Table 6. Factors important in the evaluation of four LRT design standards.

Factor	Base Case	SP-PUC Amount	SP-PUC Difference (%)	Lower Cost Amount	Lower Cost Difference (%)	Higher Cost Amount	Higher Cost Difference (%)
Avg line speed, km/h	43	43	0	35	-20	51	+20
Daily ridership (000s)	70	70	0	60	-14	80	+14
Capital costs ($000 000s)	267.5	294.0	+9.9	210.4	-21.3	348.0	+30.1
Operating and maintenance costs ($000 000s)	5.5	5.5	0	5.8	+6.3	6.0	+9.0
Capital cost per passenger, $	0.61	0.65	+6.6	0.54	-12	0.70	+15
Operating and maintenance cost per passenger, $	1.11	1.11	0	1.18	+6.3	1.06	-5
Total cost per passenger, $	1.72	1.76	+2.3	1.72	0	1.76	+2.3
Subsidy per passenger, $	0.94	0.94	0	1.01	+7.4	0.89	-5.3
Benefit/cost ratio	1.24	1.16	-6.6	1.20	-3.3	1.24	0

Note: 1 km/h = 0.6 mph.

subsidy difference between the alternatives is obscured in the system totals because of the dominance of the subsidy for the baseline bus system ($32.77 million annually) over the incremental subsidy of $6.75 million for LRT and $8.84 million for the busway. This difference is better shown by the incremental subsidy cost of $0.59/passenger trip for LRT versus $1.03 for the busway (which is 75 percent greater than that for LRT); the difference is 57 percent in terms of cost per passenger kilometer. Thus, the LRT alternative has a major subsidy advantage. In comparison with the baseline bus system, the LRT alternative will reduce the total system subsidy required, both per passenger trip and per passenger kilometer.

It should be noted that all LRT and busway designed standard alternatives have subsidy requirements similar to those of the base case and that the ranking preference of LRT over busway never changes, while with respect to the other bus alternatives it shifts only once. Use of the lower cost LRT standard results in a subsidy of $1.01/passenger. This is only slightly greater than the baseline value of $0.96, whereas the base-case standard subsidy per passenger of $0.94 was slightly lower. Such small differences, however, should be judged with caution.

SUMMARY AND CONCLUSION

The factors found to be important in evaluating the effect of different LRT design standards on cost-effectiveness measures are shown in Table 6. Although the values shown were derived from the Santa Clara County study, they lead to conclusions that may be applicable elsewhere, particularly in western cities where similar rights-of-way are available. Thus, when these factors were incorporated into benefit/cost and transit efficiency comparisons with other transit modes, it was found that the use of any one of the possible LRT design standards would lead to essentially the same conclusions concerning the relative attractiveness of LRT and other transit alternatives.

It should also be noted that other important mode-comparison factors in addition to those shown in Table 6 (e.g., compatibility with local, regional, and national plans and goals; socioeconomic and environmental impacts; direction of urban growth; and community and political support) are relevant considerations in the evaluation and selection process.

We therefore conclude that, for the conduct of similar alternatives analysis studies in other areas with similar conditions, the time and cost required to evaluate a variety of LRT design standards is neither needed nor justified. While any one of the potential design standards would lead to essentially the same conclusions concerning the relative attractiveness of LRT, a base-case standard reflecting good modern European LRT design practice is recommended for purposes of comparison. In adopting this standard for alternatives analysis, it should be recognized that a higher level of service and greater attraction of patronage can be achieved but only at a greater capital cost; conversely, while a lower capital-cost LRT design is possible, it will reduce the level of service and the number of patrons attracted to the service. Operating costs are also affected. These changes due to varying design standards tend to cancel each other out; the net result is no significant difference in the LRT cost-effectiveness measures and no significant changes in its relative attractiveness with respect to other transit mode alternatives.

REFERENCES

1. Santa Clara Rapid Transit Development Project: Phase One Summary Report. De Leuw, Cather and Co., Feb. 1975.
2. Santa Clara County Transit District Light-Rail Feasibility and Alternatives Analysis. De Leuw, Cather and Co., Final Rept., Aug. 1976.

Network Planning for Light-Rail Transit

Gerald D. Fox, De Leuw, Cather and Company, San Francisco

A common problem in the approach to light-rail transit (LRT) planning is the development and testing of less than optimal networks. This problem arises from an incomplete understanding of the application of the mode and of the opportunities inherent in its application. This paper describes how unique characteristics of LRT can be exploited by developing networks to make better use of the mode. Guidelines for network development are described and illustrated by examples. A distinction is made between techniques applicable specifically to LRT and those applicable to other transit modes. The concept of tuning a network (to match the level of investment to patronage and other benefits on a segment-by-segment basis) is presented, together with a discussion of the advantages of retaining as many future options as possible in long-range transit planning.

A number of recent urban transit development studies and corridor studies have been based on initial assumptions that establish the basic network, corridor, and sometimes even alignments. If network decisions are made prior to the selection of a mode, however, the transit designer is left with little opportunity to consider each mode in the context of a network configuration optimized for that mode. For instance, a busway may have no need for continuous construction and may be effective with only fragmentary improvements to the highway system. It can be designed to eliminate delay points and maximize the main advantage of bus transit (the one-seat ride) through selective use of surface streets.

By contrast, a heavy-rail transit (HRT) network must be continuous and grade separated, and it should be laid out to secure the highest possible level of service in major corridors in order to compensate for the need for a higher level of feeder service and a greater proportion of transfers than a bus or light-rail transit (LRT) network. Incidentally, although the term light rail often gives rise to explanatory contortions that seek to link the term to car or rail weights, it is a contraction of the term light railway, which probably originated in Britain where it is used to describe a railway constructed under the provisions of the Light Railways Act. The purpose of this act was to encourage the construction of railways early in this century in areas that could not justify the expense of building a railway to the rigorous standards of the time. A light railway was permitted to use ungated crossings and unfenced right-of-way, to operate without full signal protection, and to run in street right-of-way. Light railways could be built under a simple Light Railway Order and so did not require an expensive Act of Parliament. Staffing requirements and operating rules were less strict, and speed restrictions were imposed on unprotected right-of-way. The first light railways were powered by both steam and electricity and included some high-quality streetcar lines. Although the term still has a legal meaning in Britain, it has also come to refer to the form of transit now more generally known as LRT; it has no more literal meaning than does the analogous term highway.

While great attention has recently been focused on the technology and operating characteristics of LRT, much less has been given to the planning of test network configurations that make best use of this mode. If alternative rapid transit modes are compared on almost identical test networks, the result is not an evaluation of alternate modes but only of the alternate vehicle systems. Some communities have considered LRT for specific corridors as alternatives to freeway construction or a means of establishing transit networks in existing urban freeway or railroad corridors without considering other right-of-way options. By making such alignment decisions prematurely, the community may foreclose the opportunity to develop a logical and effective network before it has even been considered.

It is widely held that the need for urban transit will continue to grow in the years ahead. At the same time, there is concern that, unless we can become proficient at planning and constructing less costly transit facilities, rail transit will be very largely confined to a few major corridors in the largest cities. By contrast more than 50 cities in Western Europe now have rail transit, mostly LRT.

A major attraction of LRT is its potential to extend the range of rail transit to communities or corridors in which a more costly transit mode is not warranted but, while LRT may be less costly to construct, it is not easier to plan. The complexity of its conceptual design can rival or even exceed that of a fully grade-separated transit system since a great variety of right-of-way treatment is possible for individual segments and it entails a need to interact with a broad spectrum of professionals, all of whom must understand the characteristics of LRT. LRT is a relatively new transit concept, the best examples of which are still overseas; few can therefore yet claim either academic or direct experience with modern applications of the mode.

In addition to widespread unfamiliarity with the mode, there are the lack of promotional efforts like that mounted by the developers of proprietary modes, negative residual memories of streetcars in this country, and the desire to build big. This latter phenomenon, sometimes called the edifice complex, focuses on building the largest project fundable rather than matching the technical solution to the scale of a problem; it was particularly noticeable in the 1960s in Europe when a number of medium-sized cities (Bielfeld, Ludwigshafen, Nurnberg, Rotterdam) planned HRT in medium-demand corridors. In the new economic realities of the 1970s, some cities dropped these plans (Bielfeld and Ludwigshafen), while others curtailed their programs (Nurnberg and Rotterdam) to completion of segments already committed.

IDENTIFICATION OF OBJECTIVES

The first stage in developing an effective fixed-guideway network is to define the benefits expected from the investment. This enables the planner to seek a network that is focused on obtaining particular objectives rather than to respond to seductive right-of-way opportunities. Developing a fixed-guideway transit network is not an end in itself but rather the means to achieve certain transportation-related community goals. Although these goals will differ for specific communities, they will generally include many of the following:

1. To capture a larger share of the total transportation market,
2. To provide a better opportunity to hold the line on transit operating costs (compared with an all-bus system),
3. To reduce the need for automobile travel and the construction of new highway facilities,
4. To reduce the potential negative economic and social impacts of automobile disincentive measures,
5. To establish an infrastructure to guide future planning and land-use decisions,
6. To support national fuel conservation and environmental goals,
7. To provide increased capacity on the existing street system (compared with all-bus use or mixed bus and automobile use), and
8. To develop a transit infrastructure that can function effectively in a range of future energy and transportation situations.

NETWORK PLANNING CONSIDERATIONS

An understanding of the basic concepts that influence the planning of LRT networks can save much time and lead to a more effective planning process. Some of these concepts address right-of-way treatments, while others are more concerned with alignment selection. Some are valid for any fixed-guideway transit mode, while others are applicable primarily to LRT. Above all, each urban area is unique, so that there is no universally applicable approach, and a concept that is of primary significance in one place may be irrelevant in another. The rest of this section outlines some major network design considerations and discusses their application, pro-

Figure 1. Relationship between stop spacing and operating speed.

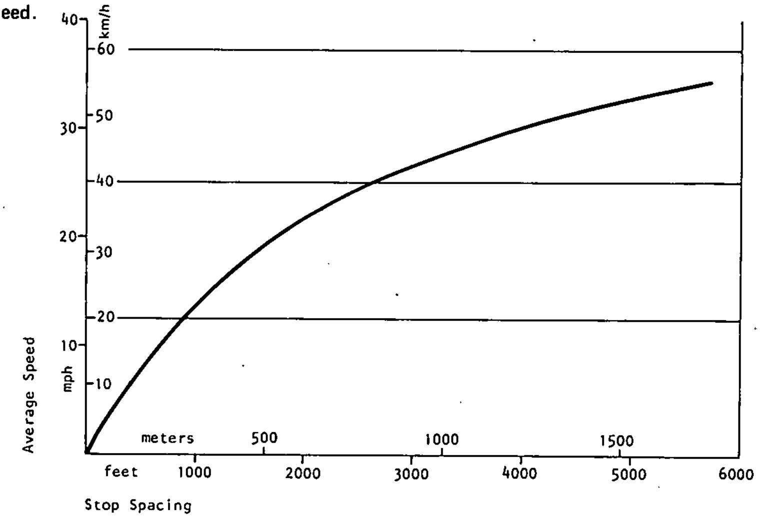
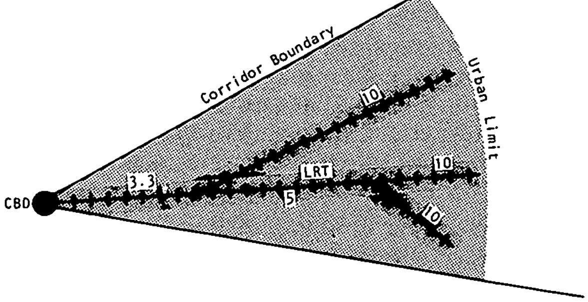


Figure 2. An example of the use of branching to serve a sector corridor, showing average headways in minutes.



viding examples. Wherever possible, recent examples have been selected since these tend to illustrate the application of planning theory in a contemporary context.

General Network Guidelines

Stop Spacing

On any guideway system with on-line stations, the maximum possible operating speed is governed by the spacing of stops and, to a lesser extent, by dwell time and vehicle performance capability. This is true regardless of mode. In downtown San Francisco, the San Francisco Municipal Railway's LRT subway will have operating speeds similar to those on the parallel lines of the Bay Area Rapid Transit System that have stops at the same stations. It follows that lines that are regional in nature should have fewer stops in order to avoid excessive travel time. This, however, requires greater walking time to reach ultimate destinations or more frequent transfer to feeder services. Most large metropolitan areas in Europe solve this conflict with a two-tier rail system. Regional transit is provided by a suburban railroad system, while LRT or HRT provides a service with more frequent stops in the denser central area.

A few cities in the United States (Boston, New York, and Philadelphia) have similar two-tier rail systems but, in major metropolitan areas in which these do not exist, the temptation to provide both types of service with a single system should be resisted lest the result fail to provide either local or regional travel in a satisfactory manner. Rail may be suitable for regional travel, local travel, or both. If, for example, loading on the regional transit links is lighter and more diffused than the local demand, then the rail transit should be targeted for local service, e.g., up to 16 km (10 miles), while the second tier is provided by a freeway-oriented bus system that serves the longer, less heavily used express links.

Figure 1 illustrates the relationship between stop spacing and average speed calculated for the Boeing Vertol light-rail vehicle (LRV). Since LRVs may need to make additional stops on surface sections because of other traffic, this will increase travel time. Figure 1 is based on a vehicle that has a maximum speed of 80 km/h (50 mph), acceleration of 1.25 m/s^2 (4.1 ft/s^2), deceleration of 1.57 m/s^2 (5.1 ft/s^2), and a dwell time of 20 s.

Access Time

Accessibility to stations plays a significant role in the convenience and hence the use of a transit system. Each rider must have access to the system twice (to and from stations) on every trip. The trip made by a rider through the system thus has different characteristics than a trip made by the transit vehicle. High speed by the latter is useful to the rider only if it can be achieved without incurring increased access time. Yet high operating speed requires widely spaced stations, for the reason outlined in the previous section; although this station spacing may lead to faster train speeds, it may actually lower the average rider's speed by increasing the access time. A recent study of the Bloor line in Toronto (1) shows that riders with between-station origins and destinations experienced an increase in average trip time for trips of up to 8 km (5 miles) when the subway replaced surface streetcars, despite the fact that the average train speed was more than twice the speed of the streetcar in mixed traffic. Even for origins and destinations at stations, the streetcar had, on average, been faster for trips of up to 3.2 km (2 miles) because of the increased headway and station access time required by the subway. Access time can thus play a major role in transit planning that is easily overlooked; this can lead in turn to less than optimal route design (2).

Difference Between Freeway and Transit Networks

Freeway and transit networks generally have different basic characteristics. Freeway networks are primarily designed to avoid major trip generators; they pass instead relatively close to them and rely on the surface street network for collection and distribution. Freeways are almost never constructed through a central business district (CBD), since they can serve it with less disruption by passing close to it. An effective transit network, however, must serve pedestrian destinations; to do otherwise requires feeder service, which increases trip time and operating cost. Effective transit systems must penetrate within walking distance of major trip generators.

A further difference between freeway and transit networks is that freeway networks tend to have strong circumferential as well as radial links. A freeway network that was primarily radial would experience enormous traffic concentrations at its focal point. By contrast, a transit network tends to have a strongly radial form with weaker circumferentials. On a well-planned transit system, the absence of strong circumferential routes is not very important because most circumferential trips can be made on radial lines, while radial trips can seldom be made on circumferential lines.

Connectivity

An important consideration in any transit system is the connectivity among the lines. Ideally, every rapid transit line should connect with every other rapid transit line, so that any trip through the system can be made with only one transfer. This goal is facilitated by constructing through lines rather than lines that turn back in the central city. Networks that have through lines avoid the need for turnback and layover facilities in the central area and are simpler from the user's point of view. The efficient application of through routing requires the interconnection of radial lines that have approximately equal demand (train size and headway).

LRT Network Guidelines

LRT is unique among fixed-guideway modes in that the designer may vary the right-of-way treatment (and hence its cost) to attain an appropriate service standard for individual segments of a network. The effective exploitation of this versatility is the key to LRT network design.

Branching

Most transportation corridors in a city are shaped approximately like a slice of pie. The apex of the sector is in the CBD but the corridor gets wider the further it is from the center. To provide transit coverage throughout the sector, the transit network must match the sector shape; this requires branches (Figure 2). Not only can LRT lines be readily branched, but the quality of construction and hence the cost of the individual branches can be made less than that of the main line in response to the anticipated patronage.

This is a fundamental LRT design concept since it provides a technique for optimizing the level of investment, segment by segment, systemwide. Multiple branching is characteristic of most well-developed LRT networks, including Boston and San Francisco. These systems also demonstrate the technique of varying investment on a segment-by-segment basis. The number of branches is limited by headway constraints and can seldom exceed five. New construction in Europe in Hannover, Braunschweig, Karlsruhe, Rotterdam, and Utrecht illustrates the contemporary application of branching (Figure 3).

Service Level

A related concept is the matching of service to patronage demand. This is achieved both by branching and by turning part of the service short of the outer terminus of a line. Figure 4, originally prepared for another report (3), illustrates how Karlsruhe matches service to demand by using both branching and short turns. Most LRT systems exhibit similar characteristics.

CBD Options

A number of network alternatives are available for the CBD, including grade-separated lines in subways or on elevated alignments and lines that operate in transit lanes on the street or on pedestrian malls. The use of design concepts similar to those now being tried for bus lanes in many U.S. cities permits the application of a variety of on-street options. The use of a contraflow LRT lane on a one-way street can simplify property access by permitting automobiles to make left turns into driveways. It can also simplify the development of a traffic-signal progression to favor transit.

Overall line length or average trip length may provide an indicator as to whether a line should be grade separated. If a line is long, grade separation may permit a significant saving in trip time. The freedom from interference from other traffic tends to increase the reliability of grade-separated lines. This is a particularly important consideration in networks that do not have emergency detour routes.

On the other hand, surface facilities in the CBD are less costly to build. They also offer greater accessibility by providing simpler, more frequent stations. A surface alignment can be expanded more readily to increase CBD coverage or system capacity. For short LRT lines, e.g., less than 10 km (6 miles), the lower speed of surface operation is not likely to be of primary concern since even the longest trip will be of short duration. Most medium-sized European systems do not plan grade separation in the CBD. Good examples include Bremen, Braunschweig, Mannheim, and Zurich.

Capacity Limitations

One of the potential limitations of LRT is that, in heavy-demand corridors or under conditions of future growth, key links in the network may become overloaded. The patronage level at which this could occur is often assumed to be 20 000 or more in the peak hour, the exact number depending on mode of operation and acceptable level of crowding.

One solution to this problem is to plan for conversion to HRT, as was done in Brussels and was once planned in several other cities. This upgrades line capacity at the cost of severing direct connection with the LRT surface lines. In Brussels the conversion of pre-metro Line 1 changed an LRT subway with five surface branches into a heavy-rail subway with two branches, greatly increasing the use of transfers. Since, as discussed earlier, speed is not a direct function of mode, travel time for many riders would have been less if the line had been upgraded with improvements on the street segments and larger cars had been used to increase capacity.

The significance of this has not been lost on European planners. The other pre-metro lines in Brussels will not be converted to metro, and they are now being equipped with new large LRVs. Early in 1977, it was decided to change the plan for the second line of Rotterdam's Metro to a semi-metro LRT line, even though construction had started. The saving in cost was suffi-

Figure 3. Use of branching on new LRT lines.

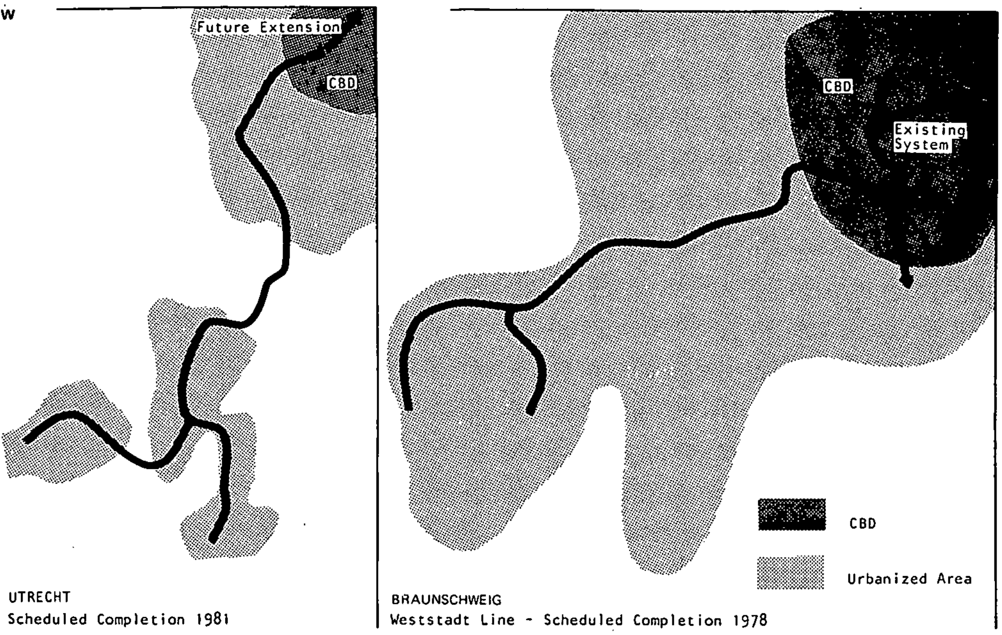
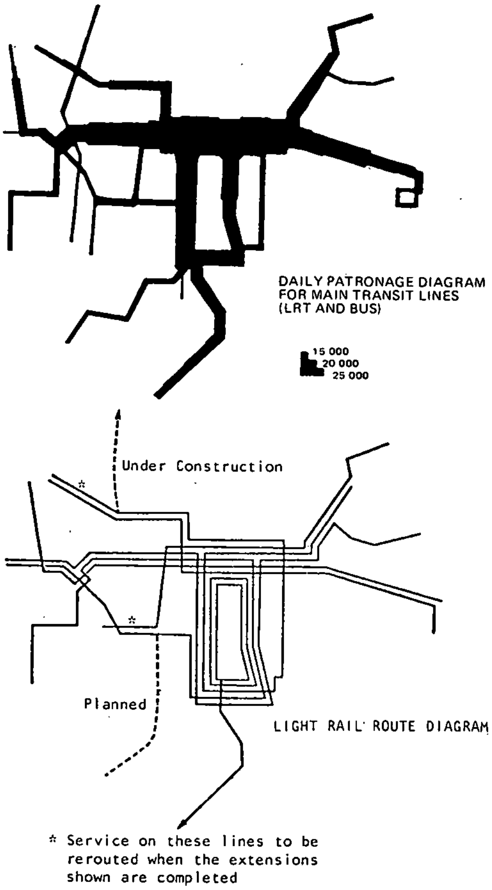


Figure 4. Balancing service and patronage: the Karlsruhe transit system.



cient to pay for an additional segment of tunnel at the west end to connect it to an existing LRT line. The change will also simplify the construction of several future suburban branches and give better coverage than the proposed metro project (Figure 5). In Germany, the pre-metro concept adopted by several cities (Stuttgart, Cologne, Dusseldorf, Bielfeld, Essen) has receded into the indefinite future, superseded by more immediate and less costly improvement concepts.

However, the capacity problem can also be approached as an opportunity. By building a duplicate section to relieve the overloaded segment, excessive concentration in a single corridor can be avoided, coverage in the CBD can be increased, and each line can function as a distributor to the other, thus providing "people-mover" circulation in the CBD as well as the line-haul function. The use of multiple LRT subways in the CBD is best illustrated by the Hannover system. The long-range plan calls for four LRT subways and one surface LRT line in the CBD. Through the use of branching, this system will ultimately serve no fewer than 16 radial lines (Figure 6).

An additional consideration, particularly for a surface alignment, is its ability to function in the event of an accident or other service interruption. On a multiline system, alternative routing may be possible. Generally the provision of additional turnback facilities and a short response time for emergency services is the most economical treatment for such situations. Bus substitution is also occasionally an effective measure.

Operating Economy

A major reason for establishing a fixed-guideway transit network is to reduce the rising operating cost of an all-bus system. The implication for the network designer is to seek to replace as many bus kilometers as possible with the minimum of LRV kilometers. In Edmonton, the northeast line will replace some 37 buses with 14 LRVs. A recent line extension in Karlsruhe added a branch to the LRT network that, by adroit operational changes, replaced 6 buses without the need for any additional LRVs (Figure 7).

Replacing close-headway buses with less frequent LRVs reduces bunching and improves the reliability of the transit service. At longer headways (more than 10 min), the potential disadvantage of the lower frequency should be compensated by regular and reliable schedules and timed connections with feeder services.

Opportunity Alignments

Opportunity alignments are those in which LRT can be readily implemented, usually because of an available right-of-way. Opportunity alignments often do permit economical construction of an LRT line, but this fact must never be allowed to substitute for a critical appraisal of the service value of each segment. In some cases the use of an obviously suitable alignment for LRT has been proposed almost as an end in itself rather than

Figure 5. Evolution of Rotterdam's Metro Line 2 to semi-metro status.

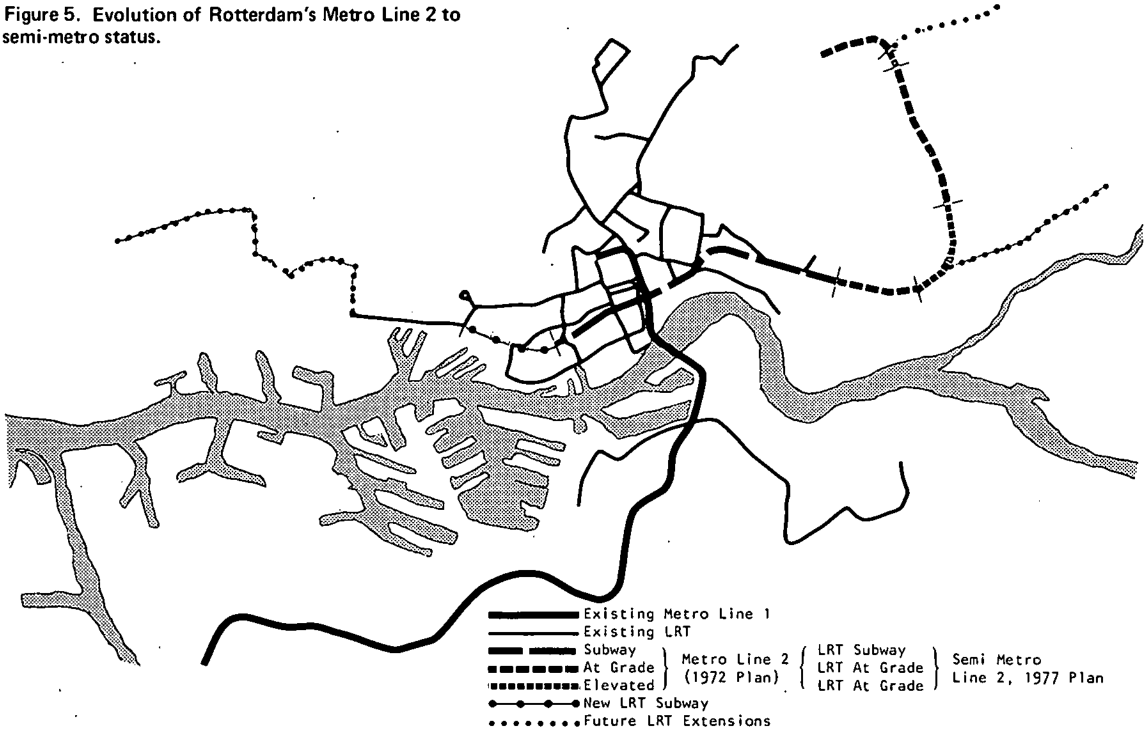
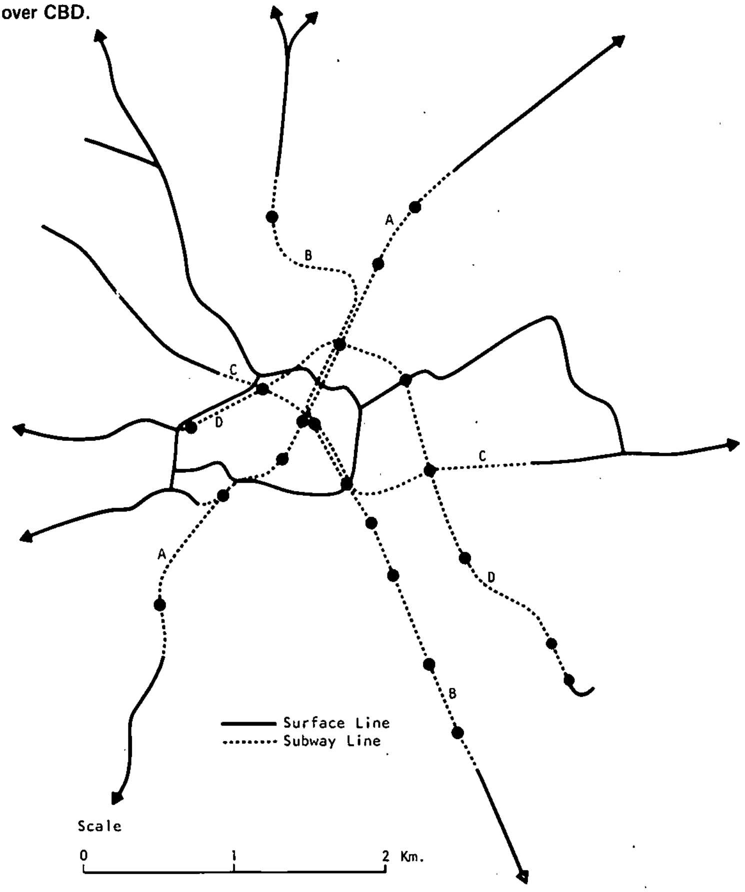


Figure 6. Planned LRT network for the Hannover CBD.



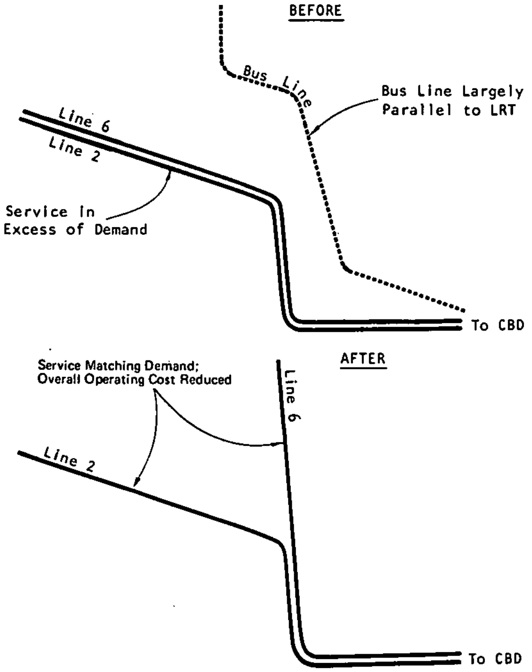


Figure 7. Extension of LRT line to replace feeder bus in Karlsruhe.

as the means to achieve a transportation goal. Other LRT proposals have been stated as a direct substitution: 10 km of LRT to replace a proposed 10-km freeway. Such proposals can seldom stand up under detailed analysis unless a wider perspective is considered.

It is an unfortunate characteristic of many opportunity alignments that they do not serve the places the transit system should serve. For instance, railroad alignments are often not well located within the corridor they are intended to serve since recent development has not been influenced by the railroads. Freeway alignments are often worse, since the characteristics of a freeway network, as discussed earlier, are different from those of a rapid transit network. Generally, freeways also occupy the corridors in which the existing highway network is least deficient (and hence show less need for transit investment). Opportunity alignments should therefore be considered cautiously and used only when they are well located.

Lack of negative impacts can never, of itself, be a valid network determinant. One common but often overlooked opportunity alignment is that of the old arterial streets frequently found in large cities that are now bypassed by the construction of freeways. These streets were often widened to increase their capacity prior to the construction of the freeway system to which their traffic was largely diverted. These arterial streets frequently penetrate the heart of the corridor and serve many of the major trip generators. By using appropriate deployment of right-of-way treatments, such streets can provide a favorable setting for an LRT median with little traffic or community disruption and considerable service potential.

Design Versatility

The problem of fitting LRT to an existing urban environment calls for great design versatility. Localized widening of a right-of-way to permit a station or the moving of houses to increase their setbacks are two techniques of potential value on major arterial streets.

The designer should not be hesitant to vary the right-of-way treatment when necessary to achieve network objectives, such as penetrating major trip generators or passing through a bottleneck, that are attainable in no other way. For instance, if the only affordable way to penetrate a community center is to operate on a street, then short sections of streetcar track should be constructed that incorporate traffic engineering measures designed to ensure its reliable and safe operation. Likewise, streetcar operation over a major bridge may be feasible when the alternative of constructing a new alignment would render the entire line unfeasible.

Selection of an Appropriate Level of LRT Technology

LRT can be developed at a variety of levels of sophistication. Many of the reports from Europe come from the handful of cities that have developed forms of LRT that have enhanced its complexity but not necessarily enhanced performance or economy.

It should be incumbent on designers to adopt the most basic form of LRT that is adequate for their particular application and meets their design goals. High-low platforms, double-ended cars, high speeds, and elaborate controls may sometimes be appropriate, but they may also prove an unwarranted expense, as Kudlick and Minister note in their paper elsewhere in this Report.

Exploiting At-Grade Capability

The capability to operate at grade is central to the LRT concept. At-grade operation is usually considered a disadvantage and, if poorly exploited, may be just that. The benefits must be understood to be realized. There is a clear design dilemma. Some LRT systems in Europe, as in the United States, are moving toward increased or total grade separation. Others, equally advanced technically, are not. Essentially the choice requires a judgmental approach, and there is as yet an insufficient body of experience to reach a generally applicable conclusion.

For the operator, at-grade operation is always inferior. It may decrease reliability and speed and sometimes causes accidents. For transit, as for highways, grade separation leads to operational improvement.

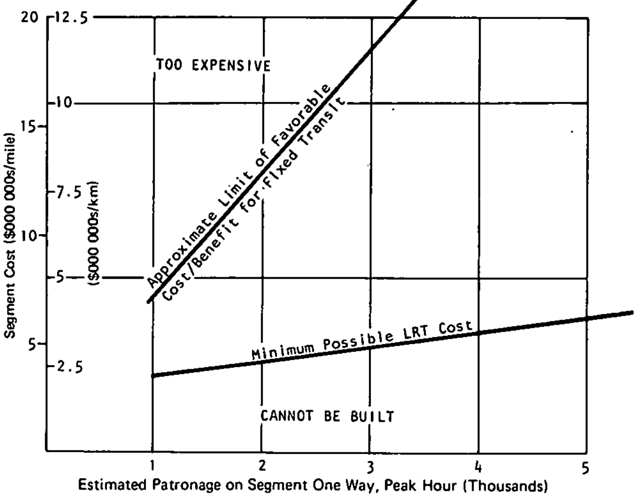
For the transit planner, there are other considerations. At-grade operation permits the use of right-of-way that would not otherwise be available. It increases accessibility, changes impacts, and can make a transit line feasible that would otherwise be too costly. Certain specific treatments, such as redeveloping a run-down street as a boulevard with an LRT median or constructing an LRT and pedestrian mall, may even be better urban design treatments than a subway alternative.

For the passenger, grade separation offers a higher quality of service in terms of speed and reliability, but at the expense of increased station access time and a smaller affordable network. Which is preferable can be decided only on a case-by-case basis by considering demand, local conditions, and right-of-way options available.

TUNED NETWORK

LRT is unique among fixed-guideway transit modes in that the designer has the ability to vary the right-of-way treatment (and hence its costs) from segment to segment of the network. The effective exploitation of this versatility is basic to LRT network design. A network in which line construction costs, service levels, and patronage are proportionately matched could be described

Figure 8. Relationship between construction cost and patronage.



as a tuned network. A tuned network would exhibit most of the following features:

1. High level of regional coverage with minimum dependence on feeder buses;
2. Investment in line segments that is proportionate to estimated patronage on a segment-by-segment basis;
3. Service levels that are responsive to patronage demand on a segment-by-segment basis, which is achieved by branching or short turns; and
4. A CBD configuration that is appropriate to the extent and loading of the network and is designed to avoid overloaded links and to function in the event of a link failure, if it is on the surface.

Although real-life constraints seldom permit the design of exactly such a network, this concept can be perceived in many existing LRT systems (e.g., Karlsruhe, as shown in Figure 4). Figure 8 illustrates the relationship between the limits of construction cost and patronage for a tuned network.

FUTURE OPTIONS

One of the few certainties in transit planning is the uncertainty surrounding transportation needs for more than a few years ahead. Consider the change in attitude toward public transportation over the past decade. One prudent response to such changes is to avoid foreclosing future options. The capability inherent in LRT to use a variety of rights-of-way, to use low-cost branches, and to respond to increased capacity needs is consistent with such a goal. It should also be noted that the direct-current electrically powered steel wheel and the steel-rail mode, now in use for more than 80 years, have proved remarkably adaptable to technical evolution and are still compatible with almost any existing or experimental train-control or power conditioning technique.

COMPATIBILITY OF RAIL MODES

The rail transit modes from streetcar to HRT have the capability to be made compatible with each other, a capability that is seldom exploited (4). In Cleveland, the LRT lines share tracks with the HRT system over part of their length; the converse is not technically possible since HRT trains cannot be safely operated on at-grade LRT segments.

The new Rhein-Ruhr system in Germany goes one step further by using identical equipment on the grade-separated and at-grade lines. This system will eventually consist of some 300 km (190 miles) of rail transit. The regional lines, between urban centers, will be largely grade separated, since high speed is required. The local lines will use the new subways in the central areas but operate on the surface elsewhere. Thus the subways will achieve higher utilization than would occur with only regional service, and the local lines will function as semi-metro operations, which would not be warranted for local service alone.

The idea of technically compatible LRT and HRT is a powerful concept of potentially great relevance in large metropolitan areas such as Los Angeles. It has inherent flexibility to respond to a range of future options; this is an idea worthy of greater attention.

CONCLUSIONS

During the last decade, interest in LRT has developed rapidly. The changed horizon of transit planning and the growing awareness of limited energy and other capital resources are forcing a search for more effective means of serving urban travel. Effectively deployed, LRT can meet that need. The effectiveness of LRT planning is dependent in large part on developing test networks that apply the mode in a manner that is appropriate to the particular application. The concepts discussed in this paper are intended to provide guidelines for achieving this goal and thereby to lessen the effort invested in studying deficient networks.

REFERENCES

1. D. N. Dewees. Some Effects of Conversion From Streetcar to Subway Transit Lines in Toronto. Centre for Urban and Community Studies and Department of Political Economy, Univ. of Toronto, Jan. 1976.
2. F. Bandi and others. Length of Walking Distances and Distance Between Stops: Their Influence on the Attractiveness of Public Transport. UITP Revue, Vol. 23, No. 3, March 1974, pp. 175-181.
3. E. S. Diamant and others. Light Rail Transit: State-of-the-Art Review. Urban Mass Transportation Administration, U.S. Department of Transportation; NTIS, Springfield, Va., PB 256 821, Spring 1976.
4. V. R. Vuchic, F. B. Day, and R. M. Stanger. Rail Transit: Characteristics, Innovations, and Trends. TRB, Transportation Research Record 552, 1975, pp. 1-18.