated by the sum of the required individual phase lengths. Limitations exist on the maximum cycle length owing to the amount of time pedestrians and vehicles must wait during a red phase. In the core of the Central Area the pedestrian stop time is most important because pedestrians tend to have a short tolerance (around 30 sec) for stop time. The cycle length should also be a factor of 3,600 sec (1 hr) so that cycles can be coordinated on a clock schedule.

The standard cycle length for the Circulator signals will be 75 sec. This is consistent with the plans for a new signal system in the core of the Central Area. Some existing closed-loop signal systems in the Central Area operate on a longer cycle (e.g., Michigan and Congress). The Circulator cycle length will be able to match the standard 75-sec and the 105-sec closed-loop cycle length systems.

9. The duration of each signal phase is based on the amount of time required to process the required demand subject to a minimum time required for clearance. The duration of an automobile phase is directly proportional to the percentage of total automobile demand moving during the particular phase. This varies by intersection. The minimum time required for each through automobile phase is the time necessary to clear pedestrians from the intersection. This time is calculated by providing a minimum walk time of 7 sec plus a don't walk time equal to the time necessary for a pedestrian to clear the intersection at an average walking speed of 1.2 m/sec (4 ft/sec).

The phase length for an LRV phase is determined by the amount of time required to clear an LRV through the intersection. This is determined on the basis of three factors: speed, length, and size of intersection.

10. Standard traffic control signs identifying the exclusive use of the LRV lanes will be placed outside of the travel lanes and LRV lanes to inform motorists of the prohibition of automobile traffic in the LRV lanes. In locations where special operations are to be undertaken, added signing features will be considered. These will include use of redundant signs, larger signs, and illuminated signals. They will be used where LRVs make turning movements or change lanes, or where traffic across the tracks is prohibited. Low-clearance signs will also be used where the wire height is less than 4.9 m (16 ft). The minimum wire height is 4.3 m (14 ft), which is larger than all legally permitted vehicles. There are a limited number of double-deck tour buses for which special routing will need to be considered because of their height. Clearance signs will be posted with a 0.6-m (2-ft) safety factor for electrical clearance. Signs will be posted at low-volume access drives for either regulator purposes (time-based restrictions) or warning purposes.

Pedestrian Movement

An important element of the TMP concerns pedestrians. Pedestrian facilities require a significant share of the potentially available public right-of-way. From a TMP perspective, the elements for pedestrians will be as follows:

1. Traffic signal phasing will always incorporate sufficient pedestrian crossing time, that is, the time for persons to cross the street walking at a reasonable speed. This is critical for such dense pedestrian zones as Inner Loop, North and South Michigan Avenue, commuter rail stations, CTA rapid transit stations and bus stops, and Circulator stations.
2. Sidewalk widths must be sufficient to accommodate peak movement volumes. Specific guidelines will be found in the Urban Design Plan being prepared as part of the Circulator project.
3. Pedestrian movements are to be managed so that they occur at intersection crosswalks. Measures such as urban design treatment would be instituted to minimize midblock crossing.
4. The pedestrian movement corridors with the highest use potential and need for space are the Loop and North Michigan Avenue corridors.

Other Vehicles

1. Truck operations: The need for goods delivery, service, and maintenance is associated with land use activities in the Central Area. The TMP includes the concept of time management for as much of this demand as can be practicably accommodated. Trucks would be able to use the LRT track areas with authorization when the Circulator is not in operation. Within the Central Area, certain streets are critical for truck and service access. Another critical truck operations component is the alley system. Alleys are most common in the Loop area, providing service for most of the properties. Access to the alleys will be maintained in the TMP.
2. Bus system: The introduction of a supplemental transit system into the downtown street system and the dedication of lanes to the LRV will require modifications to the bus system. The goal of the Circulator project is to discontinue duplicate bus service to reduce trips in the Central Area.
3. Emergency vehicles: The Central Area must continue to be accessible for emergency vehicles. Land uses cannot be landlocked, nor can any facilities be constructed to prevent appropriate access. The TMP maintains access on all streets in the system to allow for this contingency.

Property Access

Within the core of the Central Area, there is significant competition for use of the curb lanes: stopping, standing, parking, through movement, and turning movements. To facilitate circulation, the TMP recommends that the capability to make turning movements be given a high priority. Concerning property access, the TMP recommends the following:

- Access to all properties is maintained: access points are relocated to other streets or alleys where possible, or permitted across LRV tracks if necessary.
- Where driveway access is retained, access is managed by time management or directed by personnel, controlled by signals, or guided by signs and markings.
- Public alley access may be eliminated for vehicle use or may be modified to one-way directions. This is contingent on the need for goods or service access and feasible opportunities to redirect alley access to non-Circulator streets.
- Where alley access is retained, access is managed by time management or directed by personnel, controlled by signals, or guided by signs and markings.
- Curb lanes are prioritized for traffic turning purposes. Loading and service zones may be relocated, provided by recessed bays, or served by time management, or new off-street loading space may be created.
- Special traffic control devices may be needed where the crossing of LRV tracks is permitted. Midblock crossings generally will be controlled by passive measures (i.e., signs). Motorists will be required to use caution when turning, as in the case of a left turn in front of oncoming traffic. The special treatment of the pavement in a different texture and color, as well as the visible barrier separating LRV and automobile lanes on street systems, should reinforce this caution. In instances where there is a high demand for crossing the tracks (e.g., large parking garages) or locations with poor sight lines, an active measure (e.g., a signal) identifying the proximity of an LRV may be placed at the exit of the driveway to control the automobiles entering the street system.
- Plans for future developments should not provide for access locations requiring crossing of tracks. In the planning of future developments, access locations shall be prohibited along an alignment where vehicles would cross the tracks. Access on cross streets should be far enough away from the LRV street so that queues do not extend onto the tracks. Any potential impedance to LRV operations should be avoided.

Enforcement

An important element of the TMP will be enforcement activities. The enforcement concept entails various regulations and managed use of street space. Sufficient resources will be needed to operate the street system. Although an effective traffic signal control system will manage traffic flow and the best signs and markings will be used, there will be an urgent need for comprehensive enforcement activities, which will focus on seven types of actions in relation to traffic management:

1. A public awareness program is planned before the Circulator goes into operation, including training of police and fire department personnel to coordinate safety and enforcement programs.

2. A special education period during initial start-up time will require traffic control personnel in selected locations, and special delineation devices may be required.

3. The city must maintain a commitment to comprehensive enforcement without relaxation. Enforcement personnel will need to be able to issue citations for any Circulator-related violations. The adjudication process will need to be capable of processing the potential increased volume of such citations. It will be necessary for the courts to impose an appropriate penalty. If not, the credibility and effectiveness of enforcement will be reduced to the point that traffic operations will worsen. Equitable and constant enforcement is needed to achieve overall public support for traffic management regulations. The enforcement activities need to have a response capability. The policy will be to eliminate any track encroachments. The use of towing vehicles and other resources should be quick and efficient.

4. Encroachment on LRT track (i.e., delays to LRT operations) must be prevented. The issue of encroachment must apply to all sections of the Circulator system. Stopping, parking, or traveling along the LRT tracks must be prevented. Also, in a limited number of blocks where the available pavement width (outside of the LRT track zone) is less than 5.5 m (18 ft), the risks of circulation blockage are significant. Regulations prohibiting stopping, standing, and parking would require extra enforcement activities in these areas. These enforcement activities would be focused on locations most likely to have problems or most critical for Circulator or traffic operations.

Minimizing track encroachment would require patrols along the entire system. Seven areas would be considered high priority for encroachment enforcement: in the vicinity of the Chicago & North Western Atrium Center on Madison and Canal Streets, Madison Street between State and Canal Streets, State Street through the mall area to Congress Parkway, Randolph Street between State Street and Michigan Avenue, State Street between Wacker Drive and Grand Avenue, Grand Avenue and Illinois Street between Columbus Drive and State Street, and Wabash between Illinois Street and Walton Street.

With Circulator routes operating on 6-min peak-period and 10-min midday headways, encroachment enforcement needs to be continuous, especially during a normal business day (7:00 a.m. to 7:00 p.m.). These activities need to be coordinated with an incident response team that can quickly remove encroaching vehicles. This process entails various procedures for ordering towing or similar responses, available space in facilities where vehicles are impounded, and information management to document the activities.

5. Traffic signal controls at intersections must be observed. For traffic signal locations, the most critical issue is controlling pedestrian flow. People need to obey the walk and don't walk signals. This is very important at intersections where LRV turns are made or where turning phases for general traffic are included in the signal cycle. For these operations to work without delay, pedestrians will need to be managed. A familiarization period during the start-up time for this system will require the presence of traffic control officers at selected locations.

For the TMP to be effective, the field activities focus on track encroachment and intersection operations. Traffic control officers are present at many Central Area intersections. There are approximately 100 signalized intersections along the Circulator streets. Enforcement is needed most at intersections where the Circulator has turning movements and significant pedestrian volumes are anticipated.

6. "No Parking, Stopping, or Standing" signs along the alignment must be observed.

7. Because of the special nature of the Circulator project, a comprehensive training program is recommended for all involved personnel. This would be especially important in (*a*) assisting traffic control officers to understand the special traffic signal controllers and the signal phasing at key intersections and (*b*) understanding the procedures and communication system between traffic enforcement personnel and train operations personnel; these activities would identify the contingency plans associated with special problems, emergencies, and other disruptions.

Safety

Actions to promote safe operating conditions have the highest priority. These safety measures concern the interaction between LRVs, general traffic, and pedestrians. The keys to a safe operating environment are

1. Clear operating conditions, that is, all motorists and pedestrians understand how they are to use the street system (no confusion or ambiguity);

2. Reasonable operating speeds for LRVs and general traffic in relation to safe stopping distances, including reaction time and space;

3. Appropriate visibility for motorists and pedestrians to see all other traffic movements;
4. Measures to maintain awareness as to the passage of LRVs along any street; and
5. Education programs to continually support safe behavior, especially in relation to obeying traffic controls and the awareness of LRV operations.

Monitoring and Evaluation

An inventory of past, present, and future traffic volume data, such as 24-hr traffic counts and peak-hour traffic counts by turning movement, bus volumes, truck volumes, and pedestrian counts should be included in a transportation data base program. This data base is an essential resource for the TMP and requires hands-on implementation.

Any management plan needs to have criteria developed by which it can be evaluated. The management plan should be constantly evaluated and revised to respond to any changes in conditions. Three criteria have been promoted to evaluate the traffic management plan:

1. Local land use access should be maintained (at locations where access is not available from other streets and alleys).
2. Circulation of traffic should be maintained at a level where queuing at intersections does not disrupt traffic flow at upstream intersections. The primary approach to developing workable traffic conditions is first to assess the peak-hour queue conditions at intersections under future-volume conditions with optimized signal timing. If queue spillback is evident and no geometric or design improvements are available, an assessment of possible routes for traffic diversion is made to reassign future traffic volumes to the post-Circulator street system. Queue conditions are then reevaluated, and the process continues until equilibrium is reached.
3. Person delay should be minimized. The person capacity of the street system depends on the type of vehicle in use. Because transit vehicles carry more people than do automobiles, a transit lane can provide substantially more person capacity than an automobile lane. Person delay is a measure of the amount of time that a person traveling on any mode is delayed at an intersection. It is similar to the concept of vehicle delay, which is more commonly used in defining traffic impacts. The key difference between the two measures is that vehicles that carry more people can incur varying amounts of delay. Thus, a person traveling on an LRT system that has priority signalization at intersections would experience less delay than a person traveling the same route in another type of vehicle (e.g., bus or automobile). Priority signalization minimizes the delays to the modes transporting the greatest number of persons. Because LRVs would, on average, experience less delay at intersections and carry more passengers than would automobiles and buses, total person delay is lower. Evaluations of typical intersection level of service are based solely on vehicular capacity and delay; they do not account for the substantial reduction in person delay that results from the transit service.

None of these address the current "acceptable" criteria in use that dictate the free flow of traffic by use of the level of service (LOS) scale (LOS C or D is a typical standard). Because LOS deals entirely with average vehicular delay at an intersection, it is not suited to addressing new transit modes in an urban setting.

Implementation

The recommendations outlined in this paper will require interagency coordination and approval by a number of different city and state agencies. Each policy decision should be agreed upon by the city of Chicago. The specific strategies and actions outlined should be adopted by the separate departments responsible for various functions of the city, including the Department of Transportation, Department of Planning and Economic Development, Department of Revenue, Department of the Environment, Department of Law, Department of Consumer Services, and Department of Streets and Sanitation. Also, a number of ordinances will need to be passed by the City Council to allow implementation of this plan.

These implementation conditions will be challenging requirements. The commitment to ongoing management and enforcement must be maintained at a high level. The Central Area is a complex environment. Managers will need to be alert to changing situations.

Light Rail Preemption of Traffic Signals: A Question of Balance

Woodrow Hood III, Thomas Hicks, and Linda I. Singer, *Maryland State Highway Administration*

As Maryland expands its network of light rail transit facilities, an increasing number of situations arise where light rail and traffic-signalized intersections must operate in conjunction with each other. These include at-grade crossings close to signalized intersections and light rail facilities that closely parallel arterial roadways where there are closely spaced traffic signals on the arterial. These locations present the traffic engineer with unique problems that must be resolved to facilitate movement of the light rail vehicle and other vehicular traffic through the area. In most cases, the periodic preemption of a traffic signal at an isolated intersection will cause only momentary disruption to vehicular traffic. It is when more frequent preemption occurs, or when the signal operates as part of a coordinated traffic signal system, that problems arise. These include disruption of traffic signal coordination on the arterial, excessive clearance intervals needed to ensure that right-of-way has been cleared for the light rail, and excessive delay to vehicles waiting at the preempted traffic signal. In addition no two locations have the same characteristics or solutions. The traffic engineer must consider these and other factors when developing a traffic control scheme for each individual location. Maryland is evaluating several traffic control strategies for these types of locations. They include allowing the signal to cycle through other nonconflicting phases while the light rail vehicle passes through an intersection; allowing the signal controller to select, on the basis of traffic demand, which phase should be serviced first after preemption; and reducing the disruption to the signal system caused by frequent light rail preemption. The field testing and design of these strategies are addressed.

The subject of this paper is balance in terms of traffic numbers, that is, vehicles and people in quantity and travel time, and in terms of mindset, that is, perception of needs and advantages.

On the one hand, there is a continually increasing number of vehicles on local roadways; on the other, there is a move to get people out of their cars and on to buses and light rail service. The emphasis on mass transit is particularly important in the era of the Clean Air Act Amendments (CAAA) and penalties for not reducing vehicle emissions in nonattainment areas.

Our customers tell us that, assuming there is not a vast disparity in the cost of car versus transit, people make their decisions on which mode of transportation to use on the basis of time and convenience. The more their travel time can be reduced, the more likely it is that travelers will be enticed to use buses and light rail, leading to less congestion and pollution. However, there will still be people in their personal vehicles for local transportation and for getting to destinations not served by mass transit.

The result of greater transit usage is more and more situations in which transit facilities come into conflict with roadway facilities. Simply put, how do traffic engineers fairly balance the needs of car and transit users when they both must approach and traverse a heavily congested intersection?

Whatever the resolution in a particular situation, there must be a balance between the legitimate needs of drivers and transit passengers. In achieving that balance, a measure of priority must be provided to the transit operation if mass transit is to be made appealing enough to get drivers out of their cars and onto mass transit.

Most often, that priority has been provided by traffic signal preemption. Such preemption in the cases of light rail and freight train service halted some or all traffic flow at the intersection until the transit vehicle or freight train could move into and through the intersection. In some cases the complete halting of all traffic flow at the intersection could not be avoided owing to the way the intersection had been laid out. In others, where the geometrics are conducive, a balance has been achieved by taking advantage of state-of-the-art technology.

The Problem

Maryland is currently constructing extensions to its light rail system in the Baltimore downtown and metropolitan areas. For right-of-way concerns and the accessibility of most of its customers, the light rail lines are located on or immediately parallel to major arterial roadways. In the more urbanized areas, they also cross closely spaced, signalized intersecting streets. Most are at-grade crossings.

When traffic signals on these arterials and intersecting streets are very close together, they are coordinated for efficient vehicle movement. When traffic engineers preempt a signal within a traffic signal system, a measure of coordination is lost on the arterial roadway, as well as on the cross roads. Preemption sequences for transit vehicles are extremely disruptive to vehicular traffic because the priority is given without considering the impacts on the arterial or the entire system. As one might expect, the result was worst at closely spaced traffic signals and at high-volume intersections. Vehicles get stacked up between the signals and cannot move. Excessive clearance intervals are needed to ensure that the right-of-way has been cleared for the transit vehicle. Long queues develop at the intersecting roadways. Finally, there are excessive delays to vehicles waiting at the preempted traffic signals until the signals get back in step with one another.

We realized, as our traffic engineers were asked to help our transit sister agency with signal coordination, that these circumstances were unacceptable to our customers, both transit users and motor vehicle drivers. To compound the problems for our traffic engineers, no two situations are identical. Each presents new problems and requires new solutions for configuration of the roadways and the coordination necessary for the signals.

The problem—and the challenge—came down to finding a way of freezing only the movement at a particular intersection that would conflict with the transit vehicle without immobilizing the entire intersection and signal system. The trick was to keep nonconflicting vehicles moving by efficiently using the available green time in phases that did not affect the transit vehicle. Indeed, this is a delicate balance.

Meeting the Challenge

The answer to this challenge lies in newly available technology and a commitment by policy makers to customer-driven quality in transportation and to compliance with new federal requirements under the CAAA and the Intermodal Surface Transportation Efficiency Act.

Maryland has been exploring several strategies to address the problem. These include

- Allowing the signal to cycle through other nonconflicting phases while the light rail vehicle is passing through the intersection;
- Allowing the signal controller to select, on the basis of traffic demand, which phase should be serviced first after the preemption;
- Using different track clearance sequences—the signal sequences used to clear motorists from the tracks;
- Finding ways to reduce disruption to the coordinated signal system that is caused by frequent light rail preemption; and
- Holding the transit vehicle until the best possible moment within the traffic signal cycle to allow the most efficient movement through the intersection.

These different strategies are now possible through the use of state-of-the-art traffic signal controllers. The emphasis in Maryland has been on the use of signal systems to provide smooth traffic flow along arterial roadways. By definition, signal preemption runs contrary to this approach. But the new controllers allow minimal disruption, thereby adhering more closely to our original approach than was possible with earlier controllers. The previous technology was limited in its ability to balance the needs of motorists and transit users because of limitations in the "thinking" ability of the software. In this case, the policy emphasis drove the development of more advanced and specific-results-oriented software.

Learning Ground

In August 1993 Maryland successfully implemented its first experimental bus preemption system. It was installed along MD 2 (Ritchie Highway) between Baltimore and Annapolis, an arterial that carries average daily traffic (ADT) of 32,000 to 35,000.

What We Did

The preemption system consisted of bus priority control of 13 signalized intersections that operated as a coordinated signal system. The system allowed express buses to use any of three types of priority controls, depending on whether the bus stop was located on the near side or the far side of the intersection (in the Ritchie Highway case, we did not relocate any of the bus stops). The three types of priority controls are queue jumping, extending the green time, and phase reservicing.

The queue jump maneuver (Figure 1) was used at locations where the bus stopped on the near side of the intersection. This maneuver gave the bus an exclusive phase within the traffic signal sequence that would allow the bus to proceed through the intersection without any conflict from other vehicles.

Extending the green time (Figure 2) was used at locations where the bus stopped on the far side of the intersection. This would allow a bus approaching an intersection on a green indication to extend that green indication, thus ensuring that the bus got though the intersection without having to stop for a red signal. This would prevent a bus from having to stop twice at the same intersection, once for the red signal and again on the far side of the intersection to pick up and discharge passengers.

This phase extension was provided by giving the transit vehicle an additional extendable green interval to proceed through the intersection. The additional green time would be borrowed from the minor movements and then returned to the next signal cycle. The additional green interval was up to 15 to 20 sec.

The phase reservice (Figure 3) was used at a location where the bus made a left turn off the arterial to service a major park-and-ride lot. This maneuver had the effect of serving the left-turn phase twice (if necessary) within the same signal cycle. The left turn would be serviced as a normal lead left turn for all vehicles and again as a lag left turn only if a bus were present. Any other vehicles that were present during the lag portion would be serviced as well, but the lag option would be called only by the presence of a bus in the queue of left-turn vehicles.

The decision of which option to choose was made by the traffic signal controller. The system was completely automated and required absolutely no action by the bus driver. The system used a NEMA-TS2-type controller and the 3M OPTICOM Priority Control System. The control system transmitted the signal from the bus

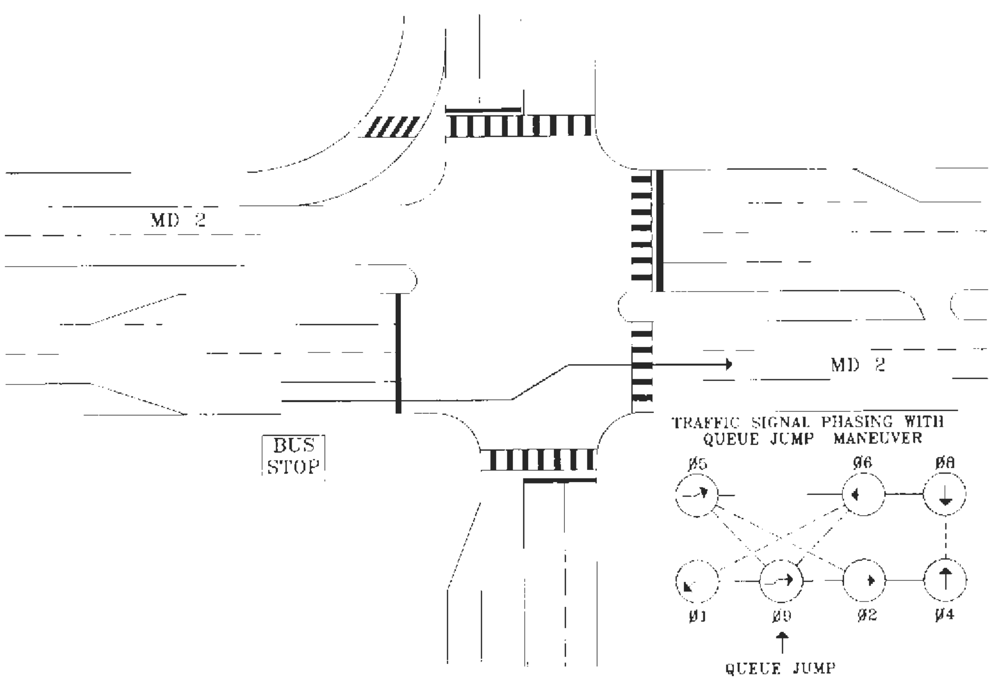

FIGURE 1 Queue jump maneuver.

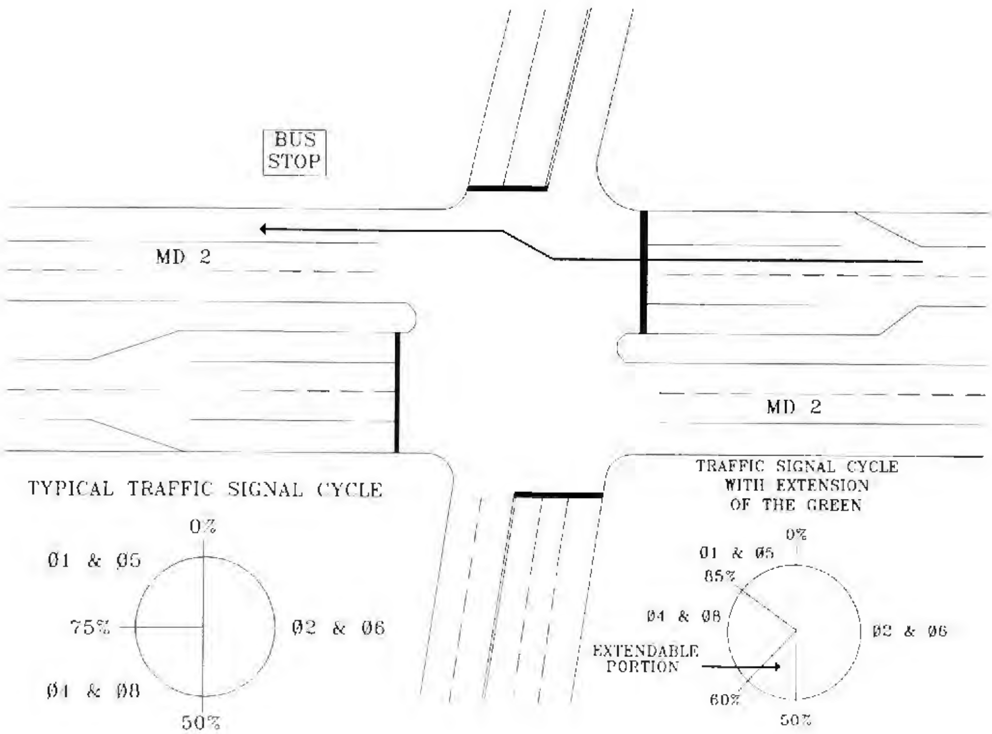

FIGURE 2 Extending the green time.

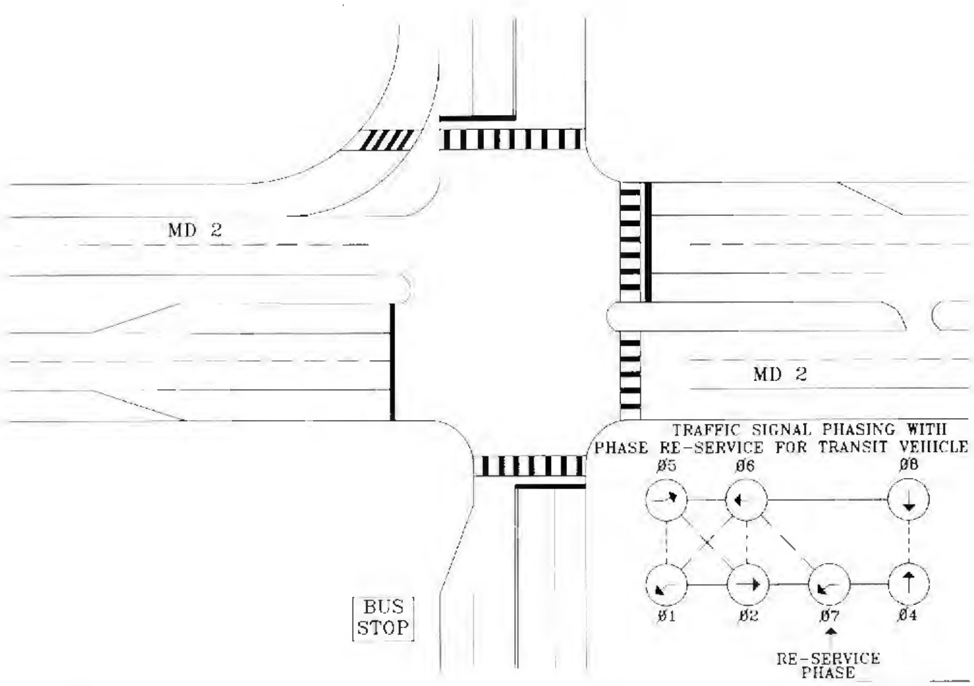

FIGURE 3 Phase reservice.

to the local intersection controller. The controller, in turn, depending upon the status of the intersection at that time, would determine what type of priority control to provide.

Results

The system reduced bus travel times by 14 to 18 percent on the affected section of roadway. This was achieved because all three types of priority controls were provided without affecting coordination on the arterial. At no time do any of the signals lose their coordination relationship with one another.

In some cases, motorists also realized a decrease in their travel time because they were able to use the extended green time provided for the buses. Very few complaints were received from motorists on the minor street approaches due to any additional delay encountered by them.

At the time the Ritchie Highway bus priority system was fully operational, we were satisfied that we had achieved great results. In reality, this was a critical evolutionary step that has led to much greater expectations in their application to the "new kid on the transit block," light rail.

Human Factors

Aside from the technical and policy implications of priority control for transit vehicles, there is an aspect that is critical to modern traffic engineering: the human factors element. A significant concern in this priority control preemption concept is whether drivers will understand and accept the different and varying traffic movements and the new signal displays. These displays are unique to transit vehicles and alert drivers to their assigned right-of-way through the intersection (Figure 4). However, for the intersection to operate safely and efficiently, motorists must also understand what the new displays indicate.

These signal displays are not covered in the *Manual on Uniform Traffic Control Devices* (MUTCD) because the situations in which they are used are new. As a result, they have received an "experimental" designation from the Federal Highway Administration. Maryland will be reviewing driver acceptance and comprehension with an eye to modifying them to make them more clearly and universally understood. The results will be reported to the National Committee on Uniform Traffic Control Devices, as with all experimental designations.

Lessons

We learned from the Ritchie Highway experience that we can balance the needs of motorists and bus riders without drastically affecting traffic flow on an arterial highway. We now believe we can transfer successfully the preemption lessons and approaches to light rail transit.

One of the more important factors in considering how to adapt the preemption phasing is whether the light rail line is a major line or a spur line. There are two levels of light rail service, and each must be treated a bit differently. Main line service requires a much tighter, set schedule, and it cannot vary if service is to remain consistent with the schedule throughout the system. As a result, main line service trains must always receive a higher priority. There is more flexibility with the spur, or feeder-type, lines because the schedules are more flexible and allow more opportunities to balance the needs of both types of vehicles at a particular intersection. The light rail train can leave the stop a few seconds later than scheduled to accommodate other vehicular movements within the intersection.

New Applications and Implications for Light Rail

MD 170 (Aviation Boulevard) at Elm Road–Baltimore Washington International Airport Spur

A grade separation is the preferred treatment for a roadway or rail crossing. However, monetary constraints precluded the option from consideration at this location.

This intersection serves as the main entrance to the Baltimore Washington International Airport (BWI), with an average of 40,000 vehicles traveling through it daily (Figure 5). Aviation Boulevard for the most part encircles the airport. At its intersection with Elm Road, it runs in an east-west direction. Elm Road runs north-south.

This light rail line is a hybrid between the main line and spur configuration. It is to function as a spur line but is designed so that at some future time it can convert to main line service.

The stop at BWI is the southern terminus of the light rail spur to BWI. This would be the beginning of the northbound trip. There is also a stop located just north of the MD 170 grade crossing. For the light rail line to serve BWI, it must cross Aviation Boulevard at Elm Road. It crosses Aviation Boulevard approximately 30.5 m (100 ft) east of the centerline of the intersection (Figure 6). This intersection is located at the west end of the system.

The crossing will be double-tracked to allow inbound and outbound trips to cross simultaneously. It will be controlled by gates and overhead cantilevered signals. The crossing will meet all federal standards for a railway grade crossing. We estimate that the crossing sequence will require 55 sec. This includes track clearance, time for the gates and warning lights to activate, and rail crossing time and rail clearance time before the gates open. All times are computed on the basis of federal requirements.

The light rail crossing will require that main street traffic be stopped. To lessen the delays at this intersection caused by preemption, it is highly desirable to serve the minor nonconflicting movements at the same time the preemption is occurring. This would allow the preemption to be exited back to the main street movements.

The minor street movements at this location will consist of a northbound leading left-turn movement and the northbound and southbound through movements. The southbound left-turn movement is prohibited at this intersection and will be accommodated at another location. The northhound right-turn movement will be controlled by gates to prevent conflict with the transit vehicles. The preemption will occur about every 15 min.

Three preemption options (Figure 7) are under study for this location. The first is a simple preemption sequence that would allow the minor movements to be served during the preemption. This preemption sequence would he used on demand by the transit vehicle; that is, no delay would be encountered by the transit vehicle. The preemption would he exited to the main street. This preemption sequence would be the most beneficial to the transit vehicle, but it would create the most disruption to traffic on the arterial roadway.

The second option is to allow the preemption to occur during a "window" within the normal traffic signal cycle. Normally when a preemption occurs, whatever phase is currently being timed is immediately exited in order to serve the preemption phase. In some cases, this could mean a phase would he exited as soon as it was given its initial green time. But the idea here is to provide a window within the traffic signal cycle during which the preemption could not occur. In the case of this location, the preemption would not be allowed when the main street phases were timing or about to begin timing. The preemption would be allowed to occur during the final 10 to 15 sec of the main street

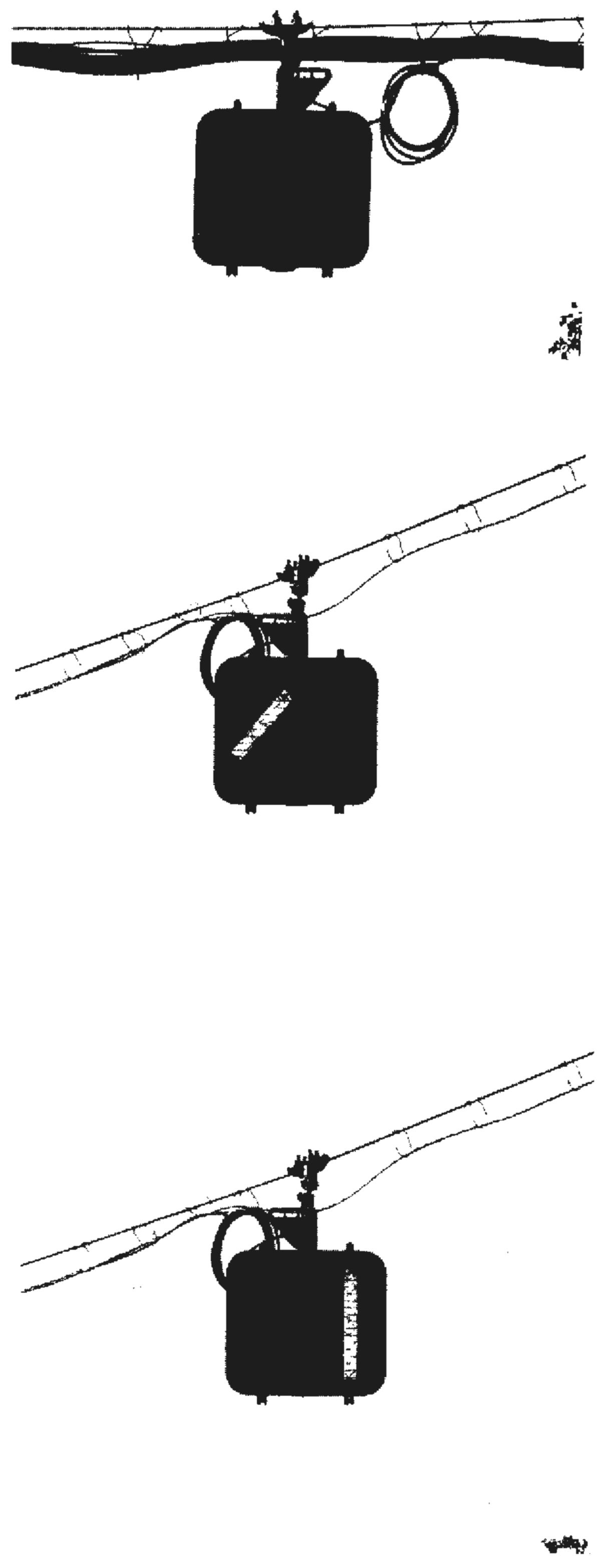

FIGURE 4 Transit vehicle display. *Top*: The transit vehicle display remains dark at all times except for the queue jump maneuver. *Middle*: The transit vehicle display shows a 45-degree white bar when the signal controller has received the call for the queue jump maneuver. This is not an assignment of right-of-way to the transit vehicle. During this display the adjacent main street through movements receive a red indication. *Bottom*: The transit vehicle signal display shows a vertical white bar when the transit vehicle has the right-of-way. During this time all conflicting movements at the intersection receive red indications.

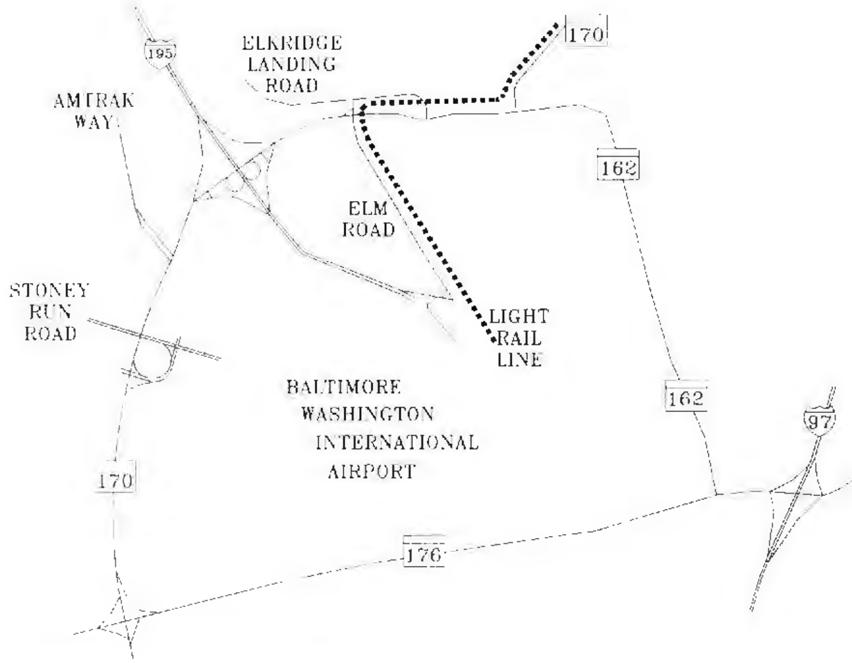

FIGURE 5 BWI light rail spur.

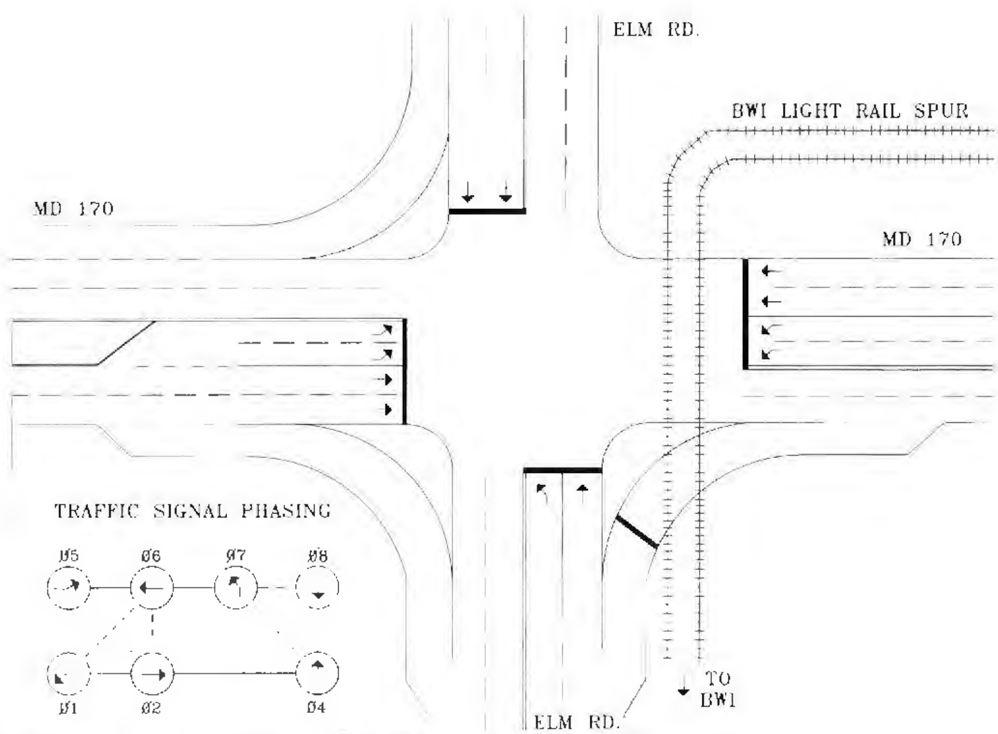

FIGURE 6 MD 170 at Elm Road/BWI spur.

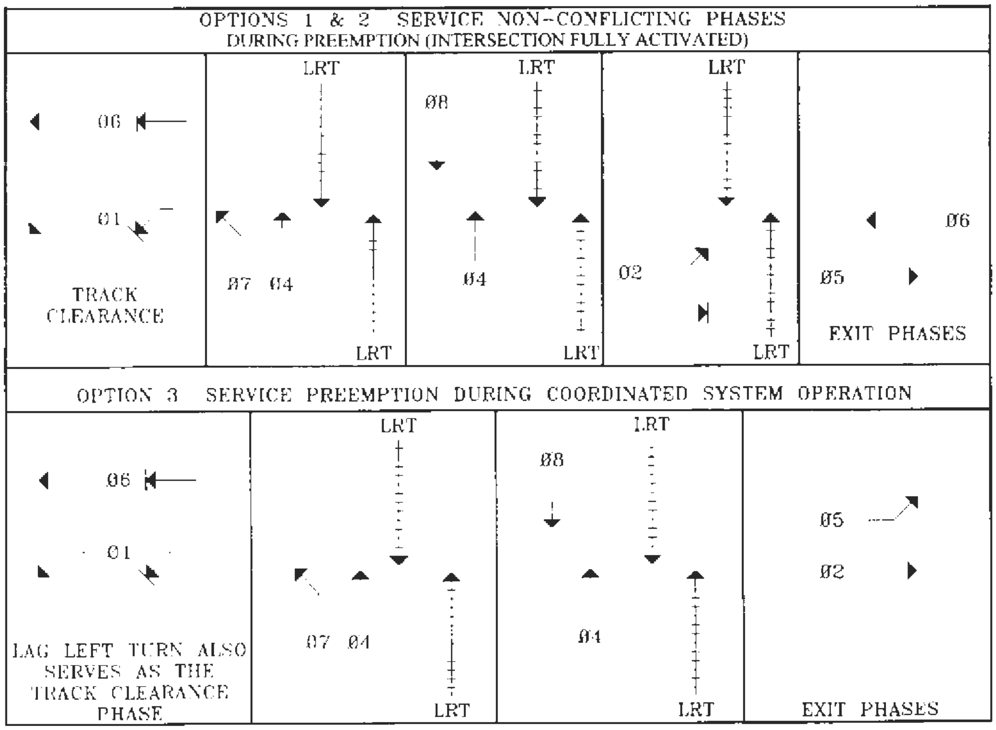

FIGURE 7 MD 170 at Elm Road/BWI spur: preemption options.

phases, or during the side street movements. The side street movements would then be served during the preemption sequence.

The third—and more desirable option from a highway standpoint—is to control when the transit vehicle is allowed to use the crossing. This would be accomplished in the same manner as the queue jump on MD 2 for the bus priority system.

The desired preemption sequence would allow the transit vehicle to use the crossing during the same point in the traffic signal cycle that the minor street phases would be active. This would be the same as the first type of preemption except that the transit vehicle would be told when to proceed toward the crossing. All track clearance intervals and other safety devices would be used accordingly.

The stops on both sides of the crossing would be used as a holding area for the transit vehicle. The train at each holding location would receive a signal from the local intersection that would tell it when it could proceed towards the crossing. The transit vehicle would receive a signal from the intersection controller to begin moving toward the intersection at the appropriate time that would allow all safety sequences to occur as the transit vehicle approaches the intersection, and would have the train reach the crossing at the desired point in the traffic signal phasing sequence. It is estimated this would cause a delay of at most 1 to 2 min to the transit vehicle. Since the trains would be sitting in a station waiting to move, the delay would probably go unnoticed by the rider. This preemption sequence would leave the coordination between the intersections intact and is the most desirable from a highway standpoint.

The second option was the one selected for initial usage at this location. This option will provide the best balance in the needs of transit and nontransit vehicles. The BWI light rail system is currently under design. It is scheduled to be fully operational in mid-1996.

MD 648, MD 176 to Eastern Avenue

MD 648/Eastern Avenue is an excellent example of the point we are trying to make. This main line light rail system runs parallel to a moderately to heavily traveled arterial roadway, and it crosses all of the side streets. Care must be taken to clear the side street traffic so it is not backed onto the tracks as a result of the arterial traffic signals and the light rail priority.

This section of MD 648 contains four traffic signals within a 503-m (1,650-ft) section of roadway, an average signal spacing of 168 m (550 ft). These four signals operate as a coordinated system. Three of the four are preempted by light rail, all in quick succession.

The light rail line runs parallel to MD 648 and is located approximately 15 m (50 ft) west of MD 648. MD 648 itself has an ADT of 14,000 vehicles in this section. The signal phasing at all three of the preempted locations consists of main street left-turn phasing, concurrent side street movements, and overlap clearance phases on the side streets to clear the crossing and the main street phases.

These same three signals use 75- and 90-sec cycle lengths and operate on the half cycle from the fourth signal in the system (using 150- and 180-sec cycle lengths). This fourth signal is at the southern end of the system and is not affected by the preemption.

The preemption sequence first uses a track clearance interval to ensure that no vehicles are stopped on the tracks and then rests in the main street phase until the transit vehicle passes. The preemption is exited back to the side streets to reduce delays. The preemption sequence along this arterial occurs an average of once every 7 min.

The problems encountered along this arterial are due to the closely spaced traffic signals and the frequency of the preemption, which can at times cause severe disruptions to traffic on the arterial (long vehicle queues, excessive stops, etc.).

The MD 648/Eastern Avenue system is currently operational. Traffic engineers are fine-tuning the signal system operations to provide a more efficient balance between the competing transit and nontransit needs.

Several alternatives under consideration include

- Having the controller serve minor nonconflicting movements during preemption sequence,
- Developing ways of getting the controller back into step faster (it can take up to four signal cycles to get the signal back into step with the other signals in the system), and
- Having the controller rest in a particular phase until the coordination clock and the local controller clock get back into sync with one another.

This latter alternative can create additional delay to other movements. For example, if the controller exited the preemption to the side street, the controller would rest in the side street phase until the coordination time clock reached the same point in the cycle. This may be acceptable at some locations that have short cycle lengths, but it probably would not be acceptable at locations that have long cycle lengths.

Unresolved Issues

An unresolved question is whether the benefits of quickly regaining the coordination on the arterial outweigh the additional delays that may arise from having the controller dwell in a phase until the local cycle time clock and the coordination time clock get back into step. Whereas the answer may differ in different jurisdictions, the political commitment in Maryland favors the former.

With the increasing usage of light rail, we must give light rail the most efficient flow along its tracks while preventing gridlock and critical traffic backups at adjacent arterial roadways. What is an acceptable amount of delay for both transportation modes is the issue.

If there is a downside to all this, it is the need for public awareness and education. Drivers have become so used to halting at an intersection for any rail movement that it has probably become ingrained. They may need some instruction on how to approach and traverse the intersection while light rail is doing the same. They need to understand the concept of shared safety.

Conclusions

In the early days of light rail, movement priorities were identical to those for all trains. Consistent with MUTCD guidance on highway railroad crossings, the intersection froze to allow the passage of the train. Clearly, whether it be light or heavy rail, traffic in direct conflict with the train must be halted for safety reasons. However, there is one point we want to stress: we must—and now we can—move away from the old mentality of "the railroad rules" to a new framework of accommodation and balance. Safety need not be compromised.

What is new, and what allows us to use this framework of accommodation and balance, is the new technology and the commitment to use common sense. And common sense means serving all nonconflicting movements at the intersection. The technological stumbling block was how to do the preemption sequence without disrupting coordination. The breakthrough is a controller that can get the intersection back into step faster and more efficiently.

There is also the policy commitment because of genuine concerns about the environmental impact of increasing vehicle usage and the loss of highway funds if pollution in nonattainment areas is not reduced. The result is a balance in meeting the needs of drivers and transit users, and at the same time taking major steps in the direction of the CAAA and the requirements of nonattainment status.

This paper began with the concept of balance. It also ends with the concept of balance. The Maryland experience proves that traffic engineers now have what it takes, or are developing what is needed, to achieve a balance between alternative transportation facilities and approaches while being environmentally sensitive. It is indeed a perfect balance.

Integration of Light Rail Transit into City Streets

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Light rail transit (LRT) has become a reality in North America. Nineteen cities in the United States and Canada have systems in operation, in addition to several short starter-line segments. The ability of light rail vehicles (LRVs) to operate in a broad range of environments (both on street and in separate right-of-way), the passenger attraction of the vehicles and service offered, and the capacity provided have made it an increasingly viable public transportation option for many urban areas. LRT, when in semiexclusive or nonexclusive right-of-way, has at-grade crossings with automobile and pedestrian traffic. These crossings have operating characteristics that are different from typical heavy/commuter rail at-grade crossings. These differences derive from the basic operational differences between light rail and heavy/commuter rail. Whereas heavy/commuter rail operates with relatively long headways and train lengths, light rail operates with relatively short headways and train consists. In addition, LRVs interact with motor vehicle traffic and pedestrians more often than does heavy/commuter rail. Because of the inherent operational differences between LRT and heavy/commuter rail and, more important, because of the increased interaction between LRVs, motor vehicles, and pedesrrians, LRT systems across the United States and Canada have placed top priority on strategies to minimize collisions and conflicts between LRVs, motor vehicles, and pedestrians. The research methodology that was followed to address these issues in Transit Cooperative Research Program Project A-5, Integration of Light Rail Transit into City Streets, is presented. The project's principles and guidelines for safe integration of LRT into city streets are summarized. Three traffic control devices that were recommended by the Project A-5 research team for possible inclusion in a new part of the *Manual on Uniform Traffic Control Devices* are described: motor vehicle turning movements, pedestrian crossing treatments, and LRT signal systems. These preliminary findings have been presented to the Project A-5 review panel but have not yet been approved by the Transportation Research Board.

In March 1994 the Transit Cooperative Research Program (TCRP) retained a team led by Korve Engineering, Inc., to conduct research with an overall objective to improve the safety of light rail transit (LRT) operation in shared right-of-way where light rail vehicles (LRVs) operate on, adjacent to, or across city streets at low to moderate speeds [about 55 km/hr (35 mph) or less]. Another objective of this research project is to develop material for inclusion into a new light rail–highway grade crossings part of the *Manual on Uniform Traffic Control Devices* (MUTCD). The title of TCRP Project A-5 is Integration of Light Rail Transit into City Streets. Hans Korve, President of Korve Engineering, Inc., served as the Principal Investigator. Subconsultants were Herbert Levinson, Senior Transportation Consultant; the Institute of Transportation Studies at the University of California, Berkeley; and Applied Management and Planning Group, Los Angeles.

The Korve Engineering research team in association with TCRP selected 10 transit properties across the United States and Canada at which extensive operational and accident analysis was conducted. The 10 LRT systems were chosen on the basis of experience with LRT operation in shared right-of-way where LRVs travel at or below 55 km/hr. The LRT systems surveyed were in Baltimore, Boston, Buffalo, Calgary, Los Angeles, Portland, Sacramento, San Diego, San Francisco, and San Jose.

For each LRT system, the research team interviewed representatives from light rail operations, light rail safety, light rail engineering, and light rail planning and from the local jurisdiction's (city or county) traffic engineering department. Following a structured interview guide developed by the research team, key safety issues, problem locations and alignments, and effective or ineffective traffic control devices (active and passive signs, pavement markings, traffic and LRT signals, pedestrian crossing treatments, etc.) were discussed. In addition to this structured interview process, the research team videotaped each system from the forward cab of an LRV to inventory traffic control devices currently being used. At-grade crossings, including cross streets and driveways, and problem locations were also video inventoried.

In addition to the on-site interviews and surveys at each of the 10 transit properties, the research team examined publications regarding the integration of light rail transit into city streets. It reviewed the extensive LRT operational and accident data collected by the Institute of Transportation Engineers Technical Committee 6Y-37, Guidelines for Design of Light Rail Grade Crossings.

The research team reviewed the video inventory and then analyzed the accident data provided by the 10 LRT systems. Each of the systems provided the research team with accident data, some of which is summarized in Table 1. After analysis of the structured interviews and the video inventories, a detailed accident analysis of problem locations, and an extensive review of ITE 6Y-37 data, guidelines and principles were developed for the integration of LRT into city streets. These principles and guidelines would apply to retrofit and extension of existing LRT systems and to the development of new LRT systems. Thus, they enable systems that are currently in the planning stages to learn from the design, operating, and safety experiences of existing LRT systems.

Principles and Guidelines

Five basic principles should guide the location, design, and traffic controls where LRVs operate on, adjacent to, or across city streets at low to moderate speeds (i.e., 55 km/hr or less). They are, in many respects, an extension of traffic safety engineering principles to LRT.

1. LRT system design and control should respect the urban environment that existed before LRT implementation. Both pedestrians and motorists grow accustomed to their urban environment. LRT systems that operate in these environments should conform, as much as possible, to the pedestrian and motor vehicle crossing needs.
2. LRT system design and control should comply with motorists' and pedestrians' expectations. Designs and controls should reinforce road user behavior; they should strive to minimize alterations in the travel patterns and traffic controls that motorists and pedestrians expect.
3. LRT system design and control should simplify decisions that drivers and pedestrians make as they interact with the LRT system environment. Traffic control devices and roadway geometry should be simple and unambiguous; they should clearly convey information to the motorist or pedestrian about the action to be taken.
4. Traffic control devices that are installed specifically to warn and protect motorists and pedestrians who interact with the LRT system should transmit the level of risk associated with the LRT system environment.
5. Forgiving design should be provided. Designs, controls, and operating practices should provide recovery opportunities for erratic or errant motor vehicle or pedestrian movements.

These five basic principles translate into the following planning guidelines for roadway geometry and traffic control design/selection:

- Unless a specific change is desired (e.g., converting a street to a pedestrian mall), attempt to maintain existing traffic and travel patterns. If travel patterns are changed significantly when LRT is implemented, motorists' and pedestrians' expectations may be violated.
- Where the LRT operates within street right-of-way, design LRT to run in the median of a two-way street. If LRT is designed to operate on a one-way street, LRVs should move in the direction of motor vehicle traffic, and all midblock access points, such as driveways, should be closed. Contraflow LRT operations should be avoided.
- Where the LRT operates within street right-of-way, separate LRT operations from motor vehicles by a more substantial element than striping.
- Provide LRT signals that are clearly distinguishable from traffic signals in design and placement without having to provide supplemental signs.

TABLE 1 Accident Summary for LRT Systems Surveyed

LRT System	Baltimore		Boston		Buffalo		Calgary		Los Angeles		Portland		Sacramento		San Diego		San Francisco		San Jose	
Period	4/92 - 7/94		7/89 - 8/93		2/85 - 11/93		5/81 - 12/93		7/90 - 6/94		FY87 - FY94		11/86 - 2/92		FY82 - FY94		1986 - 1993		7/87 - 12/93	
No. of Years	2.3		4.2		8.8		12.7		4.0		8.0		5.3		13.0		8.0		6.5	
Collision Type	No.	Pct.	No.	Pct. (a)	No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct. (b)	No.	Pct.	No.	Pct. (c)	No.	Pct.
Auto turns in front of LRV	55	86%	--	38%	0	0%	208	73%	129	56%	76	41%	--	59%	298	85%	--	27%	106	64%
Auto other	2	3%	--	58%	10	100%	(incl)	(incl)	73	31%	81	44%	--	38%	(incl)	(incl)	--	71%	50	30%
Pedestrian	7	11%	--	4%	0	0%	77	27%	31	13%	27	15%	--	3%	54	15%	--	2%	10	6%
Total	64	100%	97 (d)	100%	10	100%	285	100%	233	100%	184	100%	143	100%	352	100%	1,322	100%	166	100%
Mainline Track Miles (approx.) (e)	24		52		12		35		43		27		34		66		53		35	
Average Accidents per Year per Mainline Track Mile	1.16		1.87		0.09		0.64		1.35		0.85		0.79		0.41		3.12		0.73	

Source: Korve Engineering research team
Interview/survey at the ten LRT systems, Summer 1994

(a) Percentages for highest six accident locations.
(b) Percentages for highest two accident locations.
(c) Percentages for highest three accident locations.
(d) FTA 1992 Section 15 Report Year for FY 1992.
(e) Only includes tracks where LRVs operate in revenue service.

- Coordinate traffic signal phasing and timing near LRT crossings to preclude motor vehicles from stopping on and blocking the LRT tracks.
- Control motor vehicle turns that conflict with LRT operations by means of active standard traffic control devices.
- Provide adequate refuge areas for turning motor vehicle traffic and provide separate turn signal indications to avoid conflicts.
- When left turns can be made across median LRT tracks, provide active, internally illuminated Train Approaching signs at left-turn pockets with arrow indications to warn motorists of the increased risk associated with violations of the traffic signal.
- Create distinct pedestrian crossings by providing adequate refuge/safety areas between roadways and parallel LRT tracks.
- Channel pedestrian flows at crossings and at stations to minimize errant or random pedestrian crossings of the LRT track environment.
- At unsignalized crossings, use pedestrian gates and barriers (pedestrian automatic gates, swing gates, bedstead barriers, Z-crossings) appropriate to the type of LRT alignment and operation to make pedestrians more alert as they cross the LRT track environment. Bedstead barriers and Z-crossings should not be used at single track crossings with two-way LRT operations.
- Maximize the visual impact of LRVs in motion.
- Provide the necessary refuge area to unload and load passengers where LRT street running operations occur.

Traffic Control Devices

These principles and guidelines dictate that uniform traffic control devices be implemented to ensure the safe, orderly, and integrated movement of all traffic, including LRVs. TCRP Project A-5 called for the development of material for potential inclusion into a new light rail transit–highway grade crossings part of the MUTCD. Three highlights of the proposed material for inclusion in the manual are presented here: motor vehicle turning treatments, pedestrian crossing treatments, and LRT signals.

Motor Vehicle Turning Treatments

Motor vehicles that make illegal turns in front of approaching LRVs make up the greatest percentage of total collisions for most LRT systems (52 percent of the total collisions with motor vehicles or pedestrians at the 10 LRT systems surveyed). Moreover, because the motor vehicle door is the only protection for the driver and passengers and the LRV during a collision, turning collisions tend to be relatively severe. These facts indicate that traffic control devices that regulate turns are critical to LRT and general traffic safety.

Where turning traffic crosses a nongated, semiexclusive LRT alignment (an alignment where motor vehicles and pedestrians must cross at designated crossing locations only, for example, at an intersection) and is controlled by turn-arrow signal indications, an internally illuminated warning sign displaying the LRV front view symbol (W10-6a) or LRV side view symbol (W10-6b) should be installed, with a supplementary internally illuminated warning sign displaying the legend TRAIN, per the MUTCD, Part II, Section 2A-13 (see Figure 1). Both signs should flash when an LRV approaches. In this situation, the turn-arrow signal indication serves as the primary regulatory control device and the flashing, internally illuminated warning sign supplements it. The flashing, internally illuminated warning sign warns motorists of the increased risk associated with violating the turn-arrow signal indication. Because this warning sign is not a primary regulatory device and only supplements the primary device, only one flashing, internally illu-

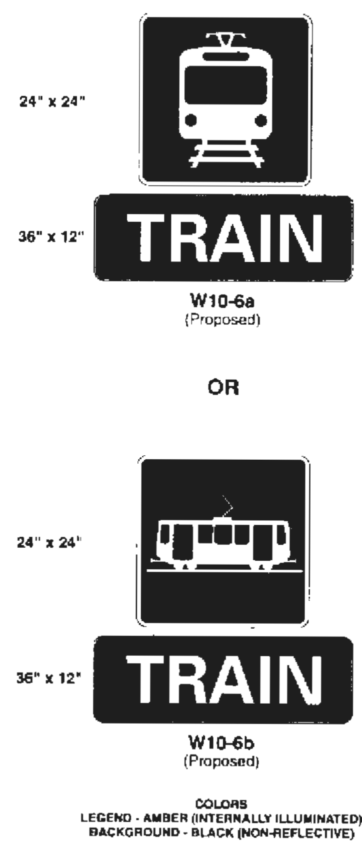


FIGURE 1 **Flashing internally illuminated Train Approaching warning signs.**

minated warning sign (W10-6a or W10-6b) should be provided for each turning movement. If this warning sign fails, motorists are to follow (*a*) the indication given by the primary regulator device, the left-turn arrow signal indications, and (*b*) the principles set forth in the *Uniform Vehicle Code*, Section 11-801 (Basic Rule):

> No person shall drive a vehicle at a speed greater than is reasonable and prudent under the conditions and having regard to the actual and potential hazards then existing. Consistent with the foregoing, every person shall drive at a safe and appropriate speed when approaching and crossing an intersection or railroad grade crossing.

Where turning traffic crosses a nongated, semiexclusive LRT alignment and is controlled by a stop sign or a signal without a turn arrow, an active, internally illuminated No Left/Right Turn symbol sign should be installed to restrict turns when an LRV is approaching. Because this sign serves as the primary regulatory control device for turning movements, at a minimum, two such symbol signs should be installed for each turning movement at a given crossing. The active, internally illuminated sign displaying the legend No Left/Right Turn may be used as an alternative to the symbol sign.

Instead of these symbol or legend turn signs, an all-red phase for motor vehicles and pedestrians may be used in combination with the No Turn on Red (R10-11a) signs when an LRV is approaching. If this strategy is used, a flashing, internally illuminated warning sign (W10-6a or W10-6b) may also be used to indicate to motorists and pedestrians the increased risk associated with violating the primary control device (the all-red signal indications).

Table 2 further summarizes the recommended practices for the active, internally illuminated No Left/Right Turn symbol sign (regulatory) and the flashing, internally illuminated Train Approaching sign (warning) for median or side-running LRT alignments where parallel traffic is allowed to proceed during LRV movements. As an alternative to the active, internally illuminated signs, as described in Table 2, passive No Left/Right Turn (R3-1,2) signs may be used to prohibit turning movements at all times (whether or not an LRV is approaching the crossing or intersection). However, alternative routes should exist and be clearly indicated by means of signing.

Pedestrian Crossing Treatments

Although collisions between LRVs and pedestrians occur less frequently than collisions between LRVs and motor vehicles (10 percent of the total collisions with

TABLE 2 Use of Active Internally Illuminated Signs for Parallel Traffic Turning Across LRT Tracks

Semi-Exclusive Gated	Stop[2]	Should	May
	Traffic Signal w/o Arrow[3]	Should	May
	Traffic Signal w/Arrow[4]	Not Recommended	May
Semi-Exclusive Non-Gated	Stop[2]	Should	May
	Traffic Signal w/o Arrow[3]	Should	May
	Traffic Signal w/Arrow[4]	Not Recommended	Should

1 Left turn signs are for median and side-running LRT alignments; right turn signs are for side-running LRT alignments only.

2 "Stop" refers to a stop-sign controlled intersection or driveway.

3 "Without Arrow" refers to a signalized intersection where the turning traffic does NOT have a red arrow displayed when a LRV is approaching, but has either a steady green ball, a red ball, or a flashing red ball displayed.

4 "With Arrow" refers to a signalized intersection at which the turning traffic has a red arrow displayed when a LRV is approaching. When a turn arrow traffic signal indication is used, an exclusive turn lane should be provided.

motor vehicles or pedestrians at the 10 LRT systems surveyed), LRV/pedestrian collisions are more severe than LRV/motor vehicle collisions. Furthermore, pedestrians are sometimes not completely alert to their surroundings, and LRVs when operating in a street environment are nearly silent. For these reasons, appropriate pedestrian crossing control systems are critical for LRT safety.

Warning Signs

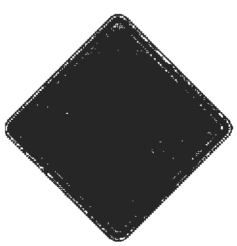
At signalized pedestrian crossings of LRT right-of-way (where pedestrian movements are controlled by pedestrian signals), the primary warning sign should be the Light Rail Transit Crossing (W10-5) sign (see Figure 2). The pedestrian signal is the primary regulatory device; the warning sign alerts the pedestrian of the increased risk associated with violating the pedestrian signal. At unsignalized pedestrian crossings of LRT street running right-of-way where LRT operates two-way, the W10-5a should be the primary warning sign (see Figure 2).

These warning signs should be mounted as close as possible to the minimum height above the ground set by the MUTCD (Part II, Section 2A-23). If these signs are mounted higher than the minimum height specified in the MUTCD [2.1 m (7 ft)], pedestrians often will not see or will simply ignore these signs. When these signs are mounted so that adequate clearance exists between the edge of the sign and the pedestrian travel path [minimum 0.9 m (3 ft) per the MUTCD, Part IX, Section 9B-2], they should be mounted with a minimum height of 1.2 m (4 ft) to better place the sign in the pedestrian's field of vision.

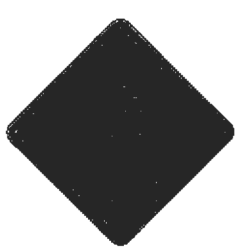
An LRV activated, internally illuminated, flashing sign with the legend Second Train—Look Left (or Look Right) may be used to supplement a W10-5 or W10-5a, to alert the pedestrian that a second (or third, fourth, etc.) LRV is approaching the crossing from a direction that the pedestrian might not be expecting when the crossing is located near an LRT station, track junction, or multiple track alignment (greater than two tracks). When this sign is activated, only one direction is illuminated at any time, Left or Right. Further, only one arrow (to the left of Look or the right of Right) is illuminated at any time: the arrow that points in the direction of the approaching, second LRV (see Figure 3).

Dynamic Envelope

The LRVs dynamic envelope should be delineated in semiexclusive street running, or nonexclusive corridors



W10-5
(Proposed)
24" x 24"
COLORS
SYMBOL & BORDER - BLACK (NON-REFLECTIVE)
BACKGROUND - YELLOW (REFLECTIVE)



W10-5a
(Proposed)
24" x 24"
COLORS
SYMBOL & ARROW & LEGEND & BORDER - BLACK (NON-REFLECTIVE)
BACKGROUND - YELLOW (REFLECTIVE)

FIGURE 2 LRT crossing signs.

W10-7
(Proposed)
30" x 18"
COLORS
LEGEND - AMBER (FIBER OPTIC ILLUMINATION)
BACKGROUND - BLACK (NON-REFLECTIVE)

NOTE:
Only One Direction is Illuminated at any time.

FIGURE 3 Second Train internally illuminated signs.

at pedestrian crossings. Contrasting pavement texture should be used to identify an LRV's dynamic envelope through a pedestrian crossing. A solid 4-in.-wide line may be used as an alternative. The Americans with Disabilities Act–approved strips can be considered a contrasting pavement texture, and their requirement may supersede the use of painted striping or other contrasting pavement texture. In an LRT pedestrian mall, the dynamic envelope should be delineated in its entirety.

Pedestrian Crossing Configurations

At signalized intersections, pedestrian movements that cross the LRT tracks should be controlled by pedestrian signals displaying the symbols for Walk and Don't Walk. At nongated, unsignalized, pedestrian-only crossings of semiexclusive right-of-way, a flashing light signal assembly [without a crossbuck (R15-1) mounted above the flashing lights] with a W10-5a sign mounted below the flashing lights should be used to warn pedestrians of an approaching LRV. At motor vehicle, gated, LRT crossings without pedestrian automatic gates (described below), a flashing light signal assembly with a crossbuck (R15-1) mounted above the flashing lights and a W10-5a mounted below the flashing lights should be used in the two quadrants without motor vehicle automatic gates. Following the principle of consistent application of signs, the W10-5a sign should also be mounted on a separate post near the pedestrian path in the quadrants with vehicle automatic gates.

In addition to the pedestrian signals, warning signs, and dynamic envelope markings described above, several pedestrian crossing configurations have proven effective in reducing collisions between LRVs and pedestrians. These barriers, and some of the LRT systems where they have been successfully installed, include the following:

- Curbside pedestrian barriers (Calgary, San Diego): Between LRT crossings, curbside barriers (landscaping, bedstead barriers, fences, and/or bollards and chains) should be provided along side-running LRT alignments for contraflow operations or two-way operations along a one-way street. They may be provided for one-way side-running normal flow alignments.
- Pedestrian automatic gates (St. Louis): Pedestrian automatic gates are the same as standard automatic grade crossing gates except the gate arms are shorter. They are used to physically prevent pedestrians from crossing the LRT tracks when the automatic gates are

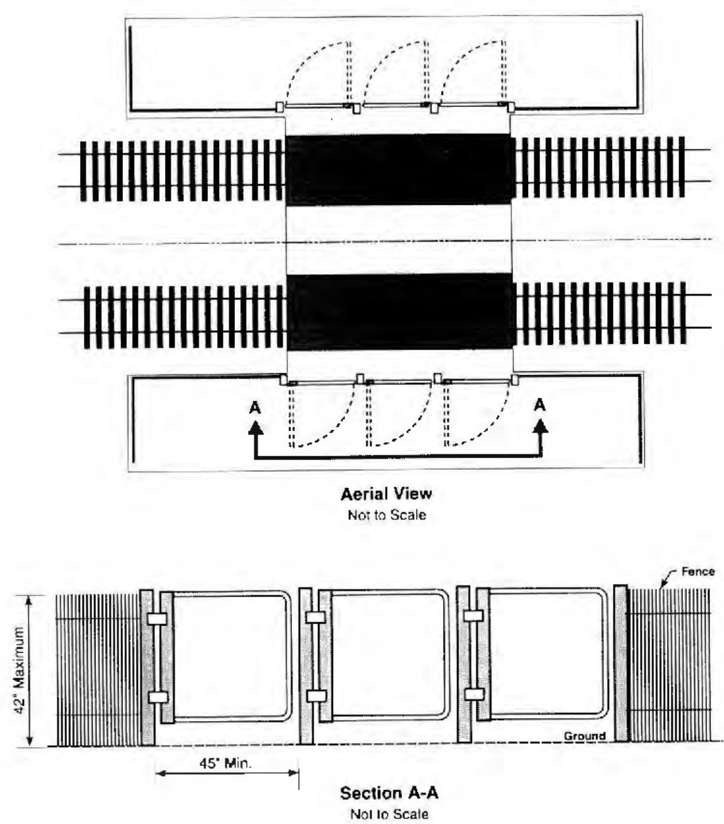


FIGURE 4 Swing gates.

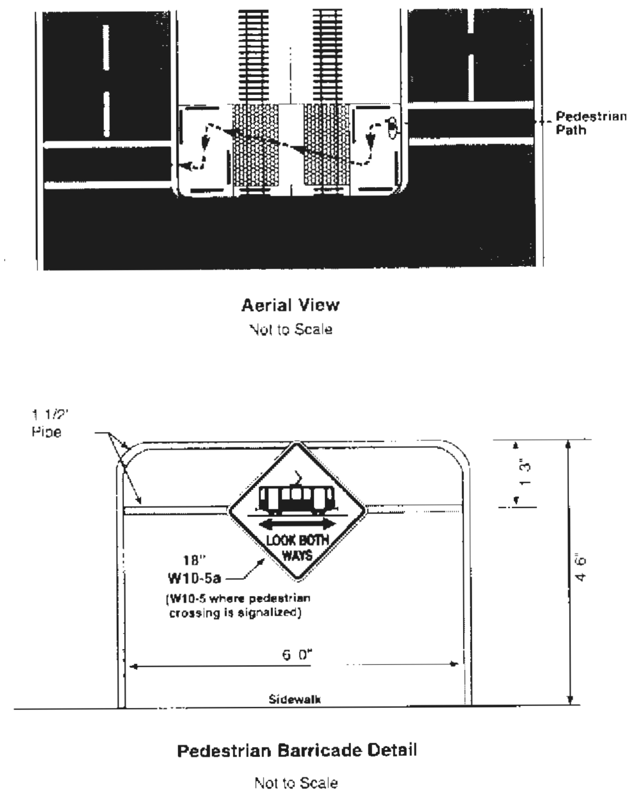


FIGURE 5 Bedstead barriers at LRT crossing.

activated by an approaching LRV. This type of barrier method should be used where the risk of a collision between a pedestrian and an LRV is medium to high. When stopping sight distance is inadequate, pedestrian automatic gates should be used.

The possibility of trapping pedestrians in the LRT right-of-way when four-quadrant pedestrian gates are installed should be minimized. Clearly marked pedestrian safety zones and escape paths within the crossing should be established.

- Swing gates (Calgary, San Jose): The swing gate alerts pedestrians to the LRT tracks and forces them to pause before crossing them, thus acting as a deterrent to running freely across the tracks without unduly restricting exit from the LRT right-of-way. The swing gate requires pedestrians to pull the gate in order to enter the crossing and to push the gate to exit the protected track area; therefore, a pedestrian cannot physically cross the track area without pulling and opening the gate (see Figure 4). The gates should be designed to return to the closed position after passage of the pedestrian. The Los Angeles LRT system plans to install them at various pedestrian crossing locations. Swing gates may be used when LRVs operate either on a single or double track.
- Bedstead barriers (Calgary): The "bedstead" concept may be used in tight urban spaces where the LRT

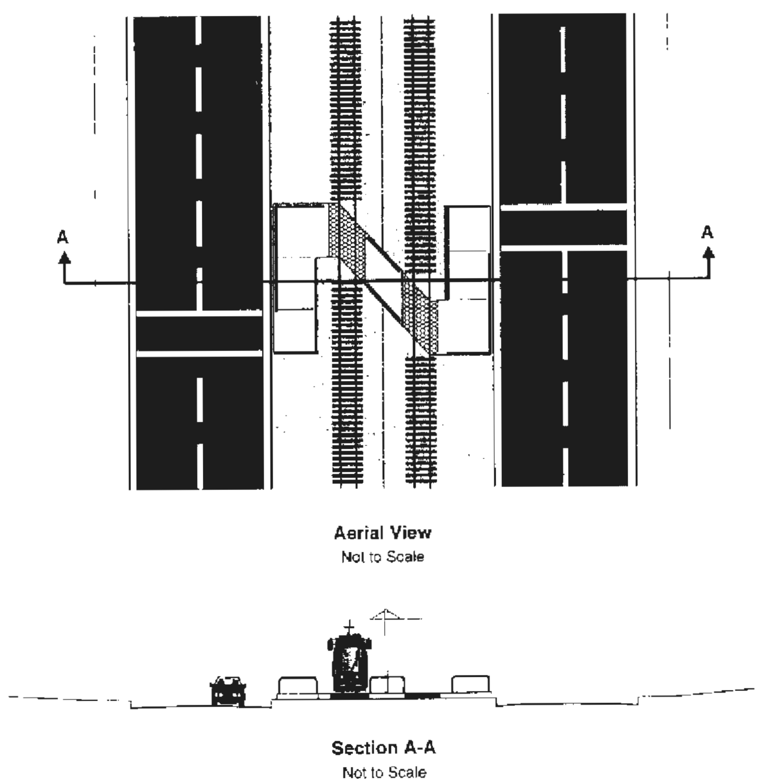


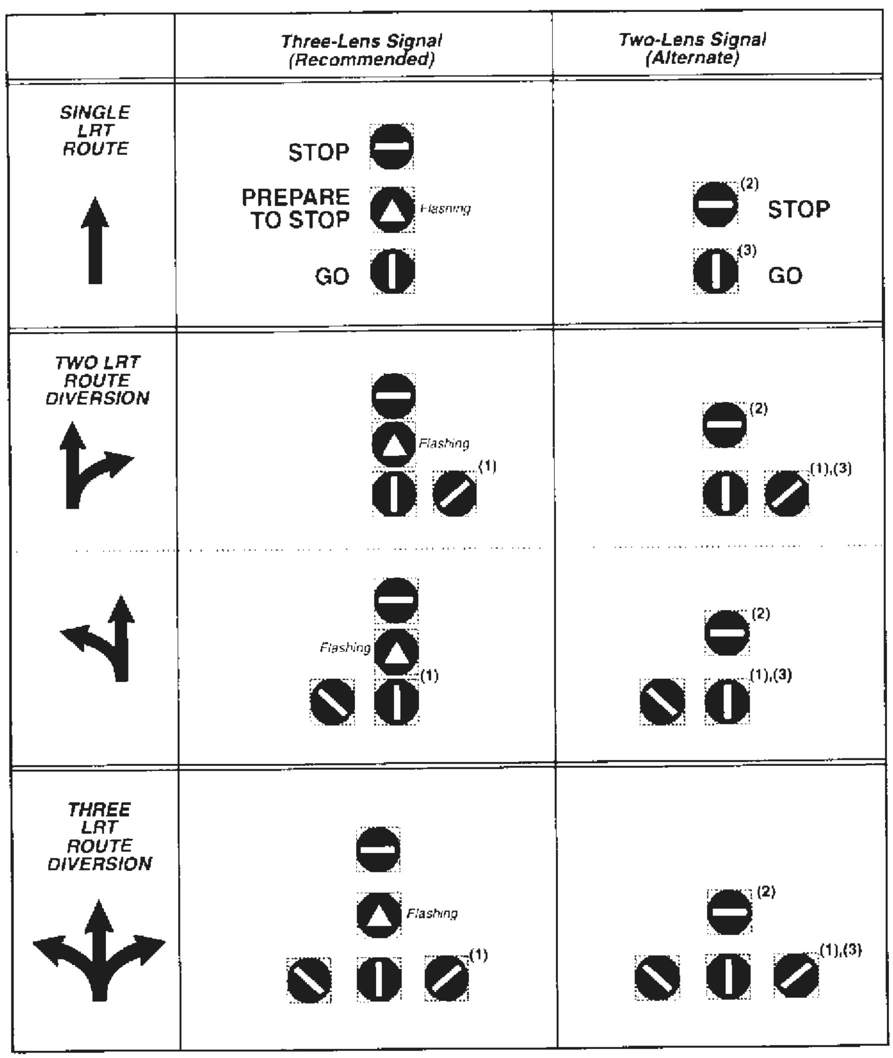
FIGURE 6 Z-crossing channelization.

right-of-way is not fenced in, such as a pedestrian grade crossing at a street intersection. The barricades are placed in an offset (i.e., maze-like) manner that requires pedestrians moving across the LRT tracks to navigate the passageway through the barriers (see Figure 5). They should be designed and installed to turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of oncoming LRVs. The barriers also provide a safe pedestrian queuing area. Bollards and chains accomplish the same effect as bedstead barriers.

Bedstead barriers may be used in crossings where pedestrians are likely to run unimpeded across the tracks, such as stations or transfer points, particularly where pedestrian risk of a collision with an LRV is low to medium (i.e., excellent to moderate stopping sight distance, double tracking, low pedestrian volume, etc.). Bedstead barriers should not be used when LRVs operate on a single track with two-way operation since pedestrians may be looking the wrong way in some instances.

• Z-crossing channelization (Portland, San Diego, San Francisco): The Z-crossing controls movements of pedestrians approaching LRT tracks. Its design and installation turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of oncoming LRVs (see Figure 6).

Z-crossing channelization may be used at crossings where pedestrians are likely to run unimpeded across the tracks, such as isolated midblock pedestrian-only



Notes:
All Aspects are White.
(1) Could be in Single Housing.
(2) "Stop" lens used in flashing mode to indicate "Prepare to Go".
(3) "Go" lens used in flashing mode to indicate "Prepare to Stop".

FIGURE 7 LRT signal aspects.

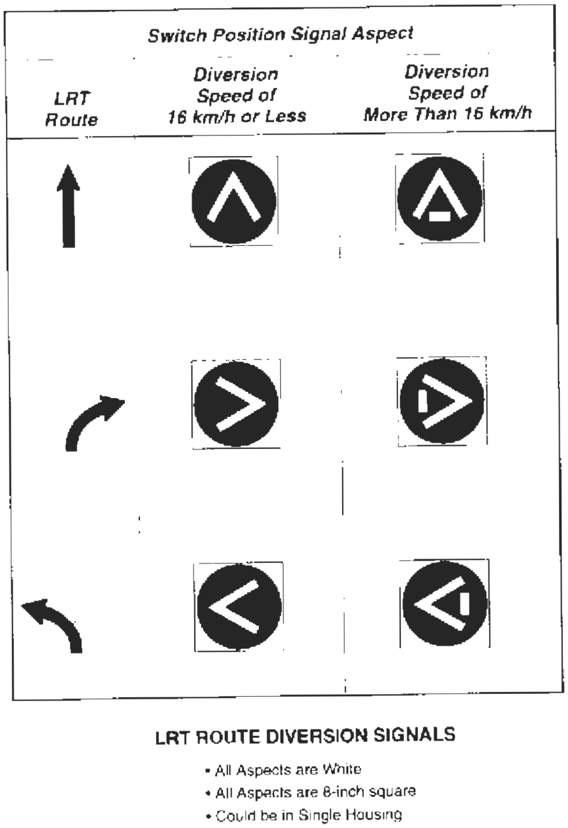


FIGURE 8 Separate signal indications for diversion switch positions.

crossings, particularly where pedestrian risk of a collision with an LRV is low to medium (i.e., excellent to moderate stopping sight distance, double tracking, low pedestrian volume, etc.). Z-crossings used with pedestrian signals create a safer environment for pedestrians than Z-crossings used alone. This type of channelization device may also be used in conjunction with automatic gates in high-risk areas. The Z-crossing should not be used when LRVs operate on a single track with two-way operation because pedestrians may be looking the wrong way in some instances.

LRT Signal Systems

Each of the 10 LRT properties surveyed for TCRP Project A-5 uses different LRT signal aspects and/or configurations (signal housing, color, etc.). For example, the LRT signal aspects range from the standard traffic signal aspect (i.e., the "ball" aspect, found in Boston, Buffalo, and Calgary), the "X" aspect (found in San Francisco), the "T" aspect (found in Los Angeles, Sacramento, San Diego, and San Jose), and the "Bar" aspect (found in Baltimore and Portland). The draft of the new part of the MUTCD addresses LRT signal indications that govern the movement of LRVs while operating on, adjacent to, or across city streets. Because motorists may be confused by the meaning of an LRT signal (e.g., motorists may interpret a green "T" signal that is visible from a left-turn pocket to mean "Turn"), they should have a format and color that are clearly different from conventional traffic signal displays. Where a light rail signal indication could cause motorists to be confused or misdirected, the signal indication should be positioned, shielded, optically programmed, or otherwise designed so that it is viewed exclusively by the LRV operators and not by motorists. The light rail signal indication should convey the intended message to the LRV operator without any supplementary signs (e.g., Trolley Signal sign). It should contrast with vehicular signals in size, shape, color, aspect, and placement.

The size of the LRT signal lenses should be a minimum of 30 cm (12 in.). In tight urban situations where LRVs operate at 40 km/hr (25 mph) or less, 20-cm (8-in.) lenses may be used. The shape of the signal housing should be rectangular (or square) and the color of the signal housing should be dark, preferably black, with a visor for each lens.

In addition to these general guidelines for LRT signal design and placement, the draft details the recommended LRT signal indications. The recommended LRT signal is the monochrome bar system where the Proceed indication is a vertical (or angled for diverging routes and switches) lunar white bar (placed near the bottom of the signal head), and the Stop indication is a horizontal lunar white bar (placed near the top of the signal head). Between the Proceed and Stop indications, a flashing lunar white triangle should be used to indicate Prepare To Stop (see Figure 7). Figure 7 also indicates the allowed alternative to the recommended LRV signal system.

LRT switch position indications (for diversion routes) should be a slanted bar Proceed indication in the standard LRT signal. Where separate signal indications are used for switch positions in street environments, the signal indication should be lunar white and display the arrow aspect [less than 16 km/hr (10 mph) route diverge] or the arrow aspect with a bar [more than 16 km/hr (10 mph) route diverge] (see Figure 8). The size of the signal lenses for LRT switch signals should be a minimum of 20 cm (8 in.) square. The color of the housing should be dark, preferably black, with a visor for each lens.

Operations and Maintenance Issues

Reorganizing for Tomorrow

Anthony J. Schill, *Niagara Frontier Transit Metro System, Inc.*

Organizations must evolve over time in response to internal and external changes. Organizations that do not evolve will fail to succeed in terms of efficiency, cost-effectiveness, product quality, and customer satisfaction. Niagara Frontier Transit Metro and its parent organization, the Niagara Frontier Transportation Authority, recently completed the transition from a traditional hierarchical structure to a decentralized model. Metro's organizational history is examined and the factors affecting organizational decision making are identified. The principal conclusions reached are that the decentralized management structure achieved by Metro has resulted in improved internal accountability and communication.

Any successful organization evolves over time in response to internal and external changes. Organizations that fail to recognize the need for change may not actually fail in the sense that they go out of existence, but they will fail in terms of efficiency, cost-effectiveness, product quality, and customer satisfaction.

Most large North American public transit systems have long histories, often reaching back to the formation of small independent electric street railway companies in the 19th century. Between 1890 and 1910, most of these smaller lines were consolidated into the major private systems that dominated the transit industry until after the Second World War and, indeed, right up to the transition to public ownership and operation.

The organizational structure of the major street railways was typically patterned after that of a somewhat distant relative, the steam railroad. The railroad was the first product of the Industrial Revolution to require a strong centralized organization to carry out its operation. Operating frequent freight and passenger service over many miles of track with a high degree of efficiency and safety, but without the technological assistance we take for granted today, required a tightly disciplined and well-organized approach to doing business.

The railroads naturally turned to the military for inspiration, since armies had long faced similar organizational challenges. Thus the "top down" type of organization, wherein orders originate at the top and then are passed through multiple layers of management, to be executed without question at the bottom, became the norm in railroading—and, by extension, the urban electric railway business.

No longer are such hierarchical arrangements seen as the only way to do business in transit. Today a strong emphasis is placed on decentralization through the "flattening" of organization, that is, reducing the number of layers of management as much as possible and placing more authority in the field.

Metro, the transit system in Buffalo, New York, has recently made the transition to a contemporary organizational format. The purpose of this paper is to examine Metro's organizational history, identify the factors that had an impact on organizational decision making, and draw conclusions about the effectiveness of the decisions that have been made.

Metro History

Niagara Frontier Transit Metro System, Inc. (Metro) is the wholly owned transit operating subsidiary of the Niagara Frontier Transportation Authority (NFTA). NFTA also operates two airports, including Greater Buffalo International Airport; two intercity bus terminals in Buffalo and Niagara Falls; and a recreational boating facility on Lake Erie. The purpose for which NFTA was originally formed, to provide terminal facilities in Buffalo for Great Lakes maritime shipping, is no longer relevant to operations.

NFTA is a public benefit corporation created by the state of New York, and all 11 of its commissioners are appointed by the governor. The commissioners also constitute the board of directors of Metro. The executive director of NFTA, who is appointed by the commissioners, also serves as the president of Metro.

The present Metro system was formed in 1974 when NFTA bought the assets of the major private local transit provider, Niagara Frontier Transit System, along with the assets of several smaller operators. At the time Metro began operations, the vehicle fleet consisted of approximately 500 buses, rail operation having been given up in 1950.

In 1978 construction began on Metro Rail, a 6-mi "starter" line comprising a 1-mi transit-pedestrian mall and a 5-mi subway. Method of operation and facilities approximate the heavy rail systems found in other cities. Metro Rail opened in phases between 1984 and 1986, and the 27-car fleet currently carries in the neighborhood of 29,000 weekday riders. The total annual ridership on Metro (bus and rail) is 30 million passengers.

System Organization

NFTA was originally formed to operate Buffalo's port facilities. Later, the two primary airports came under NFTA jurisdiction. Finally, in 1974 Metro's transit operations were added. As a result of this growth process, NFTA came to have an unwieldy organization; by 1984 there were more than 15 direct reports to the executive director, as shown in Figure 1.

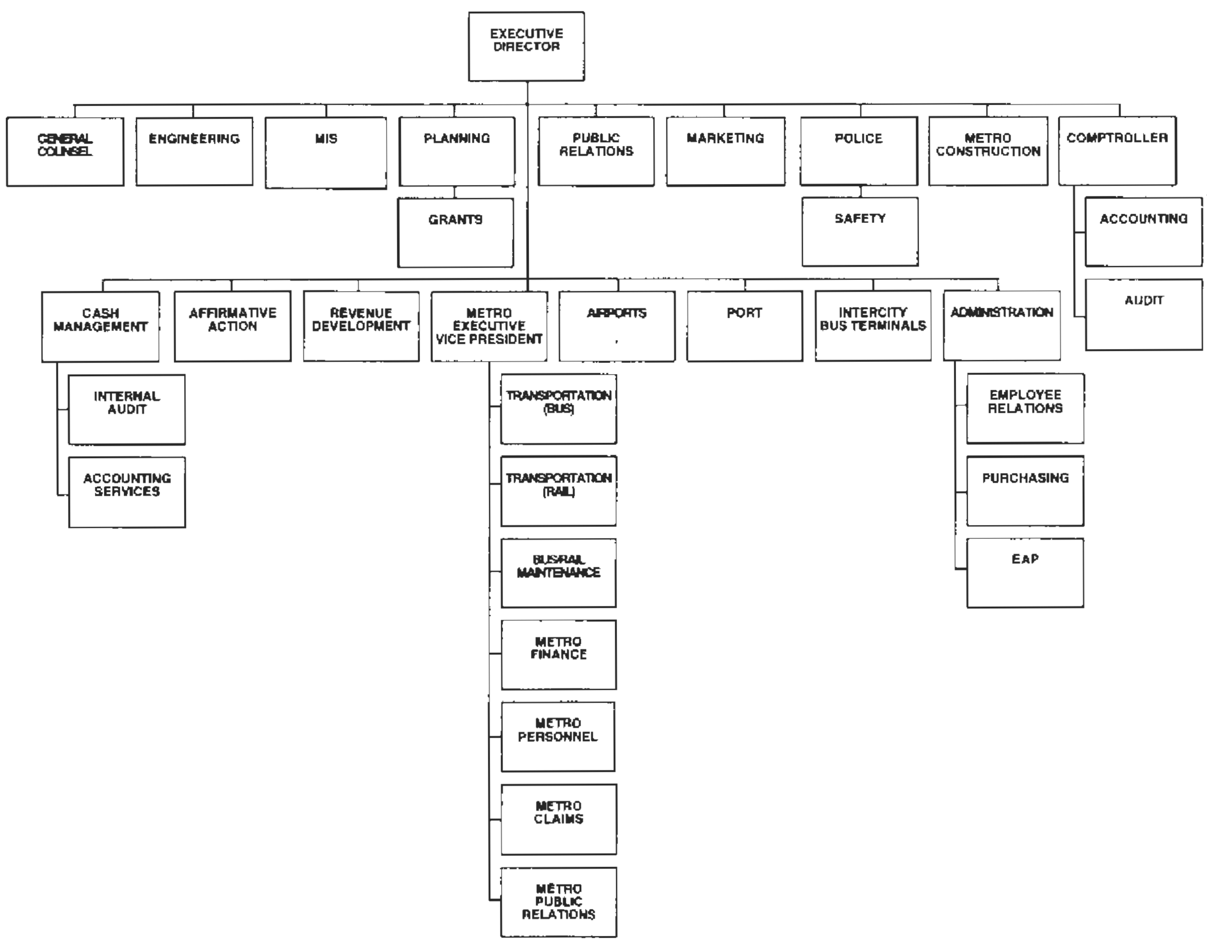


FIGURE 1 Niagara Frontier Transportation Authority, 1984.

From 1974 to 1987, Metro (bus and rail) functioned independently of NFTA except, of course, for its policy decisions and funding. Metro was organized on a stand-alone, "Chinese wall" basis intended to keep it completely separate from NFTA in order to protect other NFTA divisions from any impact of operating losses on the transit system. Consequently Metro retained its own operating and support functions, including Transportation (which included Scheduling), Maintenance, Public Relations, Finance, and Personnel. (Metro's personnel were on a different benefits program than NFTA employees.)

Until the inception of rail operation in 1984, the Metro system's organization had remained essentially unchanged since the days of private operation. Many of the senior managers had served in the same capacities for the private operator. Many of these managers had 35 to 40 years of service and were extremely familiar (and comfortable) with the then-existing organizational structure.

Metro's 1980 (pre-rail) organization, shown in Figure 2, was characterized by multiple layers of management and a strong "downtown" orientation for decision making. The two major operating units, Transportation and Maintenance, had parallel reporting structures all the way up the line. Field locations were almost totally focused on day-to-day operating issues, with all budgeting and financial responsibilities (apart from payroll submissions) being carried out in the General Office. A strong philosophy of cost control, carried over from the private era, was nevertheless present. (For a number of years Metro was actually able to "bank" federal operating assistance.)

The advent of the rail project in the late 1970s eventually brought numerous changes into both the NFTA and Metro organizations. Building a rail line was viewed as an NFTA project, although Metro would operate the line once it was built. Metro was only peripherally involved in the decision to build and in the actual construction. Indeed, Metro's management probably would have preferred to continue operating an all-bus system (Metro Rail was planned as much as an urban development project as a transit facility).

In any event, NFTA established the Metro Construction Division (MCD) to oversee system design and construction. The original rail plan underwent numerous substantial modifications as a result of community involvement and financial constraints. The intended 12-mi line (from downtown Buffalo to the State University's new campus in the suburb of Amherst) had to be

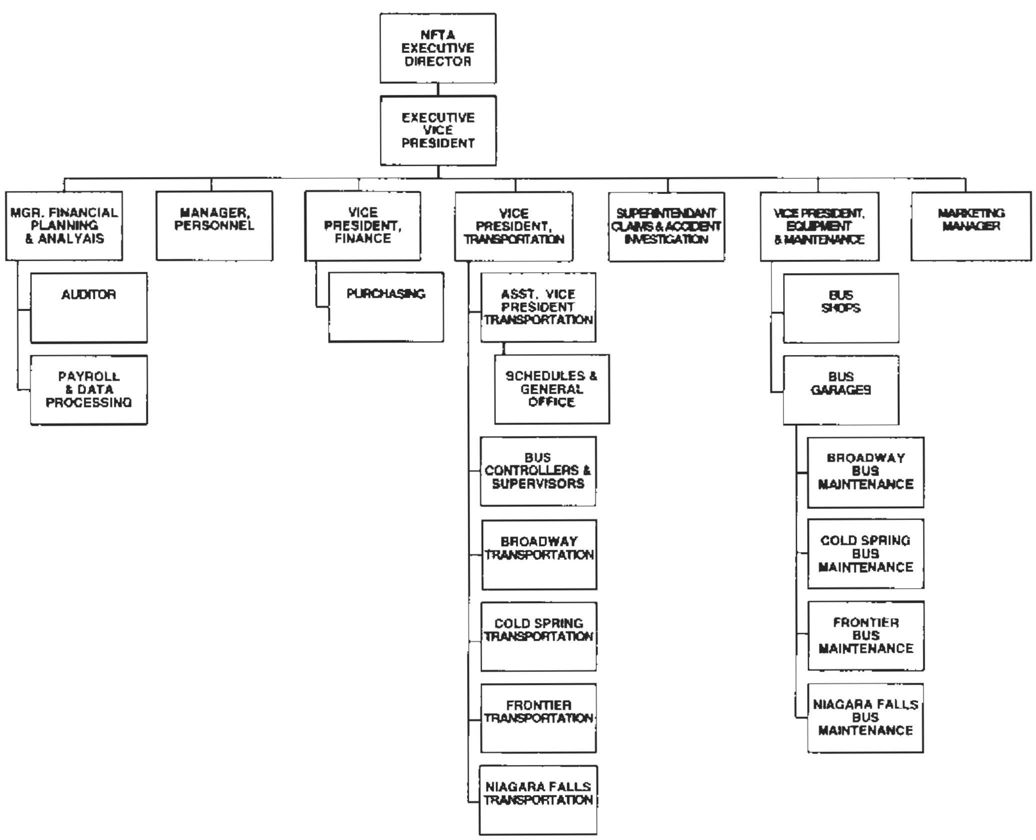


FIGURE 2 Metro, 1980.

truncated to a 6.2-mi segment ending at the older SUNY Campus at the Buffalo city line. A major contributing factor was the community's insistence on additional subway construction where above-grade operation had been planned. Ultimately, the total cost of the line rose to $550 million.

By 1981 construction had progressed to the point where it was thought desirable to begin bringing on board the management staff who would eventually operate the system. MCD's consultant on operational matters, Day & Zimmerman, drafted an organizational plan that included two major rail units, Transportation and Maintenance. The Transportation Unit would be headed by a rail transportation superintendent, who would report directly to Metro's existing senior officer, the executive vice president (who in turn reported to the NFTA executive director). Rail maintenance functions, however, would report to the vice president—equipment for the bus system, because Metro's management at the time considered bus and rail maintenance issues to be similar in nature. While not fatally flawed, this decision led to structural problems later on because rail personnel believed that important issues went unaddressed by bus-oriented officials. The overall Metro organizational plan in effect when rail service began in 1984 is shown in Figure 3. The original organization plan for just the rail functions is shown in Figure 4.

A brief look at the internal NFTA-Metro relationship is useful at this point. At the time of the 1974 NFTA takeover, Niagara Frontier Transit was not in immediate financial distress, although the operation was becoming increasingly subject to the ills common to private-sector public transit. In some respects, the joining

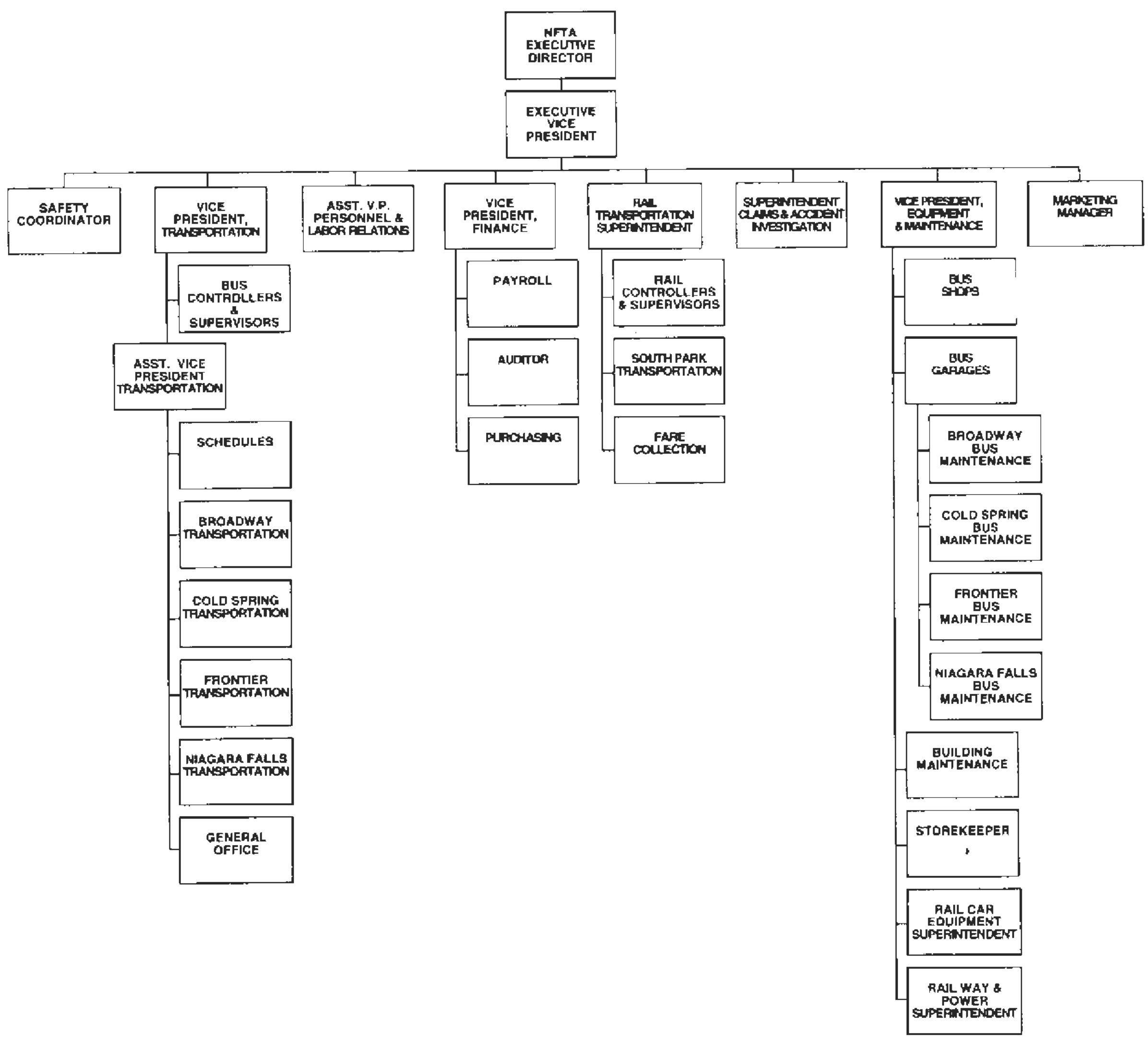


FIGURE 3 Metro, 1984.

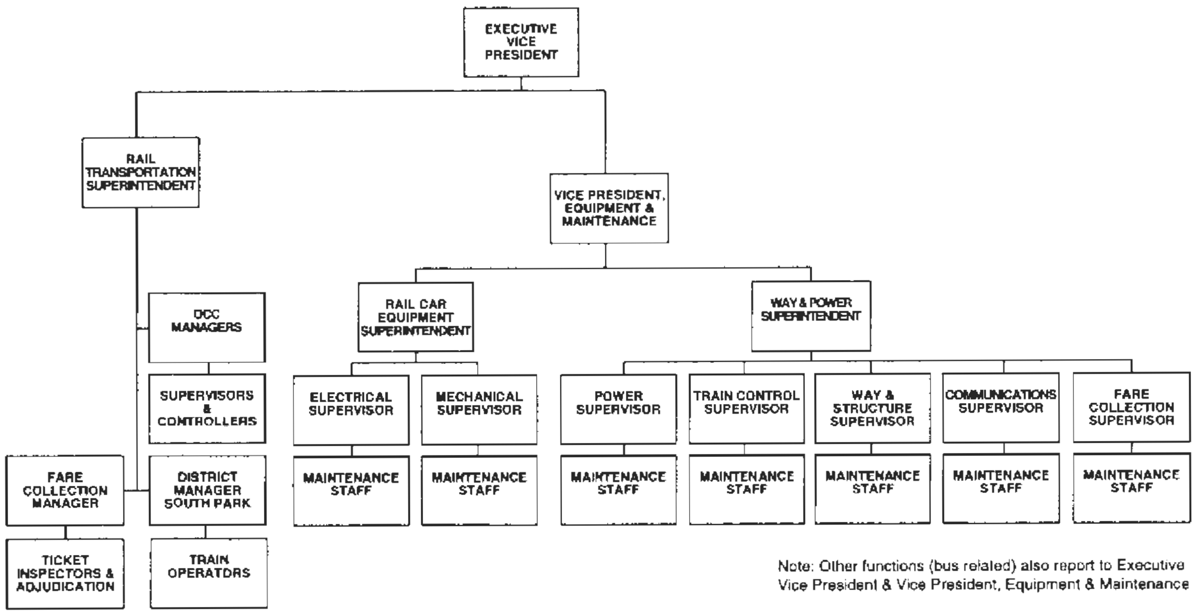


FIGURE 4 Metro Rail Division, 1984.

of NFT (i.e., Metro) to NFTA was not a happy marriage. The highly politicized environment of NFTA at the time did not sit well with Metro's once private-sector executives. Conversely, NFTA officials believed Metro was too much bound by tradition and that Metro's executives were unwilling to adapt to changing conditions. At times, the friction became intense.

At the behest of MCD, Metro recruited the rail transportation superintendent in early 1982. This person served as the sole employee on Metro Rail (excluding, of course, the NFTA employees in Metro Construction) until early 1984. At that time other operating managers and supervisors began to come on board in anticipation of the planned fall 1984 start-up of limited service on the Mall.

During this period funding was readily available to support system operation, both through start-up grants and federal operating assistance previously banked by Metro. Consequently, and despite the fact that long-promised local financial support had not materialized, rail operations began with relatively few constraints (other than good sense) on staffing decisions.

Those staffing decisions were largely driven by operating parameters that had been established years before during design. For example, the actual base of rail operations at South Park (i.e., yard, shop, and office for rail operators and ticket inspectors) was located at the southern end of the line, about 1 mi from the new bus/rail operations control center (itself adjacent to the existing downtown NFTA headquarters building). Even at South Park, the Transportation Unit was at the west end of the facility, while Maintenance was at the east end, some 800 ft away.

This geographic dispersal of units necessitated a somewhat larger staff of management employees than might have been the case had all units been housed in a central facility. In addition the technological complexity of the rail line, such as full train control, centralized power control, and a complete supervisory control and data acquisition system, all linked to the Operations Control Center (OCC), drove a decision to provide on-site management for most of the operating day. Thus the two OCC managers each covered an 8-hr weekday shift, with on-call duty officers designated at other times.

Period of Change

From late 1985 until 1987 there was continuing turmoil in the upper echelons of NFTA. During this period considerable unfavorable media and public attention was focused on NFTA, with much of that attention being given to questionable business practices. The executive director resigned under pressure in late 1985, and the chairman of the board of commissioners assumed the role of de facto acting executive director.

In due course local dissatisfaction with the situation at NFTA led to the mid-1987 appointment of a new executive director. For the first time, NFTA would be directed by a person with extensive high-level transit operating experience rather than by a political appointee.

The former general manager of a major multimodal transit system was selected to head NFTA. The new executive director immediately set out to reduce expense and to change the NFTA versus Metro mindset by consolidating all support functions. Metro's Finance, Personnel, and Public Affairs departments were folded into the corresponding NFTA units. This left the Metro executive vice president with direct responsibility for only the Transportation and Maintenance units. Figure 5 shows the 1987 reorganization.

More important, the executive director enacted internal reforms in hiring, promotion, and salary decision making. He also strengthened internal procedures designed to correct other administrative and business practice problems. As a result the public attitude toward NFTA and the staff's morale began to improve.

During this period rail operations and organization were largely unaffected. The major modification was the 1987 transfer of the rail ticket inspection/adjudication function out of Transportation to the General Counsel; this was done as part of the major reorganization mentioned earlier. Another 1987 change was the elimination, through attrition, of one of the two OCC manager positions. Structure was realigned so that the rail transportation superintendent reported to the manager, Transportation, primarily a bus-oriented position, rather than directly to the executive vice president.

Although it was not a major problem, the rail operation was somewhat disadvantaged by a bus-oriented reporting structure. Creating a totally separate rail organization having coequal status with bus was considered but was found to be not feasible owing to cost constraints. In 1989 a rail official was promoted to the position of executive vice president (later retitled general manager, Metro) and the issue became less important. Final resolution, however, did not occur until the 1994 reorganization, which is described later.

Financial Crisis

Metro experienced severe financial problems in 1989 and again in 1990. Major service cuts, including all weekend service, were threatened in 1989 but were averted at the last minute by commitments of local aid. By 1990 not all such commitments had been fulfilled, and all bus and rail service was withdrawn for 2 days. This resulted in the establishment of a dedicated source of revenue at the local level, but the total amount generated was not much more than had been received before.

These financial crises and other administrative and philosophical differences caused a deepening rift between the board and the executive director, leading to the latter's resignation in April 1990. The general counsel then headed the authority on an interim basis until the appointment of a new executive director the following October.

Although it was not evident at the time, this transition in administrations set the stage for far-reaching or-

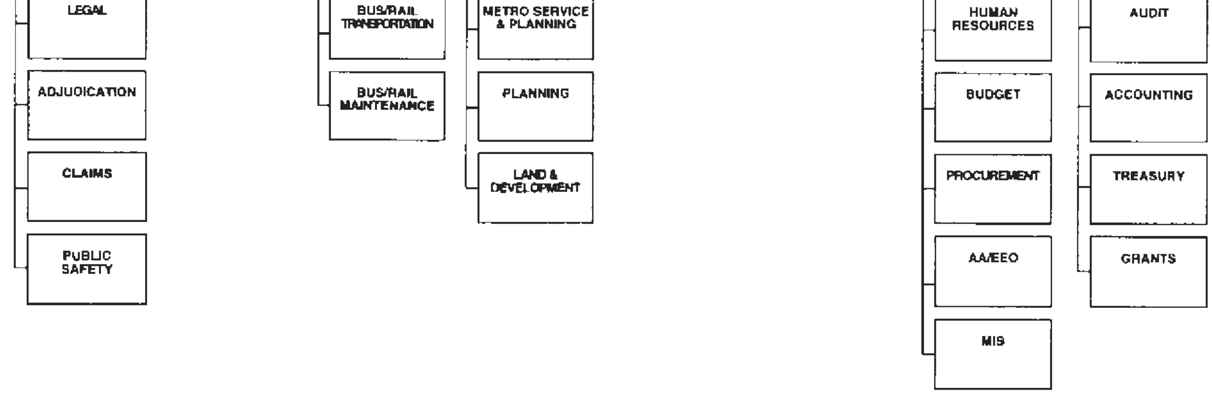


FIGURE 5 Niagara Frontier Transportation Authority, 1987.

ganizational changes throughout the authority but especially in Metro. Despite a lack of transit experience, the new executive director quickly grasped transit's financial facts of life and the critical importance of improving both efficiency in transit operations and service quality. This led to a plan to restructure the organization to achieve improvement throughout NFTA.

In 1991 the NFTA management structure was again reorganized. Nine senior management positions in addition to the executive director were created. The nine positions were general counsel, chief financial officer, and six general managers—for Metro, Transportation Services (airports, etc.), Human Resources, Engineering, Marketing/Revenue Development, and Affirmative Action. The general managers for the operating units (Metro and Transportation Services) were to have direct responsibility not only for actual daily operations but also for ensuring that broader planning, marketing, human resource, and financial needs were met through effective utilization of shared support functions. Figure 6 shows the impact of the 1991 reorganization.

Metro's 1994 Reorganization

Once the reorganization at the top was implemented, attention turned to the restructuring of individual operating and administrative support units. In the case of Metro, that restructuring focused on specific goals, including a need to

1. Create resources to address unmet needs in safety and training,
2. Place more authority and accountability in the field by eliminating much of the existing organizational hierarchy,
3. Eliminate parallel reporting structures in Transportation and Maintenance, and
4. Correct internal problems caused by having Rail Maintenance report to an essentially bus-oriented manager.

This major restructuring was also seen as essential to encouraging the realization by all employees that Metro had to become a customer-driven organization.

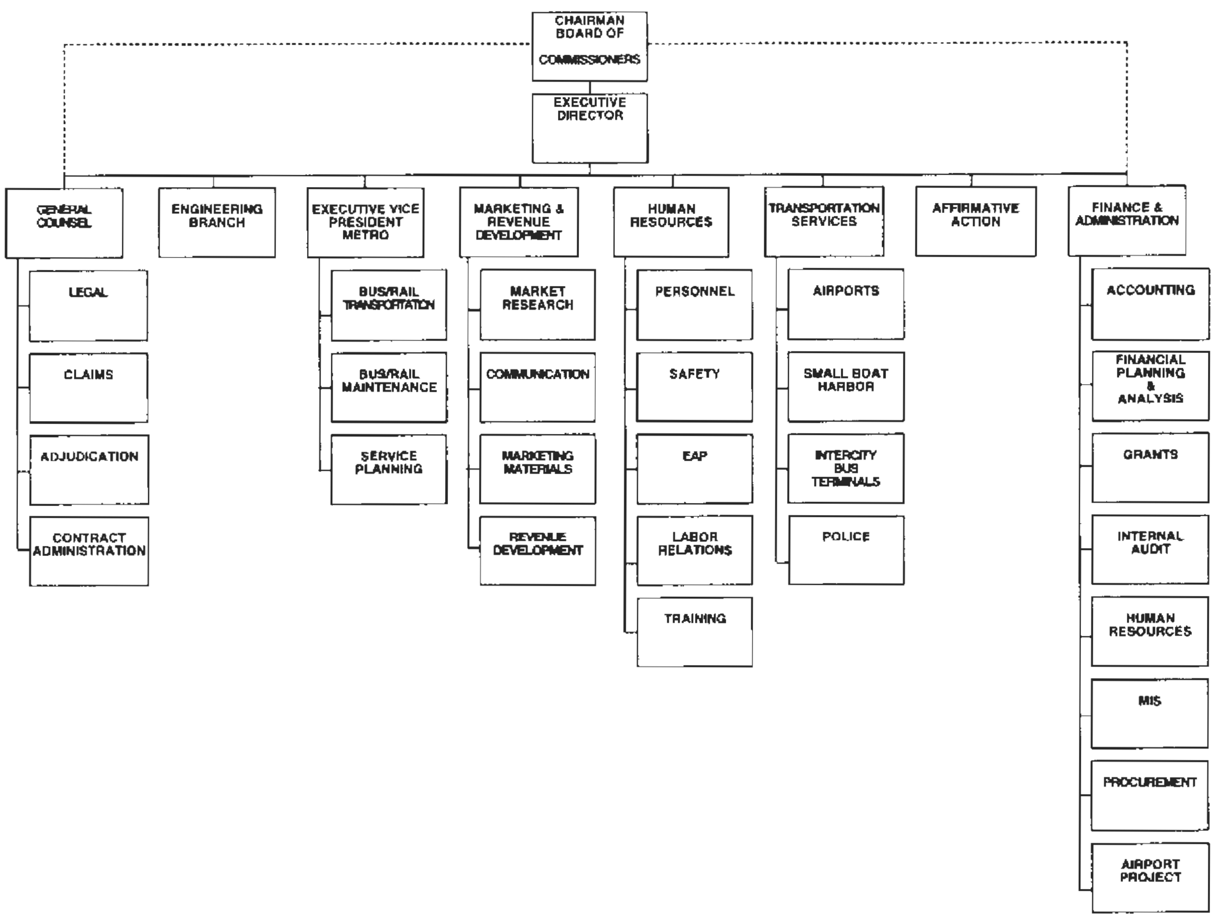


FIGURE 6 Niagara Frontier Transportation Authority, 1992.

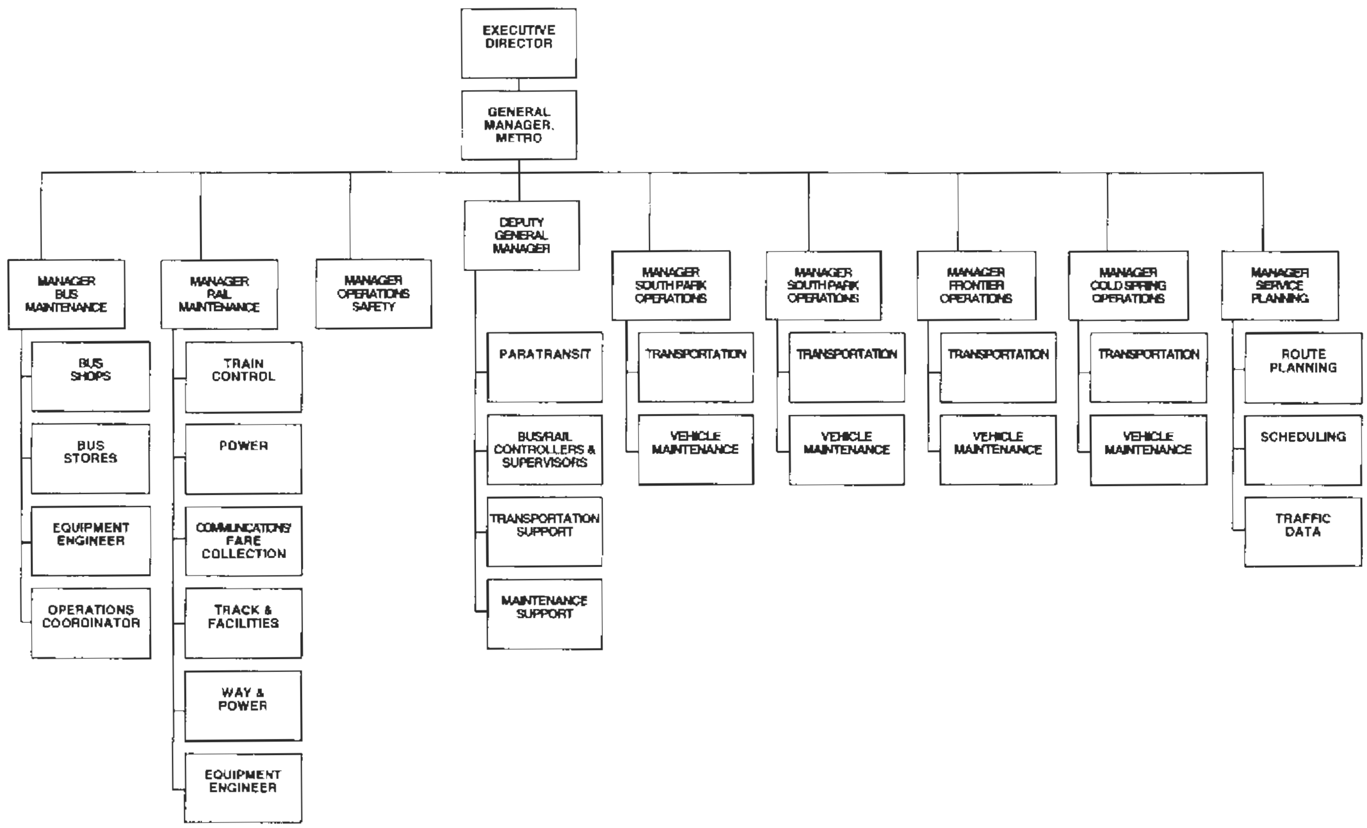


FIGURE 7 Metro, 1994.

The essence of the reorganization was the creation of an operations manager position at each of the three bus facilities and at the rail operating base. Each operations manager has full responsibility for all Transportation and Vehicle Maintenance functions at that location, including service quality and budget adherence. Each reports directly to the general manager, Metro.

Other units reporting directly to the general manager, as shown in Figure 7, are deputy general manager (Paratransit, Transportation and Maintenance Support, and Bus/Rail Control Center and Field Supervision), Service Planning, Operations Safety, Bus Maintenance (bus shops, building maintenance, and materials management), and Rail Maintenance.

Implementation of this reorganization occurred in March 1994. Whereas some problems in coordination were experienced, on the whole it has been very successful. Making one person at each facility responsible for the total operation has greatly improved coordination between transportation and vehicle maintenance activities. Placing more responsibility in the field has eliminated the need to consult "downtown" on a wide range of issues. This has expedited the decision-making process and has led to increased communication, particularly with represented staff.

Metro's new organizational structure will be tested severely in the near future. The impact of major reductions in (and possible eventual elimination of) federal operating assistance, combined with a sharp decline in our principal local subsidy, is setting the stage for a major financial crisis within the next 2 years. This crisis will be exacerbated by the expenses associated with the implementation of mandated paratransit service. In total, Metro's operating subsidies are expected to decline by more than $7 million annually while paratransit costs increase to nearly $5 million. This represents a swing of more than $12 million in a $70 million operating budget.

Since no system's operating budget can accommodate such pressures without major surgery, plans have been developed to cut union and management staffing, seek nontraditional revenue sources (e.g., Medicaid), investigate an undue financial burden waiver for paratransit, raise fares, consolidate garages, and ultimately, if no relief occurs, to substantially reduce bus and rail service.

We believe that Metro's current organizational structure will enable us to continue to provide a high quality of service even in a period of dwindling financial resources. Achieving that is certainly a monumental challenge, but it is one we can and will meet.

Assessing Effectiveness of Light Rail Transit Systems: An Application of Malcolm Baldrige National Quality Award Criteria

Burton V. Dean and Taeho Park, *San Jose State University*

Light rail transit (LRT) has recently become an attractive urban transit system alternative in the United States. To enhance this momentum of increasing public acceptability, LRT quality and performance should be continuously improved by implementing principles of total quality management and closely monitored through the use of systematic evaluation methods. A structure and framework for conducting an internal assessment of quality and performance of an LRT system using the Malcolm Baldrige National Quality Award (MBNQA) criteria are presented. This approach is applied in an LRT case study as a self-assessment of LRT operations in the Santa Clara County Transit District (SCCTD). The self-assessment examination form was developed using the 1994 MBNQA examination criteria. The majority of SCCTD Quality Council members reported thar the MBNQA criteria-based self-assessment methodology was a useful tool for evaluating the status of quality and performance of LRT operations, as well as for suggesting areas for improvement.

Light rail transit (LRT) is a medium-capacity, streetcar-type transit system that is electrically powered from overhead wires and runs along steel tracks with steel wheels. LRT operates on city streets and highways with either exclusive or shared rights-of-way. Starting in 1872 in Hanover, Germany, many European and Asian countries have adopted LRT as their public urban transportation systems. Although U.S. cities began using electric streetcars in the late 1800s and the early 1900s, LRT in the U.S. had disappeared by the 1960s in favor of automobiles and buses. However, LRT has recently become an attractive urban transit system alternative in the United States owing to its greater flexibility (or mobility) than trains, better cost-effectiveness than cars, better movability than buses in a heavy traffic urban environment, lower construction costs than rapid transit systems, and alleviation of air pollution problems. To enhance this momentum of increasing public acceptability, LRT quality and performance should be continuously improved by implementing principles of total quality management (TQM) and closely monitored through the use of systematic evaluation methods.

Takyi et al. (*1*) emphasized that the benefits from implementing TQM in transit environments will vary depending on the specific objectives to be achieved, the procedures used in applying the concepts, the support provided by top and middle management, and the level of understanding of and expectation from the TQM program. Examples of favorable results from recent TQM applications in transit systems are seen in Toronto and Cleveland. The Toronto Transit Commission, within a year of implementing its TQM program in

1991, was able to reduce employee discourtesy complaints, complaints about vehicle operation, service delays, and door operation problems by 26 percent, 19 percent, 55 percent, and 22 percent, respectively. The quality improvement program established in 1989 at the Greater Cleveland Regional Transit Authority saved $500,000 in energy costs for 2 years. Although Oswald and Burati (*2*) demonstrated that TQM can be used in the highway construction sector, Takyi et al. (*1*) found very few applications of TQM in the public sector, particularly in the transit industry. In addition, a recent issue of *Research Results Digest* of the Transit Cooperative Research Program (*3*) also reported that "to date, only a few (transit) agencies have introduced innovative TQM-based practices."

Fielding (*4*) addressed the need for an effective transit performance evaluation method in the United States: ". . . the evaluations mandated by federal, state, and local legislation in the United States are deficient. . . ." He provided four components required for performance evaluation of public enterprise: dimensions that represent the objectives that motivated public intervention, indicators that translate objectives into quantitative measures, an information system that gathers appropriate data in a consistent manner to provide cross-sectional and time-series statistics, and an incentive system that rewards managers for improving performance. He also stated that performance reports should be reviewed by a performance committee that includes employee representatives.

Examining the Malcolm Baldrige National Quality Award (MBNQA) criteria used as a quality and performance assessment tool reveals that the seven categories of the criteria are representative of Fielding's components: leadership, information and analysis, strategic quality planning, human resource development and management, quality assurance of programs and services, quality results, and customer satisfaction (*5*).

The MBNQA criteria were originally developed to serve as a basis for giving Malcolm Baldrige National Quality Awards annually to recognize U.S. companies for business excellence and quality achievement (*5*). The MBNQA criteria are designed to provide a comprehensive and structured approach to systematically assess manufacturing or service firms. Although the criteria had a strong bias toward manufacturing at the beginning, they are continuously improved through revisions based on suggestions and comments, and changes in thinking about quality systems.

The importance of quality in the service industry has been well recognized (*6*). Since 1990 there have been five MBNQA winners in the service category: Federal Express Corporation (1990), AT&T Universal Card Services (1992), the Ritz-Carlton Hotel Company (1992), AT&T Consumer Communications Services (1994), and GTE Directories Corporation (1994). The benefits from quality improvement programs revealed by the MBNQA winners are numerous. For example, Quality Action Team (QAT), an employee involvement program at Federal Express Corporation, has saved $27 million in the personnel division for 4 years, $1.5 million in recovered revenue by a computer automation QAT, and $462,000 in saved overtime payments in 6 months by a payroll QAT. Furthermore, across the United States, in corporations, government agencies, school systems, and nonprofit groups, organizations are discovering the value of using the MBNQA criteria as a do-it-yourself quality assessment tool kit to assess and improve quality (*7*).

This paper develops a structure and framework for conducting an internal assessment of quality and performance of an LRT system from a management perspective, using the MBNQA criteria. The methodology is applied in an LRT case study, as a self-assessment of the LRT operations of the Santa Clara County Transit District.

Malcolm Baldrige Quality Award Criteria and Applications

In confronting major foreign competition in its products and services, both U.S. industry and government have responded to increasing challenges in the global marketplace (*8*). The demand for continuous improvement of quality and productivity evoked national efforts to restore world leadership to the United States again, resulting in the initiation of a national quality award in 1987, the MBNQA. Annual awards are given under the auspices of the Malcolm Baldrige National Quality Improvement Act. The purpose is fourfold: to stimulate U.S. companies to achieve excellence in business and quality achievement; to recognize outstanding companies to serve as a model for other companies; to establish guidelines that business, governmental, and other organizations can use to evaluate and improve their own quality efforts; and to share information of winning companies on successful quality and productivity improvement strategies and the benefits derived from implementation of these strategies (*9*).

Award applications are reviewed and evaluated on the basis of seven MBNQA criteria categories (*5*):

1. Leadership: Senior executive leadership must be a driver for achieving organizations' common goals of customer satisfaction and retention and market share gains through quality and productivity improvement. This category examines the senior executives' personal leadership and involvement in creating and sustaining a customer focus and clear and visible quality values.

Also examined is how the quality values are integrated into the company's management system, including how the company addresses its public responsibilities and corporate citizenship.

2. Information and analysis: A company's information system is very important for fact-based management and operations and for benchmarking processes. This category examines the scope, management, and use of data and information to maintain a customer focus, to drive quality excellence, and to improve operational and competitive performance.

3. Strategic quality planning: Strategic quality planning is necessary to understand customer and operational requirements, to ensure effective and efficient deployment of the requirements at all levels of an organization, and to make the best use of resources. This category examines the company's planning process and how all key quality and operational performance requirements are integrated into overall business planning.

4. Human resource development and management: Effective human resource development and management should be tied into a company's strategic direction so that high performance workplace practices become part of an organizational strategy. This category encompasses how well human resource planning is developed to empower employees and connected with strategic directions, and how a company's job design, compensation, education and training, and recognition programs can stimulate all employees to work in efficient and productive ways.

5. Management of process quality: Continuous improvement of quality in processes of operations and services is critical in meeting or exceeding customers' needs. Key elements of process management, including management of day-to-day operations, continuous improvement of quality and operational performance, and quality assessment are examined to ensure that customer requirements and expectations are met. Actions and plans for improving supplier quality are also part of the examination in this category.

6. Quality and operational results: This category focuses on the company's achievement levels and improvement trends in quality, company operational performance, and supplier quality. Also examined are current quality operational performance levels relative to those of competitors.

7. Customer focus and satisfaction: The company's relationships with customers, its knowledge of customer requirements, and the key quality factors that drive market competitiveness are measured. Also examined are methods of determining levels of customer satisfaction and retention.

The MBNQA framework in Figure 1 presents dynamic relationships among the above seven categories (*5*). The framework is composed of four basic connected and integrated elements: driver, system, goals, and measures of progress. In the 1994 criteria, there are 28 "examination items" under the seven categories and 91 areas to address. Examination items, the main subcategories of the examination category, are given a point value. The number of items in each examination category varies from two to six. Each examination item

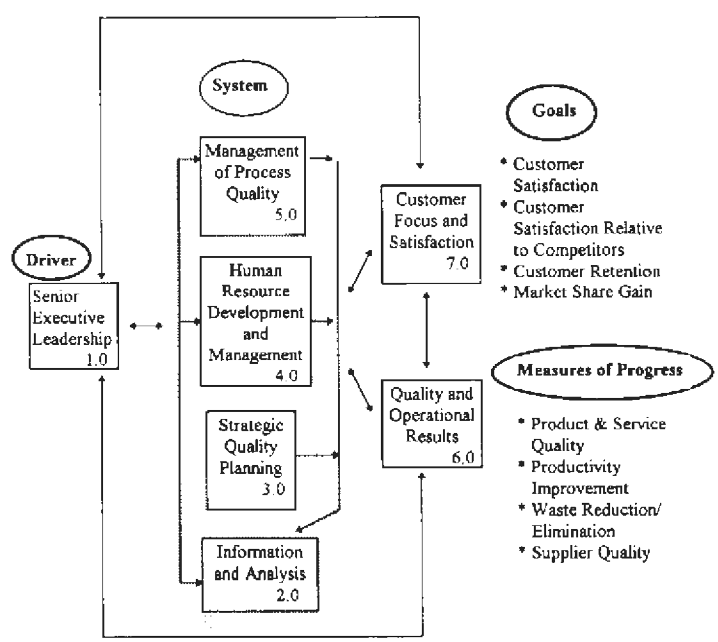


FIGURE 1 Framework of dynamic relationships among MBNQA criteria (*5*).

consists of a set of "areas to address" that require the MBNQA applicants to submit specific information.

MBNQA applications are scored on a three-dimensional scoring system: approach, referring to specific tools and techniques a company uses to improve its quality; deployment, referring to the extent of the implementation of the company's approaches throughout all relevant areas in the organization; and results, referring to the outcomes in accomplishing the purposes addressed in the examination items. A scoring guideline to be used in assigning item scores for these three dimensions is provided to MBNQA examiners.

Although the MBNQA criteria were designed to be used to make annual awards and to provide information about quality and operational performance to applicants, they have also been used as an effective self-assessment tool in many organizations (*7,10*). For instance, Digital Equipment, Inc., has not reapplied for the MBNQA since its original application in 1988; however, the company continues to use the MBNQA criteria for assessing the status of its quality. Varian Associates, Inc., has also used the Baldrige criteria as a basis for evaluating its quality system and was planning at the time of this study to apply for a 1995 MBNQA Award. Although relatively few organizations have sought the MBNQA, many want to learn how well they are performing and how they can improve their quality and productivity and prefer an inexpensive means, such as an MBNQA criteria-based self-assessment (*11*). A Quality Progress 1995 survey (*12*) has also verified that the MBNQA criteria are being used by many firms primarily to obtain information on how to achieve business excellence, and the criteria's usefulness has met or exceeded many users' expectations.

There are several different approaches to using the MBNQA criteria as a company's self-assessment tool: as a source of examiners (internal or external examiners), as assessment criteria (the Baldrige criteria with or without modification), and as a basis for internal awards. Although many companies such as McDonnell-Douglas and National Car Rental use the MBNQA criteria without modification, Control Data expanded the MBNQA criteria to structure the Control Data Quality Award with 11 categories. State (e.g., Minnesota) and company (e.g., IBM, Intel, and Honeywell) quality awards based on the MBNQA criteria have been established to promote awareness of quality and to subsequently improve quality and productivity (*7*).

Systems Description of the Santa Clara County Transit District

The California Santa Clara County light rail transit system is an updated version of San Jose's streetcar system, which had overhead electric wires and steel wheels running along street tracks. The system is one of the longest light rail lines built in the past 50 years in the United States and is the first financed in part by the 5 cent federal gas tax. It started with 9 mi of light rail, from Santa Clara through downtown San Jose, which were completed in June 1988. The entire 20-mi line was completed in April 1991 and has 33 stations. The main objective of building this light rail system is to move Santa Clara County into the future with an alternative means of transportation that can comfortably and swiftly carry many more people per traffic lane without creating traffic jams and air pollution.

Most commute day trips originate from the housing areas at the southern end of the line. Passengers may park free at one of the nine LRT stations with park-and-ride lots or take feeder buses to the stations. For bicyclists, bike storage lockers are available. Tickets are purchased from a self-service vending machine, and passengers enter the vehicle from a boarding platform. At destination stops, passengers may board feeder buses or special shuttles to travel farther. The current LRT system has 50 light rail vehicles (LRVs) and 6 trolleys, with 34 cars in service each day.

On January 1, 1995, the Santa Clara County Transit District (SCCTD) was separated from the Santa Clara County Transportation Agency and combined with the Congestion Management Agency to form an independent organization. SCCTD is composed of a 12-member board of directors, an independent general counsel team providing legal consultations, a general manager, and an assistant general manager. SCCTD consists of six divisions (Fiscal Resources, Marketing and Service Development, Planning and Capital Development, Human Resources, Transit Operations, and Transit Maintenance) and the Congestion Management Agency. Employees in the SCCTD number approximately 2,000. Each division processes two operations: bus and light rail transit. The systems description presented below is limited to SCCTD's light rail operation. Table 1 describes the key functions of the SCCTD divisions.

Case Study: Applying the MBNQA Criteria in SCCTD

Organization and Structure of Case Study

This study was organized using the systems approach, as shown in Figure 2, to test the effectiveness of the MBNQA criteria in the SCCTD (*13*). The study team met with the SCCTD director to describe the study's objectives and to obtain recommendations on the approach to be followed. The SCCTD director requested the study team to work closely with the director of mar-

TABLE 1 Key Functions of the SCCTD Divisions

Transit District Division	Key Functions
1. Fiscal Resources	• Administration • Materials Management • Financial Accounting • Purchasing Coordination • Budget and Contract • Financial Disbursements • Information Services
2. Marketing and Service Development	• Administration • Customer Service • Transportation Programs • Transit Information Services • Service Development • Marketing
3. Planning and Capital Development	• Administration • Facilities Design • Rail Design • Planning and Programming • Property Management • Grants Management • Construction Design
4. Human Resources	• Training • Personnel • Labor Relations • Health and Safety Administration
5. Transit Operations	• Administration • Light Rail and Communication Operations
6. Transit Maintenance	• Administration • Engineering • Warranty and Quality Assurance • Facility Maintenance • Roadcall • Equipment Maintenance • Way, Power, and Signal

keting and service development, who served as a liaison between the study team and SCCTD. During the course of the study, the team met frequently with the SCCTD division management to introduce the MBNQA criteria methodology and to review the study's evaluations and results.

The initial phase of the study was to orient the study team to SCCTD operations. A complete tour of all relevant facilities was conducted, along with detailed meetings with the management of each division. The study team reviewed the overall agency organization of SCCTD. Following a review of the organization charts, the study team scheduled interviews with each of the division management teams. At each division interview, information was collected on organizational objectives, division functions and activities, the measures of quality and productivity being used, and the extent to which quality information and analyses were used.

The study team found as a result of the interviews that the divisions were using three measures of quality:

- Process measures: controlling the process of delivering services to SCCTD riders and employees, such as the length of time a rider waits for trains and the frequency of accidents;
- Product measures: outcome of the service that the SCCTD can assess without involving its riders, such as downtime of cars and the mean distance (miles) between failures; and
- Satisfaction measures: surveys of riders' reactions to their experiences and analyses of customer complaints, which are the most meaningful picture of the district's perceived quality.

Quality Council: Organization and Activities

To aid in the implementation of the study, an ad hoc SCCTD Quality Council was formed. The purpose of the council was to act as a management steering committee for the study and to coordinate and review all work performed by the study team. Organizational units represented on the Quality Council were

- Marketing and Service Development, Acting Deputy Director;

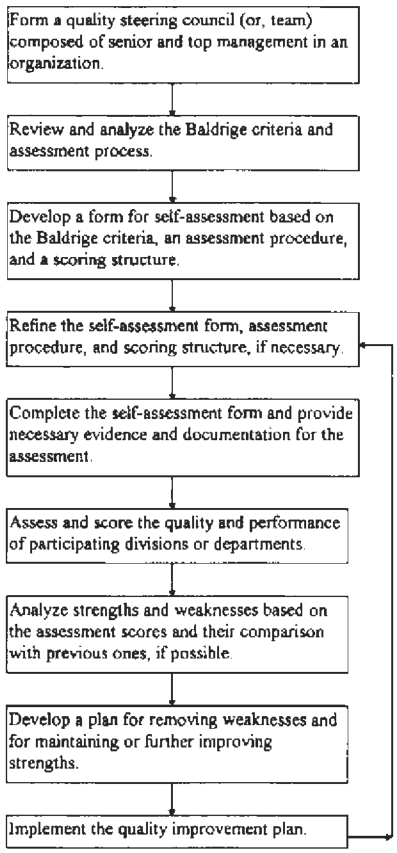


FIGURE 2 Procedure for applying Baldrige criteria to internal assessment of an organization.

- Human Resources, Deputy Director;
- Way, Power, and Signal, Superintendent;
- Transit Administration, Assistant Director—Transit Operations;
- Fiscal Resources, Deputy Director;
- Maintenance Operations, Manager;
- Light Rail Operations, Manager;
- Equipment Maintenance, Manager; and
- Planning and Capital Development, Director.

Three Quality Council workshops were held:

- Workshop 1: The objectives and plans for the case study were introduced to Quality Council members. They reviewed the MBNQA process and its criteria. The procedures in applying the MBNQA criteria to self-assessment for the LRT operation were discussed.
- Workshop 2: A draft of the Baldrige criteria-based examination form developed by the study team was reviewed by the Quality Council. The council agreed to use the 1994 MBNQA criteria scores for the examination items without any modification. In this case study, as a demonstration project, examination items were assigned for self-assessment to the council members responsible for the corresponding areas of management.
- Workshop 3: Results of the Baldrige criteria application were reviewed and discussed. Comments and suggestions were made on the examination form developed during this case study, the scores of individual examination items, the assessment procedure, and the resources required for the self-assessment. In addition, comparisons of 1994 and 1995 MBNQA criteria were discussed (5).

Development of an MBNQA Criteria-Based Self-Assessment Form

After analyzing the operations of the SCCTD LRT system, the study team developed an internal assessment form and a scoring system based on the 1994 Baldrige examination criteria. The Quality Council agreed to use the same examination categories, items, and weighted scores as the 1994 MBNQA evaluation.

In the Baldrige examination process, examiners score items on the basis of guidelines of relevant evaluation dimensions among approach, deployment, and results. [Refer to the scoring guidelines of the National Institute of Standards and Technology (5).] For example, although Item 1.1, Senior Executive Leadership, is evaluated considering approach and deployment, Item 7.5, Customer Satisfaction Results, has only one evaluation dimension, results. Each item has at least one examination area to be evaluated. The scoring guidelines presented in Table 2 are based on the 1994 Baldrige scoring guidelines, which separate approach from deployment.

Each category in the examination form is composed of three sections: objectives, terms and notes, and assessment items. Each assessment item has two subsections: the first subsection describes the item, and the second subsection lists detailed areas to be examined. Examination areas contain the dimensions in which they must be evaluated on the basis of evidence and documents submitted. Table 3 presents an example (i.e., the first item of Category V) of the structure of the examination form used in this study.

After reviewing evidence and documents provided for all examination areas relating to each item, the Baldrige examiners determine the score of the item on the basis of the scoring guideline. The examination process used in this study is slightly different from that of the Baldrige examination in that each examination area in an item is evaluated separately in using dimensions associated with it. Percentages assigned to all examination areas in the item are combined to yield a single score. A scoring calculation format is provided in the examination form, as presented in Table 3.

TABLE 2 General Scoring Guidelines (Modified from 1994 Baldridge Scoring Guidelines)

SCORE	APPROACH	DEPLOYMENT	RESULTS
0-10%	• anecdotal, no system evident	• anecdotal	• anecdotal
11-39%	• beginnings of systematic prevention basis	• some major areas of operations	• some positive trends in the areas deployed
40-69%	• sound, systematic prevention basis that includes evaluation/ improvement cycles • some evidence of integration	• most major areas of operation • some support areas	• positive trends in most major areas • some evidence that results are caused by approach
70-90%	• sound, systematic prevention basis with evidence of refinement through evaluation/ improvement cycles • good integration	• all major areas • many support areas and operations	• good to excellent in all major areas • positive trends in many support areas • evidence that results are caused by approach
91-100%	• sound, systematic prevention basis with evidence of refinement through evaluation/ improvement cycles • excellent integration	• all major areas, support areas, and operations	• excellent (world-class) results in all major areas • good to excellent in all support areas • sustained results • results clearly caused by approach

Analysis of Results

All examination items were evaluated by the Quality Council members responsible for the corresponding areas of management. The total score was evaluated to be 519 out of 1,000 points, as presented in Table 4. This score is not as high as Baldrige winners, whose scores range from 751 to 875 points. The current quality and performance of the agency are, however, considered to be reasonably good. Hart and Bogan (*14*) present a guideline for interpreting the score received, as shown in Figure 3. In providing ranges of scores in seven groups rather than exact scores, they stress the following:

1. Scoring is not an exact science: To provide an "exact score" would be misleading and could result in arguments between applicants and examiners over a few insignificant points.

2. Scoring by ranges forces applicants to focus on the continuous-improvement aspect of the Baldrige process rather than on adding to the number of points they received.

According to their score-interpretation guideline, SCCTD presents evidence of efforts in improving quality and performance of LRT operations, and some of its efforts are outstanding. Although the LRT operates on a good preventive basis instead of an error-correcting basis, prevention efforts for customer-based quality operations need further improvement. In addition, improved deployment (or implementation) and sustained results are needed.

The status of quality and performance achievement in the LRT system of the SCCTD can be interpreted based on Hart and Bogan's (*14*) seven pillars of the MBNQA evaluation as follows:

1. Leadership (70 points out of 95, i.e., 73.7 percent): Senior managers fully support quality improvement efforts. Resources are adequately invested, and some cross-functional implementation is visible.

2. Information and analysis (28 points out of 75, i.e., 37.3 percent): Activities for collecting prevention-based data have begun in some key areas. A prevention-based data collection means designing a measurement control device at the earliest monitoring point in the process to alert operators that the process is out of control. Data and findings relating to quality and productivity are not always readily accessible.

TABLE 3 Example of the Structure of Examination Form Using the First Item of Category V

V. MANAGEMENT OF PROCESS QUALITY

V.1. Objectives

V.2. Terms and Notes

V.3. Assessment Areas to Address

V.3.1. Design and Introduction of Quality Services

Concerns:

What to look for regarding:

- Existence of procedures to translate customer requirements into operations/service requirements.
  Approach Score: ____________%
  Evidence/Documentation:
  Comments/Suggested Action:
  Deployment Score: ____________%
  Evidence/Documentation:
  Comments/Suggested Action:
- Existence of an appropriate operational performance plan.
  Approach Score: ____________%
  Deployment Score: ____________%
- Adequate reflection of operations/service quality requirements into the overall long- and short-term operation/procurement/service planning processes.
  Approach Score: ____________%
  Deployment Score: ____________%
- Proper coordination and integration of the operation/procurement/service planning processes to include all phases of the operations, procurement, and direct customer services.
  Approach Score: ____________%
  Deployment Score: ____________%
- Consistent and systematic review/evaluation process for the operation and service performance, and part supplier quality and delivery capability.
  Approach Score: ____________%
  Deployment Score: ____________%

Average Scores: Approach (A) ____________%
Deployment (D) ____________%
Score for this item: 40 pts x (A + D) / 2: ______________**pts.**

3. Strategic quality planning (27 points out of 60, i.e., 45.1 percent): Senior management starts to get involved and a few fundamental processes are restructured. However, SCCTD's LRT system needs to plan and develop projects and programs to increase ridership. Quality is also still mostly a defensive posture, focused primarily on internal processes and on the elimination of occurring problems, not on aggressively identifying and planning to meet customer needs. These results imply that the SCCTD needs to restructure its fundamental processes to achieve better customer satisfaction through increasing ridership and quality of LRT operations. Since senior SCCTD managers fully support quality improvement efforts as identified in the leadership evaluation, this restructuring would, once initiated, be strongly supported by SCCTD top management.

4. Human resource development and management (108 points out of 150, i.e., 72.0 percent): Human resource management plans take quality improvement process requirements into account. As a result of the SCCTD's staff development programs, most managers and many employees have been trained in aspects of total quality management. The team approach has been used to improve quality and productivity, and significant resources have been dedicated to training. Employee survey and analysis reports show an increase in employees' involvement and an improvement in their work attitudes.

5. Management of process quality (57 points out of 140, i.e., 40.7 percent): Customer needs are reflected in service design. Cycles of evaluation and improvement are in place but not widely deployed throughout SCCTD. There is some integration of prevention and correction.

6. Quality and operational results (116 points out of 180, i.e., 64.4 percent): Quality improvement systems in many areas of operations and many support functions are strongly integrated. Trends in vendor quality show strong improvement.

TABLE 4 Quality Scores of Examination Items Evaluated by Quality Council Members

1.0 Leadership	**70 /95 pts**
1.1 Senior Executive Leadership	35 /45 pts
1.2 Management for Quality	20 /25 pts
1.3 Public Responsibility and Corporate Citizenship	15 /25 pts
2.0 Information and Analysis	**28 /75 pts**
2.1 Scope and Management of Quality and Performance Data and Information	7 /15 pts
2.2 Competitive Comparison and Benchmarking	7 /20 pts
2.3 Analysis and Uses of Assessing Unit-Level Data	14 /40 pts
3.0 Strategic Quality Planning	**27 /60 pts**
3.1 Strategic Quality and Assessing Unit Performance Planning Process	14 /35 pts
3.2 Quality and Performance Plans	13 /25 pts
4.0 Human Resource Development and Management	**108 /150 pts**
4.1 Human Resource Planning and Management	20 /20 pts
4.2 Employee Involvement	30 /40 pts
4.3 Employee Education and Training	40 /40 pts
4.4 Employee Performance and Recognition	9 / 25 pts
4.5 Employee Well-Being and Satisfaction	9 / 25 pts
5.0 Management of Process Quality	**57 /140 pts**
5.1 Design and Introduction of Quality Services	18 / 40 pts
5.2 Process Management: Operation/Service Process	18 / 35 pts
5.3 Process Management: Business and Support Service Processes	14 / 30 pts
5.4 Supplier Quality	2 / 20 pts
5.5 Quality Assurance	5 / 15 pts
6.0 Quality and Operational Results	**116 /180 pts**
6.1 Operation and Service Quality Results	11 / 70 pts
6.2 Agency Operational Results	50 /50 pts
6.3 Business and Support Service Results	23 /25 pts
6.4 Supplier Quality Results	32 /35 pts
7.0 Customer Focus and Satisfaction	**113 /300 pts**
7.1 Customer Expectations: Current and Future	17 /35 pts
7.2 Customer Relationship Management	40 /65 pts
7.3 Commitment to Customers	8 /15 pts
7.4 Customer Satisfaction Determination	16 /30 pts
7.5 Customer Satisfaction Results	23 / 85 pts
7.6 Customer Satisfaction Comparison	9 /70 pts
TOTAL POINTS	**519/1000 pts**

7. Customer focus and satisfaction (113 points out of 300, i.e., 37.7 percent): Information from some riders is gathered and analyzed. Management takes some quality improvement actions on the basis of findings. However, nonriders are not adequately surveyed. Internal customer satisfaction information should be collected and analyzed throughout SCCTD.

Suggestions for Improvement

At the third Quality Council Workshop, an evaluation questionnaire was distributed to obtain the members' opinions and suggestions on the Baldrige criteria application to the LRT system of SCCTD. Table 5 presents the questionnaire and a summary of survey results.

Overall, the evaluation responses to the MBNQA criteria-based internal assessment process indicate that the MBNQA criteria could be used as an internal assessment tool with appropriate modification. However, the Quality Council members were concerned about their ability to easily provide accurate scores in the MBNQA evaluation areas. They also mentioned that the scoring system was neither fully explained nor easy to justify, and there seemed to be much room for personal interpretation and difference in scoring from one evaluator

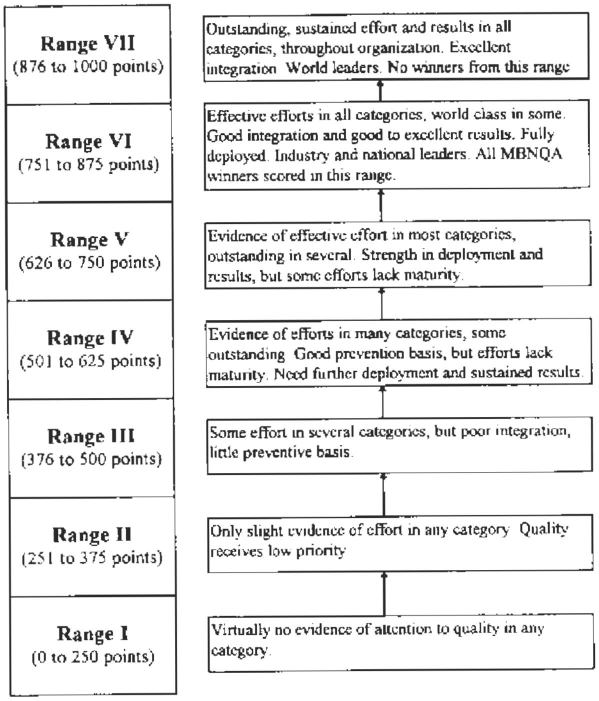


FIGURE 3 MBNQA scoring ranges: what they mean (*14*).

to another. (Intensive MBNQA training was not provided to the Quality Council during the case study.)

The Quality Council made the following key suggestions for improvement:

1. Criteria, scores, and weights require modifications for use by public agencies, including LRT systems. For example, the definition of a competitor is not appropriate for all public agencies.
2. Current assessment procedures, which are more oriented to products and profits, are less suitable for service- and nonprofit-oriented organizations such as SCCTD.
3. Planning, scheduling, and organizing services provided to customers should be weighted more. Two different concepts should be included: doing right jobs versus doing jobs right.
4. Improving efficiency may result in a loss of riders. Frequently, greater efficiency is achieved by reducing less needed or more costly LRT operation schedules in terms of a greater number of vehicles attached and running together, and less frequent operational times. However, this gained efficiency resulted in reduced ridership.
5. Some examination items and areas to address are redundant. For example, Examination Items 4.4 and 4.5 may be combined.

Concluding Remarks

This paper developed a structure and framework for conducting an internal assessment of quality and performance of an LRT system using the MBNQA criteria. This approach is applied in an LRT case study, as a self-assessment of the 1994 LRT operations of SCCTD. Self-assessment examination forms and procedures were developed using the 1994 MBNQA criteria. A newly formed ad hoc committee, the SCCTD Quality Council, used the forms and procedures to assess the quality and performance of SCCTD's LRT operation.

SCCTD's LRT operation obtained a total score of 519 out of a possible 1,000 points, using a self-assessment procedure performed by Quality Council members. Compared with Baldrige winners, whose scores range from 751 to 875 points, the current quality and performance of SCCTD are reasonably good. The SCCTD LRT evaluation presented evidence of specific efforts under way for improving quality and performance of LRT operations, and some efforts are outstanding. Although its LRT operates on a sound error-preventive basis, SCCTD should further improve operations to achieve higher customer-based quality performance. On the basis of percentage of achievement in seven categories compared with the full scores, Categories 2 (information and analysis) and 7 (customer focus and satisfaction) require the most improvement.

The current MBNQA criteria do not explicitly consider the role of unions in enhancing quality and performance. Because unions are an important aspect of LRT systems, it may be desirable to enlarge on this function in subsequent MBNQA criteria modifications. Furthermore, it is necessary for employee representatives to be involved in self-assessment processes of LRT systems.

According to comments and suggestions made by the Quality Council, examination criteria and scores assigned to the examination items in the self-assessment kit developed by the study team need modifications because of SCCTD's special nature as a government agency. Quality Council training on the format and questions contained in the self-assessment kit should also be implemented. Overall, the Quality Council believes that the MBNQA criteria and assessment procedures are a useful tool in measuring SCCTD quality and productivity. Similar results have been found in the general case of TQM methods and techniques (*15*). This study extends the previous studies of the use of MBNQA criteria in over 30 firms to the case of a public transit agency (*16*).

According to recent survey results, as obtained from a sample of 103 public transit organizations, whereas some transit system CEOs have made commitments to TQM since the late 1980s, most foundations for TQM

TABLE 5 Quality Council Evaluation Questions and Summary of Results

A. Survey Questions.

(1) Are the MBNQA evaluation areas that you responded to appropriate to the agency?
Yes: _______ No: _______
If no, please indicate which evaluation(s) were not appropriate and why.

(2) Do you think the MBNQA criteria cover all activities of the agency?
Yes: _______ No: _______
If no, please list criteria to be added.

(3) Are the scoring weights for the MBNQA criteria appropriate to the agency?
Yes: _______ No: _______
If no, please suggest any changes.

(4) Were you able to easily provide accurate scores in the MBNQA evaluation areas?
Yes: _______ No: _______
If no, please make any comments or suggestions.

(5) Do you think MBNQA criteria and assessment process are helpful in assisting the agency to improve the quality and/or operational productivity?
Yes: _______ No: _______
If no, please make any comments.

(6) In your opinion, should the agency utilize the MBNQA assessment process to improve its quality and productivity?
Yes: _______ No: _______
If yes, how would you implement it?

(7) How would you evaluate the MBNQA criteria in assessing quality and productivity of the agency?

Excellent				Poor
5	4	3	2	1

B. Summary of Survey Results.

Question No.	Yes	No	Not Answered
1	5 (72%)	1 (14%)	1 (14%)
2	5 (72%)	2 (28%)	
3	4 (57%)	3 (43%)	
4	2 (28%)	5 (72%)	
5	5 (72%)	1 (14%)	1 (14%)
6	4 (57%)	3 (43%)	

Question No. 7:

	Excellent				Poor
Scale	5	4	3	2	1
Reply No.	1		4	2	

are not yet in place (*3*). For example, transit governing boards are not actively involved in quality, quality coordinators or facilitators have generally not been designated to manage and support quality, transit employees are not yet sufficiently trained in tools and techniques for problem solving and conflict resolution, and quality programs do not appear to be very rigorous (*3*). Consequently, the use of the MBNQA criteria-based self-assessment tool would be a driver to properly identify the status of performance and quality of a public transit agency.

Extensions of this research would include recalibration of MBNQA criteria in consideration of suggestions by the SCCTD Quality Council, and then its reapplication to the SCCTD LRT system. To investigate possible deployment of the MBNQA criteria-based assessment tool to other LRT systems, these LRT systems would also need to modify the criteria to satisfy their own needs, as is done in other industry sectors (*10*).

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Organizing for Efficiency: The Denver Teamwork Experience

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The Regional Transportation District's (RTD's) first light rail system, the Central Corridor, is a 5.3-mi-long at-grade rail line that runs from a southern terminus, through the central business district (CBD), to a northern terminus in metropolitan Denver, Colorado. This first line is the spine of a planned regional rapid transit system and was designed with simplicity and the ability to expand as demands require. RTD modified and accentuated its organization in order to design, construct, and implement this transit system to ensure it would be both usable and acceptable to the Denver metropolitan communities. To enhance RTD's experience in light rail transit (LRT) construction, administration was conducted in-house, whereas design and construction management were performed by professional consultants and construction contractors. A small but very motivated RTD team was created and trained in construction procedures and standards, quality assurance, project management, materials management, and RTD's procurement and contracting procedures. This team, which included an operations superintendent, worked together, communicating and coordinating all activities to meet the priorities set by RTD's general manager to ensure that the objectives of safety, quality, budget, and operational effectiveness were achieved. As construction progressed, a larger integration/activation team evolved and a small operations start-up team was created. Operations, training, maintenance, safety certification, and staffing plans were developed, and operations personnel became involved in preparations for revenue start-up by participating in the integrated systems testing and activation. All equipment was tested, safety was certified, and revenue service was simulated to ensure that all LRT system elements functioned together to provide a safe, reliable, and efficient service. RTD's light rail system started revenue service on October 10, 1994. Typical of all new systems, the first few months were tests of flexibility and patience. It was a time of learning; adapting to equipment problems, customer needs, procedural problems, and training needs; and preparing for expansion and growth. By using the experienced professionals, technology, and innovations available, RTD has inaugurated a successful light rail system and now is looking to the future for further expansion.

The Regional Transportation District's (RTD's) first light rail system, the Central Corridor, runs from 30th Avenue and Downing Street through the Five Points Business District and downtown Denver, by the Auraria higher education campus, and then along railroad right-of-way to I-25 and Broadway (see Figure 1).

The corridor is a 5.3-mi-long at-grade rail line that meets the Americans with Disabilities Act (ADA) requirements, includes 14 stations, and carries approximately 15,000 riders per day. The northern terminus, located at 30th and Downing, is a bus transfer station and includes a small park-and-ride. At the southern terminus at I-25

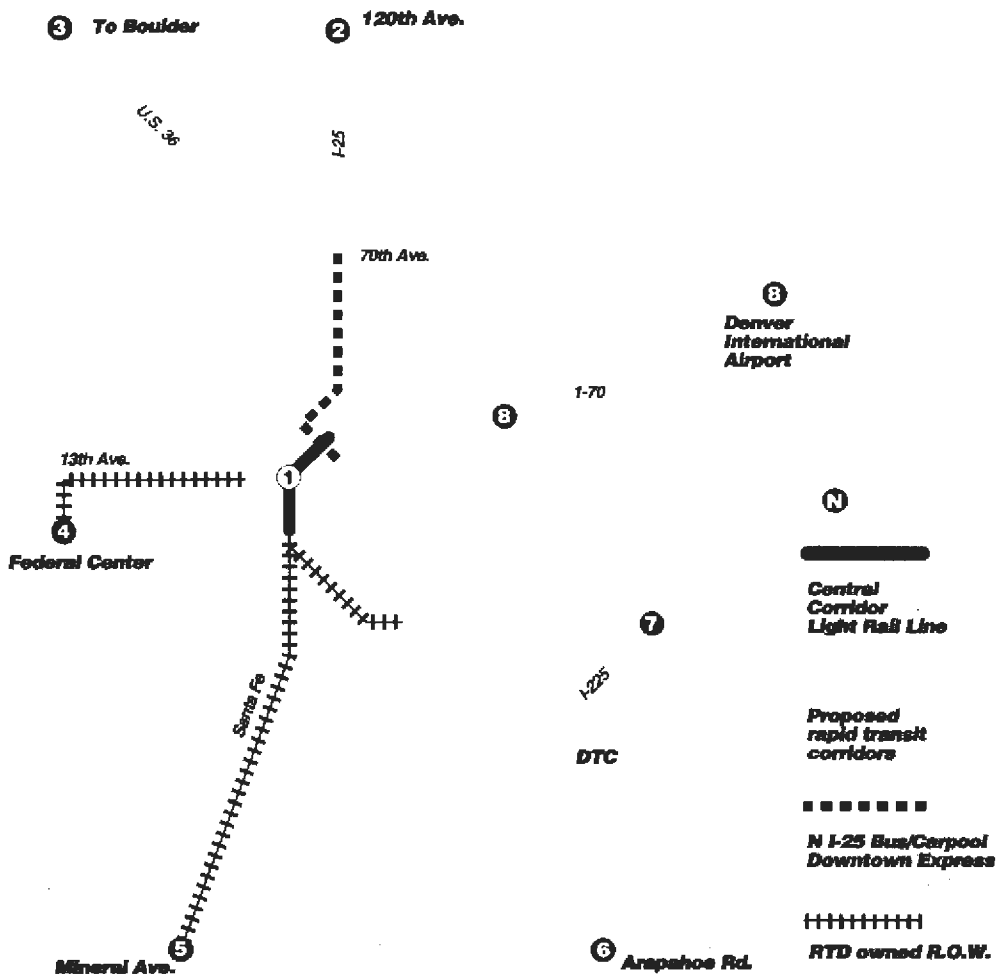


FIGURE 1 Proposed rapid transit corridors.

and Broadway, passengers from express, regional, and local bus routes also transfer to light rail transit (LRT) to complete their trip into the Denver central business district (CBD). There are also approximately 700 automobile spaces in the park-and-ride lot located here.

This first line, the spine of the planned regional rapid transit system, demonstrates light rail technology, including its efficient and reliable service, its high-speed and high-capacity characteristics, and the flexibility to operate within Denver's downtown city streets. Since its revenue service opening in October 1994, it has removed hundreds of daily bus trips from the core city area, reducing air pollution and traffic congestion. It has provided an opportunity for economic development in commercial areas along the transit line and has demonstrated RTD's commitment to rapid transit in the Denver metropolitan region (Figure 2).

The LRT line is a conventional light rail system powered by 750 VDC nominal overhead power. Using off-the-shelf technology, the system with its 11 Siemens Duewag Corporation Model SD100 light rail vehicles, capable of speeds up to 55 mph, provides the ridership capacity necessary in completing the transfer of thousands of daily bus passengers as well as hundreds of new park-and-ride automobile transfers to LRT for the trip into the CBD. For ease of operation, as well as safety considerations, most of the alignment is double tracked with typical automatic block system signals in the high-speed rail section and traffic control devices or gated crossings at all intersections.

The system was designed with simplicity in mind along with the ability to expand and grow. The organization of RTD was modified to accomplish the goal of designing, constructing, and implementing a transit sys-

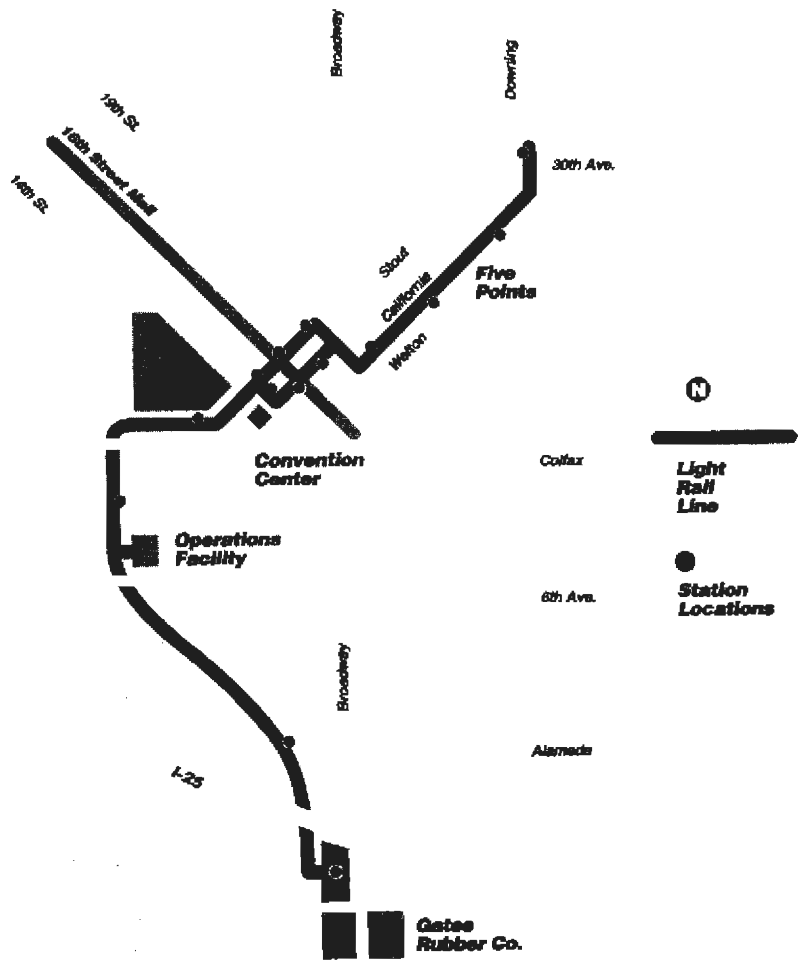


FIGURE 2 Central corridor light rail line.

tem that would be useful and acceptable to the Denver metropolitan communities.

Organizational Philosophy

Trial and error became the major means of problem solving for many emerging light rail organizations of the 1980s, principally because surface trolley systems were discontinued in the 1950s. Since that time technology had dramatically changed, and experienced rail transit personnel were retired and lost to the industry. In light of this, during the 1980s a new generation of transit professionals had to be developed to accommodate the resurgence of rail projects. After two decades of technological development throughout North America, Denver was able to take advantage of both the advances and the new-generation transit professionals.

RTD organized its design and construction team and implemented the design criteria for building its first light rail system with this philosophy in mind.

Design/Construction Team Approach

The design and construction of light rail was organized for flexibility. Because of the limited amount of committed funding and the lack of sufficient LRT experience of the staff, project administration was conducted in-house while design and construction management, as well as the actual construction, were performed by professional consultants and construction contractors. A new RTD department was formed to provide oversight of the project management responsibilities. The department was basically separated into three oversight management responsibilities: LRT project coordination, LRT systems management, and LRT community relations (Figure 3).

Ensuring minimal costs comparable with other similar systems and an aggressive schedule required the staff to be sized accordingly. As with any major project, organizing staff requires a clear, concise line of communication internally and with other governmental agencies supporting the project. As shown in Figure 3, the structure was formed to facilitate the needed communication and to maximize the efficiency of interagency interface.

To facilitate the evolution of the project, the staff was trained in team building and partnering strategies. Furthermore, staff training included construction procedures and standards, quality assurance, project management, materials management, and RTD's procurement and contracting procedures. This accumulation of training provided the framework for continuity and uniformity to the efforts of all project team members.

As a means of ensuring a simple and manageable project, six steps were integrated into the project:

1. There was one formal point of contact. RTD staff, the designer, each construction contractor, and all other parties involved had one formal contact person who took responsibility for their assignment.

2. All vital communications between project parties were accomplished in writing and filed for the project record.

3. The weekly progress meetings had agendas that were distributed. It was expected that all concerned individuals would attend and come prepared. Action items would be assigned with the item completion or report date, and solutions to problem issues were relentlessly pursued.

4. All projects and contracts had time and financial constraints. Goals were set with emphasis on schedule adherence and cost-effective solutions to project challenges.

5. All project participants understood the extent of their role, nature of their responsibilities, and the contributions expected and needed for achieving a successful project.

6. All participants held to the win-win partnering philosophy. It was understood that the successful project implementation would be a team effort. A win-win philosophy ensured that all participants—RTD staff, designer, contractor, consultant, and other external agency representatives—would achieve their objectives.

RTD's Department of LRT Construction was arranged to see that coordination and integration needs of all participants were met, and it was sized and organized to meet the priorities set by RTD's general manager to ensure that the objectives of safety, quality, budget, and operational effectiveness were achieved. As implementation of the project proceeded from preliminary engineering efforts through design, construction,

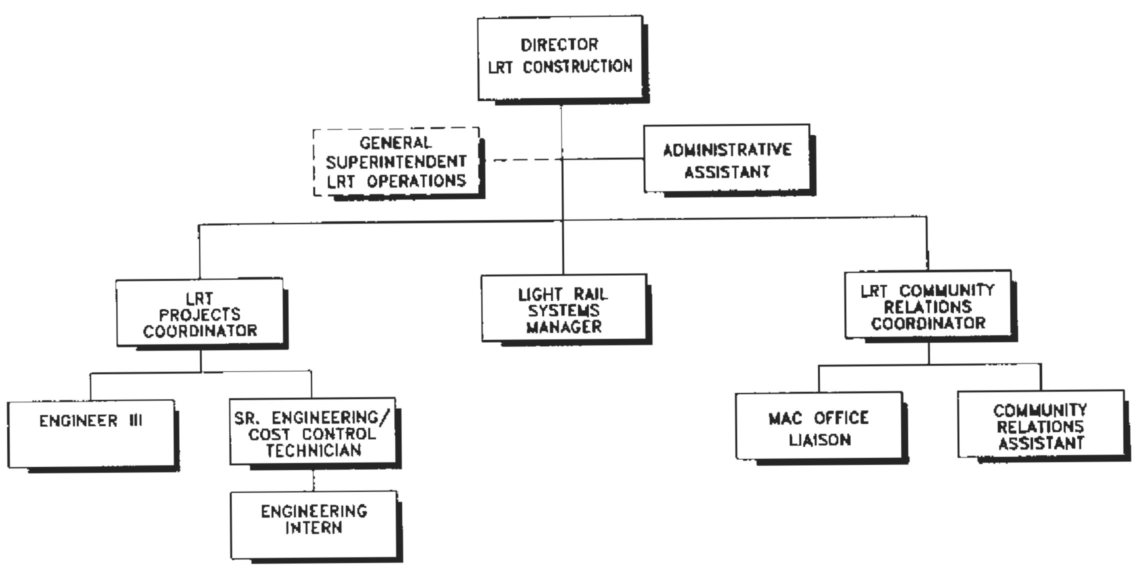


FIGURE 3 Early light rail construction.

and start-up phases, the organization evolved to ensure the maximum efficiencies of personnel.

During preliminary engineering, the Director of LRT Construction assumed the lead management role, reporting directly to the general manager with support in the areas of project controls, technical support, community relations, and operations.

During final design and construction, the director of LRT Construction, under the supervision of the general manager, led the effort with a larger team consisting of project engineers, system engineers, construction managers, an operations superintendent, and a community relations coordinator (see Figure 4). The team focus was on constructibility, system integration, utility relocation and agency coordination, right-of-way requirements, value engineering, cost control, and design integrity, all within the confines of project construction safety and future system safety.

Operations Start-Up Team

As has been noted, the operations superintendent was involved as a project team member early in the design phase of the project. This decision was based on the new philosophy that future successful revenue operation of any project greatly depended on designing and constructing a system with that goal in mind. The value of early involvement by key operating and maintenance personnel was recognized and addressed so that operating and maintenance requirements appropriate to RTD were defined and addressed in the system's design criteria and efforts. With the fiscal constraints and schedule placed upon itself, RTD took every precaution to build a system that would operate efficiently and effectively. As all of us are painfully aware, the costs associated with change orders and modifications require that close scrutiny be given to ensuring that efficiencies necessary to operate the system are addressed before start-up.

Whereas it is sometimes difficult to determine the proper timing to actually establish the initial light rail operating organization, on the basis of experiences of projects in the 1980s, it was decided that operations input was necessary during preliminary engineering. The position of general superintendent of Light Rail Operations was filled and became an extension to the design and construction staff, acting as a project manager for the procurement of rail vehicles, shop equipment, and track/appurtenances. In addition, operations personnel were involved in the development of the design criteria as well as the designing process, ensuring that operational needs and maintenance requirements were addressed appropriately. As the construction progressed, operations staff also participated in quality control and in review of any required design modifications.

Along with these project team responsibilities, the operations superintendent took on the role of developing the operations plan, training plan, maintenance plan, and safety certification plan as well as the staffing of the operations start-up team. The early preparation of the operating plan provided the training perspective necessary to ensure that project managers and engineers knew how the system should operate as they dealt with the day-to-day construction questions. The operations plan finalized the design criteria and, more important, set the stage for the interaction required from the various departments and groups within RTD involved in the project, and it introduced them to the concepts of how the proposed system would operate.

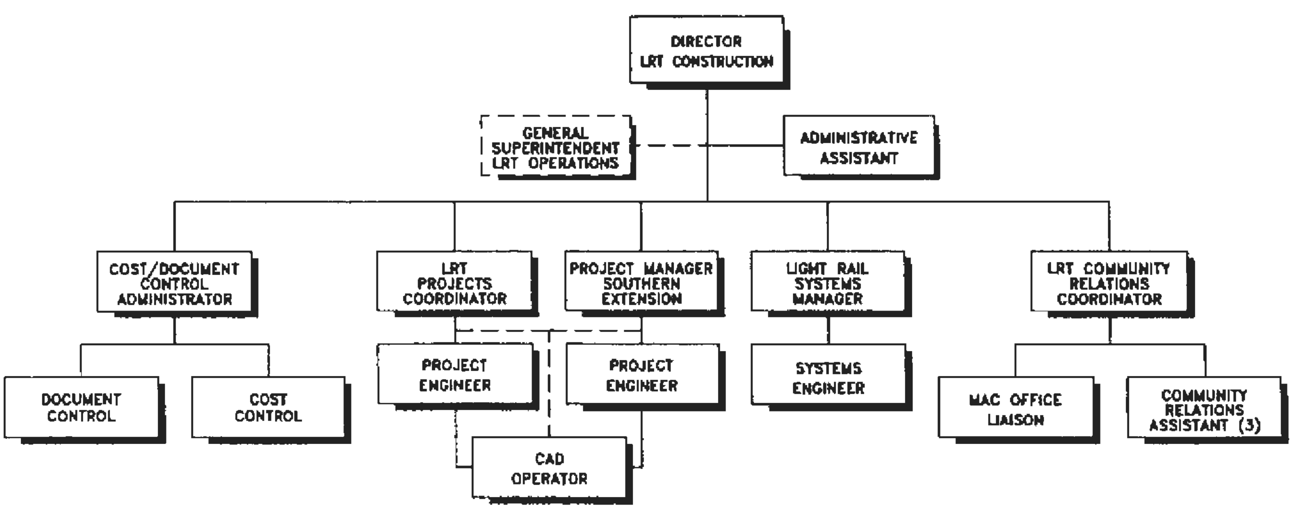


FIGURE 4 Light rail construction.

As the operations start-up team was selected and developed, several qualifications were considered: (*a*) experience and knowledge of light rail transit and system start-up; (*b*) flexibility or adaptability to changes; (*c*) enthusiasm for the project; (*d*) strong leadership skills including team building, a strong sense of vision, the ability to communicate that vision effectively to other team members, and a strong sense of the value of training both as a trainer and trainee; and (*e*) the ability to convince through displaying confidence and patience. The key operations management position selections were made on the basis of those qualifications. Figure 5 highlights the RTD start-up organization and the reporting hierarchy.

In reviewing each of the qualifications noted above, the one requiring a certain amount of experience in light rail transit was of utmost importance. To provide insight into the development of the operational organization and lend credence to the input being provided to design and engineering, a certain amount of related experience is required. In addition, a network of contacts in the industry becomes beneficial in overcoming the weaknesses in experience based on the different system operating characteristics. Peer review and property visits are also essential to provide reality checks and add insight into the needs of emerging organization.

As the system neared its construction completion date, the semitrained operations personnel began to

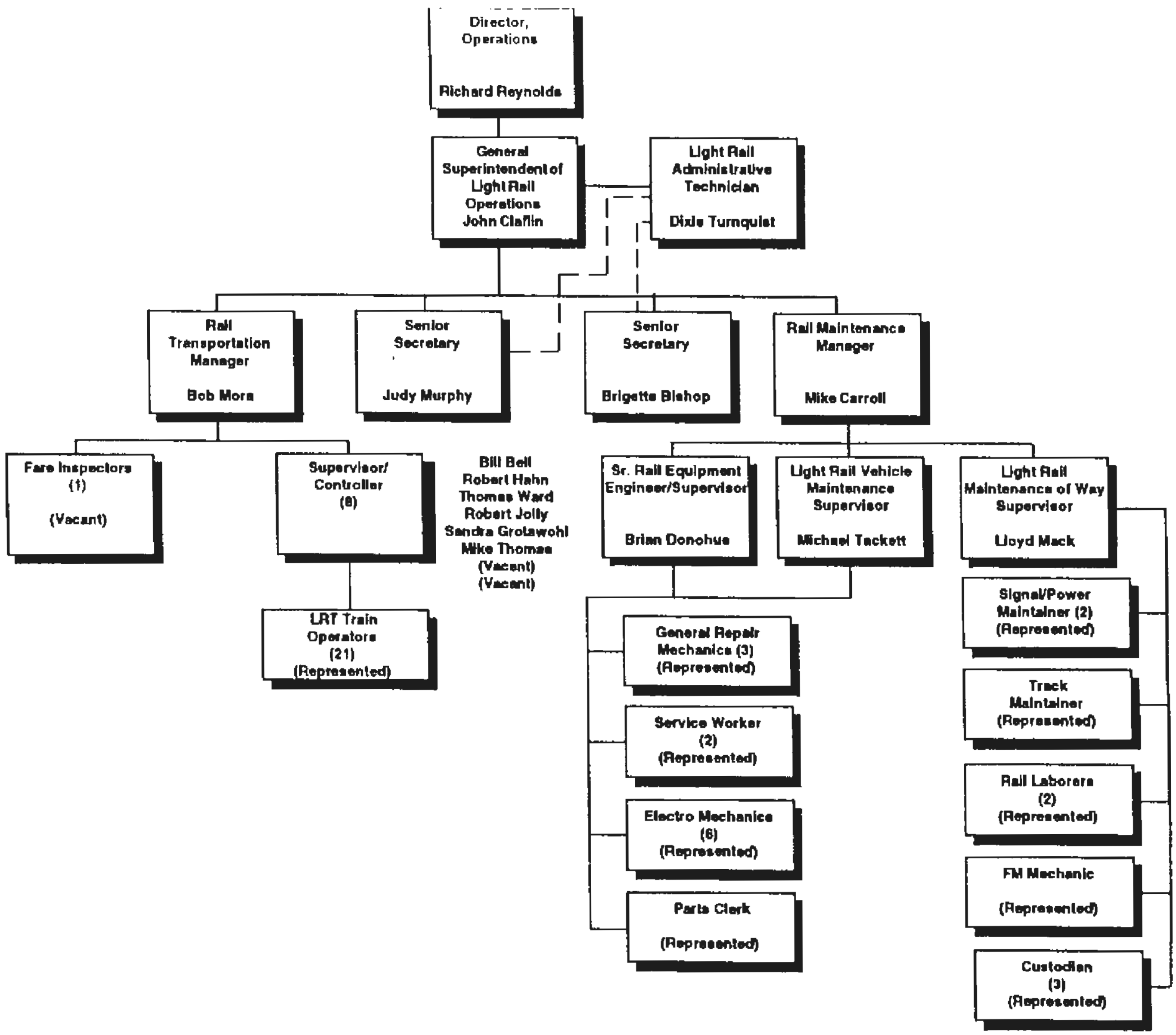


FIGURE 5 RTD Light Rail Operations start-up organization.

make final preparations for revenue start-up by participating in the integrated systems testing and, finally, activation.

Integration/Activation Team

The purpose of the system integration was to ensure compatibility among various elements of the project as well as with the entire RTD transit system. Although team members came from various departments, the systems manager was responsible for coordinating the testing and documenting the results for safety certification. Integration documentation was to verify the following project elements:

- Design documents were in compliance with the design criteria and were consistent with operating plans and procedures.
- LRT signals, city traffic signals, fare vending, communications, and traction power were compatible.
- The right-of-way, track work, stations, and other facilities accommodated and functioned with the systems elements.
- The design documents and as-built drawings were consistent with what was constructed.

In addition to ensuring compatibility with existing elements, the integration activities were also to make certain that project facilities and systems would be compatible with future extensions. The final design for these extensions would be cross-checked to ensure that specifications would share common characteristics. Some of the elements considered and carried forth were

- Track gauge, standard 4 ft 8½ in.;
- Traction power voltage, nominal 750 VDC;
- Communications and signal systems;
- LRV car body characteristics such as crush strength, anticlimber/collision post locations, clearance envelope, and weight;
- ADA requirements for station platforms and facilities; and
- Other components that may be duplicated for consistency and ease of maintenance.

As noted previously, the operations plan was used to guide the start-up and systems integration testing and prerevenue service phases of the project. The operations plan was a dynamic document, changing as required to incorporate technical advances, specific design changes, equipment changes and modifications, and budget alterations. The plan was also the guide for staff training and development needs.

The integrated systems team consisted of systems contractors/suppliers, construction management, project engineers and inspectors, RTD LRT systems engineer, operations maintenance/transportation staff, and safety compliance officers. The goals of this team were to ensure that the testing program was completed as required and the proper documentation presented for safety certification. The testing program described the objectives, methodology, management controls required, and the verification of compliance to ensure the system's readiness for revenue operation. The objectives were to verify contract compliance and completeness; validate and demonstrate the performance of the system; demonstrate the safety certification elements and service characteristics; validate the training of LRT operations staff; and integrate personnel, equipment, and procedures into the RTD transit system.

While the integration testing team provided the system elements for documentation and revenue operation, the activation team readied the entire organization for the start-up. The activation team was assigned a manager for coordination and consistency but included representation from every department within the organization. Through this coordination, the team completed the preparation required to ensure community acceptance and safety and the schedule reliability and performance needed to service the metropolitan region.

In preparation for the revenue service date of October 10, 1994, all equipment was activated, tested, and safety certified, and revenue service was simulated to make certain that all LRT system elements functioned together to provide a safe, reliable, and efficient service. The activation process, and the team designated, followed a comprehensive plan that encompassed all the activities required for the full integration into the RTD transit operation (see Figure 6).

Eleven major task categories along with checklists of many other detailed tasks were identified to complete the preparation for revenue service:

1. Select and hire the staff required to operate and support the LRT.
2. Complete all engineering and maintenance procedures and agreements.
3. Complete all transportation policies, procedures, and rules.
4. Complete training of all LRT personnel to assume their role in operations.
5. Develop and then complete all safety certification elements as well as arrange for ongoing safety evaluation and support.
6. Identify and develop security requirements.
7. Identify and complete all required agreements, ordinances, and so forth with external agencies.

8. Prepare an integrated service plan to include train schedules and revisions to bus routes and schedules.

9. Ensure that material management and inventory control requirements are integrated into the LRT department.

10. Prepare financial/budgeting requirements to ensure completion of capital projects and ongoing operational needs.

11. Provide public information including safety outreach training and marketing of the RTD's newest form of transportation alternatives.

As these tasks were actively pursued, the activation team was broken out into various committees that provided periodic updates on their progress. Because of the enormous commitment, enthusiasm, and energy on the part of all participants of the activation team, the start-up was a tremendous success. However, with the advent of this new form of transportation service, continued enthusiasm and commitment were necessary to demonstrate the effectiveness and efficiencies over the coming years. The newest RTD division of Light Rail Operations prepared itself to accomplish this task.

Operations Team Development—The 5-Year Plan

As any participant can affirm, the first few months of operation are a test of flexibility and patience. That period becomes a time of learning; adapting to equipment

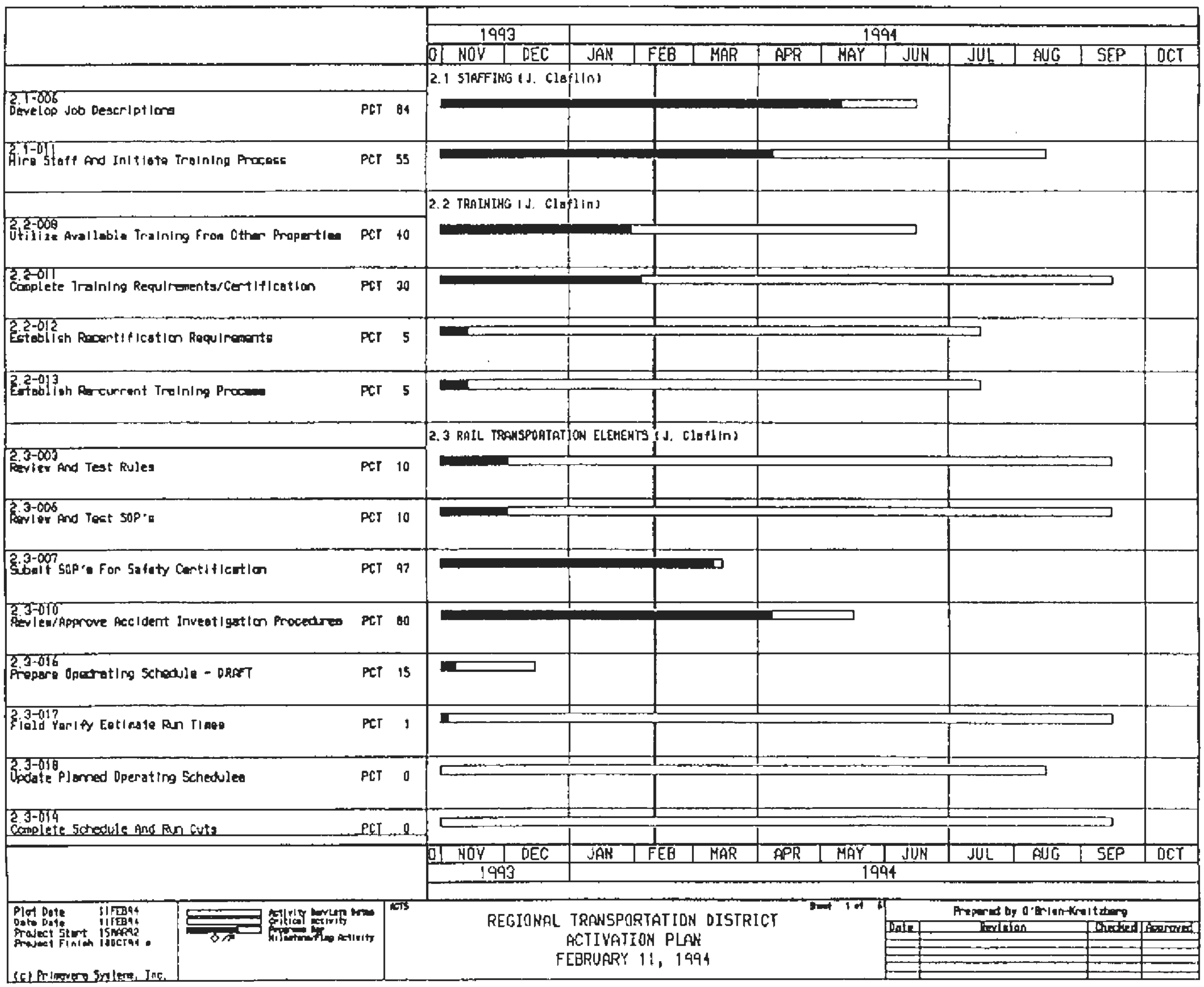


FIGURE 6 Activities required for full integration into RTD transit operation. *(continued on next page)*

problems, customer needs, procedural problems, and training needs; and preparing for expansion and growth. It is truly a time when the weaknesses of the system and the team are exposed. During this time the organizational needs must be closely scrutinized and modified to meet the challenges of the next few years. As a means of meeting the demands of change within the operation, it is essential to have a plan for organizational expansion. This plan of expansion is based on assumptions, projections, and industry examples and considers the following elements:

- System maturity including warranty expiration,
- Additional LRV/equipment procurement,
- Modifications or retrofits to existing vehicles or facilities,
- Extensions/new-start project completion,
- Scheduled service level changes,
- Labor agreement changes,
- Training needs for recertification and apprentice programs, and
- Budget constraints.

As with all other aspects of the project, the staffing of Light Rail Operations was done with budgeting as a primary consideration. In addition there was a philosophy that by using minimum staff, the amount of training and the use of time and energy could be controlled: cross-training would be given and personnel strengths and skills would be enhanced. It was hoped, too, the challenges that make the job duties more interesting and rewarding would persist.

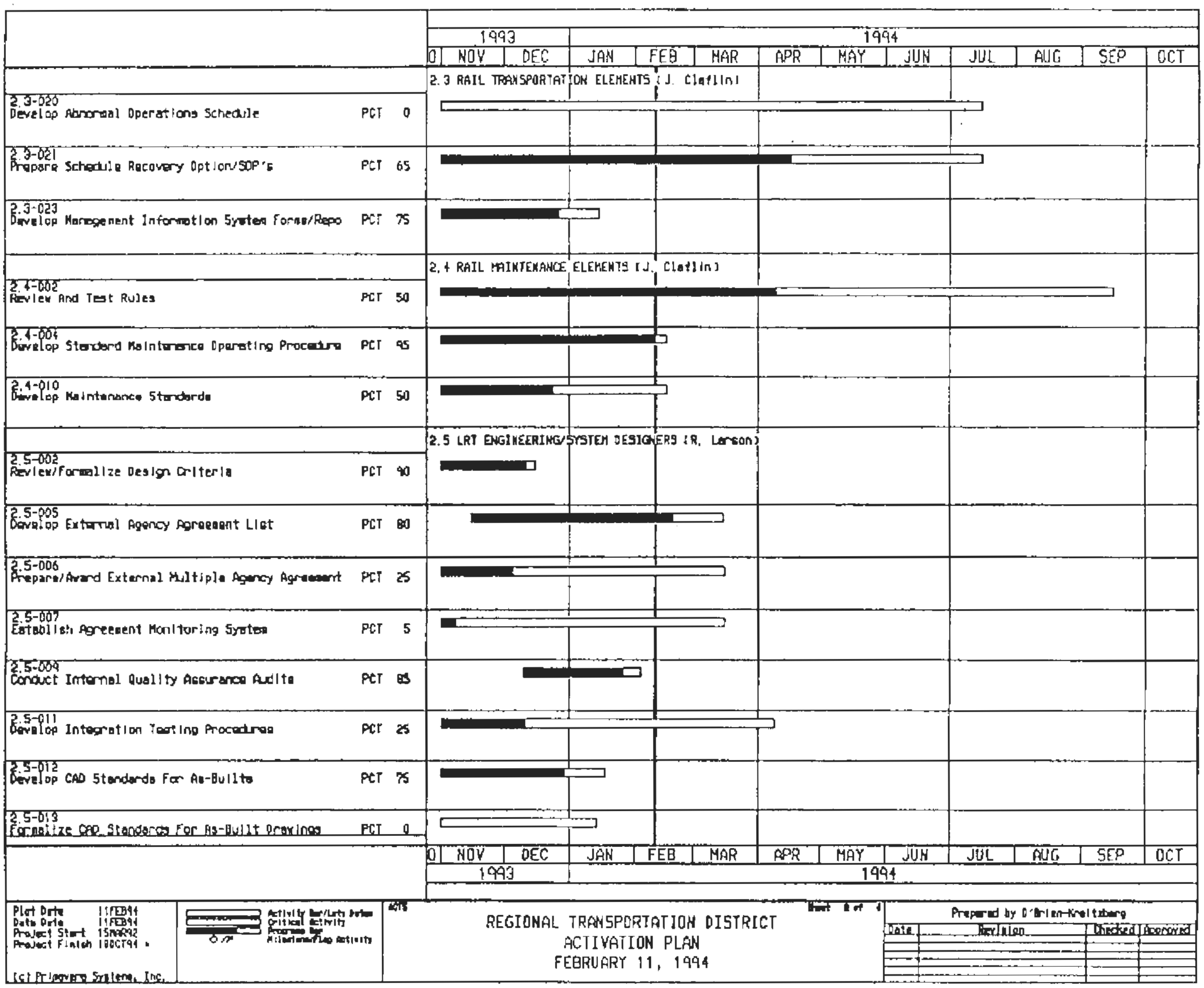
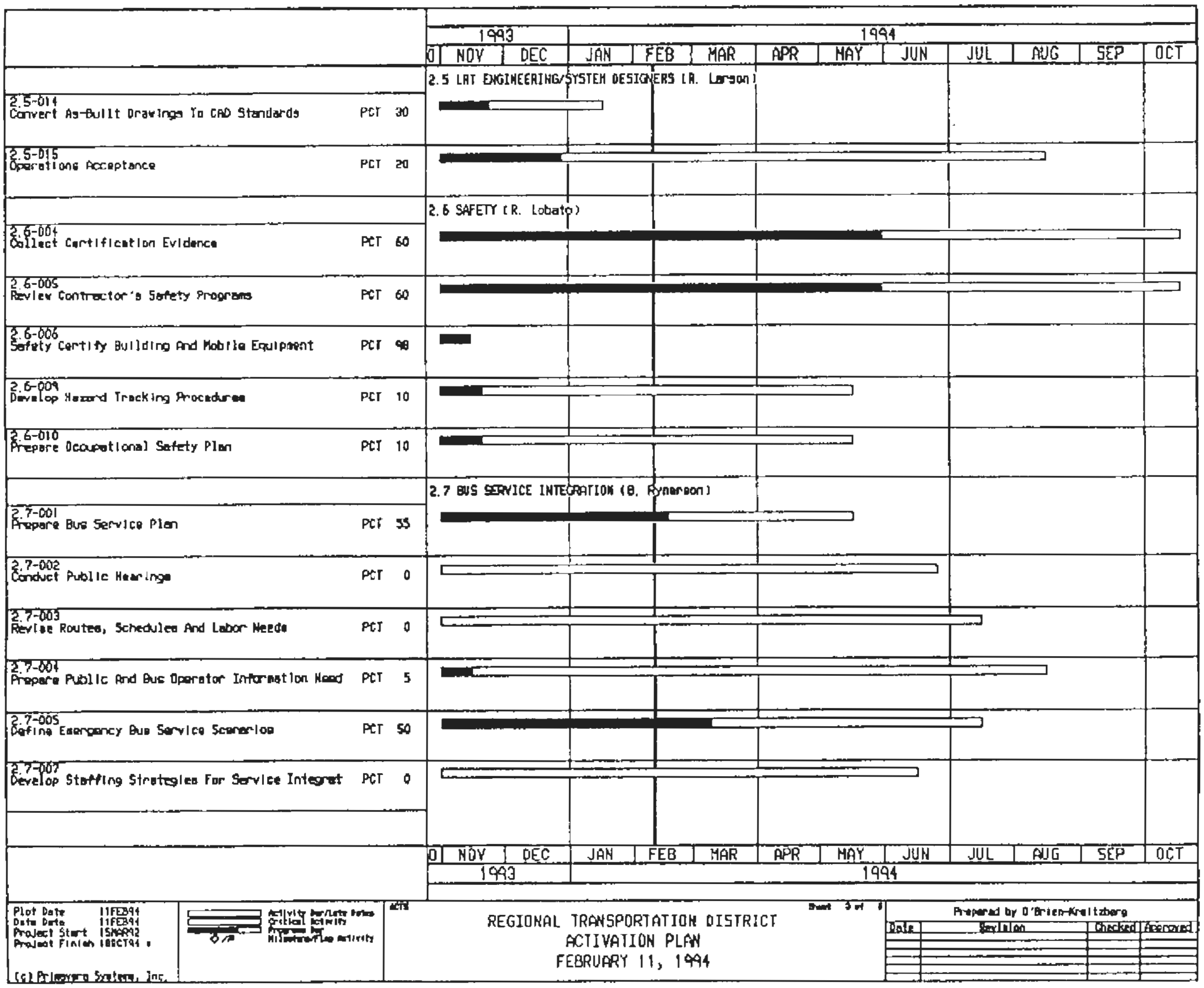


FIGURE 6 *(continued)*



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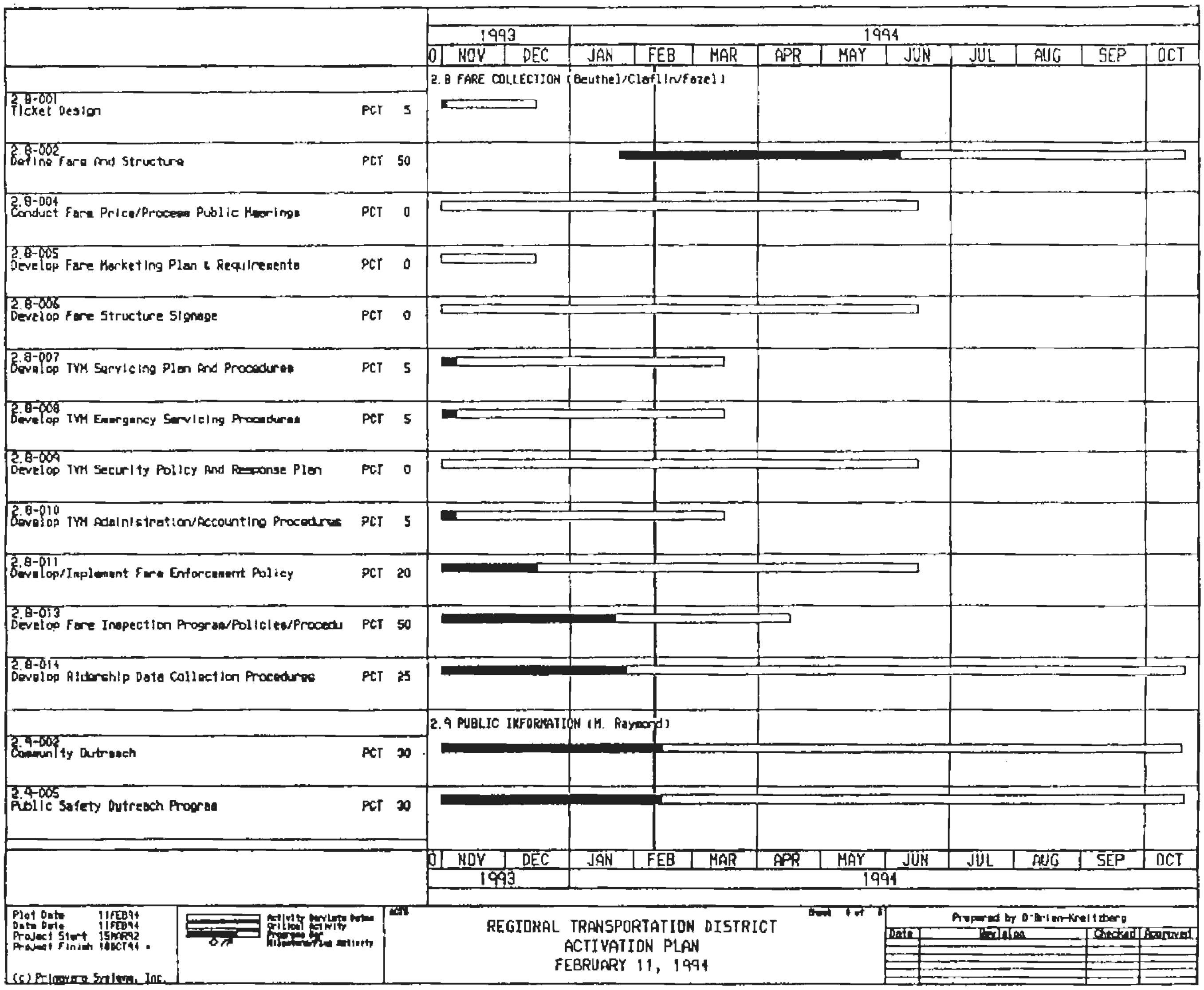

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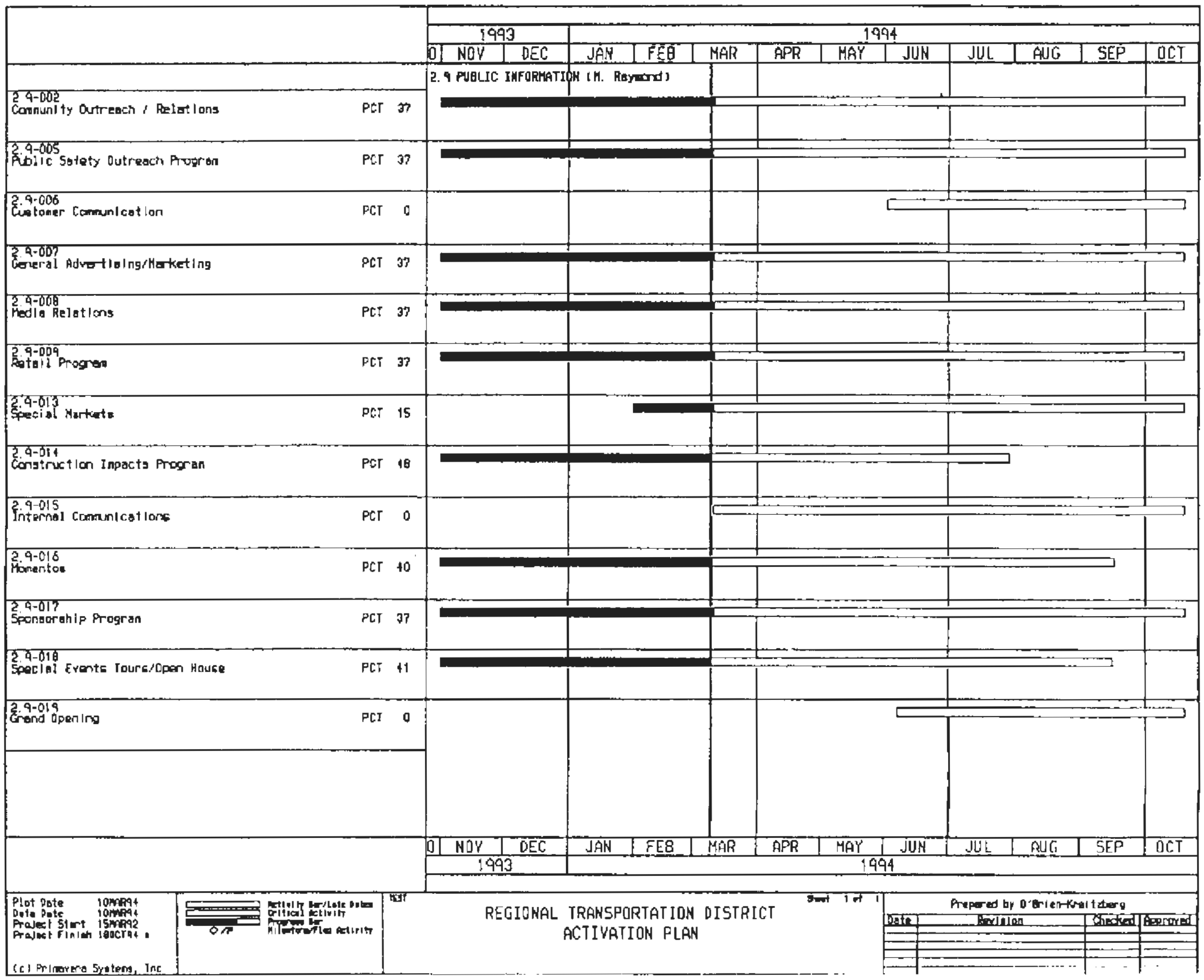

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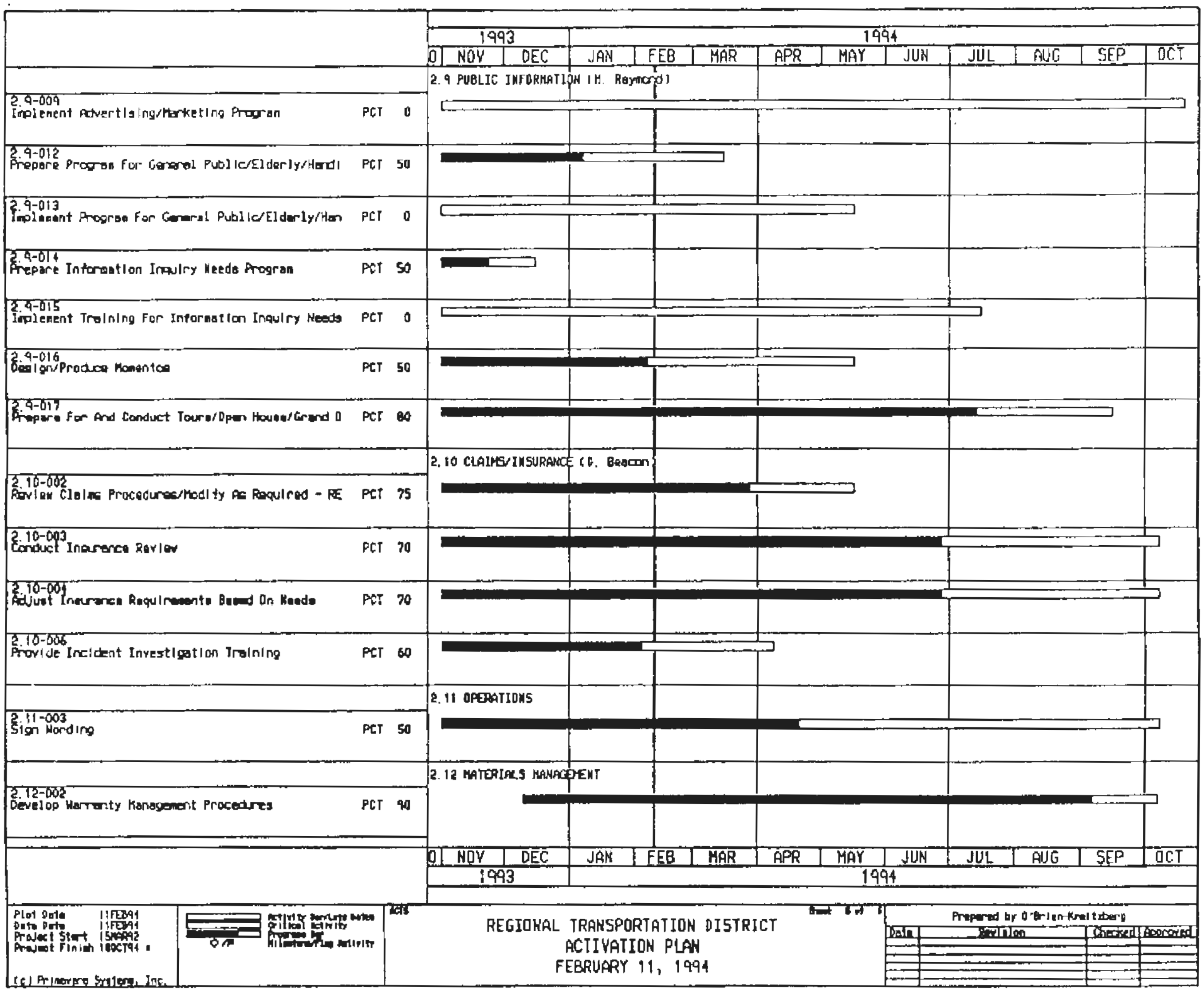

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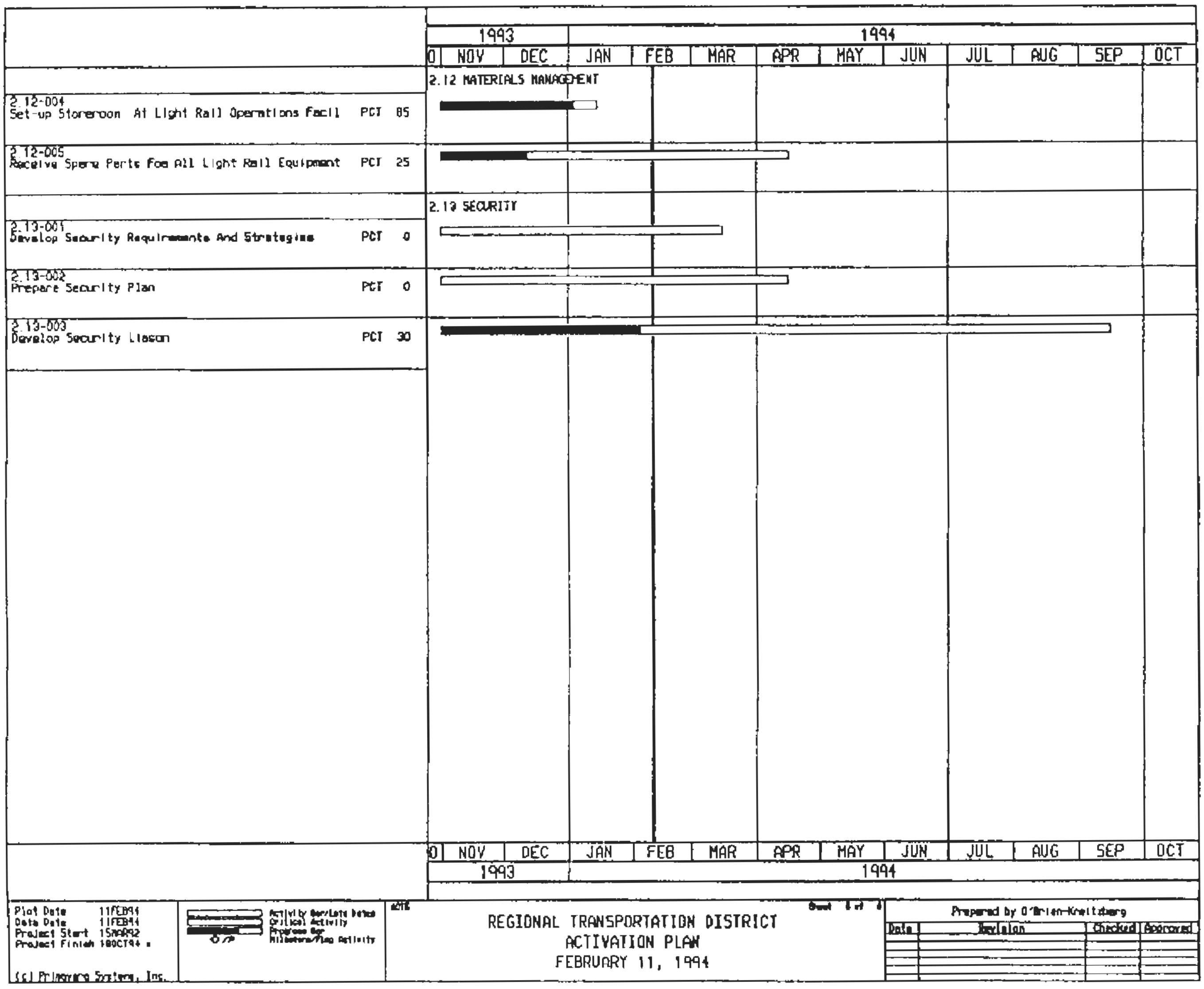

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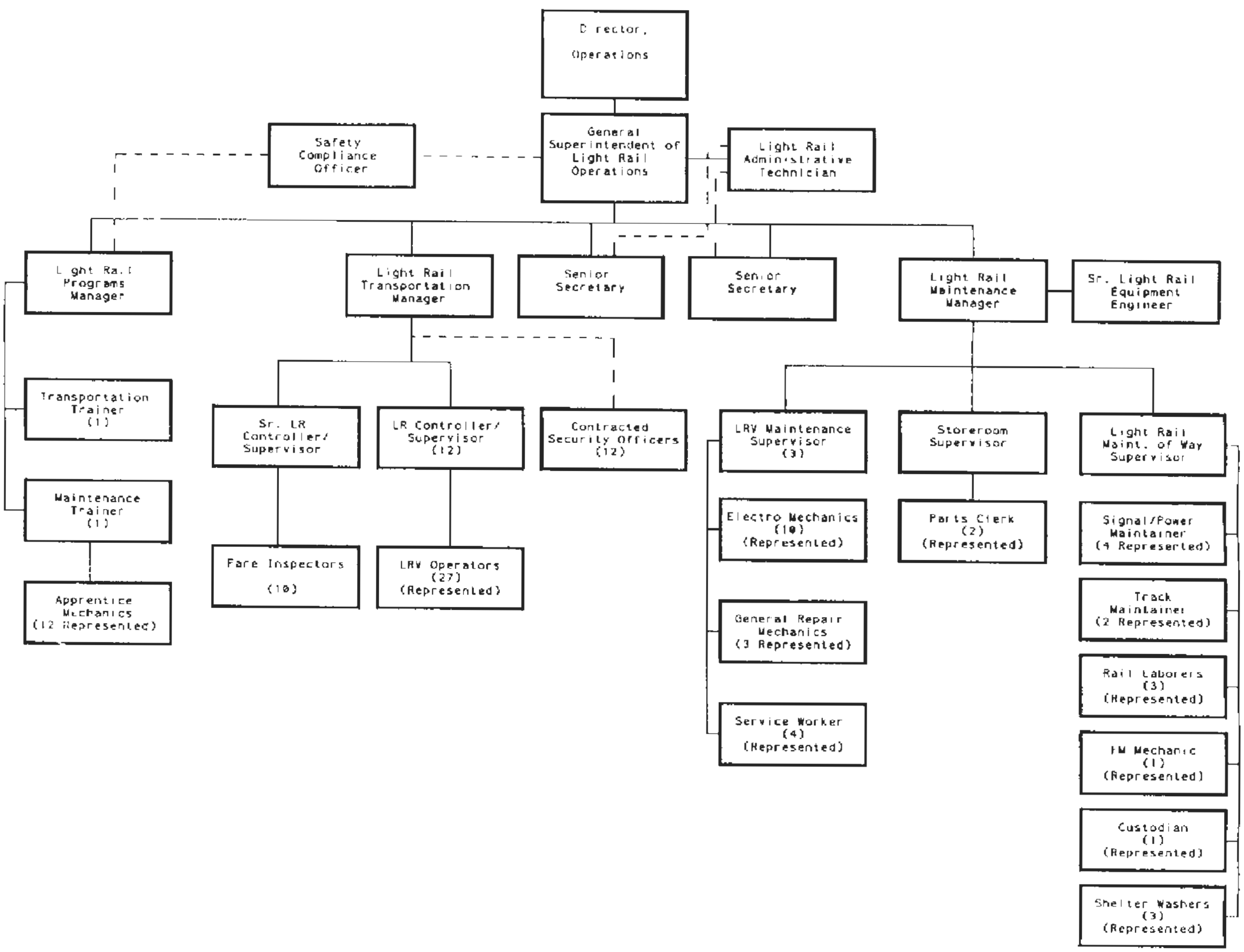

FIGURE 7 Projected growth for RTD's Light Rail Operations.

Along with these considerations is the requirement to address the areas where additional staffing may be needed or redirected. One such area that during the first year of operation has shown the need for additional staffing resources is training and safety program development. The training needs now emerging are recertification for both operators and mechanics, external agency safety training and emergency response, and the development of future employees to fill positions that open up owing to attrition or to expansion and growth. It is important that changes in full-time employees are noted early and justified thoroughly in order to provide systematically planned financial impacts.

The planned growth for RTD's Light Rail Operations is very conservative and based on the needs projected and assumed during the next few years. Figure 7 details the projected growth through 1999 and before start-up of the Southwest Corridor.

The transit industry should be pleased that the various teams involved with the RTD in Denver, Colorado, did not "reinvent the wheel," but in an effort to be efficient and effective in its process used the experienced professionals, technology, and innovations that were available. This process was accomplished with an open mind and the intention not only to learn lessons, but to remember them for future use as well.

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 400 committees, task forces, and panels composed of more than 4,000 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Harold Liebowitz is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Harold Liebowitz are chairman and vice chairman, respectively, of the National Research Council.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TRB	Transportation Research Board

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