PLACE OF LIGHT RAIL TRANSIT IN THE FAMILY OF TRANSIT MODES

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The paper attempts to clarify concepts and terminology of urban transit systems. Modes are defined by type of right-of-way, system technology, and type of service and operation. Right-of-way is shown to be the most important single feature determining mode performance and cost. Advantages of partial or full separation of transit from surface traffic are defined. The basic features of system technology are analyzed. Guided systems are compared with driver-steered systems; rail systems are compared with rubber-tire guided systems; and manually driven systems are compared with automated systems. With respect to operations, it is pointed out that commuter transit should be a supplement to, not a substitute for, regular transit. An analysis of optimal vehicle size shows that, for guided systems that are in use or may be operational in the near future, minimum vehicle capacity should be 40 to 50 spaces. Based on this analysis of mode components, it appears that potential light rail applications are in medium-sized cities as carriers serving major routes and in large cities as a supplement to rapid transit. In large cities with low densities, light rail transit or light rapid transit (fully grade-separated light rail transit) also has potential for application. Small cities and special services may sometimes also use this mode. The following rights-of-way are best suited for light rail: street and highway medians, railroad rights-of-way, aerial structures, and, in downtown areas, short tunnel sections.

Transit planning requires a thorough understanding of characteristics of different modes. However, because modes have different characteristics, many of which are difficult to quantify, relationships among them are complicated and often they are not clearly understood. The lack of a complete theoretical basis for comparing modes combined with emotional tendencies toward unimodalism or a belief in a single mode represents serious obstacles to a rational choice of transit modes.

The purpose of this paper is to define the relationships of light rail transit (LRT) with other modes and describe the most typical applications of this mode. First, we should define the modes and analyze their basic characteristics.

DEFINITION AND CLASSIFICATION OF TRANSIT MODES

A transit mode is defined by the following 3 types of characteristics:

1. Right-of-way (ROW) category,
2. System technology, and
3. Type of service and operation.

This shows that the frequent tendency to equate mode with technology is incorrect. An express bus line is a different mode than a shopper shuttle service because it differs in its type of operation even though the vehicle technology for the 2 systems is the same. Similarly, there is a tendency to equate LRT with streetcars because of the similarity of their technologies. It will be shown that, on the basis of this broader definition of modes, LRT is a distinct, well-defined mode.

The comparisons of features cannot be extensively documented here because of space limitations, but certain basics are assumed.

1. Each characteristic is analyzed by itself, other things being equal. For example, different technologies are compared assuming the same ROW and type of operation insofar as these are not a direct function of technology.
2. The latest development and comparable condition of all modes are assumed (state-of-the-art technology, efficient operation and maintenance, and the like).

Comparisons are made for the most typical, realistic situations. It is conceivable that unusual conditions may change and even reverse results of some comparisons.

Right-of-Way Categories

Transit rights-of-way vary greatly from regular urban streets to fully controlled rapid transit tunnels, viaducts, and the like. They can be classified into 3 major categories that have distinctly different features.

1. Category C includes surface streets with mixed traffic. A vast majority of bus lines in cities represent systems in this category.
2. Category B includes partially controlled ROW. For most of its length, this ROW is separated from other traffic, but some grade crossings and street running also exist. This category is broad. It encompasses modes with reserved bus lanes and curbed light rail street medians to modes with only a few grade crossings, such as the Shaker Heights, Ohio, Light Rail System and the Media Line in Philadelphia.
3. Category A is a fully controlled (also referred to as exclusive, private, or separated) ROW, that is, one without street running, vehicular or pedestrian crossings at grade, and the like. Rapid transit systems are in category A exclusively.

The dominant belief is that technology is the basic feature of transit modes. On the contrary, the ROW category is usually the most important factor determining transit system performance and its ability to attract passengers. In category C, transit vehicles on streets cannot travel faster than other traffic. In Figure 1 the standard traffic volume/travel time curve is plotted for automobile travel. Because surface transit vehicles are mixed with automobiles but also must stop at passenger stops, its travel time curve is higher. Thus, transit service in category C ROW can never be competitive with the private automobile either in speed or in overall service quality. Separated transit on the other hand is not influenced by automobile traffic; its travel time decreases as travel increases because of shorter headways. This fact is valid regardless of the technology used although, as will be shown, the ROW category does influence the choice of the most appropriate technology.

Because category B encompasses a great variety of facilities, there is no sharp distinction between categories B and C. However, the differences between typical B and C category facilities are nevertheless highly significant. They are presented here in a condensed form.

The advantages of category B over category C are as follows:

1. Higher speed, capacity, reliability, comfort, and other service quality elements;
2. Stronger system image and identification;
3. Higher passenger attraction, which is a consequence of item 2;
4. Lower unit operating cost; and
5. Stronger impact on urban form and land use (more permanence).

The disadvantages of category B when compared with category C are that systems in category B require more land and higher investments.

Category A is, on the other hand, distinctly different from category B, because of its full grade separation and control of ROW, which allows many operating efficiencies. Among these efficiencies are operation of longer trains, full signal control, high-level platforms, and enclosed stations with fare collection. These differences give category A the following advantages over categories B and C:

1. Highest capacity, speed, and productivity;
2. Highest comfort and other service quality elements;
3. Highest safety (fail-safe operation);
4. Strongest image and identification;
5. Highest passenger attraction, which results from items 1 through 4;
6. Lowest operating cost per unit capacity;
7. Strongest impact on urban form and land use; and
8. Most fully automated operation possible.

The disadvantages of category A are as follows:

1. It requires land and grade separation for the entire line;
2. It requires the highest investment; and
3. It is the least extensive network, which is a result of items 1 and 2.

This analysis shows that ROW categories largely determine overall mode performance and investment cost. The 3 categories represent 3 distinctly different performance and investment cost combinations, as shown schematically in Figure 2. Consequently, in planning transit systems, the basic decision is choosing the ROW category for the system, that is, choosing the degree of separation and control, because that choice influences most directly the overall quality of transit system performance and the approximate investment level the system will require. This decision, which should be made by political bodies with the advice of transportation planners, is followed by selecting the technology and type of operation. This should be done mostly by transportation engineers with expertise in various modes.

System Technologies

The basic technological difference among modes is method of vehicle guidance. Many physical, operational, and cost characteristics of systems depend on whether the vehicles are steered by the driver or are physically guided externally. Transit systems can again be classified in the following 3 general technological categories:

1. Driver-steered vehicles operating on highways (all types of buses),
2. Guided steel-wheel-on-steel-rail systems,
3. Systems that are a combination of items 1 and 2 (trolleybuses, rubber-tire guided systems, and dual-mode transportation). Dual-mode transportation is not currently operational. Table 1 gives a classification of modes by ROW category and technology.

Major differences caused by different technological characteristics exist among modes. Guided systems have the following advantages over driver-steered systems:

1. Narrower ROWs;
2. Superior performance;
3. No air pollution;
4. Lower noise levels;
5. Greater cleanliness;
6. Easier maintenance;
7. More durable vehicles;
8. Higher capacity and productivity because vehicles can be coupled;

Figure 1. Average travel time by surface transit, automobile, and separated transit as functions of passenger volume.

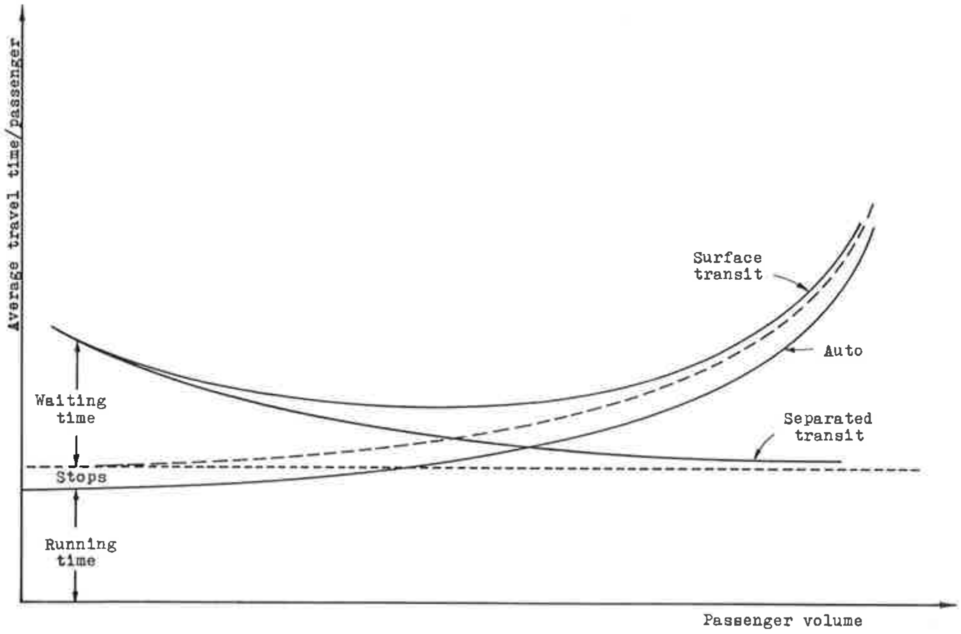


Figure 2. Relation of service quality and investment cost for transit systems in different right-of-way categories.

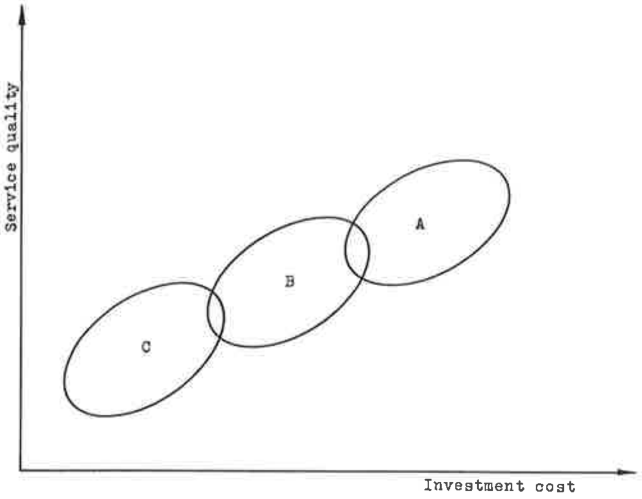


Table 1. Classification of modes by right-of-way category and form of guidance.

ROW Category	Guided		
	Rail	Other	Driver Steered
A	Rapid transit Regional rail Light rapid transit	Rubber-tire rapid transit Monorail People movers Personal rapid transit	Bus on busway only
B	Light rail transit	Dual mode	Bus partially on busway
C	Streetcar	Trolleybus	Surface bus

9. Greater safety and reliability;
10. Lower operating cost per unit of offered capacity;
11. Lower energy consumption because steel wheel on steel rail has much lower rolling resistance than does rubber tire on roadway (only true for rail-guided systems); and
12. Can be better operated in tunnels, viaducts, or park areas without significant environmental damage.

Fixed alignment that permits electric traction allows the advantages of items 2, 3, and 4 and the operational advantages of items 5, 6, and 7.

Guided systems have some disadvantages when compared with steered systems.

1. They are less compatible with other traffic, which creates problems in street operation.
2. They are limited to guideway networks only, which is uneconomical for extensive routing in low-density areas.
3. They have lower operational flexibility (rerouting, charter service).
4. They require a slightly higher investment cost (the higher cost of the guideway usually is not fully offset by the savings from the narrower ROW).
5. They offer less frequent opportunities for modernization because of the longer life of their vehicles.

These listings show that, for systems in category C, deficiencies of guided systems are significant and usually outweigh the advantages. For category A, however, the disadvantages of guided systems practically disappear, and the bus is strongly dominated by rail systems. For category B, advantages of rail outweigh disadvantages under most, but not all, conditions.

Some of the listed advantages are either decreased or changed into disadvantages for rubber-tire guided systems. Thus, energy consumption becomes higher than that for buses. This becomes clear when rail and rubber-tire guided systems are compared. Rubber-tire systems have the following advantages over rail systems:

1. Slightly better traction under normal weather [on rapid transit, the maximum gradient for rubber-tire systems is 7 percent, and the maximum gradient for rail systems is 5.5 percent (1)] and
2. Easier control of noise in curves.

The following are the disadvantages of rubber-tire systems when compared with rail systems:

1. Higher energy consumption (sometimes substantial),
2. Poor traction in wet conditions (rain, snow, and ice) that may require expensive guideway heating,
3. Much more complicated switches with slower operations,
4. More expensive and bulkier guideways, and
5. Cannot be used in categories B and C.

This comparison shows that rubber-tire guided systems are inferior to rail systems under all conditions except for some special circumstances. For example, a rubber-tire system would be less noisy on the old steel viaduct in Paris, which could not be replaced by a modern concrete structure. Actually, it should be pointed out that, if the latest developments in each technology are compared, rail remains the best technology by far for guided systems. Although magnetic levitation conceivably may become competitive with rail in the future, it currently is not developed to the stage of technological feasibility.

An interesting recently published study of rubber-tire rapid transit (5) reaches conclusions considerably different from these and much more favorable to rubber-tire systems. The study finds, for example, that rubber-tire systems use less energy than steel-wheel systems because of an estimated 15 percent lower weight/passenger of rubber-tire vehicles. However, this weight advantage is not corroborated by actual data. As a matter of fact, weight per unit of vehicle floor area of rubber-tire rapid transit vehicles is higher than the corresponding weight of many steel-wheel rapid transit vehicles. The assumption of weight advantage therefore is incorrect. The study also finds that rubber-tire vehicles have a speed advantage assuming that adhesion limits acceleration rate at higher speed; however, because, for most systems, motor power rather than adhesion is the constraint, this argument is not valid for real systems.

To complete the analysis of type of guidance, we should consider fully automated operation of transit vehicles. This potentially highly significant feature that is not yet operational requires that the ROW be fully controlled (category A) and that the vehicles be physically guided. Full automation is not, as sometimes believed, related to such features as vehicle size, off-line stations, or any other unconventional technological solutions (8). Actually, rail technology can be better adapted to full automation than can any proposed technology because it has the greatest simplicity and has no untested elements. The advantages of fully automated systems over manually operated systems are as follows:

1. Much higher frequency of service for the same operating cost,
2. Reduced energy consumption and vehicle wear through preprogrammed driving,
3. Easier recovery from service disturbances,
4. Higher capacity for a given level of safety, and
5. Lower operating cost (if labor savings outweigh cost of increased system complexity).

The disadvantages of fully automated systems when compared with manually operated systems are as follows:

1. Considerably higher investment,
2. Serious reliability problems often created by the much greater technical complexity, and
3. Guideway control equivalent to that drivers perform and a system for communicating with passengers in emergencies.

The advantage in item 1 is by far the most important advantage because it would permit high-quality transit to be used economically for lower passenger volumes, such as in cities that currently cannot justify rapid transit. It therefore would be sufficiently significant in many cases to outweigh all the disadvantages of automation.

Types of Service and Operation

Several basic elements of transit system operation needed for modal analysis will be presented in this paper. Two of these elements—frequency of service and vehicle capacity—are closely related to technologies. The other 2 elements—trunk and branch lines and regular and commuter transit—concern the transit network and the role given to transit in urban transportation.

Frequency of Service and Vehicle Capacity

The relationship of frequency of service and vehicle capacity strongly affects both system cost and passenger cost. If the operator operates large units at long headways, cost is always reduced but passenger waiting time is increased. Because full automation permits high frequency of service with short trains and no extra cost, frequency can be increased as a direct function of passenger volume theoretically to the level of line capacity. With most transit systems, this frequency would be 30 to 120 operating units/h depending on station operations, speed, safety requirements, and the like. In practice, as this frequency is approached, service reliability and efficiency begin to decrease, progressively increasing operating cost.

Figure 3 shows that, if increasing passenger volume is served by increasing frequency of operating units with fixed capacity, unit cost of the system remains constant and average passenger cost (time) decreases. When maximum possible vehicle frequency on the line is approached, operating cost begins to increase rapidly. From that point, instead of further increasing frequency, one can increase line capacity by using higher capacity operating units without any effect on unit cost. This can be done by coupling vehicles into trains.

Vehicle capacity for medium-capacity automated transit (MCAT) systems is often a subject of different opinions. Many suggestions are that small vehicles with 12 to 25 seats and some with 20 to 30 standing spaces should be used for a more personalized service. The diagram in Figure 4 clarifies some aspects of this. Figure 4 shows the physical relationship of frequency, operating unit capacity, and capacity offered on a line. The region of relevant values is delineated by rather liberal assumptions. The minimum peak-hour volume that would justify an automated system is assumed to be 3,000 persons. On the upper end is the volume of 10,000 persons/h. Beyond this light rail transit and rapid transit are clearly dominant. The lowest acceptable frequency for an automated system is considered to be 10 vehicles/h; the highest, with currently available technology, is 40 vehicles/h; with technological improvements, this would be 60 vehicles/h. These improvements may be expected in the foreseeable future. The diagram shows that for all conceivable applications of MCAT systems, which are delineated by dash lines, the absolute minimum capacity of operating units should be 50, but, in most cases, it should be 100 to 300 persons. Because modern transit systems must be designed mostly for sitting, these capacity requirements are substantial; and, because providing a given capacity by a small number of large vehicles is more efficient, it is concluded that the minimum capacity of vehicles for automated systems should be about 40 to 50 spaces, most of which should be seats.

Trunk and Branch Lines

Trunk and branch lines affect network configuration and type of operation. Ability to service branch lines without significant degradation of trunk line operation (reduced capacity and reliability) is a major asset of any transit technology. However, because operation on branches may be quite different from operation on the trunk line, compatibility of trunk and branch sections can be achieved if certain conditions are met.

1. If the trunk line has a high ROW (category A or B), branches should also be free from frequent delays to prevent service degradation on the trunk.
2. Branches should have at least moderate passenger volumes so that the same vehicles can effectively serve both the trunk and branches.
3. Because services with very low volumes require smaller vehicles (and sometimes a different type of operation, such as dial-a-ride) than do high-capacity lines, lightly traveled routes should be operated as feeders with transfers to major lines.
4. The number of branches should be limited by the requirement that the sum of frequencies on individual branches must be somewhat lower than the maximum frequency that the trunk line can handle to minimize the impact on the trunk line of deviations from schedule on branches. The only way to handle the cases in which sum of branch frequencies exceeds trunk line capacity is to couple vehicles at converging points. This operation has had limited applications in some cities (LRT in Göteborg, Sweden). Eliminating all stations from the trunk is, of course, another solution to this problem, but it has serious disadvantages, as further discussion will show.

The mode least adaptable to branching is rapid transit because it must have controlled ROW, the cost of which makes extensive branching economically infeasible. Operationally, more than 3 branches are not recommended, although there are cases

Figure 3. Unit transit costs for single-vehicle and train operation as functions of passenger volume.

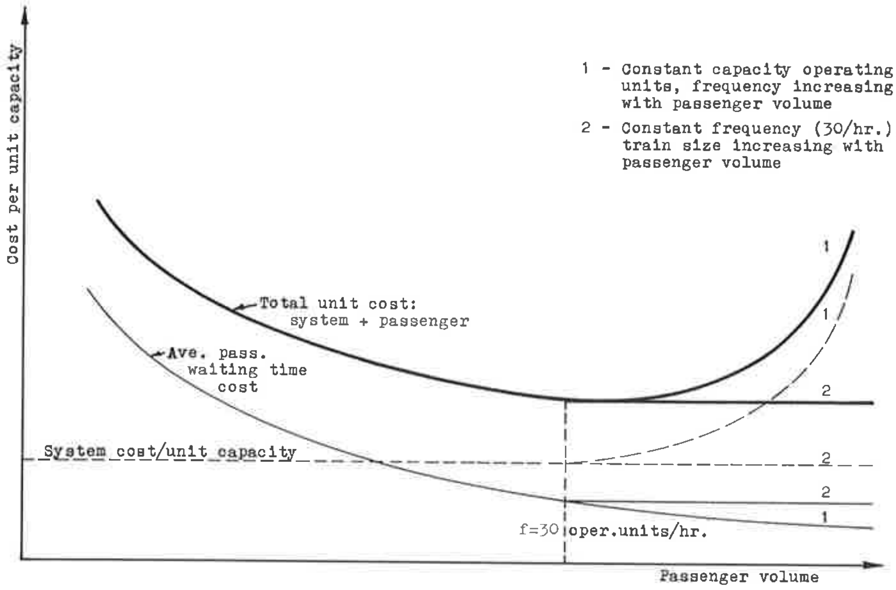
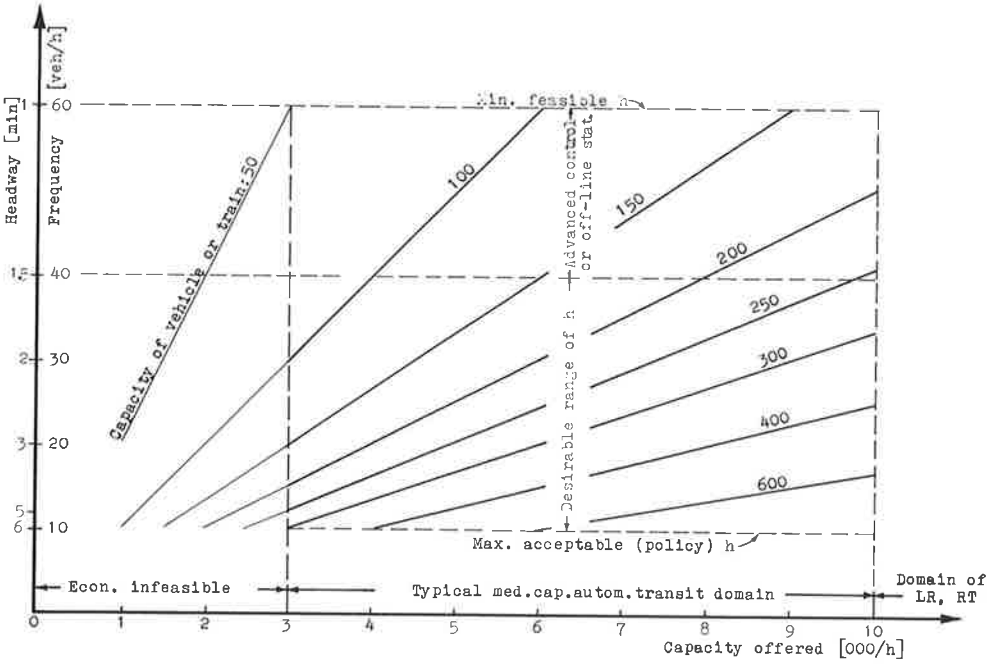


Figure 4. Relation of required frequency and operating unit capacity for medium-capacity automated transit.



where 5 to 6 branches are operated (London, Munich S-Bahn).

Because it does not require special fixed facilities, the bus mode is the mode most adaptable to branching. This physical ability often influences the operator to use it to such an extreme that the system has far more than the optimum number of branches, since it violates some or all of the conditions for merging given above.

Light rail transit is between these 2 modes. Operationally and economically, it can serve branches much more easily than rapid transit can, but much less so than buses can. In most cases, LRT is capable of serving as many branches as physical conditions, investment requirements, and operational efficiency permit.

Regular and Commuter Transit

Regular and commuter transit as shown by Sullivan (6) and Vuchic and Stanger (10) are 2 distinctly different types of service. Regular transit consists of a network of lines with stations and transfers between them; it operates during all daily hours. All vehicles usually stop at all stations although skip-stop, express, and other accelerated operations are possible. Commuter transit consists of bus collection routes in suburbs, nonstop operation into the city, and distribution on 1 or several routings through the central business district (CBD).

Consisting of many branch routes in suburbs and several routes in the CBD, commuter transit provides very low frequency of service on most origin-destination pairs. The reason for this is that, even for a very high frequency of operation, F, on the trunk line, the average frequency on any 1 route between m suburban feeders and n CBD distribution routes is equal to $F/(m \cdot n)$. Because this type of operation usually does not allow off-peak service, commuter transit is actually similar to car pools. It provides direct (no-transfer) fast service to a great number of people traveling to the CBD, but it does this very few times per day. It usually does not provide for non-CBD trips, even for those between different points along its corridor.

A schematic presentation of regular and commuter transit is shown in Figure 5. Commuter transit has some advantages over regular transit.

1. It provides a more direct (no-transfer), higher speed service for CBD-oriented commuters.
2. It requires much less dependence on the automobile for access to transit.

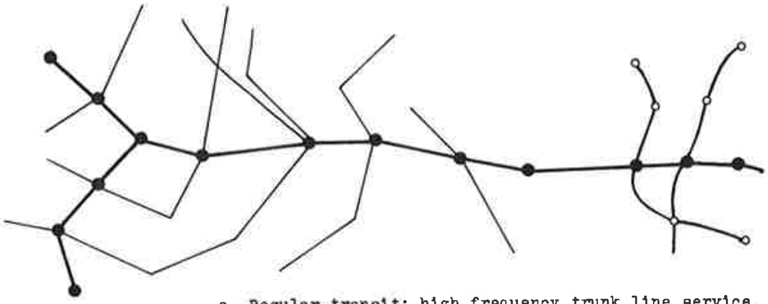
Commuter transit also has some disadvantages when compared to regular transit.

1. It can serve few non-CBD-oriented trips.
2. It offers much lower quality off-peak service.
3. It has a much lower frequency of service even during peak hours.
4. Its extremely high peak-to-base ratio and high labor intensity make it less economical.

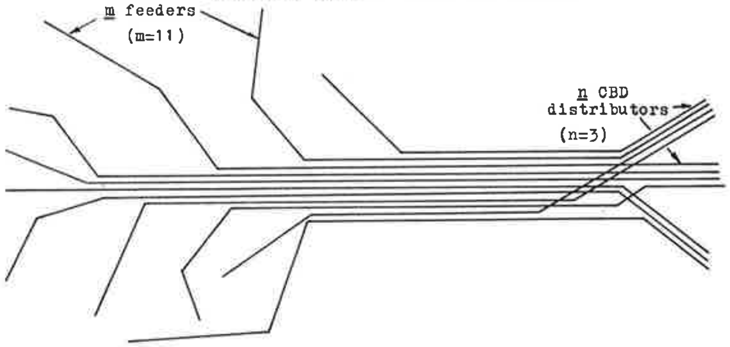
This comparison clearly shows that commuter transit, exemplified by express bus lines in many U.S. cities (Shirley Busway in the Washington, D.C., metropolitan area and many lines in New York, Boston, and other cities), represents a convenient service for regular, peak-hour, CBD-oriented commuters, but it does not provide the complete service required from transit, which is mobility throughout the urban area at all times. Transit networks consisting of each of these 2 types of services are shown in Figure 6. Commuter transit is therefore a supplement but by no means a substitute for regular transit. This conclusion is not necessarily related to the ROW category or guidance technology of modes although commuter service usually is operated by buses.

Incidentally, it can be shown that many commuter bus systems could be improved by separating operating branches into independent feeders to trunk line as well as by introducing some stations on the trunk sections.

Figure 5. Corridor service by regular and commuter transit.

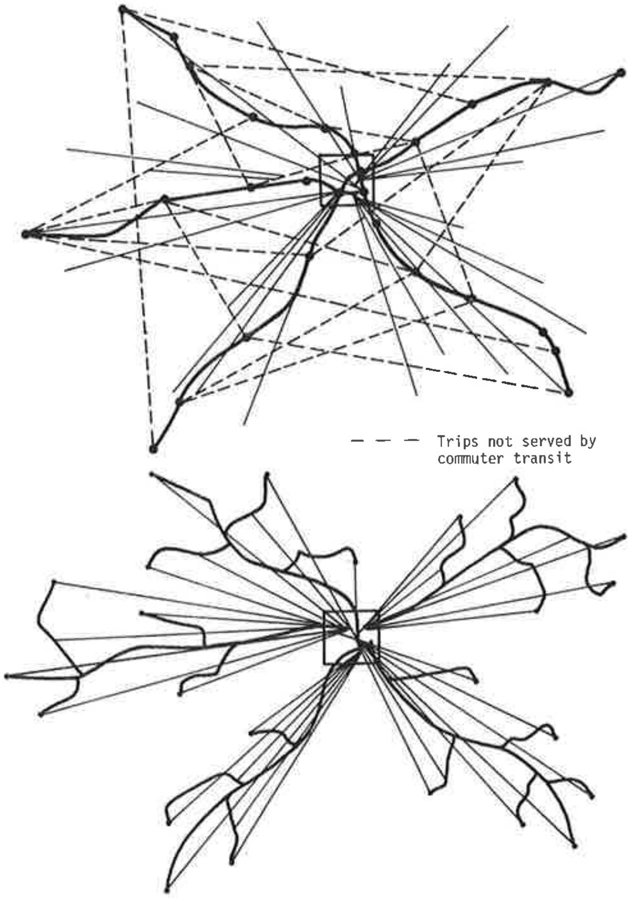


a. Regular transit: high frequency trunk line service, transfers to feeders; all-day service



b. Commuter transit: feeders travel directly to CBD; no transfers; low frequency, no service along trunk section; peak hour service only

Figure 6. Urban networks of regular and commuter transit.



A BRIEF REVIEW OF DEFINITIONS AND TERMINOLOGY

The preceding analysis of the major components and characteristics establishes the groundwork for precise definitions of the concepts and terminology related to light rail systems.

Light Rail Transit

Light rail transit is more than a technology; it is a mode that combines technology similar to that of streetcars (tramways) but operated on a category B ROW. This puts LRT into a functional category of semirapid transit. Its definition therefore must include not only information on vehicles but also information on ROW and operation. Light rail transit is a mode consisting of electrically powered, modern rail vehicles operating in 1-, 2- or 3-car trains predominantly on exclusive rights-of-way. Modern implies quiet, spacious, aesthetically pleasing vehicles that provide high-quality ride.

Pre-Metro

Pre-Metro is a light rail mode that is a transitional system, such as those found in Brussels and Düsseldorf, for rapid transit.

The boundary between LRT and streetcars is not clear because many streetcar systems are gradually upgraded into light rail systems. The "boundary" between LRT and rapid transit (RT) is, on the other hand, quite clear: RT has fully controlled ROW (category A). The 2 modes, however, can be fully compatible in operation as they are in Frankfurt.

Light Rapid Transit

Light rapid transit is a mode that has LRT vehicles and stations (platforms for up to 3 cars only) but has fully controlled ROW. This mode usually has a third-rail power supply and high-level platforms (Norristown Line in Philadelphia), which makes it a hybrid of LRT and RT. Although there are only a few of these modes in operation, this "small-scale RT" may gain wide application if full automation of transit operation is developed to an operational stage. The intermediate capacity system (ICS) planned for Toronto most probably will be this mode.

Rapid Transit

Rapid transit systems are systems operating exclusively on controlled ROW. They are capable of providing high line-haul capacity, high operating speed, and a high degree of safety (fail-safe operation). The great majority of rapid transit systems use rail technology; most other guided systems also belong in this category. Examples of these are the rubber-tire rapid transit systems in Paris, Montreal, Mexico City, and Sapporo, Japan; monorails such as the airport line in Tokyo; and medium-capacity automated transit represented by the Westinghouse Transit Expressway and Airtrans systems. Unguided technologies, such as buses and trolleybuses, have never been used for rapid transit. Buses on busways also operate on surface streets; therefore, they belong, as light rail does, in the category of semirapid transit.

COMPARISON OF LIGHT RAIL WITH OTHER MODES

Local conditions have a significant influence on the efficiency of different modes.

Comparison of modes therefore can be made only in general terms, and nontypical conditions may change some of the relationships.

Regular Bus and Streetcar Systems

Regular bus and streetcar systems belong to a different ROW category than LRT does and represent distinctly lower service quality and investment cost packages than LRT does. In areas where category C ROW is not a serious handicap, such as on suburban, lightly traveled streets where required capacity is low, the advantages of LRT are far smaller than the advantages of buses. Thus the latter mode is superior. When, on the contrary, high passenger volumes or requirements for a high-quality system justify provision of category B ROW, then LRT is superior.

Busway Systems

The busway mode is more similar to LRT than the regular bus is. Yet comparison of these 2 modes can be complicated if the busway is operated as a commuter service only. In that case, a 2-step comparison is appropriate. The first step is to compare commuter bus transit with regular bus transit (stations on the trunk section and all-day service). As pointed out, regular transit usually should be the basic system and be supplemented by commuter transit when demand justifies it. The second step is to compare regular bus transit using the busway mode with LRT mode, both of which have bus feeders in the suburbs. Preceding analyses and other studies (10) show that the bus has the advantage of easier branching and, therefore, requires fewer transfers, but it is inferior in performance (comfort, speed, capacity, and safety) on the trunk section. In the CBD, LRT usually requires higher investment facilities than buses do, but it also provides a much higher quality of service. Actually, CBD distribution represents a serious bottleneck for most busway systems, and, in most cities, this problem cannot be solved because of the inability of buses to operate in tunnels without major problems. Consequently, for a corridor with a long trunk line and when the possibility of providing partially or fully separated ROW in the CBD exists, LRT is the superior mode. If a large number of feeders converge onto a rather short common route and CBD streets are not seriously congested, the busway tends to be the favored mode.

An important point is that transit routes regardless of mode preferably should follow alignments on major avenues rather than freeways to provide better accessibility for the population in the area.

Another important difference between LRT and the busway mode is in their approach to ROW upgrading. Light rail transit is first provided high-quality ROW in the CBD, where congestion is most serious and benefits from less congested streets are the greatest. Outlying sections can have more crossings because the lower traffic density does not cause major interference. The busway mode, on the contrary, has high-quality ROW in the outlying areas but degrades to street running in CBD. This is the most serious single drawback of the busway mode.

Rapid Transit

Rapid transit, as clearly shown by Lehner (2), represents a higher quality and higher investment mode than LRT does. The superiority of LRT with respect to lower investment, greater physical compatibility with urban environment, and adaptability to staged development are important advantages, and they make LRT a more rational choice in many cities. However, transit planners should not believe that LRT can offer the same performance as RT can for a lower investment. The advantages of RT in terms of higher speed, safety, capacity, labor efficiency, and passenger attraction are significant, and, in many cities, they are more important than the lower investment and other advantages of LRT.

New Modes

New modes, mostly MCAT, which are often given the nondescriptive name "people movers," represent a promising concept because they allow higher quality transit in smaller cities than is currently feasible. This also is the primary role for many LRT applications. Actually, the following will show that the 2 concepts are fully compatible.

Various MCAT systems, such as Transit Expressway, Airtrans, the Morgantown, West Virginia, system, ATC, VAL (France), and Krauss-Maffei (Germany), incorporate various permutations of positive and negative unconventional features in their guidance technology, switching, vehicle capacity, and type of operation. Advantages of the positive innovations thus are, in most cases, either obscured or outweighed by the disadvantages of unsound features in the concept of each mode (3, 11).

A systematic approach based on analyzing each feature separately and combining them into a mode afterward is recommended as more promising for development of a successful system than the approaches used by most developers in the past. If the comparisons of individual system features previously presented are analyzed and the best features required for applications of MCAT modes are selected, one can see that the preferred features would be the following:

1. Operating unit capacity of 50 to 200 persons (the latter obviously requires coupling of cars into trains),
2. Category A ROW,
3. Rail technology, and
4. Automatic operation.

This actually defines an automated light rapid transit mode. It is thus clear that LRT systems can be designed so that they can be upgraded into an MCAT system. This compatibility of LRT with new mode concepts may prove to be highly significant in the future, provided full automation becomes operational.

POTENTIAL ROLES OF LIGHT RAIL TRANSIT

Most large cities use RT as the basic transit mode and supplement it with extensive bus networks. Small cities obtain adequate service from buses only. The medium-sized cities, however, face a dilemma if only these 2 modes are available; they need better service than buses can provide, but they cannot afford the high investment required for RT. This is the reason that only those medium-sized cities that use LRT (Zurich, Göteborg, The Hague, Hannover, and others) have adequate transit service today. Mobility in them is vastly superior to that in similar medium-sized cities in countries that have generally abandoned rail transit, such as Great Britain, France, and the United States.

Some lay observers have posed this question: Why are we returning to LRT after abandoning streetcars as inefficient? The fact is that, if the LRT concept is understood properly, it is clear that introduction of this mode is not a step backward but a major step forward in upgrading the existing surface transit systems. The potential for introduction of LRT into our cities lies in the fact that LRT is better adapted to separation and preferential treatment than are streetcars and buses, that it offers a higher service quality (speed, reliability, and riding comfort) and that it has a better image. Most important, LRT can, because of these features, attract passengers that surface transit cannot. Moreover, LRT is environmentally superior because of its lower noise and because it does not pollute the air. Many cities may find these features worth the higher investment.

The most popular question on the "volume threshold" for LRT cannot be given a simple answer. Many existing LRT lines operate successfully with peak-hour volumes that are as low as 2,000 persons; new lines with such volumes can be justified, however, only when low-cost ROW is available. At about 4,000 to 5,000 persons/h, LRT becomes operationally and economically superior to buses. At 10,000 to 12,000 persons/h RT may be superior if the ROW for it is not excessively costly. Where RT would require an extremely high investment, LRT can be a more economical solution even for 8,000 to 20,000 persons/h although service quality will be lower. It should be pointed out, however, that 2 different modes never attract the same number of passengers. Changing from bus to LRT or from LRT to RT always increases patronage.

Light rail transit can serve several roles in different cities. In medium-sized and some large, but low-density cities (Göteborg, Düsseldorf, Bremen, Amsterdam, Vancouver, possibly even Los Angeles), it can be the basic mode. In many cities with RT, complementary or feeder service can be provided by LRT (Boston, San Francisco, Milan, and Moscow). Many special services (individual corridors in small cities or resorts, shuttles, and the like) also can be operated by LRT.

CLOSING REMARKS

There are indications that LRT has potential for introduction in dozens of U.S. cities. The definitions of its place in the family of transit modes, given here, can serve for general orientation, but they must be supplemented by studies of conditions and comparisons of alternatives for each potential application. Each one of the major modes is superior to others under certain sets of conditions.

Major progress in improving technology and modernizing operations of LRT systems that has taken place during the last couple of decades in West European countries is largely unknown in the United States. Modern LRT systems can be introduced into U.S. cities with only minor modifications to local conditions. However, there are several directions in which this mode is likely to be further developed. The analyses presented here lead to certain observations with respect to the future of LRT and related modes.

Developments of LRT as well as other concepts would be greatly stimulated if research and development efforts were redirected from examination of various new systems to a systematic examination of individual mode components, such as:

1. Fully automated transit system operation (the one absolute essential of all new, guided concepts that should be developed on rail systems first to eliminate technical problems unrelated to automation from which all new systems suffer),
2. Optimal vehicle size,
3. Different guideway technologies,
4. Value and practicality of off-line stations, and
5. Acceptability of aerial structures for transit.

The federal government through the Urban Mass Transportation Administration should be the logical leader in this research and development effort. Light rail transit is the best technology for testing most of these components and concepts although applicability of their results would greatly exceed this specific mode.

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