Evaluations of Operating Light-Rail Transit and Streetcar Systems in the United States

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The goal of the research presented in this paper is to evaluate how closely each of the light-rail transit (LRT) and streetcar systems in the United States approaches the LRT concept. Both LRT and streetcar systems are evaluated because the usual pattern of development, here as in Europe, has been for streetcar systems to be upgraded gradually to LRT standards. Of the surviving networks, several run largely on reserved rights-of-way and closely approach the LRT concept; others are clearly street-car operations that possess few true LRT characteristics. Highlighting the strengths and weaknesses of existing systems should be helpful to those planning new LRT installations. The paper also stresses two of the most important qualities of LRT systems: (a) flexibility in right-of-way location and its concomitant, the ability to improve segments of systems on an incremental basis, and (b) ability of systems constructed in a trunk-and-branches pattern to provide both line-haul and collection and distribution functions, thus giving most patrons a single-vehicle ride.

There were 72 100 km (44 800 miles) of electric railway trackage in the United States in 1917 (1). Despite the current popular impression, this vast network was not located entirely in city streets. In many cities, portions of one or more streetcar lines were located in boulevard medians. The Dundalk Avenue line in Baltimore, now abandoned, was a good example. Many suburban lines operated on private rights-of-way. In addition, there was a network of intercity light electric railways that were called interurbans.

Rochester, New York, had a streetcar subway that ran into its central business district (CBD), as did the Pacific Electric Railway in Los Angeles, which operated a large network of suburban and short-haul intercity lines over more than 800 route km (500 route miles). This system included one of the first transit-freeway joint rights-of-way. Instead of building transit in an expressway median, as is now commonly suggested, the Hollywood Freeway was constructed through Cahuenga Pass in 1939 and 1940 on either side of the Pacific Electric's Hollywood Boulevard line.

Why did all these lines fail? Essentially, their demise was brought about by a combination of growing automobile ownership and improved roads. During this era of decline, roughly from the late 1920s through the 1950s, transit service continued to be provided by private companies. These operators were justifiably concerned with maintaining their profitability; it was not surprising that, in the face of declining ridership and revenues, they turned to less capital-intensive means of providing basic transit service or discontinued operations altogether.

The massive switch to buses generally resulted in avoidance of maintenance costs for right-of-way, track, and power distribution systems. Abandonment of these facilities and streetcars brought income tax write-offs, as well as substantial sums realized from the sale of salvaged materials. Finally, buses were relatively inexpensive to acquire and were short-lived vehicles that could be depreciated rapidly, so that they would not outlast the expected disappearance of the need for public transit service.

Now, since most major metropolitan transit systems are operated by public agencies as essential community services and since the specter of dwindling petroleum supplies confronts us, it is time to reexamine the potential of the electric railway. Although most cities that want to build light-rail transit (LRT) systems will have to start from scratch, there are a few places in which streetcars and suburban light electric railways survive.

OPERATING LRT AND STREETCAR SYSTEMS IN THE UNITED STATES

LRT and streetcar systems in the United States have dwindled to 35 routes totaling about 320 km (200 miles) of line and using a fleet of 1035 cars. They carry about 560 000 passengers on a typical weekday. There are 13 definable systems providing regular service in nine U.S. cities.

1. Boston—Green Line: Four routes link the CBD with residential areas in the southern and western parts of the city and in the western suburbs of Brookline and Newton. One line is the 15.1-m (9.4-mile) Riverside extension, which in 1959 replaced a commuter railroad (2).
2. Boston—Mattapan-Ashmont: This is an LRT feeder to rapid transit that was built in a former commuter railroad right-of-way (3).
3. Newark—City subway: This remainder of the former subway-surface system, built in an abandoned canal bed, extends from the CBD to northern residential areas of the city.
4. Philadelphia—City streetcars: There are seven routes, each 4.7 to 20.1 km (2.9 to 12.5 miles) long; they are the remnant, along with the subway-surface lines, of a much larger network.
5. Philadelphia—Subway-surface: Five routes share a 4.0-km (2.5-mile) subway west from the CBD, then fan out to run as streetcars in residential areas.
6. Philadelphia—Media-Sharon Hill: Two lines of four remain; they link the Delaware County suburbs with rapid transit lines to the CBD through the 69th Street Terminal at the city's western edge (4).
7. Philadelphia—Norristown High-Speed Line: This completely grade-separated line has high-platform stations, runs single cars with on-board fare collection, and feeds suburban patrons to rapid transit at 69th Street.
8. Pittsburgh—South Hills: Four physically distinct routes link the CBD with suburbs to the south of the Monongahela River. The Library and Drake lines are remnants of once-longer runs to Charleroi and Washington, Pennsylvania.
9. Cleveland—Shaker Heights Rapid Transit: Two lines were built in 1913 and 1920 by real estate developers to link their new, planned town of Shaker Heights with the CBD; the line shares 4.0 km (2.5 miles) of track with rapid transit trains (5).
10. Detroit—Downtown trolley: This short 1.3-km (0.8-mile) shuttle line through the CBD was opened in September 1976 (6).
11. New Orleans—St. Charles: The last U.S. line to use the double-truck streetcars built in the 1920s connects the CBD and a gracious residential area; it also

Table 1. General characteristics of U.S. LRT and streetcar systems.

System	One-Way Line (km)	Types of Service Offered				Through Service Routes		Revenue Service Cars	Annual Car Kilometers of Revenue Service (000s)	Passengers Carried (000s)		Avg System Operating Speed (km/h)
		Line Haul to CBD	Feeder to Line-Haul Transit	Local Urban or Suburban Transit	CBD Distribution	Number	Length (km)			Annually	Avg Weekday	
Boston									10 100			
Green Line	43.8	Yes	No	Yes	Yes	4	58.1	276		41 100	151	20.0
Mattapan-Ashmont	4.2	No	Yes	Yes	No	1	4.2	15		3 900	14	19.3
Newark City Subway	6.7	Yes	No	Yes	Yes	1	6.7	26	1 000	2 450	8	32.2
Philadelphia									40 100			
Streetcars	82.4	Yes	Yes	Yes	No	7	83.4	{350		40 000	130	14.5
Subway-surface	35.9	Yes	Yes	Yes	No	5	52.4			20 000	65	18.0
Media-Sharon Hill	19.1	No	Yes	Yes	No	2	22.4	32		4 000	14	25.8
Norristown Line	21.9	No	Yes	Yes	No	1	21.9	21		2 750	10	49.9
Pittsburgh: South Hills	39.9	Yes	No	Yes	Yes	4	54.9	95	3 100	7 000	24	22.0
Cleveland: Shaker Heights	21.1	Yes	No	Yes	No	2	30.7	57	1 800	4 720	18	37.0
Detroit: Downtown shuttle	1.3	No	No	No	Yes	1	1.3	6	–	–	–	7.7
New Orleans: St. Charles Line	10.5	Yes	No	Yes	No	1	10.4	35	1 300	7 830	25	15.0
Fort Worth: Tandy Center Subway	1.9	No	No	No	Yes	1	1.9	6	–	1 200	4	25.8
San Francisco Muni	29.3	Yes	No	Yes	Yes	5	54.4	115	–	30 000	98	15.3
Total	318.0					35	402.7	1034		164 950	561	21.9

Note: 1 km = 0.6 mile.

Table 2. Intensity of use of LRT and streetcar systems.

System	Weekday Passengers	Line Length (km)	Avg Weekday Passengers per Kilometer of Line
Boston			
Green Line	151 000	43.8	3400
Mattapan-Ashmont	14 000	4.2	3300
Newark City Subway	8 000	6.7	1200
Philadelphia			
Streetcars	130 000	82.4	1600
Subway-surface	65 000	35.9	1800
Media-Sharon Hill	14 000	19.1	700
Norristown Line	10 000	21.9	500
Pittsburgh: South Hills	24 000	39.9	600
Cleveland: Shaker Heights	18 000	21.1	900
New Orleans: St. Charles Line	25 000	10.4	2400
Fort Worth: Tandy Center Subway	4 000	1.9	2100
San Francisco Muni	98 000	29.3	3300

Note: 1 km = 0.6 mile.

serves as a tourist attraction. It is operated by a private company.

12. Fort Worth—Tandy Center Subway: This line, opened in 1963 as Leonards M and O Subway to link their department store in the CBD and its periperal parking lots, now also serves the Tandy Corporation's headquarters office towers (7).

13. San Francisco—Municipal Railway (Muni): Five routes provide service from western and southern residential areas within the city to the CBD; it is now undergoing upgrading from streetcar to LRT operation (8).

Some general characteristics of these systems (2, 9, 10, 11, 12, 13, 14) are presented in Table 1. The newest and shortest line, Detroit's downtown shuttle, is actually the imaginative use of antique four-wheel trolley cars to provide both a useful service and an attraction in its own right. It is included in Table 1 because it is operated by the Detroit Department of Transportation as part of its citywide transit system. Since it is so short and has no LRT characteristics, it is omitted from further consideration in this paper.

Even though they form a unified physical entity, Philadelphia's 118.3 km (73.5 miles) of streetcar and subway-surface lines provide two distinct levels of service. Streetcar routes run at an overall system average operating speed ($\overline{V}$) of 14.5 km/h (9.0 mph) and serve primarily as feeders to rapid transit and as local area transportation. Line-haul ridership to the CBD is secondary, since only two of the seven routes enter that area. The opposite is true for the five subway-surface lines, all of which penetrate the heart of the CBD and, operating at a $\overline{V}$ of 18.0 km/h (11.2 mph), offer somewhat faster service (although the same types of cars are used on both parts of the city system). Wherever possible, these two groups of routes are treated as separate systems.

There are substantial variations among the several systems. Some, such as the Tandy Center Subway in Fort Worth, are quite small; others are much longer and larger in terms of number and length of routes, fleet size, and typical weekday patronage. Length, however, does not govern intensity of use as measured by the number of passengers per day per kilometer of line. As Table 2 shows, the Fort Worth line is exceeded in this statistic only by the Boston, San Francisco, and New Orleans lines. Among the many causes of the variation in intensity of use among systems are the service-area population, park-and-ride opportunities, integration with other modes of transit, level of CBD development, existence of other trip generators, types of services offered, and service quality (frequency, speed, reliability, comfort, and safety).

It must also be considered that most of these systems have been in existence for many years. The newest—Fort Worth—opened in 1963. The oldest—New Orleans—traces its history to the New Orleans and Carrollton Rail Road Company, which began operating horse-drawn cars in 1834. Steam locomotives were used for some years; the line was electrified in 1893 (15). Changing patterns of urban development during the intervening years have robbed some lines of their patronage bases. Some lines have survived simply because they were the most substantially built segments or trunks of once-larger networks.

The Newark City Subway is a good example. It was completed in 1935 by the city of Newark and operated for the next 15 years (under lease to a private company) as the downtown end of a subway-surface system of several routes that had formerly run all the way downtown in the streets. These routes left the City Subway—the name that applies to the whole 6.7-km (4.2-mile) line, even though only 2.1 km (1.3 miles) are underground—at Central Avenue, Orange Street, Bloomfield Avenue, and Franklin Avenue. All of these streetcar routes were converted to bus operation about 1950, but the city insisted that the subway continue in operation. It serves only its immediate catchment area, since most of the buses run all the way downtown. This, combined with the gradual decline of the Newark CBD as a working and shopping area and the fact the line parallels a large park for most of its above-ground run, has resulted in the underuse indicated in the tables.

Similar problems of urban change have hurt ridership on Cleveland's Shaker Heights system, particularly the stagnation of that part of the CBD adjacent to the line's downtown terminal (16). As a result, morning peak-hour riding in 1973 was down to 4200 from a high of 5500 between 7:00 and 9:00 a.m. However, a large degree of recovery has been achieved since then by halving the fare and providing free transfers under the new Greater Cleveland Regional Transit Authority.

LRT lines that feed rapid transit also appear to be used at a lower level of intensity than line-haul routes. Passengers using Philadelphia's Media, Sharon Hill, and Norristown lines must change to a rapid transit line to complete their trips to the CBD. Not only are they inconvenienced by having to walk through the 69th Street Terminal to make the change, they also must pay an additional full fare because the Southeastern Pennsylvania Transportation Authority (SEPTA) has not integrated the fare structures of its several operating divisions. These two factors have always hampered ridership development on these lines.

This has not been the case in Boston. The world's first streetcar subway opened in Boston in 1897; most of it is still in service today as part of the Green Line (3). It has been extended over the years and, in the last decade, most of its stations have been modernized. However, it no longer provides streetcar service. Rather, the four lines radiating from the tunnels run largely on reserved tracks in boulevard medians; the Riverside line is completely grade separated. This line operates at a $\overline{V}$ of 25.4 km/h (15.8 mph) overall or 36.2 km/h (22.5 mph) in the section west of the subway. It competes effectively with other modes for commuter traffic to Boston from the western suburbs. Other Boston LRT lines serve heavily built-up areas, including at least four colleges and universities. Major cultural and entertainment facilities—Symphony Hall, the Museum of Fine Arts, the Museum of Science, the Municipal Auditorium, Fenway Park (baseball), and the Boston Garden (hockey and basketball)—all are served by the Green Line.

The subway portion of the Green Line is the only rail transit facility that follows the spine of Boston's elongated CBD, which stretches from Government Center around the Boston Common to Back Bay (2). The Green Line also has direct interchange stations in the CBD with all three of Boston's rail rapid transit lines and, at North Station, with Boston and Maine commuter rail services to the northern suburbs. In addition, it also intersects many bus routes throughout its service area. All of this results in outstanding system connectivity. These factors help explain why the Green Line is the most heavily used of Boston's four line-haul rail transit routes and carries more passengers daily than any of the others, as well as why it is the most intensely used U.S. LRT system (Table 2).

COMMUNITY CHARACTERISTICS OF THE SERVICE AREAS

Boston's example clearly demonstrates that transit systems exist successfully only as useful parts of the total urban fabric. To understand and evaluate existing LRT and streetcar systems, it is necessary to describe the kinds of populations and communities they serve.

Several socioeconomic indicators were developed by using data from the 1970 U.S. Census at the census-tract level to show how LRT service areas in different cities compare with one another. Tracts through which LRT or streetcar lines pass have been analyzed and are assumed to be synonymous with the service area; i.e., most park-and-ride and feeder-bus patrons are ignored. Data have not been assembled for the shortest systems: Detroit, Fort Worth (which serves no resident population), and Mattapan-Ashmont (the shorter of Boston's two systems). Table 3 presents the results of the census-data investigation. The various LRT and streetcar systems can be seen to serve populations ranging from 47 000 to nearly 760 000, or from roughly 1 to 15 percent of the population of the total metropolitan area, depending on their location, length, number of routes, and so on.

The mean income levels and income distributions shown for the several service areas indicate that LRT, although it accommodates substantial numbers of poor people, is a vehicle for all classes. The Shaker Heights Rapid Transit System provides an example. While it serves several tracts in Cleveland in which the mean annual income was about $5500 in 1970, its main rider pool comes from Shaker Heights, where the 1970 mean income was $26 674. Similar variations from tract to tract may be observed in other LRT service areas, although they are not always so pronounced.

For Boston's Green Line, the mean income in 1970 was $11 250 for LRT tracts in the city of Boston, $17 693 in Brookline, and $22 896 in Newton, compared with $10 272 for the city of Boston as a whole. This shows that LRT, in some of its present applications, serves markets made up largely of riders who could, if they wished, choose to use other transportation.

Age composition is rather stable. Where the group of riders under 18 is smaller (Boston, New Orleans, San Francisco), the difference is shared relatively evenly by the groups of those 18 to 64 and those 65 and over. LRT serves areas of cities that have large black populations (e.g., Newark, Philadelphia, Cleveland, and New Orleans); in the San Francisco service area, a substantial non-black minority population (mostly Asian-Americans and some Mexican-Americans) is included. The sex groupings confirm only that females slightly outnumber males generally.

Variations in the density of development of the service areas may be more important to system development. Table 4 lists the total population, number of housing units, and land area for each service area and then uses these data to calculate the population per square kilometer, the number of housing units per square hectometer, and the number of people per housing unit. The last, as expected, is generally smaller in the CBDs than in the residential areas of core cities, which in turn show smaller values than suburban areas. Densities of population and housing units are also relatively low in the CBDs, since these are principally areas of work rather than residence (San Francisco is an exception). However, both peak for residential areas within city boundaries, then trail off in the typically newer, more spread-out suburban areas. It may be noted for reference that building plots of 15.2 by 30.5 m (50 by 100 ft) represent a density of 20 housing units/hm^2 (8 housing units/acre), assuming single-family houses and allowing for street right-of-way.

Some interesting inferences can be drawn by evaluating these indicators in light of the figures on system use developed in Table 2. This is done in Table 5. Only CBD-oriented systems are included, since the rapid transit feeder lines (Media-Sharon Hill and Norristown) and Philadelphia's streetcar network do not exhibit similar patterns. The two indicators of the intensity of use of the systems decline together. This would seem to indicate larger pools of regular riders on the more intensely used systems. In San Francisco, some trips to the CBD may be made on other modes: automobiles or the Bay Area Rapid Transit (BART) line that begins in Daly City. Both this line and a freeway parallel each other along the southeastern edge of the streetcar service area. The Muni streetcars operate at relatively low average speeds, as the table indicates. This problem has been recognized, and a current program to upgrade the system (described in a later section of this

Table 3. Summary of socioeconomic indicators for the service areas of LRT and streetcar systems.

System	Population (000s) Service Area	Metropolitan Area	Core City	Mean Family Income ($)	Percentage of Families With Income Under $5000	$5000 to $9999	$10 000 to $14 999	$15 000 to $24 999	$25 000 and Over	Percentage of Population Under 18	18 to 64	65 and Over	Race (%) White	Black	Other	Sex (%) Female	Male
Boston Green Line	282	2899	641	15 102	16	27	23	20	14	18	67	15	92	5	3	56	44
Newark City Subway	47	2055	382	8 902	27	37	23	11	2	32	63	5	63	35	2	51	49
Philadelphia		4818	1950														
Streetcars	758			8 647	24	37	25	12	2	32	56	12	60	39	1	53	47
Subway-surface	254			8 778	22	37	26	13	2	31	58	11	47	52	1	53	47
Media-Sharon Hill	110			13 519	8	27	33	25	7	32	57	11	99	1	–	53	47
Norristown Line	66			17 005	8	23	27	28	14	30	60	10	96	4	–	51	49
Pittsburgh:																	
South Hills	157	2401	520	12 822	11	30	32	21	6	34	56	10	97	3	–	53	47
Cleveland:																	
Shaker Heights	91	2064	751	16 589	20	25	20	18	17	30	56	14	65	34	1	54	46
New Orleans:																	
St. Charles Line	77	1046	593	12 291	32	30	16	12	10	25	60	15	64	35	1	54	46
San Francisco Muni	275	3110	716	12 732	16	28	27	22	7	21	64	15	80	11	9	51	49

Table 4. Density of development in the service areas of LRT and streetcar systems.

System	Population	Housing Units	Area (km^2)	Persons per Square Kilometer	Housing Units per Square Hectometer	Persons per Housing Unit
Boston Green Line						
CBD	8 570	5 021	4.9	1 700	10.2	1.7
Brookline	52 659	20 968	10.6	5 000	19.8	2.5
Newton	45 057	12 779	26.2	1 700	4.9	3.5
Other Boston city	175 871	71 561	14.2	12 400	50.4	2.5
Overall	282 157	110 329	55.9	5 000	19.7	2.6
Newark City Subway						
CBD	9 296	3 771	1.8	5 200	21.0	2.5
Other	37 186	13 070	5.4	6 900	24.2	2.8
Overall	46 482	16 841	7.2	6 500	23.4	2.8
Philadelphia						
Streetcars						
CBD	16 484	10 108	3.1	5 300	32.6	1.6
Other	741 546	242 333	85.5	8 700	28.3	3.1
Overall	758 030	252 441	88.6	8 600	28.5	3.0
Subway-surface						
CBD	5 590	3 561	0.8	7 000	44.5	1.6
Other	248 536	83 430	25.1	9 901	33.2	3.0
Overall	254 126	86 991	25.9	9 800	33.6	2.9
Media-Sharon Hill	110 210	36 275	36.0	3 100	10.1	3.0
Norristown Line	65 682	20 277	36.5	1 800	5.6	3.2
Pittsburgh: South Hills						
CBD	2 944	1 401	1.0	2 900	14.0	2.1
Other	154 307	46 968	62.9	2 500	7.5	3.3
Overall	157 251	48 369	63.9	2 500	7.6	3.2
Cleveland: Shaker Heights						
CBD	1 201	419	4.4	300	1.0	2.9
Shaker Heights	36 306	12 885	16.1	2 300	8.0	2.8
Other Cleveland city	53 646	21 877	13.7	3 900	16.0	2.4
Overall	91 153	35 181	34.2	2 700	10.3	2.6
New Orleans: St. Charles Line						
CBD	2 604	1 933	3.1	800	6.2	1.4
Other	74 026	30 020	16.1	4 600	18.6	2.5
Overall	76 630	31 953	19.2	4 000	16.6	2.4
San Francisco Muni						
CBD	23 509	19 275	2.8	8 400	68.8	1.2
East of Twin Peaks	87 520	38 456	8.3	10 500	46.3	2.3
West of Twin Peaks	164 237	63 552	31.1	5 300	20.4	2.6
Overall	275 266	121 733	42.2	6 500	28.8	2.3

Note: 1 km^2 = 0.4 $mile^2$ and 1 hm^2 = 2.5 acres.

paper) should raise the system speed substantially.

Philadelphia's subway-surface system must compete with rail rapid and commuter rail services in some portions of its service area. Four commuter rail stations—49th Street, Angora, 52nd Street, and Overbrook—serve portions of West Philadelphia that are within the catchment areas for subway-surface routes 10, 11, 13, and 34; they may be taking some riders who otherwise would use the trolley, especially at peak commuting hours. Darby, at the outer end of route 13, is also served by commuter rail. North-south bus routes crisscrossing West Philadelphia act as feeders to the Market-Frankford subway-elevated system and may provide faster trips downtown (in either real or perceived terms) for some subway-surface service-area residents.

The Newark City Subway, as noted earlier, has the smallest total service-area population of any of the LRT and streetcar systems studied. While several of the former rail routes that have been converted to bus routes run through to the CBD, there still are some routes that feed the City Subway at Franklin Avenue, Park Avenue, and Norfolk Street. It may be that riders from these feeder lines and from commuter trains who use LRT to reach CBD offices from Pennsylvania Station are swelling the number of subway users; this would inflate the figure for the number of rides per person residing in the service area.

On the basis of the limited data and statistics presented in this section, the following conclusions appear to have at least some validity, although the small number of systems makes generalization difficult.

1. Existing LRT and streetcar systems usually are located in areas of moderate to high population and housing-unit density.
2. LRT and streetcar systems serve financially and ethnically diverse populations. Systems that serve CBDs or feed rapid transit lines are able to attract large numbers of riders who could use other modes of transportation but find LRT to be convenient.
3. Although the data are not conclusive, it does appear that systems operating in areas of relatively high

Table 5. Comparison of intensity of use and trip characteristics of CBD-oriented systems.

System	Avg Weekday Passengers per Kilometer of Line	Annual Rides per Capita in Service Area	Average Operating Speed (km/h)	Estimated Typical Trip Length (km)	Estimated Typical Trip Time (min)
Boston Green Line	3400	146	20.0	7.2	22
San Francisco Muni	3300	109	15.3	5.5	21
New Orleans: St. Charles Line	2400	102	15.0	5.2	21
Philadelphia subway-surface	1800	79	18.0	5.0	17
Newark City Subway	1200	52	32.2	4.5	8
Cleveland: Shaker Heights	900	52	37.0	12.6	20
Pittsburgh: South Hills	600	45	22.0	11.3	31

Note: 1 km = 0.6 mile.

Table 6. Type of right-of-way occupied by LRT and streetcar systems.

System	Location of Line (km)							Percentage of Line			Avg Operating Speed (km/h)
		Surface									
	Subway or Tunnel	Grade Separated	Private Right-of-Way	Median	Reserved Lane	Mixed Traffic	Total	Grade Separated	Reserved	Mixed Traffic	
Boston											
Green Line	7.2	17.1	0	15.3	0	4.2	43.8	55	35	10	20.0
Mattapan-Ashmont	0	4.2	0	0	0	0	4.2	99	–	–	19.3
Newark City Subway	2.1	4.6	0	0	0	0	6.7	99	–	–	32.2
Philadelphia											
Streetcars	0	0	0	0	4.2	78.2	82.4	–	5	95	14.5
Subway-surface	4.0	0	0	1.6	0	30.3	35.9	11	5	84	18.0
Media-Sharon Hill	0	0	16.2	0	0.3	2.6	19.1	–	87	13	25.8
Norristown Line	0	21.9	0	0	0	0	21.9	100	–	–	49.9
Pittsburgh: South Hills	1.1	0	28.2	0.8	0	9.8	39.9	3	73	24	22.0
Cleveland: Shaker Heights	0	11.3	0	9.8	0	0	21.1	53	47	0	37.0
New Orleans: St. Charles Line	0	0	0	9.0	0.2	1.3	10.5	–	88	12	15.0
Fort Worth: Tandy Center Subway	0.8	1.1	0	0	0	0	1.9	100	–	–	25.8
San Francisco Muni	5.2	0	1.6	4.2	0	18.3	29.3	17	20	63	15.3
All systems	20.4	60.2	46.0	40.7	4.7	144.6	316.7	25	29	46	21.9

Note: 1 km = 0.6 mile.

population density are used more intensively than lines in lower density areas, even though the latter may offer higher average operating speeds.

EVALUATION CRITERIA

As Table 1 indicates, the average operating speeds of the various LRT and streetcar systems have a broad range: 15 to 50 km/h (9 to 31 mph). The remainder of this paper examines the sources of these variations and attempts to classify each operating system as an LRT or streetcar system. The concise definition adopted by TRB's Committee on Light-Rail Transit in spring 1976 (17) is the yardstick against which each existing system was evaluated. The prime consideration in this definition is right-of-way location.

Light-rail transit is a mode of urban transportation utilizing predominantly reserved but not necessarily grade-separated rights-of-way. Electrically propelled rail vehicles operate singly or in trains. LRT provides a wide range of passenger capabilities and performance characteristics at moderate costs.

Relevant information on each LRT and streetcar system was assembled to permit evaluation (2, 4, 7, 14, 16). Table 6 describes the types of right-of-way occupied by each system, listing the types in descending order of protection of interference from other traffic. The percentages of the lines that operate on grade-separated or reserved rights-of-way are also shown in Table 6.

Right-of-way location is a principal factor affecting overall average speed ($\overline{V}$). Higher $\overline{V}$s generally coincide with greater degrees of reservation and lesser interference from other traffic. The aptly named Norristown High-Speed Line is completely grade separated and achieves a $\overline{V}$ of 50 km/h (31 mph); the Philadelphia streetcar system, which has a $\overline{V}$ of 14.5 km/h (9 mph), has only 5 percent of its lines located on the lowest quality right-of-way reservation. There are exceptions however. Boston's Mattapan-Ashmont Line has only one crossing at grade but averages only 19.3 km/h (12.0 mph). The St. Charles Line in New Orleans is 88 percent reserved yet averages only 15.0 km/h (9.3 mph), while the Media-Sharon Hill lines, which are 87 percent reserved, average 25.7 km/h (16.0 mph).

Other factors must be examined. These include frequency of passenger stops, frequency of at-grade crossings, track traffic patterns, signal systems, and vehicle performance (4, 7, 9, 10, 14, 16, 18, 19, 20, 21). Indicators for these system elements are presented in Tables 7, 8, and 9.

Boston Green Line

The Green Line, 43.8 km (27.2 miles) of line and four routes totaling 58.1 service route km (36.1 service route miles), is the larger of the Boston area's two physically separate systems. Only one of its routes has any unreserved street trackage: 4.2 km (2.6 miles) or 10 percent of the system total at the southern end of the Huntington Avenue line. The remainder of this line and the surface portions of the Beacon Street and Commonwealth Avenue routes are located in reserved boulevard medians. The line to Riverside was converted from commuter rail to LRT operation in 1959 and is completely grade separated. All lines, as described earlier, pass under the CBD in subway.

Despite having 90 percent reserved right-of-way, the system $\overline{V}$ is only 20.0 km/h (12.4 mph). The Riverside line has a $\overline{V}$ of 25.4 km/h (15.8 mph), Commonwealth has a $\overline{V}$ of 16.1 km/h (10.0 mph), Beacon has a $\overline{V}$ of 16.4 km/h (10.2 mph), and Huntington has a $\overline{V}$ of 17.4 km/h (10.8 mph). Perhaps the major reason these $\overline{V}$s are so low is the intensity with which the system is used. It is not uncommon for cars to carry standees in the subway even during base periods, and crowding occurs during rush hours, even though two- and three-car trains are operated. As a result, loading and unloading are slow, especially when the left-hand sides of Presidents' Conference Committee (PCC) cars (which have only a single set of doors) are at center-island station platforms. On the surface portions of outbound trips, $\overline{V}$ is further restrained by a pay-as-you-leave fare collection system that requires each alighting patron to use the car's front door. Other factors affecting performance may be noted in Tables 7, 8, and 9. Although stations have typical LRT spacing, the reserved, at-grade portions of the system average an at-grade crossing every 0.32 km (0.2 mile). Most of these crossings are controlled by street traffic signals. Some of those along Commonwealth

Table 7. Frequency of stations and at-grade crossings.

Item	Boston: Green Line	Boston: Mattapan-Ashmont	Newark City Subway	Philadelphia: Streetcars	Philadelphia: Subway-Surface	Philadelphia: Media-Sharon Hill	Philadelphia: Norristown Line	Pittsburgh: South Hills	Cleveland: Shaker Heights	New Orleans: St. Charles Line	Fort Worth: Tandy Center Subway	San Francisco Muni	All Systems
Stations or car stops													
Grade separated	15	7	10	0	8	1	22	0	9	0	4	2	78
Reserved	54	1	1	29	11	38	0	80	19	45	0	45	323
Street	25	0	0	434	147	11	0	8	0	5	0	136	766
Total	94	8	11	463	166	50	22	88	28	50	4	183	1167
At-grade crossings (in reserved right-of-way)													
Railroad flashers or preemptive traffic signals		1	0	0	1	31	0	7	0	0	0	0	
Nonpreemptive traffic signals	{48	0	1	10	3	11	0	0	20	16	0	{39	
Warning signs		0	0	14	0	3	0	36	0	1	0		
No protection	0	0	0	0	0	0	0	0	0	81	0	0	
Total	48	1	1	24	4	45	0	43	20	98	0	39	323
Grade separations (overpasses and underpasses)	26	8	8	0	0	2	36	14	26	1	0	2	145
Avg spacing, km													
Stations (separated and reserved)	0.58	0.6	0.68	0	0.29	0.42	1.05	0.37	0.76	0.19	0.64	0.23	0.43
Car stops (lines in streets)	0.16	0	0	0.18	0.21	0.24	0	0.31	0	0.26	0	0.13	0.19
Stations or car stops (entire system)	0.47	0.60	0.68	0.18	0.21	0.39	1.05	0.37	0.76	0.21	0.64	0.16	0.27
Grade crossings (reserved right-of-way only)	0.32	2.09	3.38	0.19	0.53	0.37	0	0.66	0.50	0.10	0	0.14	0.29

Note: 1 km = 0.6 mile.

Table 8. Track traffic patterns and signal systems.

System	Track Traffic Patterns: Double Track Kilometers	Double Track Percent	Single Track, Two-Way Running Kilometers	Two-Way Running Percent	Single Track, One-Way Running Kilometers	One-Way Running Percent	Total (km)	Control of Train Operations: Automatic Block Signals Kilometers	Automatic Block Signals Percent	Street Traffic Signals Kilometers	Street Traffic Signals Percent	Unsignalled Kilometers	Unsignalled Percent	Total (km)
Boston														
Green Line	43.8	100	0	–	0	–	43.8	24.3	56	19.5	44	0	–	43.8
Mattapan-Ashmont	4.2	100	0	–	0	–	4.2	4.2	100	0	–	0	–	4.2
Newark City Subway	6.7	100	0	–	0	–	6.7	6.7	100	0	–	0	–	6.7
Philadelphia														
Streetcars	61.3	74	0	–	21.1	26	82.4	0	–	82.4	100	0	–	82.4
Subway-surface	35.1	98	0	–	0.8	2	35.9	3.4	9	32.5	91	0	–	35.9
Media-Sharon Hill	13.7	71	5.4	29	0	–	19.1	5.4	29	4.8	25	8.9	46	19.1
Norristown Line	20.8	95	1.1	5	0	–	21.9	21.9	100	0	–	0	–	21.9
Pittsburgh: South Hills	27.0	68	10.6	26	2.3	6	39.9	26.4	66	10.6	27	2.9	7	39.9
Cleveland: Shaker Heights	21.1	100	0	–	0	–	21.1	17.9	85	0	–	3.2	15	21.1
New Orleans: St. Charles Line	9.0	86	0	–	1.5	14	10.5	0	–	10.5	100	0	–	10.5
Fort Worth: Tandy Center Subway	1.9	100	0	–	0	–	1.9	0	–	0	–	1.9	100	1.9
San Francisco Muni	29.3	100	0	–	0	–	29.3	0.8	3	24.2	82	4.3	15	29.3
All systems	273.9	87	17.1	5	25.7	8	316.7	111.0	36	184.5	58	21.2	6	316.7

Note: 1 km = 0.6 mile.

Table 9. Characteristics of revenue service vehicles.

System	Fleet Type	Fleet Number	Mechanical Data: Axles	Motors	Kilowatts per Motor	Acceleration ($m \cdot s^2$)	Balancing Speed (km h)	Car Body: Type of Unit[a]	Avg Weight (Mg)	Operability in Trains: Percentage of Fleet Equipped	Staff per Car	Age of Fleet (years)	Seats	Power Collector[b]
Boston														
Green Line	Boeing Vertol	32	6	2	157	1.2	80	A: DE	31	100	1	1	52	P
Mattapan-Ashmont	PCC	276	4	4	41	1.8	72	S: SE	17	83	1	26 to 36	52	T
Newark City Subway	PCC	15	4	4	41	1.8	72	S: SE	17	0	–	26 to 36	52	T
Philadelphia	PCC	26	4	4	41	1.8	72	S: SE	16	0	–	28 to 31	54	T
Streetcars and subway-surface	PCC	350	4	4	41	1.8	72	S: SE	16	0	–	29 to 36	45 to 53	T
Media-Sharon Hill	Suburban	32	4	4	41	1.6	97	S: DE	19 to 22	41	1	28 to 45	59	T
Norristown Line	High speed	21	4 to 10	4 to 8	75 to 93	0.7	145	S(19), A(2): DE	24 to 95	90	1	36 to 53	52 to 141	S
Pittsburgh: South Hills	PCC	95	4	4	41	1.8	72	S: SE	16	0	–	28 to 32	50 to 54	T
Cleveland: Shaker Heights	PCC	57	4	4	41	1.8	72	S: SE	17 to 20	91	1	29 to 31	60 to 62	T
New Orleans: St. Charles Line	City streetcar	35	4	2	48	0.8	43	S: DE	20	0	–	53 to 54	52	T
Fort Worth: Tandy Center Subway	PCC	10	4	4	41	1.8	72	S: DE	–	0	–	32	30	T
San Francisco Muni	PCC	115	4	4	41	1.8	72	S: SE	17	0	–	26 to 30	53 to 60	T

Note: 1 kW = 1.3 hp, 1 m = 3.3 ft; 1 km = 0.6 mile, and 1 Mg = 1.1 ton.

[a] A = articulated, S = single unit, DE = double ended, SE = single ended.

[b] P = pantograph, T = trolley pole, S = third-rail shoe.

Avenue are known to be preemptive, but exact information was not available.

As of August 1977, most of the cars in use were PCC cars, but 32 new Boeing Vertol light-rail vehicles (LRVs) have been accepted for service. Fully 83 percent of the PCC fleet is equipped for multicar operation, as are all of the LRVs. PCC acceleration is adequate, as is maximum speed, given the system's physical restrictions (grade crossings, sharp curves in the subway, proximity to traffic when operating in streets and on some narrow medians). The somewhat higher balancing speeds of the new LRVs will be beneficial principally on the Riverside line, where station spacings outside the subway are a relatively long 1.37 km (0.85 mile) and there are no grade crossings. The Green Line clearly meets the criteria of the definition of an LRT system.

Mattapan-Ashmont Line

The Mattapan-Ashmont Line, 4.2 km (2.6 miles) long, feeds the rapid transit Red Line (Harvard-Ashmont) at its south end. It is virtually all grade separated; there is one at-grade crossing. Average station spacing is 0.60 km (0.37 mile) but, because there is little deviation from the average—0.16 km (0.1 mile) or less—there are no long runs at balancing speed. Only single cars are run, but peak-hour headways are as close as 2 min. This line also clearly fits the LRT definition.

Newark City Subway

The Newark City Subway, 6.7 km (4.2 miles) long, also has only one street crossing at grade. This crossing, at Orange Street, is controlled by a nonpreemptive traffic signal, the only significant impedance to speed on the line. This, combined with somewhat longer station spacings than on the two Boston systems, as well as much lighter patronage, results in a substantially higher $\overline{V}$ of 32 km/h (20 mph). Single PCC cars are operated; the line has double tracks and is block signaled throughout. This system, too, is correctly classified as LRT.

Philadelphia Streetcars

The city streetcars of Philadelphia do not now form a system that meets LRT criteria. Only 5 percent of trackage is reserved, and that is only reserved by having lines painted on paved streets to mark off the lanes containing the tracks. Although the initial costs for such reservations are low, their effectiveness depends on enforcement. This does not seem to have been adequate so far, and the lanes have not increased streetcar speeds enough to lure many people out of their automobiles, as had been hoped by the U.S. Environmental Protection Agency, which ordered their installation. Route 6, which has about 2.7 km (1.7 miles) of reserved lanes, still runs at a $\overline{V}$ of 14.5 km/h (9.0 mph); Route 15 continues to be the slowest in the system at a $\overline{V}$ of 11.7 km/h (7.3 mph), although it has not quite 1.5 km (1 mile) of reserved lane in a total length of 13.4 km (8.3 miles).

Opportunities for increasing $\overline{V}$ appear to be minimal. If stops were made every other block instead of every block and if the traffic signals at intersections between stops were made preemptive, the number of stops could be halved. However, this might not be practical on many portions of the streetcar lines.

Philadelphia Subway-Surface Lines

The five subway-surface lines link West Philadelphia residential areas with the CBD. Just to the west of the CBD, they pass through University City, home of two major universities: the University of Pennsylvania and Drexel University. Because they run in a 4.0-km (2.5-mile) subway under University City into the heart of the CBD at City Hall, their $\overline{V}$ is somewhat higher; it ranges from 15.1 km/h (9.4 mph) for Route 10, which leaves the tunnel after only 3.2 km (2.0 miles) of its 9.3 route km (5.8 route miles), to 19.8 km/h (12.3 mph) for Route 36, which in addition to a full 4.0 km (2.5 miles) in the subway includes 1.6 km (1.0 miles) of median trackage. The $\overline{V}$ for all five routes is 18.0 km/h (11.2 mph), which puts it at the lower end of the 16 to 32-km/h (10 to 20-mph) range usually quoted as typical of LRT.

Single PCC cars are used. Headways in the subway shrink to as little as 30 s during peak periods, about as close as is physically possible. Any further increase in car throughput would require consideration of multicar operation during rush hours.

The subway was opened in two stages. The eastern portion was completed in 1905 as part of the Market-Frankford subway-elevated line construction. In this segment, express subway trains use the center pair of tracks in a four-track tunnel, while streetcars use the outer pair and provide local service at three stations not served by rapid transit. The West Philadelphia section of the tunnel opened in 1955. It was built entirely within street lines and thus includes three 90° curves that have 20-m (100-ft) radii around which cars must creep. This routing, which was chosen to reduce construction costs, has resulted in long-term operating inconvenience.

Like the Green Line, the subway-surface lines provide a good illustration of LRT's branching capabilities. There are at least two happy results of having a group of branches joined to a trunk that is planted firmly in the CBD. First, the branches act as distributors in the residential areas so that patrons may board and alight within walking distance of their homes yet have a single-vehicle, no-transfer ride downtown. Second, service on the trunk can be very good, even during nonpeak hours. The subway-surface lines run at 12 to 20-min intervals at these times, and four of the five routes pass under the University of Pennsylvania. Average base headways between the university and the CBD are about 3 to 5 min. Despite the deficiencies noted above (much street running and sharp curves in the subway), the subway-surface lines offer a quality of service that, although it lacks high speed, must be considered to be within the spirit of the LRT concept.

Media-Sharon Hill Lines

The Media-Sharon Hill lines serving Philadelphia's southwestern suburbs constitute a nearly perfect example of the LRT concept. They are located predominantly (87 percent) on reserved right-of-way but include some street running where this could not be economically avoided. Stations are spaced on average 0.42 km (0.26 mile) apart. At-grade crossings occur every 0.37 km (0.23 mile), and there are two areas of grade separation. The track traffic pattern combines double-track (71 percent) and single-track (29 percent) operation, all with two-way running. Single-track segments are protected by block signals, but double-track portions are largely unsignaled except for blind curves. In peak hours, both local and zone express services are run.

The cars used truly fit the LRT concept, even though they antedate the use of the term by many years. Three series of cars are operated in regular service; they were built in 1932 (10 cars), 1941 (9 cars), and 1949 (13 cars). The newest group is equipped for operation in two-car trains. All of the cars can reach nearly 100 km/h (60 mph) but rarely exceed 80 km/h (50 mph) on the lines now operating (one of two abandoned routes had 100-km/h track). Even so, the $\overline{V}$ is 25.8 km/h (16 mph) to 27 km/h (17 mph) for Media and 23 km/h (14.5 mph) for Sharon Hill.

Recent events on the Media-Sharon Hill lines serve to illustrate how the concept of incremental improvements can be applied on a small scale. Two short segments of second track that together total less than 1.6 km (1 mile) were installed on the Media line within the last 5 years to eliminate the single-track running that had caused operating delays while cars waited in sidings for opposing traffic to clear. Operations were thus improved at moderate cost. Other work included the reconstruction of old passenger shelters and the placement of additional shelters at stops.

Norristown High-Speed Line

The Norristown High-Speed Line, which is completely grade separated, is one of only two LRT systems operating in the United States that has high-platform stations, and it is the only one that has a third-rail power distribution system. Although these characteristics may make it seem more like rapid transit than LRT, the line's use of on-board fare collection at all times and mostly single-car trains allows it to be classified as LRT.

In addition to being free of grade crossings, the line has the longest average interstation spacing of any system discussed: 1.05 km (0.65 mile). Effective station spacing is further increased through use of a unique flag-stop indicator system that allows trains to skip stops if there are neither boarding nor alighting passengers. Each intermediate station platform has a cord that passengers pull to light a white signal located far enough in advance of the station to allow car operators to stop safely. If the signal is lit, the car stops; otherwise it runs past at full speed.

These factors permit the fleet of truly high-speed cars to attain a $\overline{V}$ of 50 km/h (31 mph), which is fast for rapid transit, let alone LRT. Changes in motor field taps now limit the maximum speed to about 110 km/h (70 mph), but the cars were capable of 145 km/h (90 mph) for two decades. Between 1950 and 1952, before these changes were made, rush-hour expresses that made only two intermediate stops covered the 21.9 km (13.6 miles) to Norristown in 17 min, a $\overline{V}$ of 77 km/h (48 mph).

Three distinct classes of cars are used. There are 9 cars dating from 1924 to 1929, 10 cars—the wind-tunnel-tested Bullets—from 1931, and two 4-car, triple-articulated trains originally built in 1941 for express Chicago-Milwaukee service—the Liberty Liners—that were acquired secondhand.

Pittsburgh South Hills Lines

The South Hills lines in Pittsburgh are CBD oriented but do not have a downtown subway. They circulate through the business district on unreserved tracks in city streets. The question of these lines' survival has been debated for the last decade, but the decision now has been made to retain and improve them (22).

In its heyday, the Pittsburgh Railways—private predecessor of the public Port Authority Transit—ran city streetcars, suburban car routes, and interurban lines to smaller cities around Pittsburgh. All used the same tracks in the city; the interurbans used suburban lines to the fringes of the urbanized area. As noted earlier, the Library and Drake lines are remnants of once-longer interurban routes. The Mt. Lebanon line is a suburban operation. One streetcar line remains, the route that runs up and over Mt. Washington.

The two interurban lines, which run on private right-of-way outside the CBD, are the longest and fastest routes; the Library line is 20.4 km (12.7 miles) long and has a $\overline{V}$ of 25.7 km/h (16 mph), while the Drake line is 17.4 km (10.8 miles) long and has a $\overline{V}$ of 24.9 km/h (15.5 mph). The Mt. Lebanon line, 11.7 km (7.3 miles) long, includes the only median trackage, a stretch of 0.8 km (0.5 mile). Despite its considerable length of reserved right-of-way, it operates at a $\overline{V}$ of 13.8 km/h (8.6 mph) because it has closer stop spacing—0.29 km (0.18 mile)—and more frequent grade crossings—0.50 km (0.31 miles)—than are found on the interurbans. The streetcar line, which runs on narrow streets and up steep grades over Mt. Washington, averages only 11.3 km/h (7 mph). The overall system $\overline{V}$ is 22.0 km/h (13.7 mph); station spacings follow typical LRT practice. On average, street crossings on the reserved portions of the system occur every 0.66 km (0.41 mile). There are 14 grade separations.

Standard PCC cars run singly on all lines. Fully two-thirds of the line length is protected by block signals, including three sections of single track that have passing sidings. This is the last operating example in the country of what was once typical light-density electric railway practice, i.e., sidings long enough for only three or four cars and equipped with equilateral turnouts so that both tracks diverged instead of having a through route and a siding as is usual in railroad practice.

New track standards adopted by Port Authority Transit—45-kg (100-lb) rail, 61-cm (24-in) tie spacing, and 30.5-cm (12-in) slag ballast section—should, when fully implemented, result in better ride quality than now exists on much of the system. In addition to improving its open track, a portion of the right-of-way north of Castle Shannon is being rebuilt with track embedded in concrete for joint use by buses and rail cars. The Mt. Washington tunnel has been paved for the same reason. This construction, when completed, will result in one of the more unusual examples of joint right-of-way use.

In its present state, Pittsburgh's system must be categorized as a hybrid. The two interurban lines clearly fall into the LRT classification; the Arlington-Warrington line over Mt. Washington is just as clearly a streetcar. Finally, the Mt. Lebanon route, because of its frequent stations and grade crossings, can best be described as a streetcar line that has incipient LRT right-of-way qualities.

Shaker Heights Rapid Transit

Shaker Heights Rapid Transit, which is now part of the Greater Cleveland Regional Transit Authority (RTA), is a second example that seems to epitomize the LRT concept. Its two branches operate in broad suburban boulevard medians in Shaker Heights, then join to run on a 9.6-km (6-mile) grade-separated trunk line to downtown Cleveland. The last 4.0 km (2.5 miles) into Cleveland Union Terminal are run on tracks shared with the rapid transit trains of the RTA's east-west line to the airport. This is another example of joint use: different types of electric rail vehicles use the same tracks.

As originally conceived, the Shaker Heights Rapid Transit was to have used heavy multiple-unit cars like those used until recently by the Illinois Central Railroad in Chicago. This concept was carried through into the construction phase and is evident in the heavy-duty line between downtown and Shaker Square, the junction of the two branches. Even though three- and four-car trains are run during peak hours, the system resulting from the use of light-rail technology is much more compatible with its surroundings in Shaker Heights than railroad commuter cars would have been.

Table 10. Classification of systems as LRT or streetcar operations.

Category	System	Avg System Operating Speed (km/h)
Light-rail rapid transit	Norristown High-Speed Line	49.9
Light-rail transit group 1	Cleveland: Shaker Heights	37.0
	Newark City Subway	32.2
	Philadelphia: Media-Sharon Hill lines	25.8
	Fort Worth: Tandy Center Subway	25.8
Light-rail transit group 2	Pittsburgh: South Hills	22.0
	Boston	
	Green Line	20.0
	Mattapan-Ashmont	19.3
	Philadelphia subway-surface	18.0
Streetcar	San Francisco Muni	15.3
	New Orleans: St. Charles Line	15.0
	Philadelphia streetcar	14.5

Note: 1 km = 0.6 mile.

The average station-spacing figure shown in Table 7 may be somewhat misleading. On the branches, stations are typically 0.5 km (0.3 mile) apart; west of Shaker Square the average distance between stops is 1.6 km (1 mile). Virtually the only impediments to operation are 20 nonpreemptive traffic signals for at-grade crossings on the branches. Despite these, Shaker Heights Rapid Transit is the country's second fastest LRT system. Trains are protected by block signals except at the far outer ends of the branches, and all but five of the PCC cars are equipped for multi-car operation.

St. Charles Streetcar Line

The St. Charles streetcar line, part of one of the few large transit systems still operated by a privately held utility company, is prized almost as highly by New Orleanians as are the cable cars of San Francisco by their local supporters. It is called a streetcar because the last regularly used pre-PCC city cars in the country serve the line. Although 88 percent of the route is reserved in the median of St. Charles Avenue, operating speeds are at streetcar levels because of the short distances between car stops—0.19 km (0.12 mile) on average—and the high frequency of grade crossings—about every 0.10 km (0.06 mile). Because of these conditions, faster cars would be of little use, and there appears to be no special pressure to make the line speedier.

Patronage is sufficient to require short headways all day: 3.5 to 4.5 min during peaks and 5 to 5.5 min during midday. The reasons for this high ridership lie in the areas served by the line. For most of its length, it passes through a gracious, tree-shaded, but rather thickly developed residential area. Low- and mid-rise apartments are interspersed among the single-family homes. A thriving subregional shopping area is located at the turn from St. Charles Avenue to Carrollton Avenue. Both Loyola and Tulane universities are served. At its inner end, the line circulates through the CBD on street track and reaches the edge of the French Quarter. It serves both residents and tourists. Although the reserved right-of-way gives the line the appearance of LRT, it functions as a local streetcar.

Tandy Center Subway

The Tandy Center Subway in Fort Worth is unique in two ways: It is the only U.S. LRT line that serves as a shuttle between a CBD and peripheral parking lots, and it is privately owned and operated without public subsidy. The line was opened in 1963 by Leonards Department Store. Both the store, actually a complex of several buildings, and the LRT line have changed ownership twice since then. The present owner has embarked on an improvement program for the line, which had been allowed to deteriorate under the previous management. Although the cars used by this system are secondhand PCCs from the abandoned Washington, D.C., streetcar network, they do not look it. All have been air-conditioned and modified for high-platform passenger loading. Constructed for single-end running, they have been reworked for double-end operation. Under the latest refurbishing project, the cars are being stripped to the frames and fitted with new car bodies that have contemporary styling. The propulsion equipment is also being overhauled but not significantly altered.

San Francisco's Municipal Railway

San Francisco's Muni operates one of the most diverse surface transit fleets in the country: streetcars, trackless trolleys, buses, and—of course—cable cars. The streetcar system is now in a transitional period during which it is being upgraded to LRT standards. Like other systems described previously, this one has the basic strength of five branches tied to a central trunk line leading to a vital CBD. This basic characteristic is enhanced by the dense development of the system's service area—a result of its location on a peninsula and the fact that two tunnels built to overcome steep grades also provide grade separation for portions of four of the five routes. Despite long-standing track reservations amounting to 29 percent of the total line length, operating speeds have been low because of frequent passenger stops and cross streets.

The improvement program is geared to alleviate some of these problems. As part of the BART construction project, a tunnel for Muni rail cars was provided under Market Street from Embarcadero to the east portal of the Twin Peaks Tunnel. Not only will this eliminate traffic congestion, but the number of stops along Market Street will be reduced by about 75 percent, to seven underground stations (18).

Less dramatic, but already in service, is 2.6 km (1.6 miles) of track in Judah Street converted from unreserved street trackage to reserved median. This was accomplished by building up the area around the tracks to a height of 7.6 cm (3 in) above the street paving and surfacing it with rough, exposed aggregate concrete (23). This increases the amount of reserved line to 37 percent of the total, as shown in Table 6. Emergency vehicles are allowed to use the median paving, as are drivers making left turns into their own driveways. Thus, the right-of-way is not exclusive, but it is reserved. Some cross streets are reported to have been cut off, but the exact number affected has not been obtained.

As mentioned earlier, the improvement program—which also includes new LRVs, reconstruction of tracks and power distribution systems, and new maintenance facilities—is expected to allow running time to be reduced. The L Line, which is 12.6 km (7.8 miles) long, will be covered in 34 instead of 52 min. This will increase $\overline{V}$ from 14.5 to 22.2 km/h (9.0 to 13.8 mph). Similarly, the one-way running time for the N Line, 11.3 km (7.0 miles) long, is expected to drop from 50 to 35 min, increasing $\overline{V}$ from 13.5 to 19.3 km/h (8.4 to 12.0 mph). This will bring the Muni lines into the same range of average operating speeds as Boston's Green Line.

SUMMARY

When all is said and done, the systemwide $\overline{V}$ rather accurately summarizes all the factors that determine whether a system should be classified as essentially LRT or as a streetcar operation (Table 10). Even though the Muni is becoming an LRT system and the St. Charles line appears on the surface to have an LRT right-of-way, both now provide streetcar service. The only anomaly is Pittsburgh, in which there are two LRT lines, a slow but largely off-street route (Mt. Lebanon), and a true streetcar line. It does not appear coincidental that the Pittsburgh system in its present state and at its typical trip time of 31 min has the smallest daily ridership of any CBD-oriented system except Newark and Shaker Heights, which pose special problems of urban and transit system development.

Some systems, such as the Shaker Heights Rapid Transit and the lines in Philadelphia's western suburbs, must be fast so that typical trip times are not unduly long. Speed, however, is not everything. The four systems in the group that have a $\overline{V}$ between 18 and 22 km/h (11 and 14 mph) include two heavily used CBD-oriented operations—Boston's Green Line and Philadelphia's subway-surface lines. Typical trip times for these systems are about 20 min. More importantly, these lines connect vital elements of the urban core with each other and with residential areas. For the latter, the trunk-and-branches configuration allows most riders to have a single-vehicle ride.

The currently operating LRT systems serve the kinds of medium- to high-density urban and suburban areas that future development may well have to emulate as decreasing amounts of fossil fuels, especially petroleum, make it more and more expensive to sustain the automobile-oriented spread-out style of life. This process might be called the Europeanization of American cities. Given the role that LRT plays in many areas of Europe and the vitality of the cities thus served, such a trend might be more acceptable than we now think. Certainly, the quality of life along Boston's Green Line supports this notion.

REFERENCES

1. F. Rowsome. Trolley Car Treasury. McGraw-Hill, New York, 1956.
2. W. O. Adams. The Central Subway System of the Massachusetts Bay Transportation Authority. Traffic Quarterly, July 1965, pp. 443-457.
3. B. J. Cudahy. Change at Park Street Under. Stephen Greene Press, Brattleboro, VT, 1972.
4. J. W. Schumann. Media-Sharon Hill Lines of SEPTA: Analysis of a Semi-Rapid Transit System. Louis T. Klauder and Associates, Philadelphia, 1970.
5. R. J. Landgraf. History of the Shaker Heights Rapid Transit. Greater Cleveland Regional Transit Authority, May 1975.
6. Detroit Opens Trolley Line. Modern Railroads, Vol. 31, No. 10, Oct. 1976, p. 33.
7. S. Scalzo. Leonards M and O Subway. Electric Transit Journal, Aug. 1963, pp. 2-11.
8. W. D. Middleton. Let's Take a Last Look Down Market Street. Headlights, July-Aug. 1975, pp. 2-7.
9. Light-Rail Transit Systems. General Motors Transportation Systems, Warren, MI, 1975.
10. Lea Transit Compendium: Light-Rail Transit. N. D. Lea and Associates, Huntsville, AL, Vol. II, No. 5, 1975.
11. J. A. Navarro and E. A. Parker. The M and O Subway, Fort Worth, Texas. Institute for Defense Analysis (Urban Mass Transportation Project), Washington, DC, Res. Paper No. P-582, Dec. 1969.
12. E. O'Hara. Take a Ride on the T. Transportation USA, Winter 1976, pp. 9-12.
13. K. C. Springirth. North American Trolleys. K. C. Springirth, Erie, PA, 1976.
14. Light Rail Transit: Technology Sharing. Transportation Systems Center, U.S. Department of Transportation, Cambridge, MA, May 1977.
15. J. L. Guilbeau. The St. Charles Street Car or the New Orleans and Carrollton Rail Road. J. L. Guilbeau, New Orleans, 1975.
16. R. J. Landgraf. The Shaker Heights Rapid Transit System. Greater Cleveland Regional Transit Authority, July 1973.
17. Light Rail Transit: A State-of-the-Art Review. De Leuw, Cather and Co., Chicago; and U.S. Department of Transportation, 1976.
18. J. Anderson. First BART—Now Muni Metro. Passenger Train Journal, Spring 1975, pp. 13-14.
19. H. E. Cox. PCC Cars of North America. J. W. Boorse, Philadelphia, 1963.
20. W. D. Randall. Railway Passenger Car Annual. RPC Publications, Godfrey, IL, Vol. 3, 1976.
21. Rebuild Track in Heavy Boston Traffic. Progressive Railroading, Vol. 17, No. 7, July 1974, pp. 47-48.
22. D. Leherr. Light-Rail Trolleys Proposed. Pittsburgh Post-Gazette, March 5, 1976, pp. 1 and 4.
23. E. T. Myers. Muni: The Second System. Modern Railroads, June 1974, pp. 60-62.

Operational Idiosyncrasies of a Subway-Surface System

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The objectives of this paper are to acquaint the reader with the behind-the-scenes activities that constitute the day-to-day operations of Philadelphia's subway-surface system and to pinpoint techniques and methods that new systems could adopt to avoid some of the problems SEPTA faces. The paper discusses daily operations, service interruptions, training, accident prevention, and support activities. The problems discussed are accompanied by a discussion of the solutions adopted or those that would be adopted if there were adequate funds and local cooperation. Specific recommendations for new systems are summarized.

A daily rider of Philadelphia's subway-surface system might describe a typical journey as follows: