RAIL TRANSIT—CHARACTERISTICS, INNOVATIONS, AND TRENDS

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Rail transit, including streetcar, light rail, rapid transit, and regional rail, is a family of transportation modes with a broad range of service, operational, and cost characteristics. Consequently, these modes may be used efficiently for various conditions. As a result of numerous technological and operational innovations of rail systems during the last two decades, rail transit can be highly automated, reliable, and comfortable and can operate with minimal environmental intrusion. Although several U.S. systems (e.g., Lindenwold Line and Bay Area Rapid Transit) have some advanced features, general knowledge and understanding of rail systems in this country lag behind those of some western European countries and Japan. Based on a comparison of the population characteristics of selected European and U.S. cities, this paper shows that, among cities with similar population size and density, European cities generally have a much greater application of rail transit. Despite extensive research into new technologies, no new mode has emerged with performance and cost characteristics superior or comparable to rail technology. Thus, to achieve more efficient and economical transit systems, information about rail modes must be increased and these modes must be included among the alternatives considered in transit planning.

•MODERN transit planning places increasing emphasis on the development of alternatives and their comparative evaluation. For this purpose, a thorough knowledge of different transportation technologies and familiarity with the latest technological developments and general trends in uses of individual modes are needed.

Numerous recent developments and innovations in rail transit have received little coverage in professional literature, and the technical material generally available about modern rail transit technology is limited. The purposes of this paper are to present a definition, description, and classification of modern rail transit systems and to provide an overview of the characteristics of different rail transit modes.

Rail transit consists of a family of modes with different technological, operational, and service characteristics. On the basis of these features, rail modes are classified into four categories: streetcar, light rail, rapid transit, and regional rail. Each mode offers ranges in service quality, types of operation, and costs. The composite range of features among the various rail alternatives permits an efficient use of rail transit over a wide range of travel requirements and conditions.

FAMILY OF RAIL SYSTEMS

Streetcar

Streetcar systems consist of one, two, and occasionally three rail vehicles operating mostly on streets in mixed traffic, sometimes with limited separation from street traffic on private rights-of-way. Although their comfort and dynamic characteristics are good, when they operate in mixed traffic their service quality is often unsatisfactory. Street conditions generally keep operating speeds below 12 mph (20 km/h). The comfort, schedule reliability, speed, and passenger attraction of streetcars are consequently similar to those offered by surface buses and are inferior to those of other rail modes.

The positive qualities of streetcars include a higher capacity and a more distinct image than that of buses, and a lower cost for right-of-way than for other rail modes. Selective application of traffic priority measures including reserved lanes and provision of some private rights-of-way (both of which are inexpensive improvements) can greatly enhance the attractiveness of the streetcar mode. Yet, the greater facility with which buses serve low-density areas and the trend to upgrade heavily traveled streetcar lines into higher quality rail systems have resulted in the conversion of most streetcar lines to either bus or light rail; consequently, this mode has experienced a general decline in ridership and a diminishing role in urban transportation.

Light Rail

Light rail systems (Figures 1 and 2, Table 1) typically have articulated six- or eight-axle vehicles or multiple unit trains of up to three four-axle cars. Modern light rail vehicles, such as the six-axle vehicles produced by Boeing and several European manufacturers, incorporate high comfort levels, high- and low-level boarding capabilities, and modern electronic control and communications equipment. Although their purchase price is high ($300,000 to $400,000/car), their high capacity and operating speed and long life (25 to 30 years) make their cost per passenger-mile (kilometer) similar to the corresponding cost of other transit modes. Costs, however, vary greatly with local conditions, operating practices, system characteristics, and, of course, with time.

Light rail operates substantially on private rights-of-way that are often grade separated. Tunnel sections are frequently used in the most critical areas of the city, and this greatly enhances the quality of service light rail vehicles offer. The alignment standards and station features of light rail systems can be the same as those of rapid transit systems; however, the same light rail vehicles can also operate on existing streetcar lines with curb height stops. This flexibility allows the staged upgrading of a network to new rights-of-way with continuous service and immediate use of new route sections. Such staging permits investments to be tailored to local conditions, the desired service quality, and the availability of capital funds. This is an important advantage of light rail over rapid transit, which requires immediate construction of complete lines at high cost. In fact, many cities are staging their rapid transit construction by using light rail as an interim mode (e.g., Pre-metro in Brussels and Stadtbahn in Hannover and Frankfurt).

Exclusive rights-of-way generally constitute 40 to 90 percent of a light rail network and allow operating speed to average 12 to 16 mph (20 to 25 km/h); individual lines, however, often exceed 20 or even 30 mph (30 or 45 km/h) when they have fully private rights-of-way (e.g., Norristown Line in Philadelphia and lines in Cologne and Gothenburg). On grade-separated sections, frequencies can approach 90 vehicles/hour with little technical or organizational difficulty and high reliability. Frequencies of up to 140 vehicles/hour have been achieved (Philadelphia) with strict operational control and somewhat reduced reliability. Capacities with high service quality can reach a substantial 18,000 persons/hour/track.

Light rail networks are typically characterized by fairly good coverage of central areas (either in tunnels, on viaducts, or on at-grade private rights-of-way) and have extensions branching out at-grade on a number of radial routes. Interstation spacings generally average 1,200 to 2,600 ft (350 to 800 m) and, therefore, attract medium-to-long trips. Occasionally, park-and-ride and kiss-and-ride access modes are used in suburban areas.

There are at least 30 cities in Europe with modern high-quality light rail systems. Most of the cities using light rail have a population between 300,000 and 1,500,000 and

Figure 1. Boeing light rail vehicle.

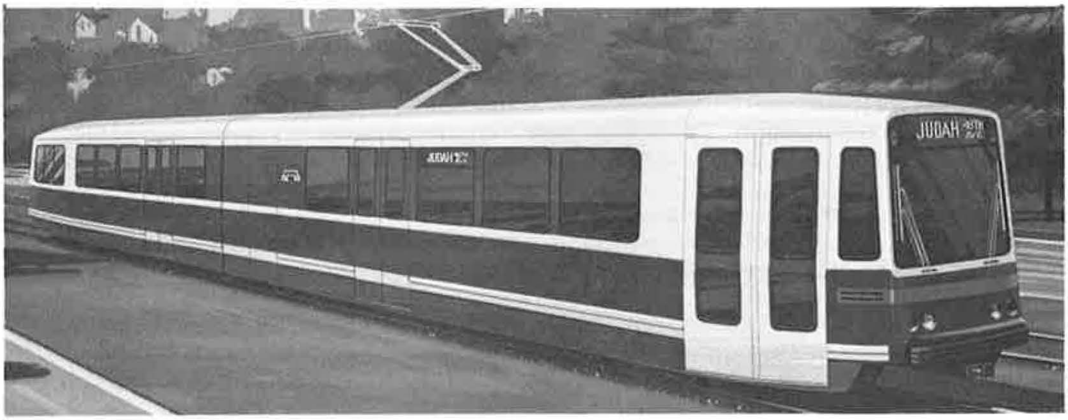


Figure 2. DUWAG light rail vehicle interior.

Table 1. Technical and system characteristics of urban rail modes.

Item	Streetcar	Light Rail	Rapid Transit	Regional Rail
Fixed facilities				
Exclusive right-of-way, percent	<40	40 to 90	100	90 to 100
Way control	Visual	Visual/signal	Signal	Signal
Fare collection	On vehicle	On vehicle or at station	At station	At station or on vehicle
Power supply	Overhead	Overhead or rail	Third rail or overhead	Overhead or third rail
Station platform height and access control	Low	Any type; low or high, fully controlled	Fully controlled; high level	Any type; low or high level
Vehicle characteristics				
Minimum operational unit	1	1 (4-axle)	1 to 3	1 to 3
Maximum train composition	3	2 to 4 (6-axle)	6 to 10	6 to 10
Vehicle length, m	14 to 20	20 to 33	15 to 23	20 to 26
Vehicle capacity, seats/vehicle	16 to 40	16 to 80	36 to 84	80 to 125
Vehicle capacity, total/vehicle	80 to 180	80 to 335	100 to 250	100 to 290
Operational characteristics				
Maximum speed, km/h	60 to 70	60 to 125	90 to 130	90 to 160
Operating speed, km/h	10 to 25	20 to 45	25 to 60	30 to 70
Maximum frequency				
Peak hour, joint section/h	140	40 to 120	20 to 40	6 to 30
Off-peak, single line/h	5 to 12	5 to 12	5 to 12	1 to 4
Capacity	10 000	3 000 to 18 000	6 000 to 30 000	10 000 to 40 000
Reliability	Poor	Good	Excellent	Excellent
System aspects				
Network and area coverage	Dispersed, good area coverage	Good CBD coverage; branching is common	Predominantly radial; some CBD coverage	Radial, limited CBD coverage
Station spacing, m	250 to 500	350 to 800	500 to 2000	1200 to 4500
Average trip length	Short-to-medium	Medium-to-long	Medium-to-long	Long[a]
Relationship to other modes	Can feed higher capacity modes	Park-and-ride, kiss-and-ride, bus feeders possible	Park-and-ride, kiss-and-ride, bus feeders	Outlying: park-and-ride, kiss-and-ride, bus feeders, CBD, walk, bus, light rail

Note: Figures shown are typical ranges for existing systems. 1 mile = 1.6 km. 1 ft = 0.3 m.

[a]U.S. average = 36 km.

a density between 3,000 and 15,000 residents/mile^2 (1,200 and 6,000 residents/km^2), although values outside these ranges can be found. In North America, Shaker Heights, Newark, Philadelphia, and Pittsburgh have some lines that have light rail characteristics but obsolete equipment. Interest in light rail, is, however, rapidly increasing. Boston, San Francisco, and Toronto are modernizing their lines in preparation for new equipment, Edmonton is building a new system, and a number of other cities (Dayton, Austin, and Portland) have been actively planning light rail systems.

Economically, light rail is an extremely attractive mode because of the wide variety of service quality and cost options it offers. Typical cost ranges for different types of facilities are given in Table 2.

There is some similarity between radial lines of light rail and the busway concept represented by the Shirley and El Monte Busways. Most significantly, both light rail and the busway have partially exclusive rights-of-way, but because of different technologies, their operational and service characteristics differ considerably. The bus can provide more extensive residential area coverage, but has a lower quality line-haul service and unreliable at-grade CBD distribution. Light rail offers limited suburban collection but offers an excellent line-haul service with stops and the possibility of reliable, high-capacity service downtown within tunnels. Rail technology further provides a more stable and comfortable ride and less environmental intrusion and has as an advantage the possible conversion of its line-haul and CBD operation to full automation, which would create a viable dual-mode (manual and automated) system. Typical busway costs, e.g., $4 to $5 million/mile ($2.5 to $3.1 million/km) for the El Monte Busway, appear roughly comparable to those for light rail.

Rapid Transit

Rapid transit (Figure 3, Table 1) consists of long four-axle rail vehicles operating in trains on completely private rights-of-way that allow high speed, high reliability, high capacity, rapid boarding, and fail-safe operation.

Rail transit vehicles are usually operated in units from 2-car married pairs to 10-car trains. Rapid transit has the highest service quality of all transit modes, and recorded capacities of lines with stations have been as high as 45,000 passengers/hour. Some of the recently opened systems (in Sao Paolo and in Paris) have been designed for a capacity of 80,000 passengers/hour. Capacity volume, however, results in low comfort. The maximum seated capacity is approximately 30,000 passengers/hour, but most systems are designed for volumes from 8,000 to 25,000 passengers/hour.

Most rail rapid transit lines in U.S. cities are basically radial, and there is limited coverage of city centers except in Manhattan. Modern European rapid transit systems, however, have been designed with networks covering large central areas and, thus, also offer service for the medium and short trip and the longer urban commuter trip. Area coverage in the suburbs is often helped by park-and-ride or kiss-and-ride transfer facilities or by bus feeders. In part, these supplementary services are required because of low population densities and rapid transit's longer station spacings in these areas. Generally, average trip lengths on rapid transit systems are longer than those on surface transit and range from 3 to 7 miles (5 to 12 km).

The need for rapid transit depends greatly on the specific travel patterns, topographical constraints, and character of the city. The typical regional population of these cities that have rapid transit ranges from 1 million upward (exceptions are 450,000 at Oslo and 880,000 at Rotterdam). Similarly, population densities served vary significantly; some rapid transit systems serve an extreme density of 80,000 persons/mile^2 (31 000 persons/km^2), but since park-and-ride and kiss-and-ride have been used as popular feeder modes, higher densities and CBD size no longer are the prerequisites they once were. Thus, the service area of the Lindenwold Line has only 3,400 persons/mile^2 (1313 persons/km^2).

The well-known drawback of rapid transit is its high capital cost brought about mostly by the need to provide fully private rights-of-way (Table 2). Furthermore, costs of automated vehicles are also high. However, because of its high service quality, rapid transit has a greater capability to attract passengers when compared with other modes. This is the major goal for any transit service.

With respect to operations, rapid transit systems are rather diversified. Modern systems operate trains of any length that the station platform can accommodate without full automation and with one-person crews (e.g., eight-car trains in Hamburg since 1957, six-car trains in Philadelphia since 1969). Stations may be operated without personnel by using remote closed-circuit TV surveillance (Lindenwold Line). Most U.S. rapid transit systems, however, still use trains that have two-person crews (up to four persons in Boston) plus station personnel. When there is a modern type of operation and efficient management, however, rapid transit can be highly labor productive; the Lindenwold Line carries 171 daily passengers/employee (including administrative personnel and police).

The latest systems have extensive train automation that also allows some operational improvements and savings in energy and vehicle maintenance. These are significant in high-capacity systems, but for other systems the benefits from automation often do not outweigh the increased cost and reduced reliability at least as long as the train crew is retained. Elimination of the last crew member on rapid transit systems is probably achievable with relatively minor innovations of control and operations. There is presently, however, no serious work in that direction, although unproven automated technologies are being investigated. Consequently, the highly automated rapid transit systems in operation today [e.g., Bay Area Rapid Transit (BART)] require a considerably higher investment cost than do nonautomated systems, but they do not have the reduced operating cost and higher frequency that full automation could bring (21).

Regional Rail

Regional (commuter) rail systems (Figure 4, Table 1) consist of large, high-speed rail vehicles operated individually or in trains, usually by railroad companies. The service is characterized by long average trip lengths, large interstation spacing, and very comfortable riding. Passenger volumes are heavily peaked, highly directional, and predominantly suburb-to-CBD. Most regional rail networks in our cities consist of a number of radial lines from the CBD and have stations located at suburban town centers. Kiss-and-ride, park-and-ride, bus feeders, and walking are used as access modes. Central city stations are often combined with intercity rail stations, but they are limited in number and provide little downtown coverage.

In recent years another kind of regional rail system has emerged. When there are alignments, station spacings, and speeds similar to those for commuter rail, these systems have frequencies of service and CBD distribution similar to those for rapid transit. Examples include Germany's S-Bahn, Paris' R.E.R., Philadelphia's Lindenwold Line, and San Francisco's BART. These modern regional rail systems give metropolitan regions with many distinct satellite communities an excellent regional transportation network.

Because regional rail service is usually provided by railroad companies, the cars are usually larger and heavier than rapid transit cars and have very high seating capacity (in double decker cars, up to 160 passengers/car). The tendency in new cars is to use 2- or 3-vehicle married units in trains of up to 10 vehicles. The service quality of regional rail is generally high for European systems, but it is quite variable among American systems that have been severely hurt by inadequate financing, lack of modernization, disinterested management, and obsolete labor practices.

The capital investment required for regional rail depends heavily on whether modernization of an existing railroad line or an entirely new regional rapid transit system is considered. The former usually involves very low costs (track renovation, electrification, and station construction); the latter, because of high alignment standards, requires an investment cost higher than that for rapid transit. Recent vehicle costs have been about $400,000. Operating costs vary greatly with labor practices, i.e., size of crew, which is typically much larger than the operation actually requires, particularly on U.S. systems.

Table 2. System costs for rail transit modes.

	Mode			
Cost Item	Streetcar	Light Rail	Rapid Transit	Regional Rail
Right-of-way, $millions/km				
At-grade	0.2 to 0.9	0.2 to 0.9	1.9 to 6.0	0.3 to 1.3
Elevated	—	3.1 to 7.5	5.0 to 9.4	—
Tunnel	—	10.0 to 20.0	10.0 to 20.0	1.2 to 31.3
Station, $millions/station				
At-grade	Very low	Very low	0.5 to 2.0	0.5 to 2.0
Elevated	—	0.5 to 2.0	1.0 to 3.0	
Tunnel	—	4.0 to 5.0	4.0 to 6.0	5.0 to 15.0
Vehicle per 1000 vehicles	110 to 200	250 to 400	160 to 400	250 to 400
Operating per car kilometer	0.75 to 1.06	0.94 to 1.44	1.00 to 3.00	1.50 to 4.50

Note: Few new regional rail systems have been built recently in the United States. Conversion of existing track for such service involves low investment, but new center city track would incur very high investment. These data are based on 1972 dollars. 1 mile = 1.6 km.

Figure 3. PATGO rapid transit train.

Figure 4. Regional rail transit in Munich.

About the Family of Rail Systems

Tables 1 and 2 give some important characteristics for each of the four rail mode categories. These features define the modes and distinguish between them. In summarizing, two points are reemphasized. First, rail transit is a family of modes, ranging from operating and service characteristics of the streetcar to those typical for rapid transit and regional rail systems. Depending on local conditions, individual rail modes can be efficiently used for many conditions in medium and large cities.

Second, the combination of service and cost characteristics offered by different rail modes overlaps, as shown in Figure 5. There is no boundary, for instance, between the streetcar and light rail categories. Similarly, light rail can be designed to function much like rapid transit and to be gradually converted to it. Third, when its scale is magnified, rapid transit can become a regional rail system. For these reasons, generalizations regarding rail systems with respect to both cost and service characteristics (e.g., rail systems are expensive) are in most cases incorrect, and they should not be used.

RECENT TRENDS AND INNOVATIONS OF RAIL TRANSIT

In the United States, there is little information on or understanding of the trends and current state of rail transit. The available information is often inadequate or misleading, and many trends in technological modernization, operational changes, and system concepts are ignored or go unnoticed. Recent trends in rail transit systems in this country and other countries are reviewed below.

Patronage Trends on Rail and Other Modes

The trends of transit patronage in the United States since 1945, when transit ridership on all modes was extremely high, show a steep decline in streetcar and trolleybus ridership during the period after World War II. This reflects not only a general shift of the surface transit mode riders to the automobile but, even more, the conversion of streetcar into bus services in most cities.

The reasons for the abandonment of streetcar systems were often legitimate. In many situations the replacement of streetcars by buses improved service and traffic conditions. However, lack of funds for maintaining and improving streetcar systems often encouraged operators to abandon streetcars in favor of buses, even when this meant sacrificing the streetcar's superior operational and service features. Particularly counterproductive were the cases in which streetcars operating on reserved medians that could have been upgraded into light rail systems were replaced by buses operating on streets in mixed traffic. Moreover, pressures to use rubber-tired vehicles were exerted on transit operators by competitive transportation industries. Thus, the streetcar systems were in some cases discontinued for reasons of short-term economic convenience and political pressure. The direct loser was the traveling public; reduced mobility by transit negatively affected urban development.

The steep decline of bus ridership following World War II occurred despite the fact that during this period an intensive conversion of streetcars and trolleybuses to bus operation was under way. Thus, even the expansion of bus services did not compensate for the decline in ridership. The basic causes for this decline were increasing automobile ownership and highway construction and a simultaneous neglect of maintenance and actual deterioration of transit service. Except for incidental purchases of new vehicles, most U.S. systems did not undertake any significant improvement of bus operations, such as provision of bus lanes, signal actuation by transit vehicles, and better information.

Rapid transit systems were equally neglected: poor maintenance, obsolete equipment, lack of information and marketing, and increasing fares. However, their inherent features made them much more competitive with automobile travel than was

Figure 5. Service quality versus investment cost for rail transit modes.

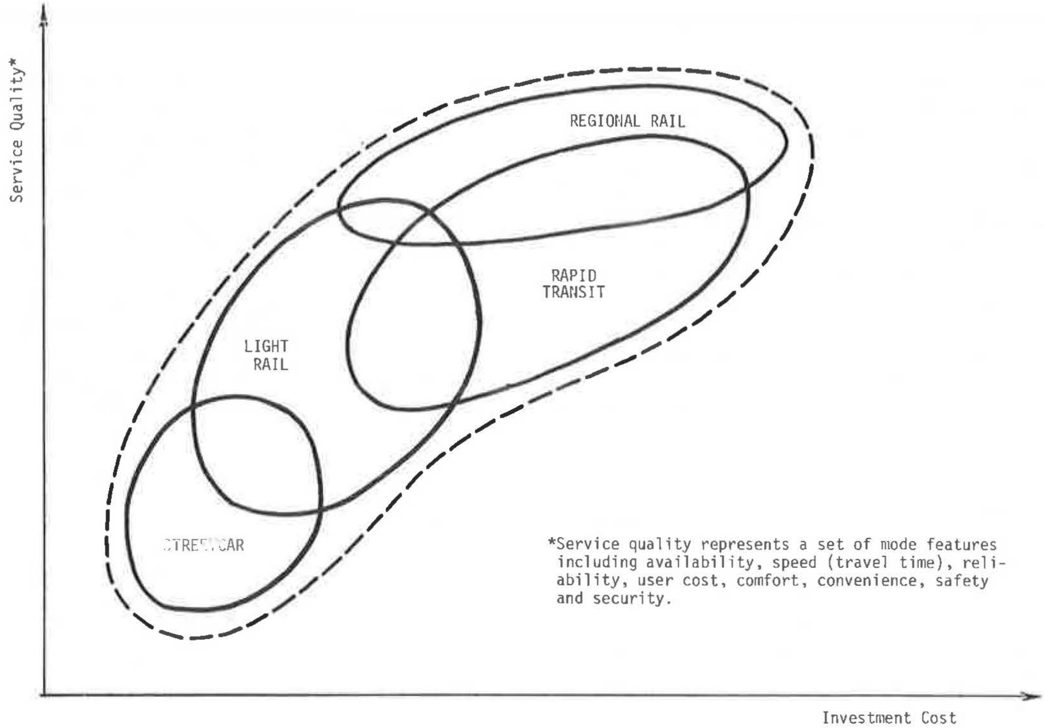
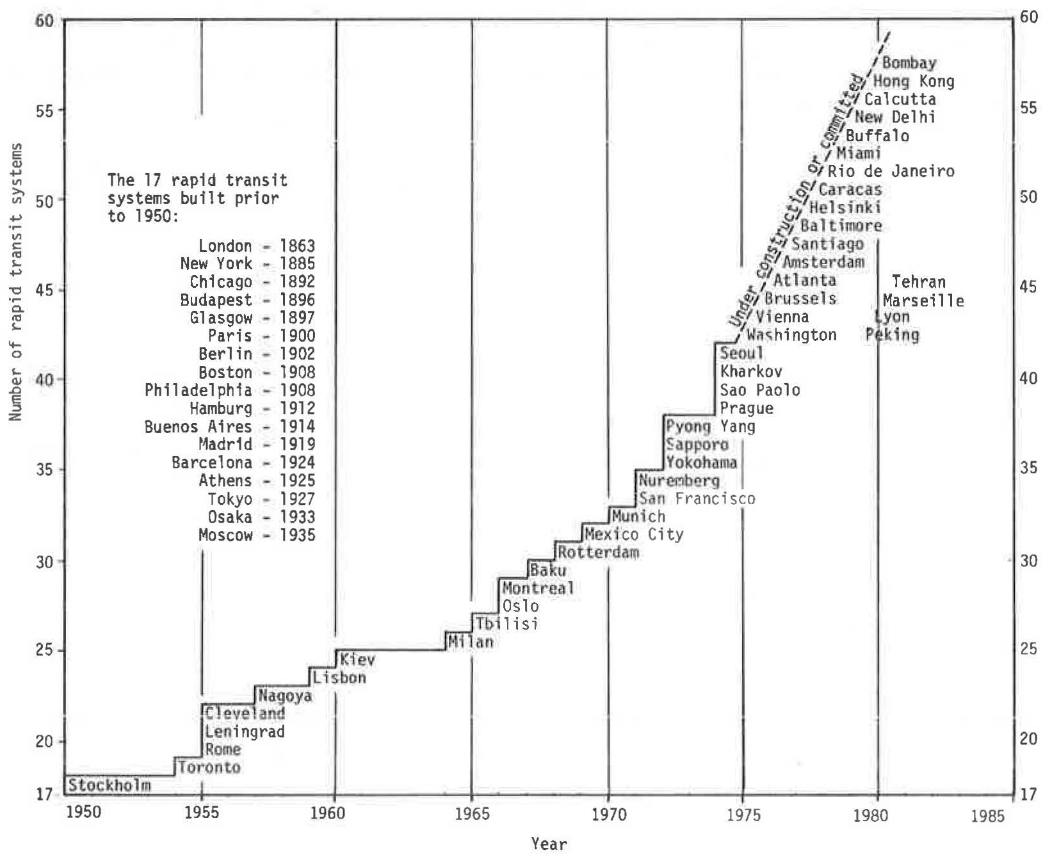


Figure 6. Number of rapid transit systems in the world since 1950.



surface transit. Their total separation of right-of-way secured independence from street traffic conditions and guaranteed high reliability, high frequency of service, and network simplicity. These were important features that contributed to a much higher retention of passengers by rapid than by surface transit.

U.S. regional commuter rail systems have also exhibited high patronage stability. The limited available data show that ridership did not change between 1960 and 1970 (9). In fact, systems increased their share of the transit market during that decade by 5.4 percent. Similar trends have been observed in other countries.

Policies Toward Transportation Modes

Operational experience, performance records of different types of services, and the passenger trends strongly indicate that the most important characteristic that makes transit service competitive with the automobile is the provision of an exclusive right-of-way. Separation of transit from other traffic and interference ensures a certain level of reliability of the total transportation system under all conditions, including major storms and other emergencies. Preferential treatment of transit through special signals and reserved lanes, although highly significant, represents a rudimentary type of service upgrading. Higher types include exclusive medians with grade crossings, underpasses and overpasses at busy intersections, exclusive busways, and, finally, fully controlled transit rights-of-way.

Greatly increased interest in transit improvement in U.S. cities has begun to stimulate interest in semiexclusive and exclusive transit rights-of-way. A number of cities have or will soon have rail rapid transit under construction (Washington, Atlanta, Baltimore, and others) or in planning (Los Angeles, Miami); several have exclusive busways in operation (the Shirley Busway in the Washington, D.C., metropolitan area and the El Monte Busway in Los Angeles) or in planning (Hartford, Milwaukee). Many cities have opened bus lanes in central areas, and there has been a rapid increase in the planning of new light rail transit systems (Edmonton is constructing; Dayton, Portland, Rochester, Vancouver, and Toronto are planning; and Denver and San Diego are considering such systems).

The question of whether to use buses or rail systems on exclusive rights-of-way has been studied carefully in several countries that have much automobile ownership and an interest in major improvements of public transportation (15). Exclusive busways have been built so far only in the United States and in one British city (Runcorn). In several U.S. cities (New York, Boston, and San Francisco), contraflow freeway bus operations have brought considerable improvement to bus service quality. In all other countries, provision of fully grade-separated rights-of-way has always been made only for rail vehicles. The advantages of buses (better suburban distribution and immediate availability) were considered to be heavily outweighed by the following advantages of rail systems:

1. Greater capacity range because of an ability to form trains;
2. Better CBD operation because of ability to operate in tunnels;
3. Greater passenger attraction;
4. Lower operating cost per passenger served;
5. Lower negative environmental impact (lower noise level, no air pollution);
6. Higher safety and conduciveness to full automation; and
7. Higher reliability, particularly under high demand and adverse weather conditions.

Once a decision to choose a rail mode is made, the next choice is that of the specific rail mode. A number of medium-sized cities in Europe that required a high-quality transit system but could not afford the big investment of rapid transit have selected light rail systems that are fully separated from other traffic only in limited areas of the central city where congestion is most acute, transit operations are most seriously impeded, and the beneficial effects of separating transit from surface traffic are the greatest. In outlying areas, it is usually easier to find semiexclusive rights-of-way for transit, and traffic congestion in those areas is lower anyway. Thus, for a limited investment, these cities have alleviated their most serious traffic problems.

A good example of selective separation of transit is in Brussels, which has five streetcar lines that converge into one joint section as they approach the central city. Approximately 2 miles (3 km) required 20 min of travel time during the off-peak and up to 45 min during the peak when transit is operated on streets. A tunnel was built for this section only (the lines continuing at-grade in the outlying areas), and the travel time is now 8 min during the off-peak and during the peak because of full control of operations and no disturbances from other traffic. Solutions similar to this one have been adopted in Cologne, Frankfurt, Stuttgart, and other cities.

Based on the policy of maximum separation of transit from street and highway traffic for over a decade, there has been extensive construction of new systems and extensions of existing rapid transit systems and electrification of existing railroad lines. Construction of such facilities for all rail modes has been accelerating in recent years and is presently more intensive than ever before. In West Germany alone, 15 cities are presently building new rail systems or expanding existing ones. Figure 6 shows the accelerated frequency of openings of new rapid transit systems in the world since 1950.

Financing of Rail Systems

Construction of rail systems is not much cheaper in other countries than it is in the United States. The average cost per mile (kilometer) of way shows a great similarity for most countries. Yet rail transit improvements have been undertaken in many foreign countries much more vigorously than in the United States. In recent years, because of the environmental and energy crises, the urban transportation policies in all countries have become considerably more in favor of public transportation and opposed to additional construction of urban highways and downtown parking facilities. These changes in policy have resulted in further intensification of efforts to expand and improve rail transit systems particularly because of their superior environmental characteristics: low noise, no air pollution, minimum space taking, and low energy consumption per passenger-mile (kilometer).

Although details of financing methods vary from country to country, in most cases the basic philosophy adopted has been that a reliable and efficient transportation system is a prerequisite for the economic and social health of each city and that systems must consist of a modern network of streets and highways and a complete system of adequate public transportation throughout the urbanized area. A total network coverage of the area and all-day, everyday service are particularly emphasized. The concept that transit should be only a supplement to private transportation and operate solely during peak hours in radial directions has been rejected in most developed countries because such a system leaves large segments of the population without adequate mobility and has a detrimental impact on the social, physical, and land use characteristics of the city. In addition, such a system is highly inefficient and uneconomical. An important element in the justification of rapid transit construction is often the reduction of operating costs over those of surface modes (4).

In West Germany, which has a similar governmental organization to the United States, the federal government sponsored a thorough study of urban transportation problems. Based on the principles developed by that study in 1964, legislation was passed that introduced a special tax of \$0.03/gal (\$0.008/liter) on gasoline (3 percent of the total gasoline price) that goes into a special federal fund for the improvement of urban transportation facilities. This fund is matched by the states and divided between improvements of streets and highways (55 percent) and transit facilities (45 percent). This method of financing has resulted in vigorous construction of grade-separated rail facilities, other major additional improvements, and a continuing highway development program in most West German cities.

Had a tax of \$0.02 to \$0.03/gal (\$0.005 to \$0.008/liter) in the United States been introduced, it would have been sufficient for major transit improvements in our cities before conditions reached their present crisis stage. Such proposals, however, were opposed as inequitable and an excessive charge on the motorist although gasoline prices in the United States are only 30 to 50 percent of the prices in most European countries. Recently, however, greater increases in gasoline prices have been introduced without severe complaint or reduced demand but also without any benefit to public components of transportation facilities: improved urban streets and highways and modern transit facilities.

Technological and Operational Innovations

Numerous technological and operational improvements of rail systems have been tested and introduced in various countries during the last 20 years. As a consequence of these developments, many features of rail systems have been virtually perfected. The following are some examples of these improvements.

Land Use and Transit Integration

A careful coordination of rail transit planning and urban design has resulted in the extensive provision of reserved transit rights-of-way and the creation of stations integrated with stores, offices, malls, and plazas. Often these improvements are introduced as components of comprehensive traffic restraint schemes for central cities (e.g., Toronto, Hamburg, Stockholm, Munich, and Vienna).

System Design

The development of modern, large-capacity, lightweight vehicles combined with provisions for reserved rights-of-way and favored treatment at intersections created the concept of light rail systems. Improvements to this mode continue. Hannover, which is constructing tunnels for the CBD sections of its light rail system, is designing a computer-controlled monitoring system for up to 100 vehicles on branch lines to increase its schedule adherence at-grade and to coordinate their travel so that regular 2-min headways are ensured at the converging points to joint tunnel sections. Also under study is direct computer control of key intersections along the branch lines to guarantee regularity of light rail vehicle travel. For its light rail system, Gothenburg has used a tunnel construction method that roughly halved tunnel costs.

Many European systems have tracks of the highest quality. Welded rails are placed on cushioning plates, switches have elastic points that eliminate the sound and shocks caused by joints, and overhead catenaries are automatically regulated for a constant tension, which guarantees good contact and minimum wear throughout the year.

Passenger Comfort

As a result of these technological improvements, comfort and noise levels have been greatly improved on all rail modes. A modern rail vehicle on a well-maintained track now provides more comfort and creates less noise than a single passenger car driving on a concrete roadway at the same speed. The smoothness of ride of the new vehicles of the recently modernized 11-line Munich S-Bahn (regional rail), achieved by preprogrammed acceleration with controlled jerk, sophisticated suspension, and excellent track, is not matched by any rail system in the United States.

Energy Consumption

Vehicle propulsion has been improved to provide the maximum acceleration rates that passenger comfort allows up to speeds of 25 to 32 mph (40 to 50 km/h), e.g., Lindenwold Line and the Munich S-Bahn. At the same time, as a result of numerous analyses and computer simulations, energy consumption has been minimized on several systems through programmed control of speed profiles that use coasting extensively (e.g., Hamburg, Moscow, and Stockholm), introduction of thyristor chopper control, regenerative braking (San Francisco), and even through optimal vertical profiles between subway stations (Munich). The maximum speed versus maximum acceleration trade-off has often been analyzed for different operating conditions to achieve the optimal balance between operating speed and energy consumption.

Operating Productivity

Extensive automation has been achieved, and its primary purpose was to reduce operating costs. When advanced fare collection methods and special vehicle design are used, even eight-axle light rail vehicles that have a capacity of 200 to 300 persons are operated by one person (Cologne). Rapid transit trains, as previously mentioned, are also operated by one person [Philadelphia (Lindenwold Line) and Hamburg].

Based on extensive testing and measurements, the Paris RATP can increase line capacity and improve service regularity by special methods of reducing station standing times and by better enforcement of strict adherence to the schedule. This method has proved to be much cheaper and more effective for achieving the same goals than through larger and better performance vehicles.

Fare collection has been automated on many European transit systems for convenience, boarding speed, and labor cost savings. Features being used range from ticket dispensing equipment to automatic ticket checking equipment to fully automated canceling equipment that are used with self-service (honor) fare collection. Bus systems and light rail and rapid transit systems use the features often on board the vehicle. Generally, more than one mode is integrated into the fare payment for increased user mobility and system flexibility. Furthermore, European systems make extensive use of prepaid tickets and seasonal passes to increase both passenger convenience and operational efficiency (6).

RAIL TRANSIT IN THE UNITED STATES

The United States was the leader in rail technology and operation for a number of years several decades ago. However, while many foreign systems have been vigorously improved and modernized, U.S. systems have suffered from underinvestment and a decrease in technical and managerial expertise. The leading role of the United States was consequently lost after World War II.

Present Condition

Although the Lindenwold Line in Philadelphia and the New York, Chicago, and San Francisco rapid transit systems have some unique features and innovations that do not exist elsewhere, U.S. rail systems are generally extremely obsolete in their technology and type of operation. Several observations confirm this condition.

1. There are few transit systems in the world that have less attractive, less safe transit stations that those, for example, along the Broad Street Line in Philadelphia or along many routes in New York City.
2. A survey of noise levels of rail rapid transit systems in 11 U.S. and European cities undertaken by Operations Research, Inc., in 1964 showed that all 4 U.S. systems

included in the survey were on the top of the list ranking levels of noise (12).

3. The condition of track on many commuter railroads in U.S. cities is probably worse than the condition of any corresponding facilities in Europe or Japan.

4. Labor practices in railroad companies are more obsolete than in any corresponding operations in Europe. Many regional rail systems are operated by crews of up to nine persons although two or three would suffice for modernized operation.

5. The newest streetcar vehicles operating in the U.S. cities are 22 years old; some regional rail vehicles are over 60 years old.

6. Many systems have limited speed because of unsafe track conditions, and some cities require every streetcar to make a safety stop before every diverging switch, a practice abandoned in Europe decades ago.

7. Numerous technical innovations, such as the above-mentioned switches with elastic points, constant-tension overhead catenary, and fare collection machines, are not known to exist even by most persons in the rail industry and operating agencies.

The neglect of rail technology and operations in the United States is also reflected in the extremely expensive and yet unreliable rolling stock and train controls for our most recent systems. Several of them have suffered from rather elementary mechanical and electric failures that result in excessively frequent service slowdowns and interruptions. Low reliability is not a typical problem of rapid transit systems. For example, the newly opened rapid transit system in Munich was built by using extensive experience from other cities so that, although the system was entirely new, it had only two major delays in its service during the first 18 months of operation; both were caused by factors out of control of the operating agency.

Expertise and General Knowledge About Rail Transit

This lagging expertise and lack of information about many modern technological developments in rail systems and policies are a serious problem in the United States. Frequent justification for ignorance of foreign developments is given by claims that U.S. cities are different or that Americans are unique in their love for the automobile. Although it is true that conditions are not identical in any two cities of the world, the claim that solutions from other countries do not apply to U.S. cities is incorrect.

Most frequent is the simplistic argument that rail transit is justified only in large cities that are densely populated; European cities use rail systems because their population density is greater than that of U.S. cities. Neither of these two arguments is correct. First, population size and density are not sufficient factors to determine feasibility of rail systems: A medium-sized city with low average density may have either topography or high-density corridors that require rail transit. Second, European cities that use rail modes extensively do not have more people or more dense populations than many U.S. cities that have no rail systems (Figures 7 and 8).

The belief that Americans are unique in their love for the automobile is also highly questionable because in most West European countries automobile registrations increased several times during the 1960s (in Italy more than six times from 1960 to 1970). However, although this automobile ownership increase in European countries did divert some passengers away from transit, transit patronage trends differ considerably from those in the United States. Although there are many physical, economic, and social differences between the United States and some European countries, it is quite clear that the basic policy toward urban transportation, improving both public and private modes in a coordinated manner, has already shown distinct positive results and is leading toward a stable situation in urban transportation.

The lack of knowledge about rail modes among transportation planners and engineers results in a misinterpretation of their proper application in urban transportation. U.S. cities that could efficiently use light rail systems have been planning systems similar to BART or the Lindenwold Line and, therefore, incur much higher costs than are rationally justified. However, buses and busways are planned for many corridors that would clearly be more efficiently served by rail transit, which would attract

Figure 7. Population densities of selected cities and application of rail transit modes.

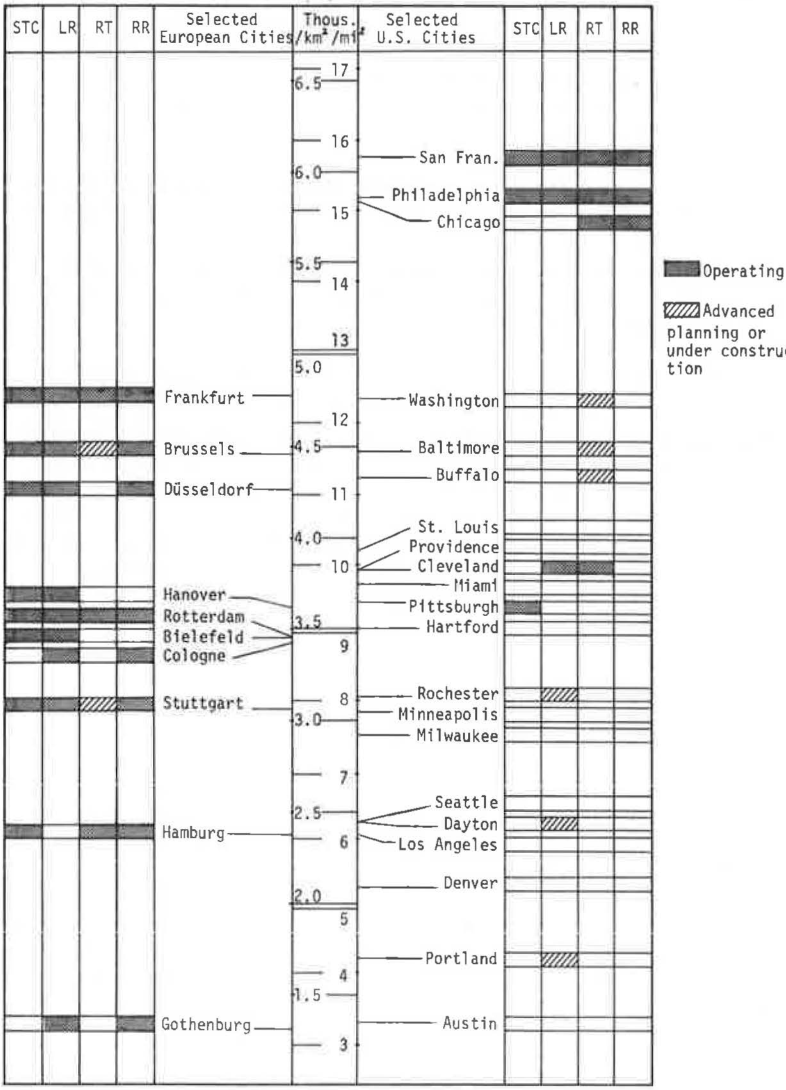
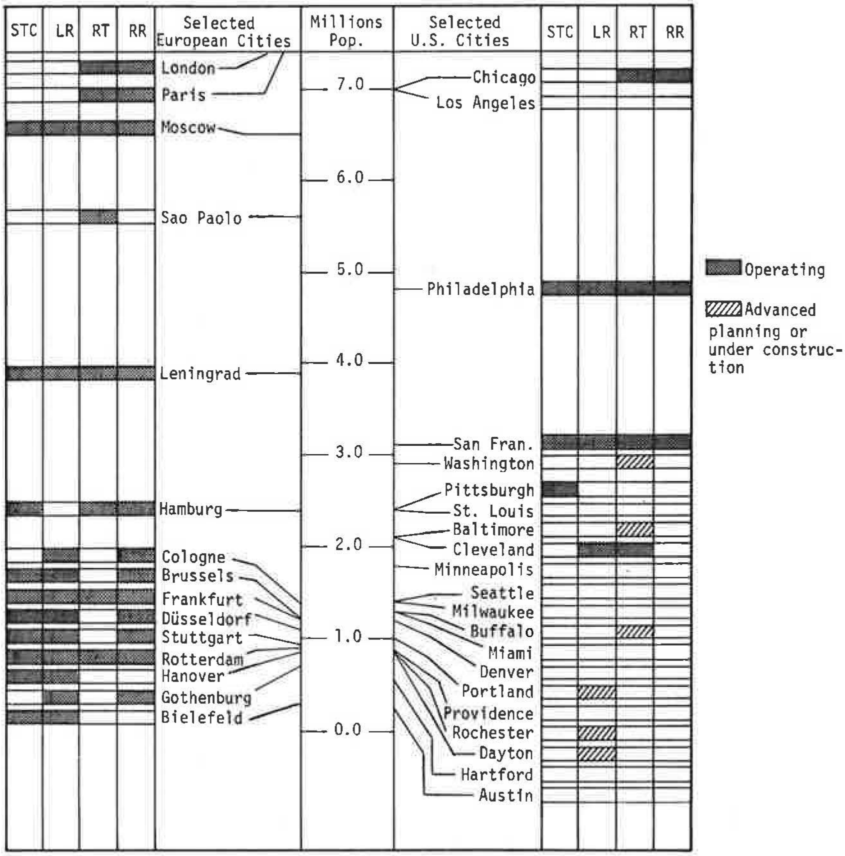


Figure 8. Population of selected cities and application of rail transit modes.



considerably greater patronage and have lower operating costs. Errors of both types result in the introduction of a nonoptimal mode of transportation and a less than optimal allocation of funds.

A major problem is that many consulting firms and planning agencies not having expertise in rail systems simply ignore them or find a superficial justification of the system they had decided to plan. A common practice is not to consider light rail at all and to compare rapid transit of the highest standards with a single type of bus on the basis of minimum cost (articulated buses are also commonly ignored). For understandable reasons, this type of selection is strongly prejudiced toward a lower cost and lower service quality system that, consequently, attracts low patronage.

Another important fact is that modern urban transportation systems cannot be achieved by using minimum investment cost as the sole criterion for decisions on mode selection. The common procedure used by successful modern systems is to base the transit plans and selection of mode on policies for achieving specified levels of public transportation service. The selection is then made of the most economical system (mode) that will provide the specified service quality. Drastically different modes such as rapid transit and surface transit should, therefore, never be compared solely on a cost basis because of the great difference in the quality of service they provide and patronage they attract (23).

Contrary to this procedure, several mode selections (and theoretical studies) in our cities have wrongly focused on the search for the minimum cost solution and ignore the differences in the number of users and service quality, which are often quite drastic.

Underutilization of Rail Systems

Rail technology offers a variety of modes that can operate effectively under different urban conditions. Despite extensive efforts to develop other types of guided technologies, none has so far been proved to be superior or even equal to rail in its overall performance (cost, dynamic characteristics, energy consumption, noise, and so on). However, much funding is being allocated in the United States and in Western Europe to the development of new technologies, most of which are clearly inferior to rail. Why is the large potential of rail transit underutilized?

Several factors cause this underutilization. First, the lack of knowledge about modern rail technology leads to nonoptimal decisions about modes. As a result, an extreme categorization of modes is set up and results in the polarization of alternatives. This tendency to polarize systems into the highest standard of rapid transit and the minimum-investment surface buses is widespread. The fashion to have a real rapid transit system and the belief that the flexibility of bus (a largely misunderstood feature) is the best mode for surface transit have resulted in a large gap between these two modes. Most medium cities fall into this gap, since they have travel demands less than optimal for rapid transit yet too large to be handled efficiently by surface buses. This problem is extremely serious not only in the United States, but also in France and Great Britain. Recently, however, the interest in light rail systems, which are best suited for this intermediate system role, has increased rapidly, and efforts to build new light rail systems in our cities are paralleled by similar actions in Australia, France, the Netherlands, and Great Britain. This mode was recently endorsed by the Organization for Economic and Community Development as the system that offers a better service quality and that is more economical than buses and more quickly implemented than rapid transit.

Second, there is confusion intentionally caused by opponents of improved public transportation through the above-mentioned incorrect statements and modal comparisons.

Third, there are pressures exerted by developers of new modes who capitalize on the low expertise of public officials in transit technology.

Finally, transit agencies also carry part of the blame; they often take a conservative attitude and oppose changes in policies and procedures proved helpful elsewhere rather than lead in their introduction. Reluctance to consider full automation of train running, honor fare collection methods, and lack of initiative in modernizing labor practices are good examples of such an attitude.

CONCLUSIONS

1. Modern rail transit incorporates a family of modes that have undergone a great deal of improvement in technology and operational concepts in recent years. These modes offer a wide range of quality of service and cost options that allow a broad spectrum of applications in different types and sizes of cities.

2. Several European countries have used this potential of rail transit to a much greater extent than the United States and have developed rail systems encompassing all modes. Although transit planning in our country has recently broadened its scope and incorporated some innovations, our lagging behind modern developments in rail systems is still serious. It has resulted in narrower choice of modes, lower reliability, and higher costs of rail systems here than are typical for the countries more advanced in this area.

3. European cities that have successful rail systems do not have more people and are not more densely populated than many U.S. cities that are often claimed to be unsuitable for rail transit.

4. Rail systems, particularly light rail and rapid transit, should be included in studies of alternative transportation solutions for all medium and large cities, especially when partially or totally private transit rights-of-way are considered desirable.

5. Despite extensive work on the development of new modes in recent years, no new technology has emerged that has been proved superior or even comparable to modern rail technology in performance and cost characteristics, including speed, reliability, comfort, noise, and energy consumption.

6. Unlike new systems, no demonstration of rail systems is necessary; their technical and economic feasibility are well known and continue to be substantially reconfirmed worldwide. However, intensification of the research and development of individual components of rail technology (propulsion, energy consumption, weight reduction, reliability, automation, and lower cost construction techniques) appears to be justified by its potential gains in improved performance and reduced cost in the near future.

7. A number of U.S. cities presently have advanced plans for various rapid transit and light rail systems. In most cases these projects are integral parts of plans for major revitalization of cities. This healthy initiative to reverse the trend of our urban decay has been recognized by the Congress and the federal government. The intent of recent legislation for increased federal assistance to transit has been to stimulate that trend. However, the presently allocated funds are inadequate, and inconsistency in their distribution had led to some serious setbacks in implementing these systems. The allocation of funds should be determined on the basis of real needs of our cities rather than by a requirement that the needs be squeezed into an arbitrary level of funding.

REFERENCES

1. Transit Fact Book—1973-1974. American Transit Association, Washington, D.C.
2. Automobile Facts and Figures 1973-4. Automobile Manufacturers Association, New York.
3. J. E. Burns, E. F. Necco, and J. I. Williams. Contemporary German Light Rail Streetcar-Subway Cars and Service. Inspection Team Rept., unpublished Metropolitan Boston Transit Authority rept., Boston, April 1971.
4. Rail Transit: The Operators' View. Chicago Transit Authority, 1974.
5. P. Giraudet. Programmed Departures Bring Capacity Dividends. Railway Gazette, July 1974, pp. 257-259.

6. R. Gutknecht. Alternative Approaches to Public Transport Fares With Their Traffic and Revenue Implications. 40th International Union of Public Transport Congress, The Hague, Rept. 5a, 1973.
7. L. Hoel. Public Transport Innovations in Principal European Cities. Professional Course in Urban Transportation, Carnegie-Mellon Univ., May 1973.
8. R. Hope, ed. Urban Railways and Rapid Transit—A Railway Gazette Management Study Manual. IPC Transport Press, Ltd., London, 1972.
9. Economic Characteristics of the Urban Public Transportation Industry. Institute for Defense Analyses, for U.S. Department of Transportation, 1972.
10. Metropolitan Railways of the World. Regie Autonome des Transports Parisiens, International Union of Public Transport, 1973.
11. K. Leibbrand. An Analysis of Different Forms of Rapid Transit. In Urban Mass Transit Planning (W. S. Homburger, ed.), Institute of Transportation and Traffic Engineering, Berkeley, 1967.
12. Operations Research, Inc. Comparison of Noise and Vibration Levels in Rapid Transit Vehicle Systems. National Capital Transportation Agency, Washington, D.C., 1964.
13. F. Pampel. Zur Frage der künftigen Verkehrsmittel für den öffentlichen Personennahverkehr. Erich Schmidt Verlag, Bielefeld, Germany, 1959.
14. Railway Gazette International. IPC Transport Press, Ldt., London.
15. P. Reynaert. A Consideration of Underground Urban Transport Systems: Metropolitan Railway, Underground Tramway, or Motorbus Tunnels? 37th International Union of Public Transport Congress, Barcelona, Rept. 9, 1967.
16. Statistical Abstracts of the United States. U.S. Department of Commerce, 1973.
17. Light Rapid Transit. University Practicum in Rapid Transit, Edmonton, Alberta, Canada, 1972 (updated 1973).
18. Typen-Empfehlung für Schienenfahrzeuge des öffentlichen Personen-Nahschnellverkehrs. Verband öffentlicher Verkehrsbetriebe, Cologne, 1970.
19. Die Zweite Ebene des Schienengebundenen öffentlichen Nahverkehrs. Verkehr und Technik, Erich Schmidt Verlag, Bielefeld, Germany, 1971, 1972, 1973.
20. V. R. Vuchic. Light Rail Transit Systems—A Definition and Evaluation. Urban Mass Transportation Administration, U.S. Department of Transportation, 1972.
21. V. R. Vuchic. Rapid Transit Automation and the Last Crew Member. Railway Gazette, Oct. 1973, pp. 383-385.
22. V. R. Vuchic and R. M. Stanger. Lindenwold Rail Line and Shirley Busway: A Comparison. Highway Research Record 459, 1973, pp. 13-28.
23. V. R. Vuchic. Comparative Analysis and Selection of Transportation Modes. Course in Public Transportation State-of-the-Art II, San Diego, Oct. 1974.