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Light Rail Transit Surface Options

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Abstract

Current interest in Light Rail Transit (LRT) is anchored in its functional and economic capabilities which derive from operations at surface street level. European cities have shown that light rail can be successfully co-located with growing automobile traffic. There are no unique forms and approaches to LRT surface operations. European experts have come up with a range of design concepts of varying cost and differing impacts on adjoining vehicular and pedestrian movements. This report reviews and illustrates the applications of many of the more successfully used design and operational concepts. Topics include design concepts using man-made or vegetation barriers to separate traffic and means to delineate and separate movements with contrasting pavement textures and curbs. Considerable coverage is given to use of modern signalized traffic control and traffic management techniques. This report also deals with an essential element of LRT surface operations, self-service or barrier-free fare collection.

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Author(s)

E S. Diamant, L. A. Dondanville, J. F. Hall, W. H. Korve, R. T. Sauve, G. S. Shunk, T. J. Stone, and Vukan R. Vuchic

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LIGHT RAIL TRANSIT

Surface Operations

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Chapter 1

INTRODUCTION

Light Rail Transit (LRT) is, basically, a surface mode of transportation. Although some of the recent installations in North America and western Europe feature grade separated segments, the interest in LRT is anchored in its functional and economic capabilities which derive from operations on the surface.

For many years a view has prevailed, mainly in Europe, that these capabilities outweigh the disadvantages of surface rail in cities and that LRT is worth preserving as a major urban transit mode. This view has been bolstered by the success of innovative route and traffic designs in many European cities which showed that light rail could be successfully, and to some extent painlessly, colocated with growing automobile traffic.

To the many North American observers who were learning about light rail first-hand in their visits to western Europe, another factor eventually became apparent. There were no unique forms and approaches to LRT on-surface operations. Not only were there as many ways to design an LRT route as there were available rights-of-way, but within each kind of right-of-way, the European transit experts had come up with a range of design concepts of varying cost and different impacts on adjoining vehicular and pedestrian movements. It was also evident that the European transition from the prewar streetcars to the modern LRT had

been gradual and pragmatic. There were few, if any, abrupt changes requiring dislocation of traffic or pedestrian movements and little, if any, period of public adjustment to the relatively new mode. Even where LRT was preserved at the expense of drastic grade separated reconfigurations such as at Cologne and Dusseldorf (see the Appendix to this report), the changes were local and costly, to be sure, but not necessarily traumatic.

The prevailing view of LRT in North America has been, of course, different. While it is generally acknowledged that LRT may be a competitive modal choice, and even an attractive one given the right environmental circumstances, there has been little agreement on what sector of transit needs it can best serve or on what actual cost it might entail. For the great majority of North American cities, LRT would be an entirely new transit mode, which would be perceived as an ancestor to the streetcar systems which had been removed from the urban scene decades ago. In this environment, the benefits of LRT surface operations are often discounted and the impacts overstated. In one way or another, each American city that takes transit seriously will deal with LRT on the basis of perceptions and analysis in which design for surface operations will be the predominant issue. For the most part, the pioneering LRT design efforts in North America will rely on the European experience. To be sure, ingenuity and compelling needs to fit the new mode to local constraints may in time lead to new design concepts. Meanwhile, developing the planners' awareness of current design practice is the important first step from which will follow the rational assessment of

LRT opportunities and costs. To help in the awareness-building process, this report deals exclusively with design and operational LRT practice, discusses design principles, and illustrates with examples the basic design concepts of LRT surface operations.

The reader will find that four topics dominate the discussion of LRT surface operations:

1. How to safely and selectively prevent adjoining vehicular traffic from sharing the LRT right-of-way with minimum impact on the operations of either mode.
2. How to safely prevent pedestrians from deliberately or inadvertently entering the LRT right-of-way.
3. How to isolate crossing and cross-turning motor vehicles from light rail vehicles at intersections and crossings where the two modes must share the same right-of-way.
4. How to adapt new concepts of fare collection to LRT operational characteristics so that its overall economic efficiency may remain high.

It should be obvious that in theory the pedestrian and vehicular conflicts could be controlled partly by legislation as well as by design. For instance, one may make it illegal for pedestrians to traverse LRT

tracks except at marked crossings; vehicles may be legally prohibited from running on the LRT tracks; and the speeds of LRT may be set so low as to preclude almost all possible LRT/motor vehicle accidents. New and sweeping legal restrictions on vehicular and pedestrian movements are difficult to enact and even more difficult to consistently enforce. In practice, therefore, the conflicts must be avoided and controlled by the application of proven design and operational principles, some of which are discussed in this report. It is not argued here that the design makes the law unnecessary. Rather, the mutual objectives of safety and enhanced operations can be met by applying design and operational principles which for the most part are supported by existing traffic control laws.

Accordingly, this report reviews and illustrates the application of many of the more successfully used design and operational concepts. The topics include:

- Use of manmade or vegetation barriers to separate vehicular traffic. The barriers need not always be massive and visually offensive (i.e., railroad crossing gates). Subtle means, such as pavement painting, texturizing or curbing, can also be used to delineate and separate vehicular and pedestrian movements.

- Use of modern signalized traffic control and traffic management techniques to safely separate conflicting LRT and motor vehicle traffic. The approaches need not always be as drastic as the closure of cross streets. More subtle and more equitable means, such as geometric channelization of traffic and synchronization of LRT movements with prevailing signal cycles, can also be used to attain fairly high speed and high frequency LRT operation with minimal impact on the speed and congestion of adjoining traffic.

Ultimately, the LRT surface operation issue will resolve on the answers to two questions.

- What level of service and safety can be achieved on the LRT tracks and the adjoining streets through the application of these design principles?
- To what degree can the light rail transit vehicles be favored over the automobiles through the provision of priority treatments before the local jurisdictions, and indeed the general public, perceive that the delays to automobile users are excessive?

The answers to these questions are difficult to generalize since they depend on local street geometrics, traffic volumes, light rail line characteristics and individual values. However, some fairly broad design guidelines are presented in this report. Since generalizations are difficult, and probably meaningless for the purpose of this report, the design solutions are developed for a series of prototypical urban settings which could accommodate new LRT lines. The cases selected for illustration include: a line with right-of-way located in a preexisting arterial median, a line in a street which would require taking some right-of-way from existing traffic lanes and parking areas, a line crossing a street at a midblock location, a line operating in mixed traffic, a line in a pedestrian mall, and a line operating in a contra-flow direction with adjoining traffic.

The techniques used in solving the locational and operational design problems include geometric changes, development of pedestrian crossings, parking zone restructuring, and traffic lane redesign. Estimates of

volume to capacity ratios are used to indicate the changes in congestion or delay to motor vehicles that can be expected to arise as a result of making such physical and operational changes. Traffic volumes and LRT operational details (speed, headway, train size) are handled parametrically. From the point of view of traffic impacts, the analysis is limited to a "worst case" situation which would result from the introduction of a preemptive traffic control strategy. The analysis shows clearly and quite conservatively the range of parameters within which surface operations may be found feasible. The primary feasibility criterion used is that traffic volume to capacity ratios should be maintained at levels acceptable to the community wherever possible. It is important to note that this criterion is not applicable equally to all communities. To be sure, transit-oriented communities would tend to support measures which favor transit vehicle progression rather than smooth traffic progression. The actual level of traffic congestion which would be tolerated is open to question. The guidelines given in the design examples assume typical attitudes would prevail.

The last topic of this report deals with an essential element of LRT surface operations, self-service or barrier-free fare collection. The technique avoids the need for costly control of passenger access to vehicles through gates or turnstiles. It makes possible the use of low cost stations. It makes possible the operation of a high capacity light rail vehicle (LRV) with only one operator, thus eliminating the time-consuming and economic-efficiency-defeating procedure of fare collection

by vehicle operators. The true economic consequences of self-service fare collection as applied to American transit systems have only recently been considered, and the institutional implications are still not fully explored. Yet, the technique is shown to be the basis of economic viability of any large-scale LRT installation. Accordingly, the report reviews some of the factors affecting its implementation. The technique's economic impacts are also discussed.

A final word on the production of this report is in order. The work resulted from the efforts of a number of investigators. Their contributions are identified with each chapter. Three of the contributors, Messrs. Diamant, Fox, and Vuchic, also spent much time researching the various operating and design practices of several American and European LRT systems.



Chapter 2

DESIGN CONCEPTS FOR LRT SURFACE OPERATIONS*

INTRODUCTION

LRT is the only guided transit mode which operates on streets jointly with automobile traffic. This capability is extremely valuable since it allows use of available or inexpensive right-of-way (ROW) for surface operations in modern, high performance transit networks. There is a direct correlation between the attractiveness of LRT and the extent to which high performance is achievable in at-grade operations. Where the level of performance is too severely limited by conflicts with auto and pedestrian traffic, rerouting to a less sensitive area can be considered. In extreme cases, grade separation may be warranted. However, as an increasing proportion of LRT lines become physically separated from motor vehicles, the cost and operational characteristics of LRT begin to more closely resemble those of conventional rail transit.

*The material for this chapter was furnished primarily by Dr. V.R. Vuchic and Messrs. H. Korve and R. Sauve.

Consequently, the most important consideration in the layout of surface LRT lines is reducing the impact of potentially conflicting transit, automobile, and pedestrian movements. The possibility of conflict arises at intersections and at other points on the line where the likelihood exists that the LRT route might be shared with automobiles or pedestrians. Conflicts can, at best, lead to a slowdown of LRT operations and, at worst, to accidents. Recognition that conflicts are inherent in shared roadways and a determination of ways to resolve those conflicts are, therefore, crucial LRT design issues.

Modern LRT design practice combines the latest techniques in urban roadway design, traffic control, and operation of rail vehicles, and as a result, LRT lines can in many cases provide service comparable in speed and quality to higher cost rail rapid systems. Where conditions permit surface operations, this can be done with minimum impact on motor vehicle and pedestrian traffic, e.g., on street medians in roadways and on entirely private rights-of-way in newly built areas.

The proportion of an LRT line upon which surface movements can be accommodated with minimum impact depends directly upon the traffic characteristics of the adjoining and crossing streets. Traffic volumes, street geometrics, and surrounding land uses are all important to technical decisions regarding which LRT route segments do not require grade separation. Ultimately, these decisions rest with the responsible

agencies and concerned public groups, but it is important to understand conditions which lead to conflict in movements, to identify strategies which resolve conflict, and to quantitatively articulate the residual impacts of those strategies.

In extreme cases, full separation of rail vehicles from conflicting automobile and pedestrian movements might be required. This could result in better performance characterized by higher speed, increased reliability, and greater safety. For example, conditions sometimes dictate that LRT be operated like rapid transit in tunnels within central business districts in cities such as Bonn, Cologne, Mannheim, and ^{Hannover} ~~Hamburg~~, West Germany. However, in most cases of LRT design, the high performance objective may be relaxed and the route may be located in a separated right-of-way such as street medians. In the extreme, light rail still could operate within automobile traffic lanes in mixed traffic (street running), if it could be shown that cost advantages outweigh the implementation disadvantages. The extreme case of street running is possible on short sections of lightly traveled streets where friction with other traffic is not serious or in pedestrian malls where conflicts with pedestrian movements can be controlled.

In this chapter, key design and operational concepts of LRT lines are reviewed, with emphasis on geometric and traffic control treatments at intersections and other crossings. To some extent, reference is made to

German design practice because it provides an enlightening point of departure for the still developing U.S. design methodology for surface LRT lines. In more specific terms, vehicle conflicts along LRT lines and at stations are examined; methods to eliminate and/or control these conflicts are discussed; and safety aspects are evaluated. Various intersection and midblock crossing control strategies are reviewed, including traffic signal control, both with and without preferential treatment, as well as the use of railroad gates and flashing signals. Requirements for pedestrian crossings are examined, safety hazards identified, and mitigating measures proposed.

DESIGN OF SURFACE LRT LINES IN MIDBLOCK LOCATIONS

In the following paragraphs, the range of locations and design treatments for LRT lines within street and highway rights-of-way at midblock locations away from street intersections and other crossings is summarized in sequence, from the simplest designs with minimum acceptable dimensions to those with more desirable cross-sectional widths. Those of minimum width are used under restricted conditions. Wider cross-sections provide for higher performance and are more desirable where suitable conditions exist.

Friction and conflicts exist along any roadway to varying degrees for any mix of motor vehicles, pedestrians, and light rail vehicles. Along the LRT route, and away from intersections and other crossings, it is

necessary to place the design emphasis on minimizing the conflicts that could occur when locating the LRT ROW within the road geometry, by physically separating passing traffic streams through geometric, landscape, or textural design of the road, and by controlling pedestrian movements.

Surface LRT lines often may be located within street rights-of-way, sharing automobile traffic lanes or adjoining traffic or parking lanes. Alternative locations include:

- . Streets where automobile traffic has been removed to create pedestrian malls;
- . Central locations in mixed traffic flow, sharing two lanes with other traffic;
- . Central locations on exclusive medians;
- . Lateral locations operating symmetrically in two directions; and
- . Lateral locations operating asymmetrically in one direction.

Each of these alternatives is discussed on the pages that follow.

LRT in Pedestrian Malls

Pedestrian malls with LRT are being introduced in an increasing number of west European cities. Malls have been successfully introduced in Munich, Zurich, Mannheim, Amsterdam, and Dortmund, and are also being implemented or considered for some U.S. installations such as Portland, Oregon, and Buffalo, New York.

The response to LRT operations in malls has been positive, since passengers are conveyed as close as possible to their destinations. Pedestrians wait at stops in a hospitable, relatively safe environment, usually close to the entrances of major stores, pedestrian concourses, and restaurants.

The safety record for these facilities has been excellent. In the United States until quite recently, the design emphasis has been on pedestrian/busway malls. The Minneapolis Nicollet Avenue, Philadelphia Chestnut Street, and Portland, Oregon malls are good examples of major improvements over former conditions. However, concerns have been voiced elsewhere regarding safety, noise, and emissions problems associated with the buses.

Undoubtedly, some of the concerns could be allayed through strict enforcement of traffic and environmental laws. In European cities which have adopted pedestrian/LRT malls, a less favorable view is taken of bus operations in malls. According to reports from Zurich (Bahnhofstrasse), Mannheim (Planken), Dortmund, Munich, and several other cities, LRT has proved better suited to pedestrian malls than buses for the following reasons:

- Tracks are for the most part flush with the pavement, although minimum depth recess is used in some malls to physically distinguish the LRT ROW from the pedestrian area, and to discourage delivery vehicles from sharing the right-of-way.
- Safety is felt to higher because of the precisely defined path of rail vehicles (numerical data are not available, however, since local factors vary among different malls).
- There is a much lower noise level and a total absence of exhaust emissions resulting from the use of electric traction motors.
(Electric trolley buses would also display these advantages.)

To insure safety, the speed of LRVs in European malls is usually restricted to 25 km/h (15 mph). Because of such low speeds, it is not practical to make malls much longer than 1 to 2 km, a distance traversed in some 5 to 10 minutes with an average operating speed of some 12 km/h.

This is seldom a serious limitation for two reasons: first, few passengers travel through the entire mall since it is usually in the area of maximum density of trip destinations; second, most shopping and office streets suitable for malls are not much longer than 1 to 2 km.

Design treatments for light rail in malls vary significantly. In some cities, solid white lines delineate the track zone as a warning to pedestrians. At stops, low steps are used to facilitate boarding (e.g., Zurich). At the very successful Planken Mall in Mannheim, Germany, however, tracks are positioned in the pavement without any curbs or pavement markings, but different surface materials are used to contrast the light rail clearance area from the remainder of the mall. Additional experience is needed to evaluate which of these approaches is superior. More detailed data and geometrics relative to pedestrian malls are provided in Chapter 3.

LRT Central Operation in Mixed Flow

Central location designs in mixed traffic represent minimum ROW alternatives and can be used in roadways with as few as four lanes. Interference between LRT and auto traffic within the four-lane cross section can be considerable.

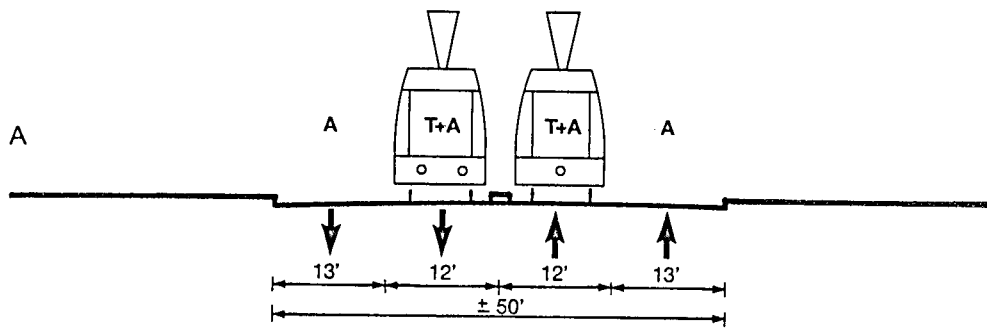
LRV stops may cause delays to motor vehicle traffic or require pedestrian islands; left-turning autos may cause delays to light rail vehicles. More details of the impact of this design are contained in Chapter 3.

A typical street cross section for LRT central operation on four lanes in mixed traffic is illustrated in Figure 2-1(A). Because of resulting conflicts, mixed flow design may be acceptable only in streets with LRT service at large headways (5 minutes or more during peak hours) and where auto traffic can be handled without excessive delays either in the remaining lanes or by diversion to alternate routes. These problems have caused most light rail system planners to turn away from the mixed flow alternative in favor of the separated right-of-way solutions discussed in subsequent sections.

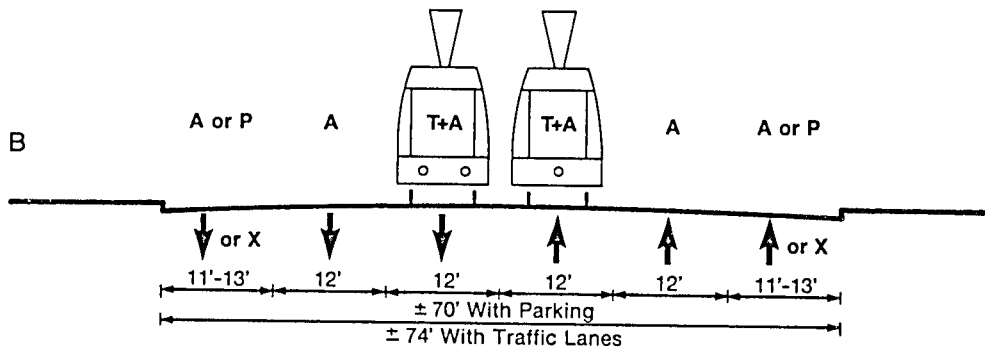
LRT mixed flow operations can be improved considerably if automobile left turns are prohibited between major intersections.

Potential prohibitions include:

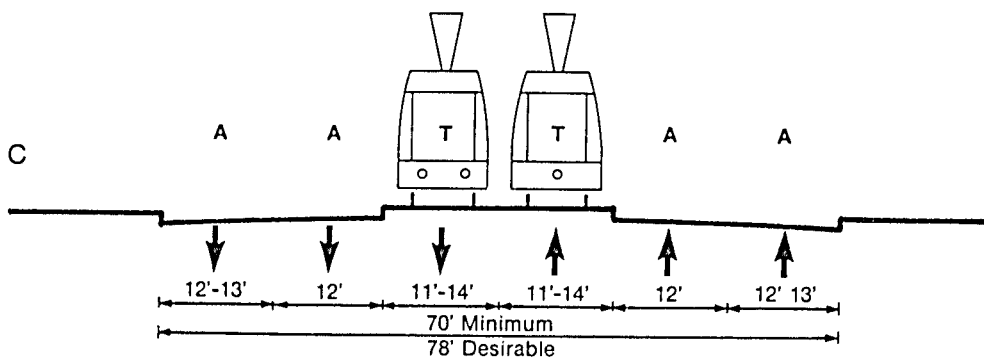
- Prohibition of left turns across the LRT line between intersections.
- Prohibition of left turns across the LRT line at minor cross streets.



Four Lanes - Mixed Traffic



Six Traffic Lanes or Four Traffic and Two Parking Lanes - Mixed Traffic



Conversion of Central Traffic Lanes to Exclusive LRT Median Use

FIGURE 2-1
LRT CENTRAL OPERATION,
SURFACE STREETS

- . Prohibition of left turns in and out of minor cross streets.
- . Closure of minor side streets at minor intersections.

These restrictions should be treated with care and alternate traffic routes should be worked out carefully. There can be community opposition to this type of action because it exacerbates access problems and increases through traffic on local streets.

Separation by a solid painted line, forming a reserved LRT lane, is a common solution. In recent years, however, physical separation by use of curbs has become more common. Amsterdam has several four-lane streets which leave only a single lane for automobile traffic in each direction. In this application the curbs are mountable, so in the event of vehicle breakdowns or emergencies, automobiles can cross the curbs and use the paved LRT track area.

The experience with this low cost method of separation has been very good. There has been a reduction of conflicts and hazards for both LRVs and automobiles. Recent San Francisco MUNI improvements included similar design features along a segment of the Judah Street Line. Where the number of auto lanes was reduced from two to one, congestion and delays increased in proportion to pre-existing traffic volumes and street capacity. Where curb parking was replaced by a driving lane,

however, street capacity was not reduced, but parking and loading are accommodated differently. A typical street cross section for central LRT operation in mixed traffic on six traffic lanes or four traffic lanes and two parking lanes is illustrated in Figure 2-1(B).

LRT Central Operation in Curbed Medians

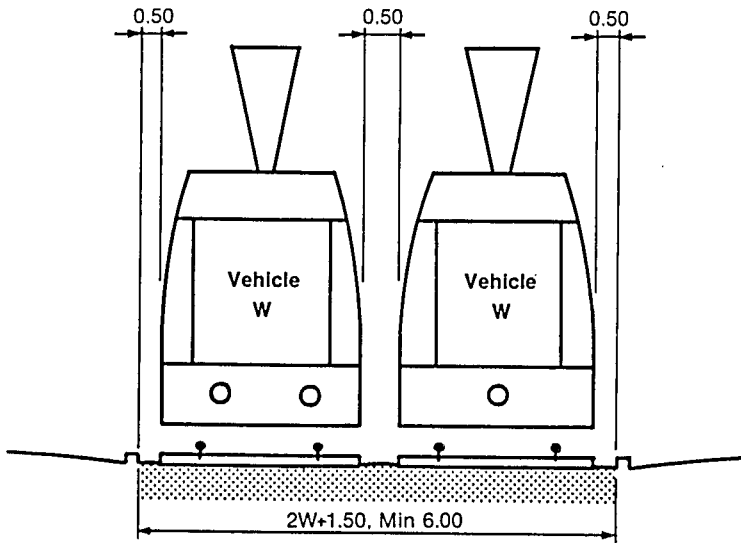
The curbed median is by far the most common type of design treatment. On new alignments where land is available, LRT should always be provided a separate ROW. Elsewhere, a decision must be made as to whether to convert existing medians (which years ago may have carried streetcar tracks) for LRT use or to convert existing automobile traffic lanes into LRT curbed medians.

In considering the feasibility of creating a separate LRT ROW, a number of factors are usually considered, including the geometrics (space availability), the impact on automobile traffic (expected increase, or sometime decrease, in congestion and delays), and benefits to transit passengers. A widely used criterion in western Europe in weighing the benefits of a separate ROW for LRT is the number of persons carried by transit versus the number of auto passengers, rather than the number of automobiles displaced or the increase in congestion due to loss of traffic lanes.

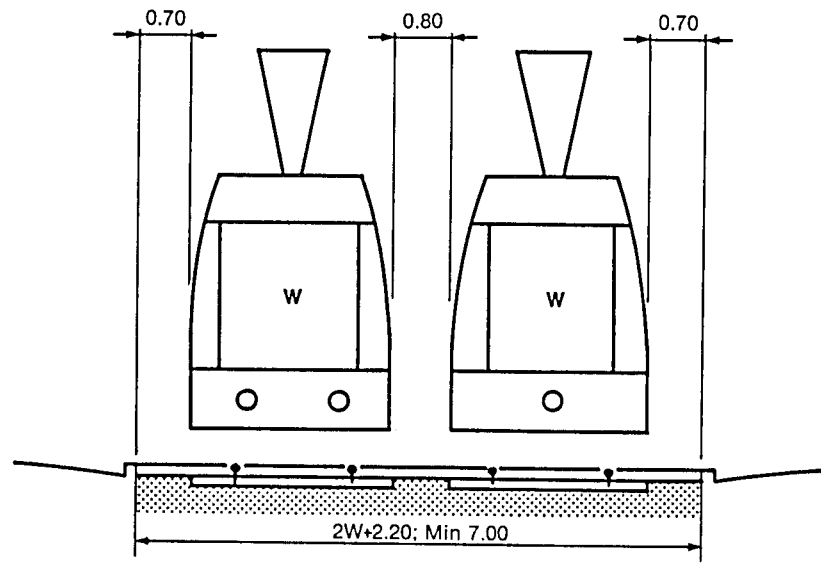
When an LRT line carries at least as many persons per hour as the automobile traffic in the same direction and other factors allow the change, provision of a separate LRT lane is considered warranted. In some European countries, this is felt to be a conservative criterion, and separate LRT ROW may be provided even for lower volumes of LRT patronage to give priority to transit and encourage increased transit ridership.

Wider streets with or without pre-existing LRT tracks in the roadway can be reconstructed into streets with curbed LRT medians. A minimum width median usually results. Figure 2-1(C) shows how conversion of the Figure 2-1(B) cross section from mixed traffic to median operation could be accomplished. Both minimum and desirable cross sections and lane widths are shown.

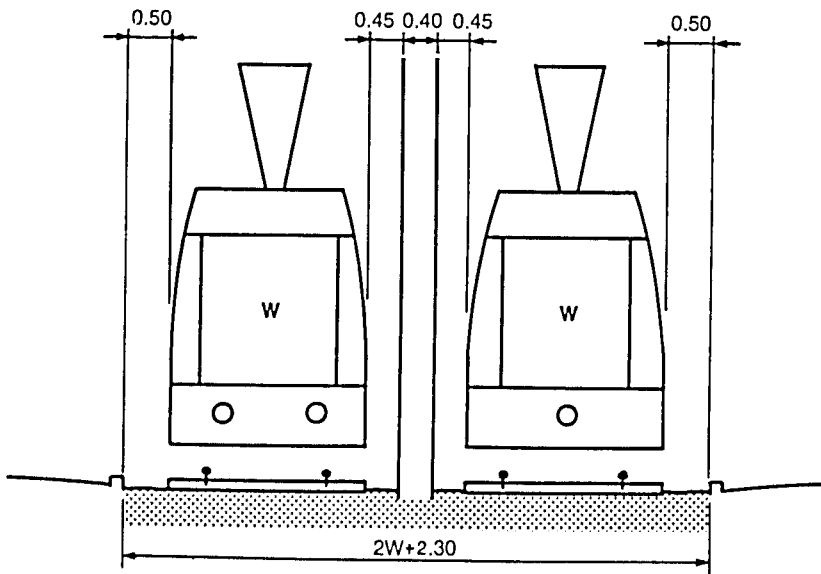
Figure 2-2 illustrates minimum widths for curbed medians for Light Rail tracks typically used in West German cities. The narrow medians have several shortcomings. They offer minimum separation from other traffic and safety is decreased. Wider cross sections must be provided at all stops, and the possibility of providing landscaping is eliminated. Track maintenance is also more difficult in the constrained area. Often the conversion of street traffic lanes or in-street LRT tracks to the curbed median design may also eliminate or reduce curbside parking as driving lanes are shifted outward.



With Lateral Overhead Wire Suspension



Joint Utilization With Buses (Moderate Speeds Only)



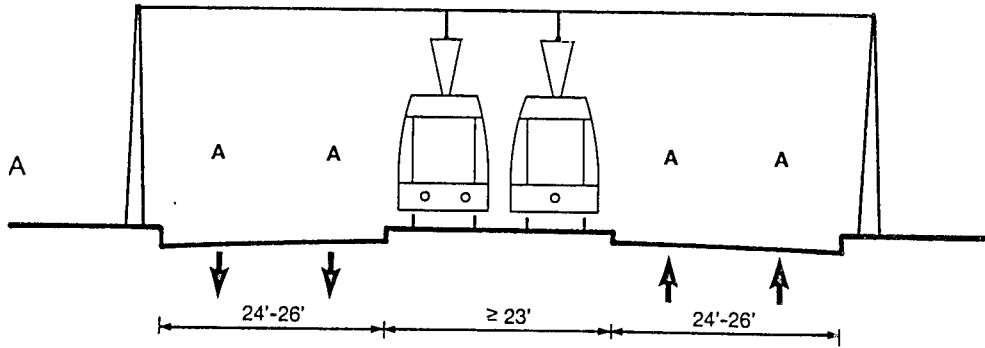
Center Pole For Overhead Wire Suspension

NOTE: DIMENSIONS ARE METRIC
1 METER = 3.28 FEET

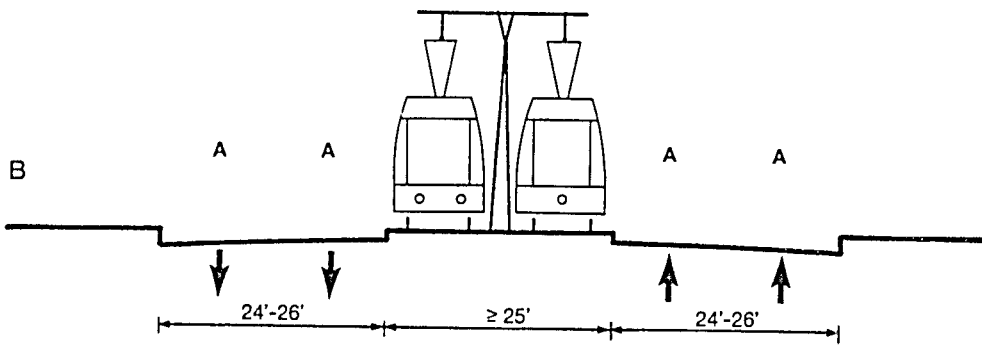
FIGURE 2-2
MINIMUM WIDTHS OF CURBED MEDIANS
FOR LIGHT RAIL TRACKS
(WEST GERMAN PRACTICE)

On the positive side, the new design not only greatly benefits the LRT, but results in smoother and safer auto traffic flow and increased pedestrian safety at crossings, since the median can serve as a refuge island at intersections. Esthetics may also be improved, particularly if the median can be sufficiently wide to accommodate some landscaping. When there is no parking lane, or parking cannot be eliminated, the number of travel lanes for auto traffic is reduced and the impact of the lower capacity must be evaluated.

Where sufficient ROW width is available, the curbed median can be designed to higher standards to provide 6 to 10 feet (2-3 m) clearance on each side of the car. This allows a passenger stop or a left-turn lane to be provided without changes or with only minor changes to track alignment at intersections and to the intersection approaches. Figure 2-3 illustrates typical cross section dimensions for more desirable widths found in Western German LRT design practice. Medians of desirable width can permit higher operating speed because they provide greater separation from roadways. Landscaping can be introduced to provide esthetic amenity. The greater width facilitates design of safer pedestrian crossings with fence protection and good visibility. It also provides width for traffic signals and signs. Finally, the design of turning lanes and passenger stops at intersections presents fewer problems.



Lateral Overhead Wire Support



Central Pole Wire Suspension

FIGURE 2-3
LRT CENTRAL OPERATION
IN CURBED MEDIANS

Busways and LRT in Curbed Medians

In recent years several cities (Pittsburgh, Pa., Belgrade, Amsterdam) have constructed paved tracks in curbed medians for joint use by buses and emergency vehicles. Lane-sharing by LRT and buses has the advantage that bus passengers can also benefit from any priority treatment given to LRT; capacity of transit service is increased; and capacity and flow of auto traffic in other lanes also may be improved. In Munich, joint use of the LRT ROW by buses is seen as an additional advantage since it permits continued transit service when LRT stoppages occur. However, where signal preemption is used at intersections, special detection equipment is necessary to accommodate both LRT and buses.

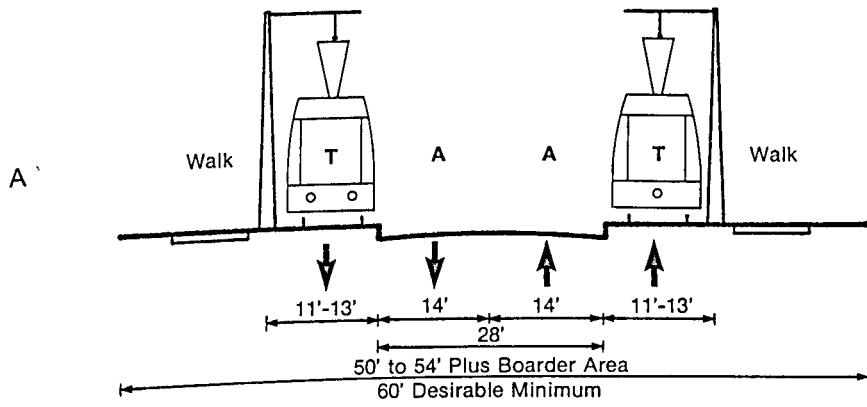
On the negative side, a major problem exists with joint bus/LRT lanes: a strong temptation is created to allow other vehicles such as taxis or even car pools to use the ROW, thereby drastically changing the character and decreasing the quality of transit operation. Buses tend to damage pavement, necessitating rather frequent resurfacing, sometimes made more difficult by the narrow ROW. Track repairs are more difficult than on open (unpaved) track structures. Consequently, joint bus/LRT lanes are most advantageous for those line segments on which the frequency of LRT vehicles is low or moderate (i.e., little interference between bus and automobile traffic). More transit passengers would then enjoy the benefits of improved service, a fact which often outweighs the problems caused by the mixed operation of rail vehicles and buses.

LRT in Lateral Locations with Symmetrical Operation

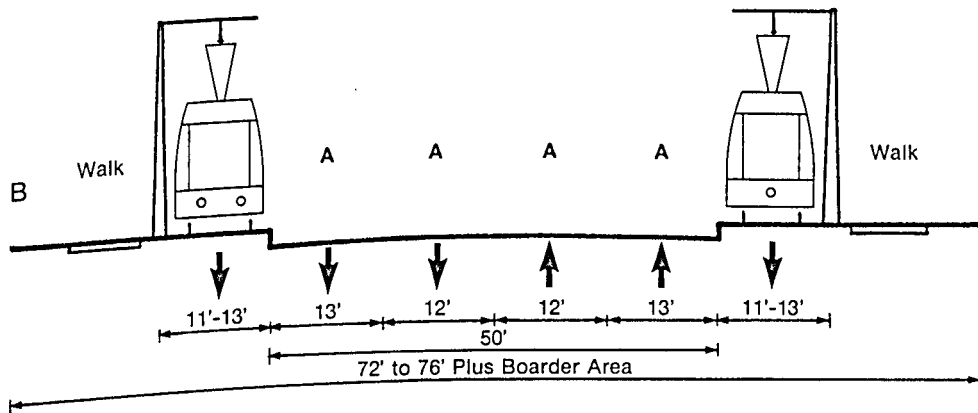
In some cases, a curbed separate ROW for LRT can be located laterally on one or both sides of the roadway. A typical cross section for symmetrical location of the tracks with one on each side of the street is shown in Figure 2-4. This treatment has the following advantages and disadvantages compared with the centrally located curbed median design.

Advantages are:

- This treatment requires less overall width because space need not be provided between tracks. Depending upon lane width, this may make the difference between dedicating only two lanes of the roadway to LRT as compared to the median design which can require more than two lanes.
- It increases the safety of pedestrian crossings since it provides increased visibility of LRT traffic from both directions.
- It provides more area and better protection for pedestrians at stops since the sidewalk can be used in lieu of station platforms.



Two Traffic Lanes



Four Traffic Lanes

FIGURE 2-4
LRT SYMMETRICAL OPERATION
AT LATERAL LOCATIONS

Disadvantages of this alternative are:

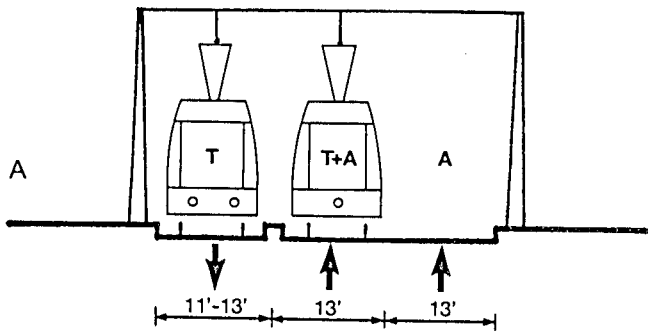
- It may conflict with pre-existing parking.
- It can greatly restrict midblock access.
- It requires a buffer zone between the track and the sidewalk if satisfactory speed is to be safely achieved.
- It is more difficult to regulate operations at intersections; left turns for LRT are very difficult and conflicts arise with tight-turning auto traffic.
- It requires greater capital outlay for installation of the power distribution system. Separate poles are necessary for each track. This also causes a greater visual impact.

Because of the serious disadvantages, symmetrical lateral design is very seldom used. One example is found on the Ring Strasse in Vienna, where reconstruction of this street to relocate LRT into a central median has recently been proposed.

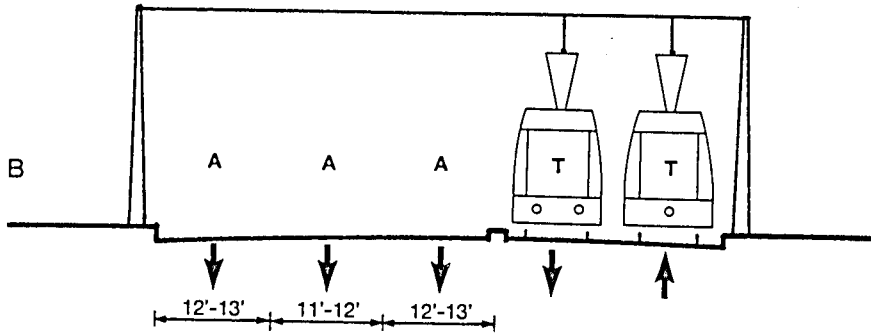
LRT in Lateral Locations with Asymmetrical Operation

Lateral positioning of LRT tracks with asymmetrical operation is feasible in several different situations, both with tracks in the roadway or in a separate curbed location. On one-way streets with two-way LRT movements, the tracks are often located to the left of auto lane(s) so that opposing flow is between the two LRT lanes and not between an LRT lane and an auto lane. If width is not adequate for two LRT and two auto lanes, it may be necessary for auto traffic to share one of the tracks, as shown in Figure 2-5(A). In such cases, a curb between tracks is desirable to separate the LRT cars traveling in the opposite direction from other traffic. On wider roadways, it may be possible to provide two or more auto traffic lanes with one-way or two-way auto flow, and exclusive lanes for LRT within the paved street area or in a separate curbed area, as shown in Figures 2-5(B) and 2-5(C).

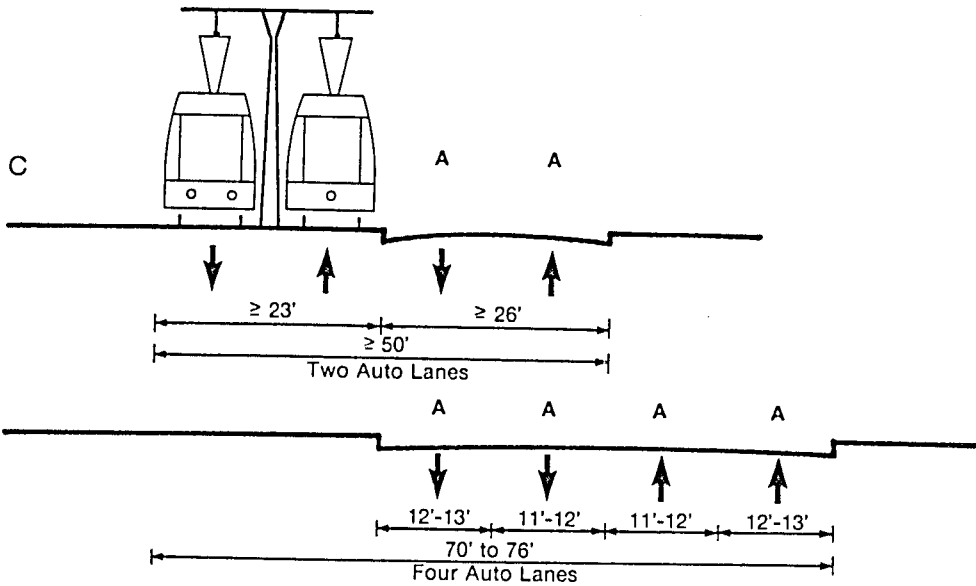
A curbed asymmetric lateral location on one side of the street has characteristics similar to symmetric lateral track design except that regulation at intersections is even more difficult. Passenger stops for the travel direction closer to the curb may require changes in the alignment of either the roadway or the tracks. Consequently, this design is not very common. It can be used successfully only in special cases such as along a park on one side of a street, or where LRT ROW is in the same corridor, but somewhat independent of the roadway.



Contra-Flow With Shared Lane on Two-Lane One-Way Street



In Exclusive Lanes Between Curbs On Multi-Lane One-Way Street



In Curbed Area Next to Two-Way Street

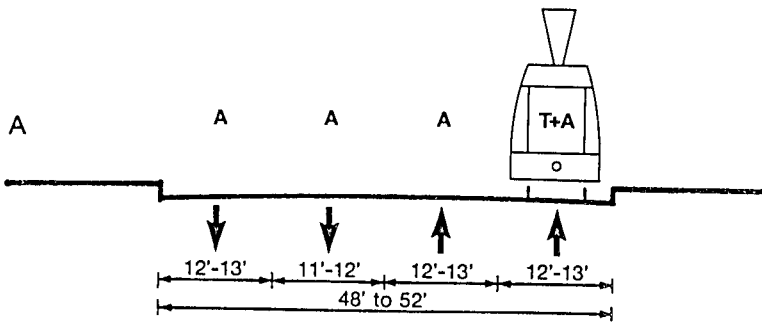
FIGURE 2-5
LRT TWO-WAY ASYMMETRICAL OPERATION
AT LATERAL LOCATIONS

Several possible variations exist for one-way asymmetric operation of LRT at lateral locations. Examples are illustrated in Figure 2-6.

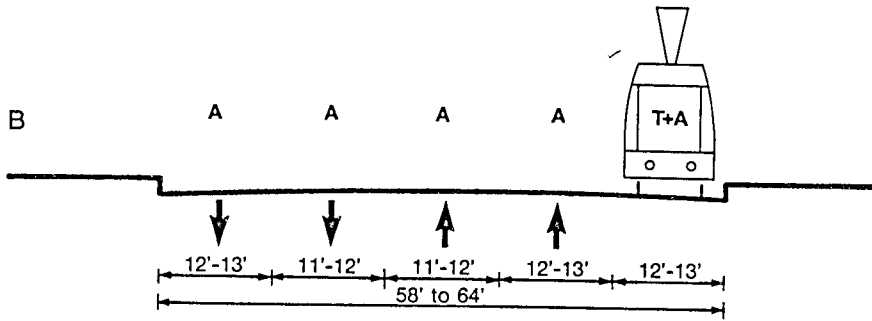
Potential applications include:

- . Route termini where a one-way turn-around loop encompassing one or more blocks can expand the service area.
- . Operation of the LRT line over a pair of one-way streets.
- . Operation over central area streets where the street pattern is predominantly a one-way grid.
- . Intermediate points along a route where separation of tracks by one or more blocks for a short distance would expand the service area.

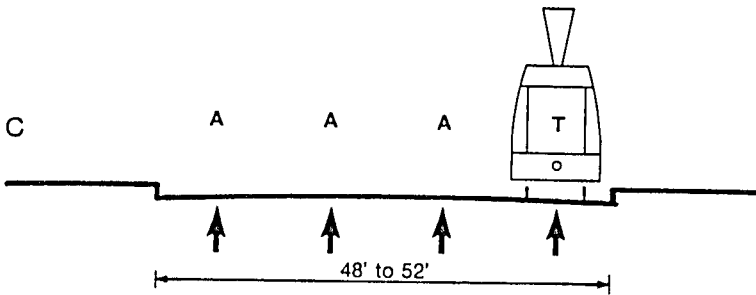
Figure 2-6(A) illustrates an example of one-way LRT operation in mixed traffic on a two-way street with the LRT sharing a curb lane. Figure 2-6(B) illustrates one-way LRT operation on an exclusive lane adjacent to auto traffic lanes on a two-way street. Typical one-way LRT operation on a one-way street with the LRT vehicle operating in the direction of auto flow is illustrated in Figure 2-6(C). A variation of this with LRT operating contra to one-way auto flow is shown as Figure 2-6(D).



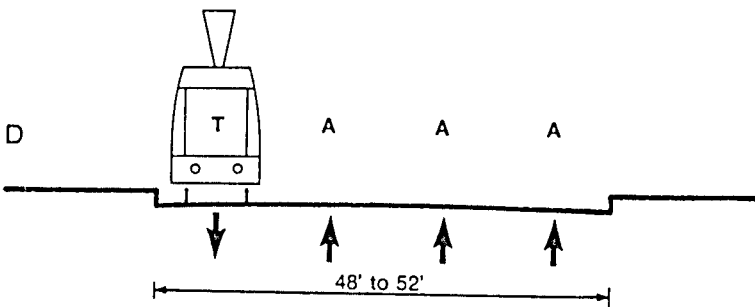
On Two-Way Street With Shared Traffic Lane



On Two-Way Street With Separate Auto Lanes



One-Way Street With LRT in Direction of Auto Flow



One-Way Street With LRT Contra-Flow

FIGURE 2-6
LRT ONE-WAY ASYMMETRICAL OPERATION
AT LATERAL LOCATIONS

While variations of one-way LRT operation at lateral locations have the advantage of allowing LRT passengers to alight directly to the sidewalk, they have the disadvantage that a pedestrian could step from the curb into the path of an LRT vehicle. Other disadvantages of variations where LRT travels in the same direction as auto flow include the possibility of automobiles or trucks violating the LRT lane to unload or stand illegally. This may be partially overcome when LRT has exclusive use of the lane by slightly raising the pavement or changing its texture. This should clearly distinguish the LRT lane from the other traffic lanes and the sidewalk. By operating LRT contra to auto traffic lanes on a one-way street, obstruction by auto traffic is minimized because automobiles occupying the LRT lane would be guilty of traveling in the wrong direction in that lane.

Numerous other variations of LRT track design are possible. In all cases, however, the elements which influence the design and the specific dimensions are similar to those discussed here: available space, relationships of vehicles in adjacent lanes, access of pedestrians to stops, design and control at intersections, esthetics, and ease of maintenance. Many other factors which can have variable significance under different local conditions may also require consideration.

DESIGN OF SURFACE LRT LINES AT INTERSECTIONS AND CROSSINGS

The basic goal in designing surface LRT lines is to provide for fast and safe transit service while minimizing adverse impacts on pedestrian and automobile movements. Modern LRT design practice shows that this goal can be met by physically separating the conflicting movements, but without resorting to costly grade separation, and otherwise controlling movements in order to provide for the equitable and safe sharing of the roadway. It is primarily at LRT intersections and crossings that modern design has made possible the high level of transit performance which has sparked the renewed interest in light rail transit. The success of these design treatments depends upon separation of LRT from automobile lanes, upon the design of intersection approaches, and upon providing separate traffic control signal phases for light rail. In this manner, designers provide spatial and temporal separation of light rail vehicles from other vehicles and from any movements with which they would conflict. Due to the extreme importance of intersections relative to the capacity of the entire street network, careful and sophisticated design and traffic regulation is required to ensure both adequate handling of light rail vehicles and maximum utilization of the street's potential to carry other traffic. For this purpose, a number of advanced traffic engineering measures have been developed in recent years in the countries where modern light rail is used extensively, particularly in West Germany, The Netherlands, Switzerland, and Sweden.

This section presents some general principles of design and regulation of intersections to accommodate light rail lines with emphasis upon the traffic control measures which can be employed. The next chapter presents examples of the application of these design principles to specific situations.

In general, there are four strategies for providing the necessary separation between LRT and other traffic, and thereby eliminating or reducing friction and conflict points at intersections or midblock crossings. These are:

- . Reduction of the number of traffic approaches.
- . Separation of traffic flows by roadway design changes.
- . Grade separation of traffic flows.
- . Separation of traffic flows by signaling.

Within each of these strategies different techniques can be used to reduce interference and conflict. Techniques pertaining to each of these strategies can be used together and most are not mutually exclusive.

Reduction of Intersection Approaches

Reduction of the number of approaches at an intersection can be achieved by conversion of one or both of the streets to one-way operation, or by closure of some of the approach legs. Conversion of a two-way cross street to one-way operation significantly reduces the number of automobile/pedestrian conflicts at an intersection (Figure 2-7). The number of automobile/LRV conflicts is also reduced, but the number of LRV/pedestrian conflict points remains the same.

If both streets were to be made one-way, the automobile/LRV conflict points would be further reduced, as would the median, merging, and internal points of interference. Closure of one or more of the approach legs at an intersection obviously would reduce the number of conflict points. This, however, is an extreme solution whose consequences need to be evaluated on a case-by-case basis. Local opposition due to any potential increase in congestion and loss of accessibility could prevent the implementation of this strategy. At midblock crossings of a two-way street, one-way traffic flow would not be a helpful strategy because it would not appreciably affect the points of interference. In this case, a different strategy must be employed to facilitate LRV movements.

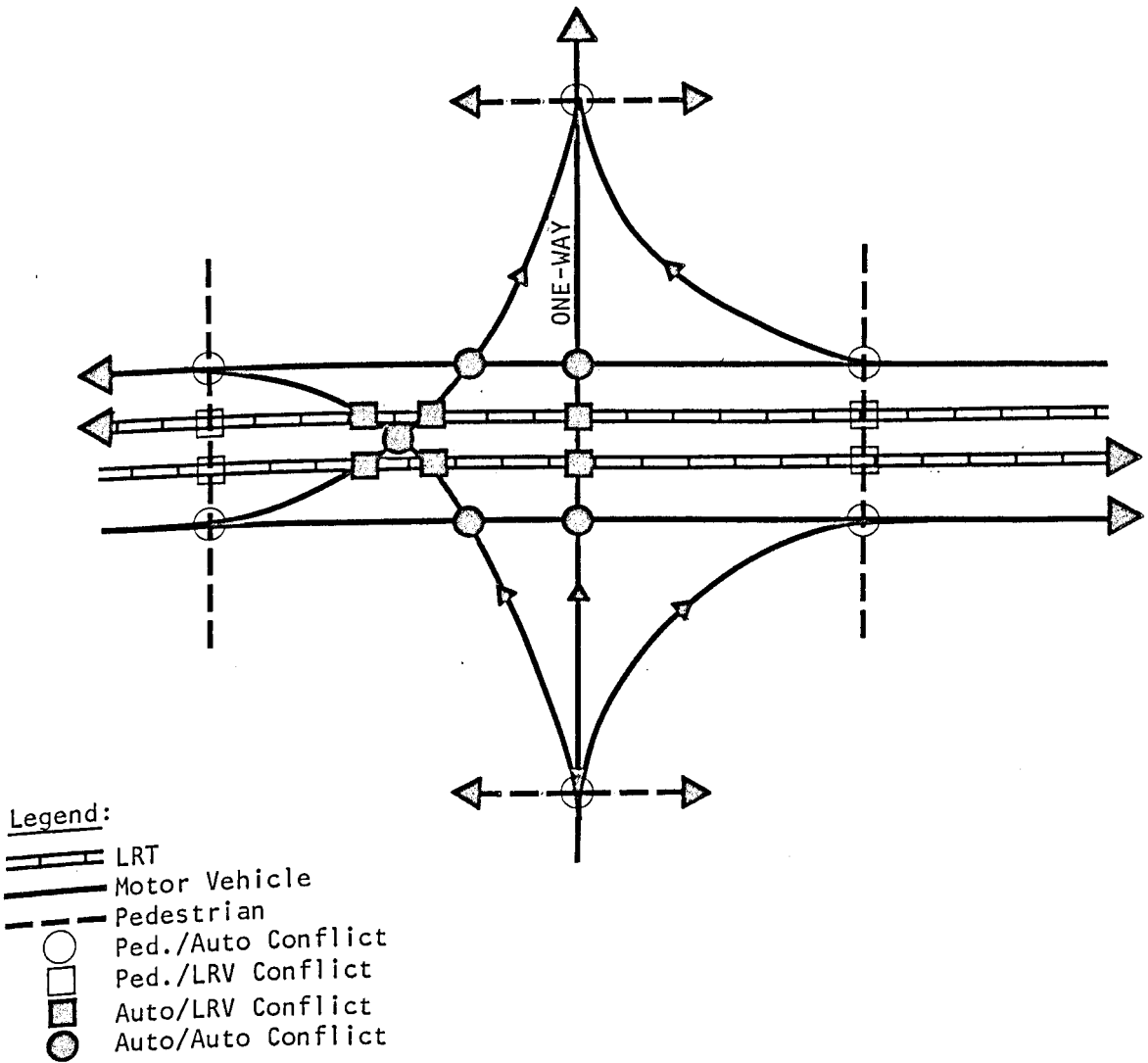


FIGURE 2-7
**POTENTIAL CONFLICTS
 AT ONE-WAY CROSS STREET**

Separation of Traffic Flows through Roadway Design Changes

Roadway design can be used to separate traffic flows by:

- . Development of separate through traffic lanes.
- . Development of right- and left-turn lanes.
- . Development of medians.
- . Prohibition of certain turning or through movements.

The delineation of through traffic lanes reduces interference with turning traffic at the intersection and, by inference, the friction between turning motor vehicles and LRT. Unless turns across the LRT tracks are prohibited, the development of through traffic lanes must be complemented with the provision of separate turn lanes. Through lanes can be developed as is customary in traffic engineering practice by painting stripes on the pavement or by curbs. Curbed medians obviously provide a more effective way of separating parallel automobile and LRV traffic along the line and are especially valuable at intersections in providing for the orderly movement of turning motor vehicles across the LRT tracks. Depending upon the width of the roadway, the traffic volumes, and the parking provisions on the through street, the demarcation of turning lanes may create undesirable congestion. Hence, a case-by-case decision must be made as to the worth of this strategy.

A more extreme strategy for achieving separation between light rail and automobiles or pedestrians is the prohibition of certain traffic movements at the intersection. Movements that could be prohibited include left turns across the LRT tracks, cross traffic traversing the tracks or turning left across them, and pedestrian movements. Obviously, this strategy is worthy of consideration where vehicular and pedestrian volumes affected by these restrictions are relatively small, or where alternate paths for the displaced movements are available and the resulting traffic volumes and inconvenience are tolerable.

Specific applications of the principle of separation of traffic flows by roadway design changes include median operation, mixed flow operation, and contraflow operation.

Median Operation. A variety of design control techniques is available for median operation. Cross-street and left-turn conflicts can be eliminated in some locations by closing the median at minor cross streets. This treatment is appropriate for sections of the line where cross streets carry low volumes of traffic, are numerous, and are closely spaced. Great care must be exercised in decisions to close streets to account for the change in traffic circulation patterns and access restrictions for businesses, residents, and emergency vehicles.

Mixed Flow Operation. With mixed LRV/auto flow, conflicts and interference occur at all points along the street between light rail, motor vehicles and pedestrians. Accidents are more likely as motor vehicle left-turn movements and queuing behind the turners cause significant delays for both light rail and autos.

Possible methods of reducing friction and conflicts between automobiles and LRT in mixed flow operations such as elimination of left turns, installation of channelization, and banning automobiles from the tracks at midblock locations, were cited earlier. Left-turn prohibition between intersections can be accomplished through signing, traffic bars, or median islands, the latter placed between the tracks. Installation of center channelization islands at the cross street approaches would prohibit cross-street through movement and left-turn movements (Figure 2-8). All cross-street and left-turn motor vehicle/LRT conflict points would be eliminated. This treatment is highly effective in increasing safety and reducing delay, but has a negative effect on circulation. It is most appropriate for low-volume local and collector type streets. Elimination of the cross-street through movement would cause diversion to other streets. Banning automobiles from the tracks at midblock locations would restrict use of the center lane to LRT movement plus motor vehicle left turns at specified intersections. This could be done with striping.

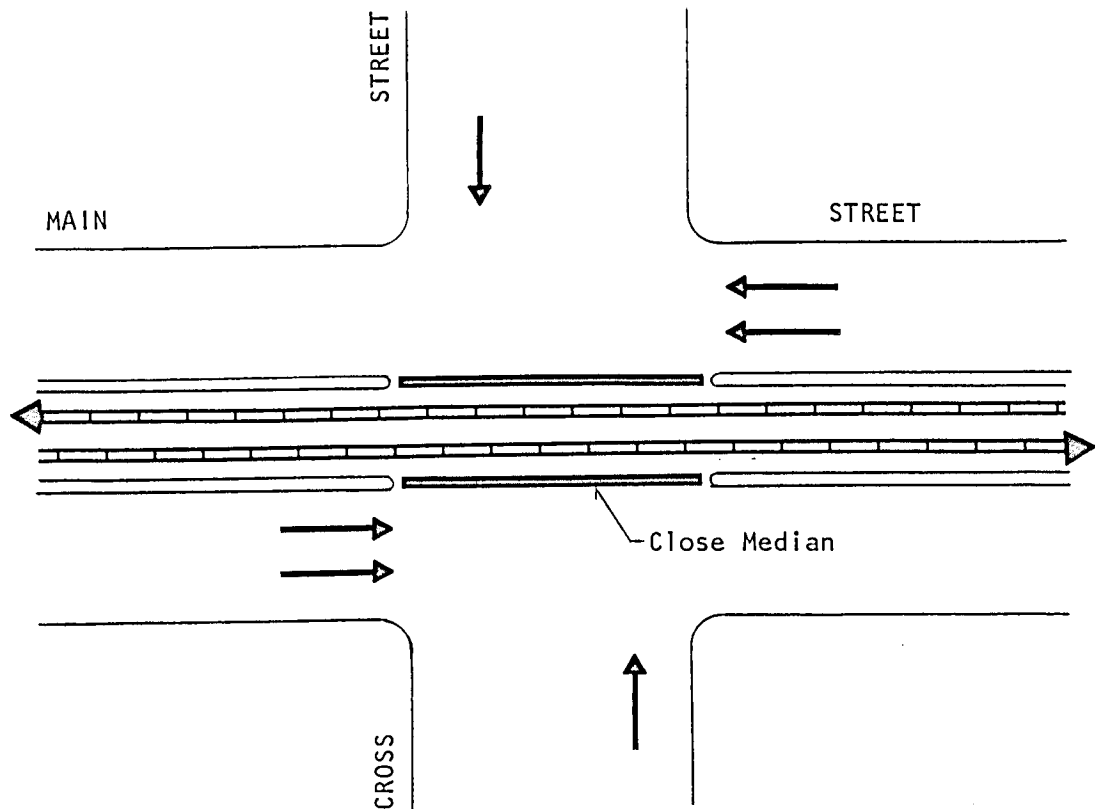


FIGURE 2-8
CLOSURE OF CROSS STREET
TO ELIMINATE CONFLICTS

Contraflow Operation. With the special case of contraflow LRT and motor vehicle operations, the introduction of a one-way light rail line on a one-way street has less effect than on a two-way street. Normally, the turn across light rail tracks which presents potentially the most hazardous conflict at intersections originates in the traffic flow parallel to the moving light rail vehicle and is difficult to observe from the LRV operator's location. In contraflow, parallel movements are in opposition. Each vehicle operator can easily see the other and the chance of a collision is reduced. Temporary blockage of the traffic lane by left-turning autos may occur, however, so it may advantageous to provide a left-turn lane. In this way, the chances of rear end accidents occurring between autos are minimized.

Should the opposing movements be heavy, installation of a separate traffic signal indication in addition to the left-turn lane should be considered. In an effort to reduce overall vehicle delays primarily during off-peak and evening hours, it is also advantageous to detect approaching LRVs so that the left-turn phase would only be actuated when demand exists.

Grade Separation of Traffic Flows

Grade (vertical) separation of the LRT ROW relative to the roadway completely eliminates conflicts and friction with automobile and pedestrian measurements. Localized grade separation at unique and

widely spaced intersections can maintain the overall low cost and high performance characteristics of modern surface LRT lanes with some financial penalties. There are no hard and fast rules to apply in describing which intersections should be grade separated. However, the following effects should be considered as a minimum: the volume of motor vehicle traffic affected, the cost of the grade separation, the delays to the motorists and transit users, and the safety problems and community disruption caused by the at-grade crossings. In any event, this interesting subject is not explored in greater detail here. Rather, the focus of this study is the identification of locations of possible conflict, the assessment of impacts arising from limiting some traffic and pedestrian movements, and the definition of specific mitigation measures that can be adopted to promote efficient operation of all modes without resorting to the costly remedy of vertical separation.

Where conditions require that LRT be grade separated at closely spaced intersections, or where surface operation is not possible even between intersections, longer segments of line must be grade separated in tunnels or on elevated structures. Many modern light rail lines contain fully grade separated segments. As the fraction of grade separated line increases, so does the system cost which, in the limit, will approach the cost of conventional exclusive ROW rapid transit. By restricting grade separation to isolated intersections, the cost increments can be controlled and kept to a minimum.

At individual intersections or crossings the LRT right-of-way can be separated by depression or elevation. There are no rules of universal applicability to help make the design decision. In most cases it will be found that elevating the LRT ROW will be less costly and more easily implemented than depressing it below the roadway. However, there will be adverse visual and community effects due to the approaches to the crossing (to achieve a 14 foot (5.51 m) clearance over the roadway, the approaches will extend from 300 to 500 feet (118-197 m) on either side of the intersection). If a station were to be located near the intersection, the length of the approach section would need to be increased even more, and special facilities such as pedestrian overpasses would be called for to provide station access. Depressing the LRT ROW or the crossing street might then be an alternative, but higher costs could be incurred for relocation of utilities and for turning ramps (in the case of the depressed cross street).







Separation of Traffic Flows by Signaling

The separation of traffic flows in time by signs or traffic signal control is a well-utilized traffic engineering technique. However, use of only one phase each for through and cross traffic could create a number of hazardous conflict points between light rail vehicles and automobile and pedestrian traffic, in addition to the customary auto-

mobile/automobile and/pedestrian conflicts (Figure 2-9). A simple refinement of this control technique, the addition of a left-turn phase, can eliminate the LRT-induced conflicts as shown in Figure 2-10. Figure 2-11 shows that LRT/pedestrian conflicts also must be controlled with special signaling. It is also shown that unless all pedestrian movements are stopped (in the second phase) automobile/pedestrian conflicts with turning vehicular traffic will persist. Obviously, where pedestrian traffic is heavy, an additional pedestrian crossing phase could be added to the signal cycle, thereby reducing available green time for autos. Where consideration also might be given to the addition of preferential LRT phases (as discussed later in this chapter), the combined impact of pedestrian and LRT phases upon the traffic flow could become too severe for public acceptance. It is important, therefore, that opportunities for control of LRT/automobile/pedestrian conflicts through signalization be planned and evaluated carefully at intersections with heavy automobile and pedestrian volumes.

West European transit officials report that with such planning, it is frequently possible to increase the overall capacity of the intersection as well as the safety of light rail operations. They indicate that the quality and level of sophistication of the intersection controls actually can give individual drivers clearer instructions and make them better oriented at complex intersections than they are at intersections with simpler designs and conventional controls.

Legend:

-  LRT
-  Motor Vehicle
-  Pedestrian
-  Auto/Auto Conflict
-  Auto/LRV Conflict
-  Ped./Auto or Ped./LRV Conflict

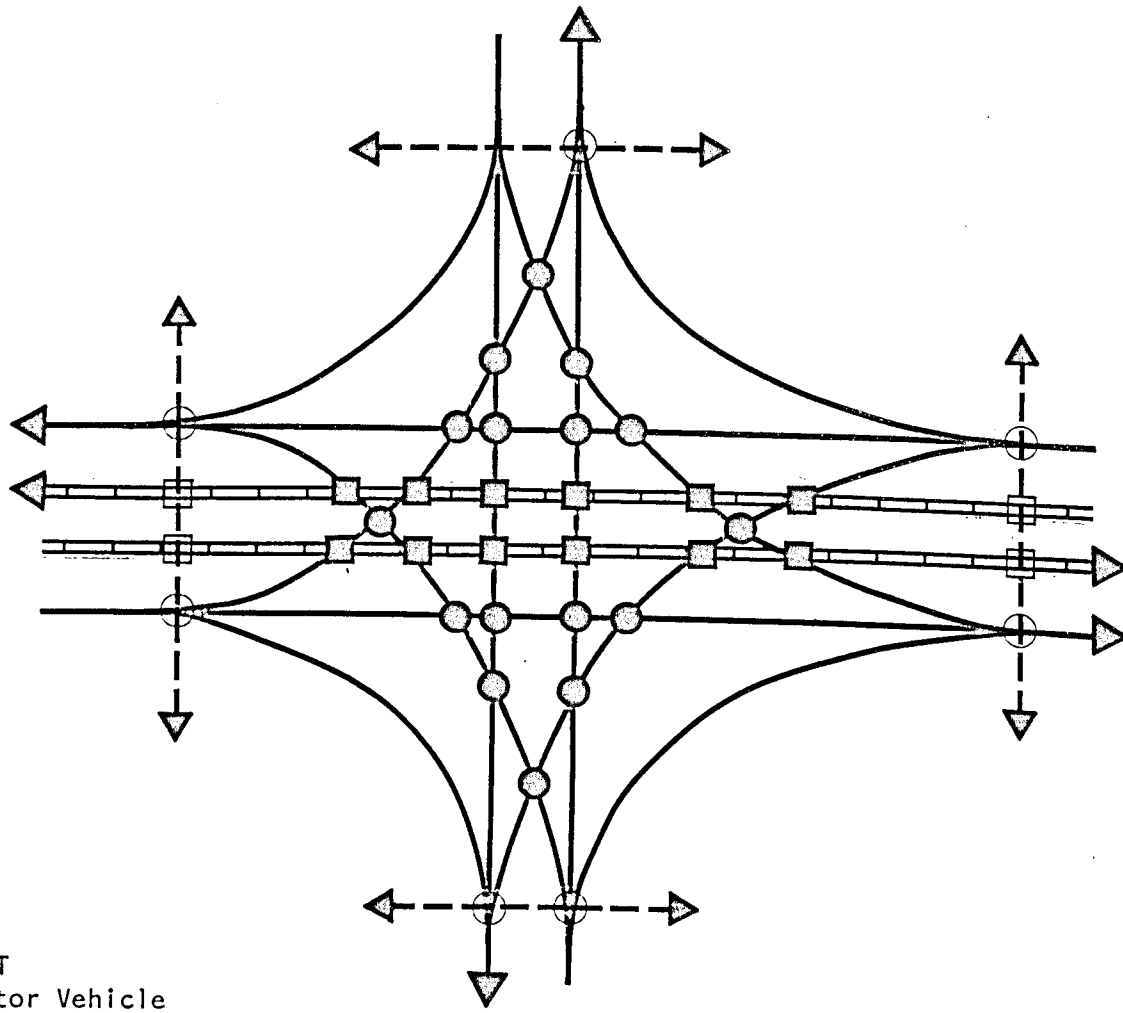
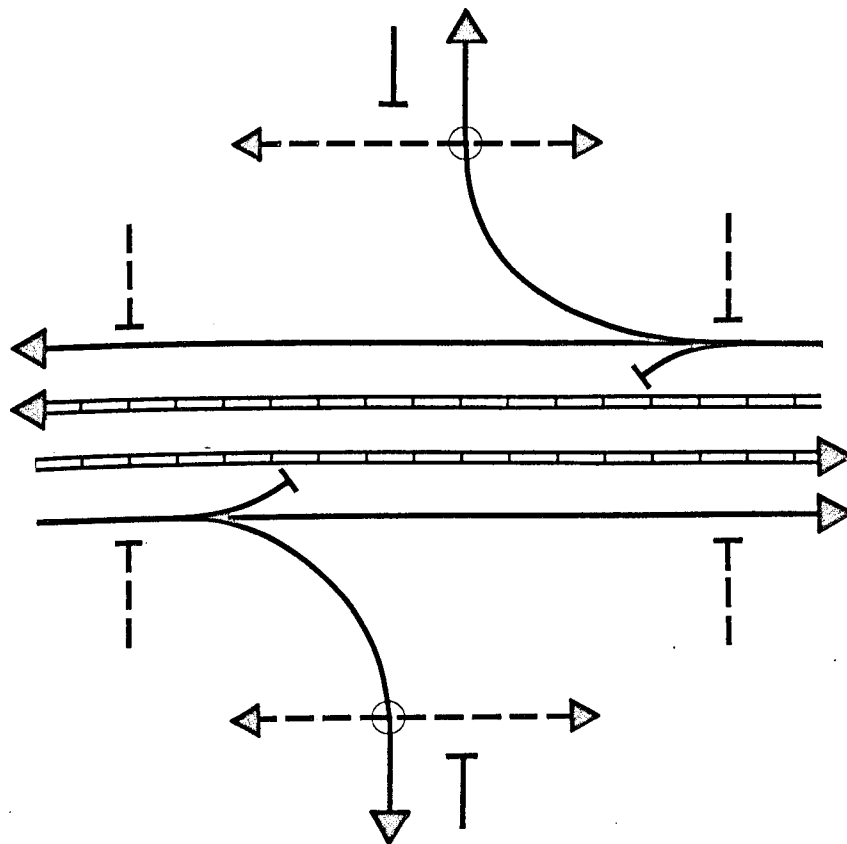


FIGURE 2-9
POTENTIAL LRT/AUTO/PEDESTRIAN
CONFLICTS AT INTERSECTIONS



Legend:






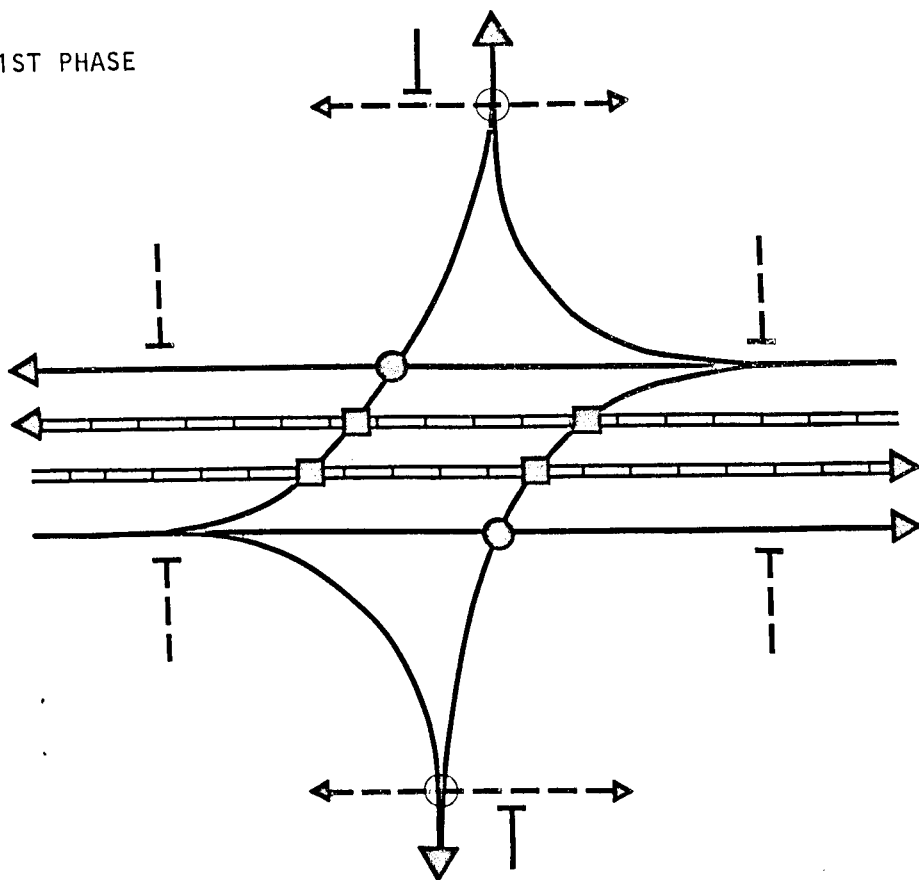
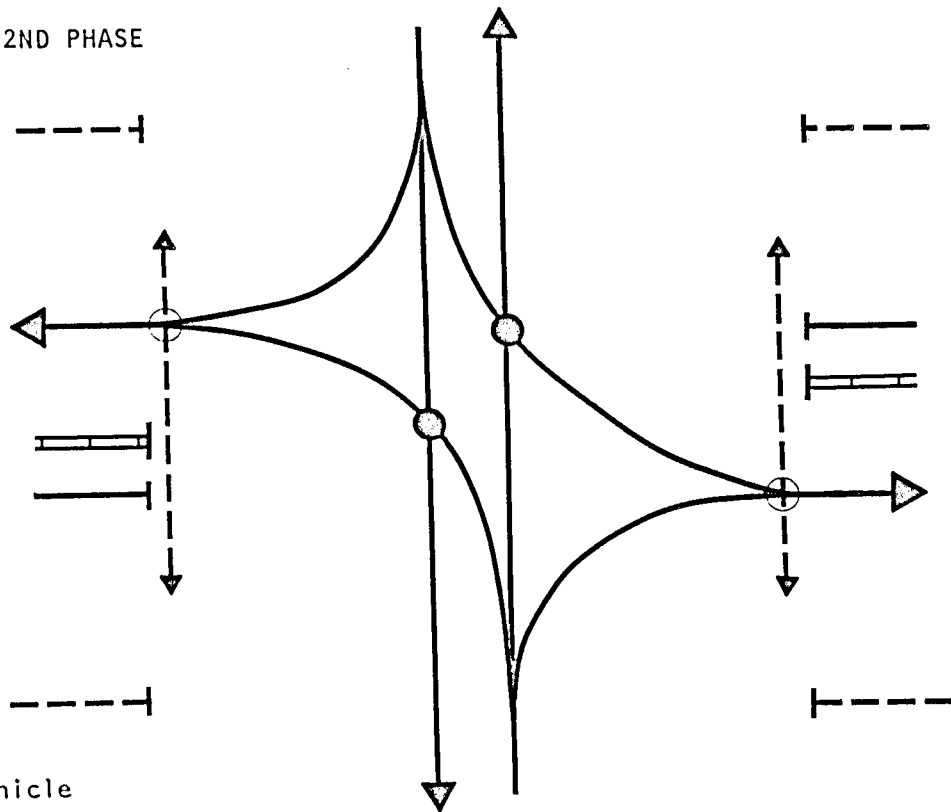
-  LRT
-  Motor Vehicle
-  Pedestrian
-  Ped./Auto Conflict
-  Stopped Movement

FIGURE 2-10
**REDUCTION OF CONFLICTS AT INTERSECTIONS
 THROUGH LEFT-TURN PROHIBITION**

1ST PHASE



2ND PHASE



Legend:

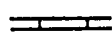
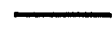






-  LRT
-  Motor Vehicle
-  Pedestrian
-  Ped./Auto Conflict
-  Ped./LRT Conflict
-  Auto/LRT Conflict
-  Auto/Auto Conflict
-  Stopped Movement

FIGURE 2-11
CONTROL OF LRV/PEDESTRIAN CONFLICTS
THROUGH TRAFFIC SIGNALS

Motor vehicle traffic volumes and patterns and local street geometrics directly affect the choice of traffic control applications, the LRT operation, and certain design features of the line such as the location of platforms and gates. A number of topics relating to the elimination of potential auto/LRT and pedestrian/LRT conflicts are discussed below.

Left Turn Control. Correct movement of motor vehicle left turns across LRT tracks is of importance since it is critical to safety. Since left-turning traffic must cross the adjacent centrally located LRT tracks, there is a possibility that turning vehicles will be delayed or stop on the tracks to yield to opposing traffic flow. The approaching light rail vehicles therefore would be delayed, and their stopping must be controlled by early detection and provision of adequate lines of sight and signals. Improperly used left-turn signalization can degrade light rail performance by unnecessarily long stops or slowdowns. Motor vehicle movements also can be adversely affected by delays in receiving their green signal indication.

Consequently, this movement usually requires special attention, and there are several ways to solve the problem. A first strategy is to eliminate left turns as described above. Where permitted by the street network, parallel traffic desiring to turn left can be redirected to approach the intersection on the cross street. This is feasible only where the side streets can handle the increased vehicular traffic volumes. With the left turns eliminated, the intersection is designed

with through traffic lanes only, and can be regulated by a two-phase signal cycle. While left-turning vehicles then would have a less direct and longer path to negotiate,* the safety of all movements at the intersection is, in most cases, considerably increased since the most difficult turning movements, left turns across both the LRT track and the opposing heavy traffic flow, are eliminated. The signal is simplified to two-phase operation; both basic phases (straight through on both arterials) are usually longer in duration than with three-phase operation and therefore provide a higher capacity with each movement.

*When left turn movements are prohibited entirely, vigilant enforcement is required. This is especially true if the prohibited left turn was permitted prior to installation of LRT and alternative routes for turning movements are inconvenient. Careful study must be made of the potential new route that vehicles must take such as making right turns around the block or turning left at another intersection. This kind of diversion can cause increased through traffic in community areas which may be negatively affected. A more common approach is to control intersection crossing conflicts due to left turns across light rail tracks by a special left-turn signal phase that would hold crossing traffic when an LRV passes through the intersection. When a left-turn phase is used, a left-turn lane should be provided for queuing of turning vehicles. Approaching LRVs must be detected before reaching the intersection to activate the signal. It is possible to operate the signal without LRV detection on a fixed cycle basis, but signal time would be wasted when transit vehicles do not cross the intersection.

An alternative is to actuate a "No Left Turn" sign just prior to the approach of an LRV. At all other times, the left-turn signal would remain uncontrolled. This method would result in minimum motor vehicle delays during periods between LRT movements. A potential problem is that auto drivers may not always observe the sign. Accident avoidance is usually most successful when a consistent control treatment is used.

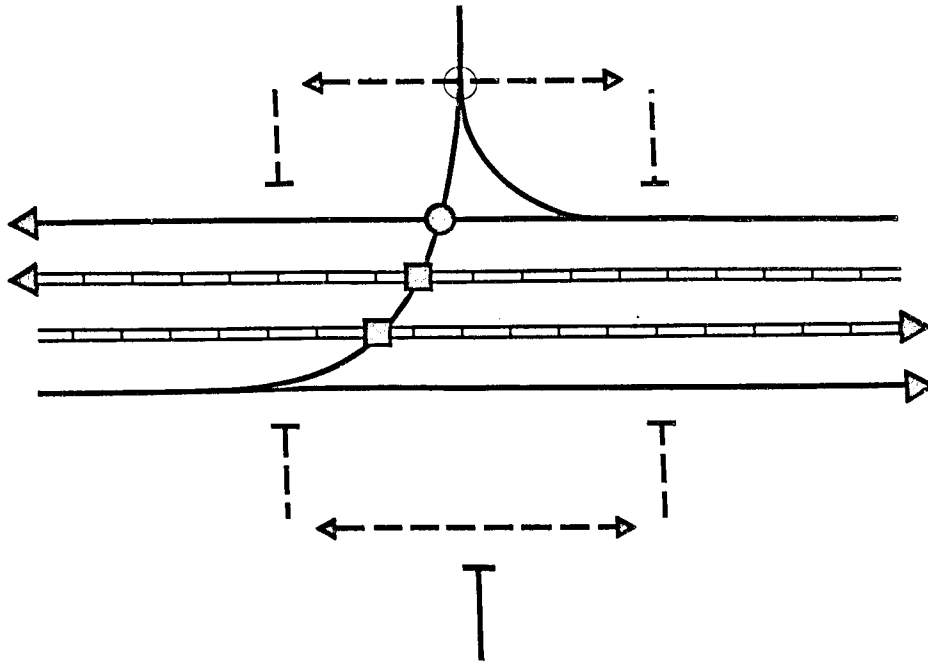
In another variation, left-turning traffic is allowed to cross the track approaching the intersection in the same direction prior to the intersection. This design, discussed in German practice, is recommended only for special cases where the arterial is very wide and the intersection capacity is critical. Although there are locations where this design operates without signals (Philadelphia), signal control is recommended because it eliminates the slowing down of LRVs and reduces the possibility of accidents. The signal should be actuated by an approaching LRV sufficiently in advance so that downstream queues in the left-turn lane can be cleared and the LRV can proceed through the signal without slowing down.

Finally, relocation of left turns to midpoints between intersections with fully coordinated signals can provide a so-called "free left turn." The solution is extensively used in Dusseldorf with great efficiency.*

*The design is based on the following principle: when signals of two intersections along a street are synchronized as an alternate signal system (i.e., when intersection A has a green phase for the street, intersection B has a red phase for it, and vice versa), vehicle platoons in opposite directions meet exactly at each intersection during its green phase. In other words, through bands on the time/distance signal timing diagram intersect exactly at signal locations. At midpoints between the intersections the platoons "miss" each other, i.e., first one platoon (e.g., northbound) passes, then the other one (southbound). Thus, there is no time at that location when full crossing of the street could be made without stopping, i.e., interrupting progression of one of the flows. But if a left turn from the street into a side street is permitted such a midpoint, the turning vehicle can receive a green indication when the opposite platoon has passed without interrupting through movements in either direction. Details of this design and operation are described in Appendices 1 and 2.

Left-Turn Control on One-Way Streets. Upon conversion to one-way cross street operation, left turns need be controlled from one direction only. To control left turns, it is necessary to add only one additional signal phase at signalized intersections. Operation of the intersection is simplified and a shorter cycle length results. Figure 2-12 illustrates the control of conflicting movements and depicts how resulting potential LRT conflict points can be eliminated. At the resultant less complex intersection, simpler traffic control equipment can be used and operating costs can be cut. An obvious primary consideration of conversion to one-way street operation is the traffic impact. If the roadway system conforms to a grid pattern, conversion can be more readily implemented. Improved safety and capacity usually result at the expense of increased travel distance for some trips and less convenient access.

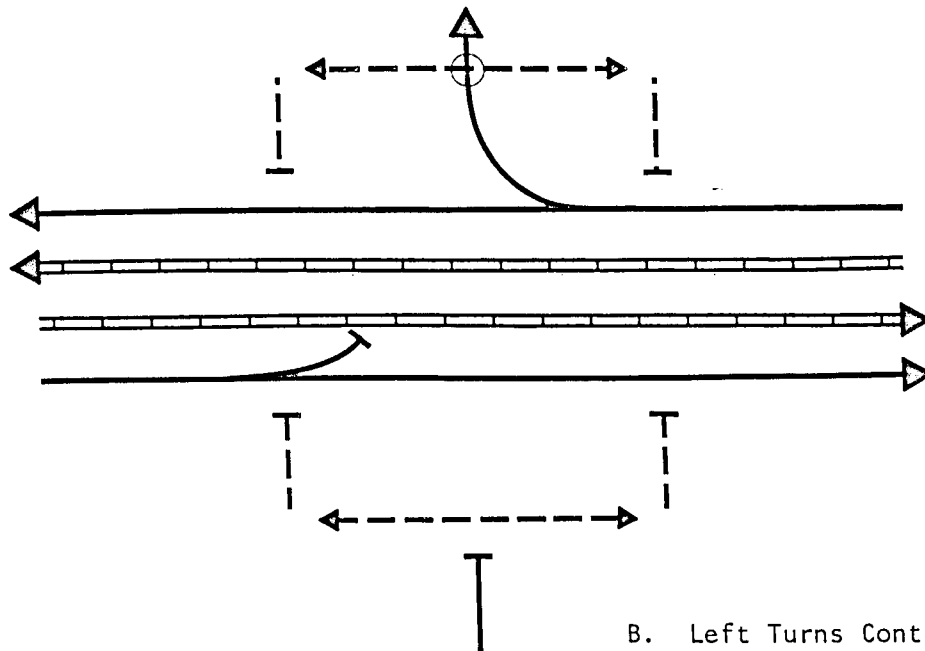
Signalization. It is clear from the preceding discussion that signals play a major role in regulating the different vehicular flows and in separating modes and directional movements of traffic. A basic prerequisite for effective use of signals for LRT regulation is the availability of special signals for LRVs (more precisely, for all transit vehicles). Such signals have been used extensively in many European countries for more than twenty years. In Germany, the currently used signals were developed during many years of testing and experiences with several other versions.



A. Left Turns Uncontrolled

Legend:

- LRT
- Motor Vehicle
- Pedestrian
- Auto/Auto Conflict
- Auto/LRV Conflict
- Ped./Auto Conflict
- Stopped Movement



B. Left Turns Controlled or Prohibited

FIGURE 2-12
CONTROL OF CONFLICTS
AT ONE-WAY CROSS STREETS

For example, signals with white points were in use for many years before they were superseded by the "white line" design.

Figure 2-13 shows a possible traffic signal hardware arrangement at an intersection. For this design, an island has been added in front of the station platform for installation of the motor vehicle and LRT signals. Programmed visibility signal heads are shown. These devices allow programming of the field of vision so that drivers see only the signals directing their own movements. With the arrangement depicted, pedestrian signal heads can be used to control each leg of the pedestrian crossing. Separate crossing phases can be used. A pedestrian could move from the curb to the platform on one traffic signal phase, and then from the platform to the opposite curb on the second movement. This could shorten the intersection signal cycle and speed up the clearance phase. This type of signal phasing requires that adequate pedestrian refuge areas be provided at the mid-intersection stopping points.

There are three basic types of signal controls of LRVs. With the first type, LRVs receive identical signals along with one or more automobile traffic movements. Typically, through LRVs are usually given the same phase as through and right-turning auto traffic. In this case, the signals for LRT have the same timing as the regular signals for other

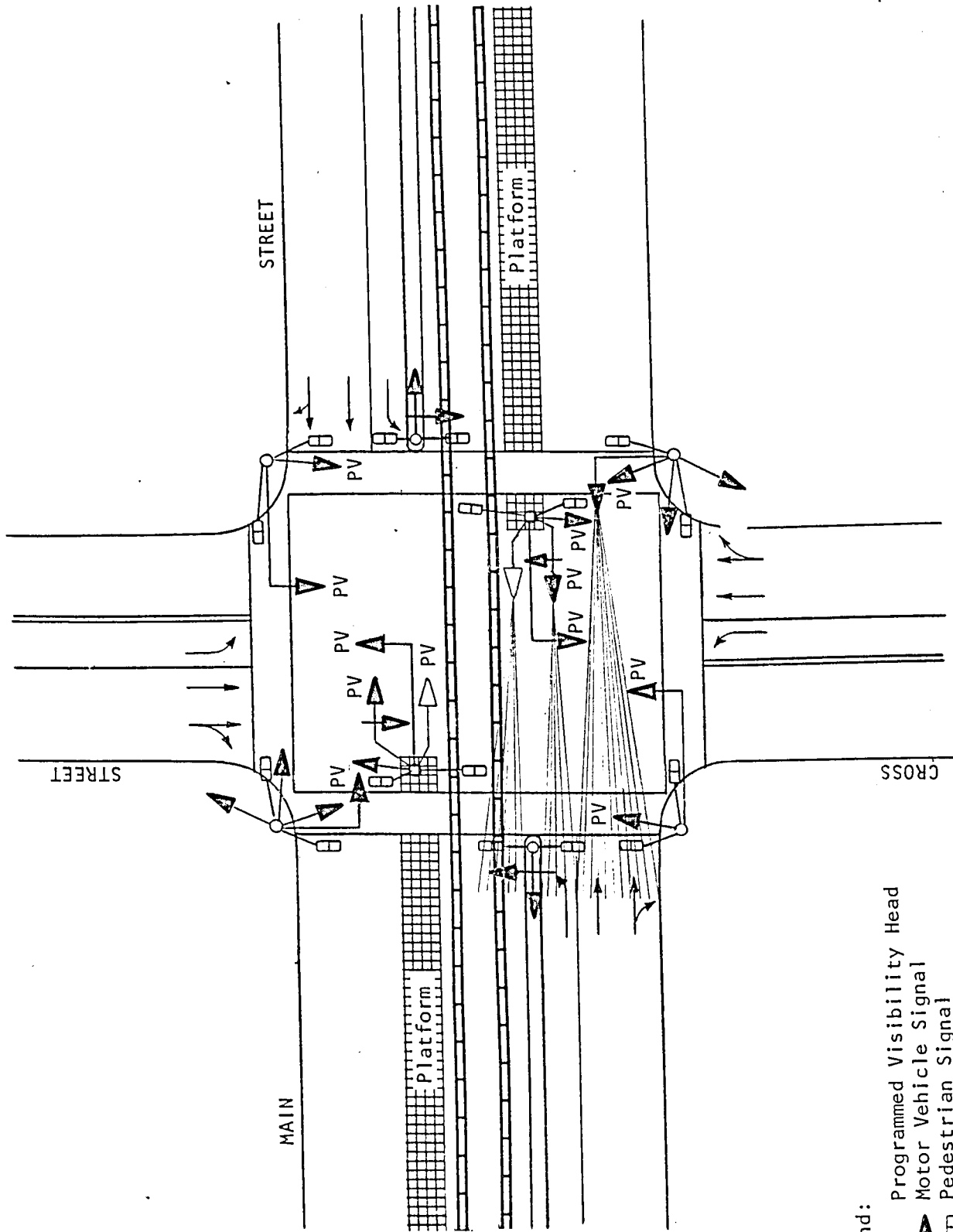


FIGURE 2-13
TYPICAL TRAFFIC SIGNAL
INSTALLATION WITH LRT

- Legend:
- PV Programmed Visibility Head
 - ▲ Motor Vehicle Signal
 - ◻ Pedestrian Signal
 - ◉ LRT Signal
 - Field of Coverage of PV Traffic Signal



traffic. When left-turning auto traffic is not provided with a special phase and must yield to straight through LRVs, it is common to give LRT a short advance interval so that its passage through the intersection is assured.

With the second type of treatment, special phases (also fixed-time) are provided for LRV movements when they would conflict with other traffic movements. This is achieved exclusively by the LRT signals.

The third type of signal controls are on-call signals, usually actuated by LRVs contacting detectors. A typical installation would make use of detectors mounted on the overhead wires. Actuation is commonly used to extend a green interval, either prior to the "normal" time (leading green), or after the interval (lagging green).

Most signals used to control intersections with LRT lines are of the fixed-time type. The actuated LRT signal can change the lengths of individual intervals or phases, but the background cycle and phase timing remain fixed. To date, west European experience with the fixed-time signals has been much better than with traffic-actuated signals. Fixed-time signals permit exact preprogramming of flows throughout a street network. One of the best applications of this concept for a number of years has been the signal system in central Dusseldorf. Under the direction of Dr. Wolfgang von Stein, the signal system in that city has been designed with extreme precision. There are

a number of original, highly imaginative solutions for maximum capacity and minimum interruptions of flow for both LRT and auto traffic, with light rail being provided various types of priorities in many instances. Signal timings are carefully tailored to traffic flow on major arterials, and at many locations are tailored even to the turning movements. Synchronization is so precisely planned that congestion seldom occurs. Coordination of green intervals makes capacities along major arterials rather uniform so that a major overload of a single intersection, which can cause long delays and disturbances in all flows in the network, hardly ever occurs. Excessive traffic volumes cannot enter the system since they are "cut off" at the first intersection. Many examples of these modern traffic control solutions are found in Dusseldorf.

LRT Turning Movements. LRT vehicles turning left from centrally located tracks can move together with other left-turning traffic in two parallel left-turn lanes without special signals. However, this could cause delays to the LRT vehicles if they must yield to all through vehicles traveling in the opposite direction, even individual automobiles. On the other hand, the turning LRVs, particularly articulated vehicles or trains, block the opposing through traffic for somewhat lengthy time intervals. From the standpoint of transit operations, it is therefore desirable, and sometime imperative, to provide special signal phases for left-turning LRVs. This phase can be shared with the left turn for motor vehicles, providing the turning lanes are well designed and marked.

LRTs executing right turns from centrally located tracks require full signal separation from traffic approaching the intersection in the same direction. This can be achieved in two ways: first, by providing a direct turn track and controlling the turning movement by a special phase, normally occurring in advance of the straight through movements; and second, by the very specialized technique of "weaving" the track and through lanes across each other prior to the intersection and controlling the crossing of LRT vehicles by a "signal island" arrangement.*

*As described in Reference 1, the presignal forming the signal island is for only one direction of traffic and can be fully synchronized with the main intersection signal, i.e., it can provide full progression. In an ideal case, the LRT should have a far-side stop at the preceding intersection and arrive at the presignal during the red phase at the main signal. The presignal is red for other traffic, green for the LRT, allowing it to proceed to the near-side stop at the curb without stopping. The dwell time of the LRT vehicle, which is seldom longer than 20 seconds if self-service fare collection is used, may coincide with the remaining red phase of the main signal. The presignal turns green several seconds prior to the main signal, allowing full progression of highway vehicles and avoiding any additional delay to them because of the signal island. The LRT vehicle is also ready to proceed through the intersection to make its right turn during the green phase, not suffering any signal delay.

On intersection approaches from which LRT lines proceed straight and into a left or right turn, it is common to provide a wider median with a third track for the turning vehicles. The best example of extensive use of this layout at a number of successive intersections is found on the Ring Strasse in Mannheim. This arrangement permits either light rail vehicle, the one going straight or the one turning, to proceed if it receives a green phase before the other. It eliminates the possibility of one vehicle blocking the other's movement.

Gates

A rather drastic means of controlling or separating traffic and LRT movements is to supplement traffic signal control with railroad-type gates. Generally, gates will increase safety at a crossing, but the adverse consequences associated with their use (increased delays to motor vehicle traffic, increased LRT headway required to maintain reasonable cross vehicular traffic flow rates, esthetics, and community impact) have confronted planners with a difficult problem. Hence, a basic question in the design of modern surface LRT lines is: when are gates needed?

Gates have been installed throughout the United States at railroad crossings where little or no protection previously existed, primarily at isolated midblock crossings in suburban or rural areas. Some local

regulatory bodies have taken the position, based on public safety considerations, that LRT operating at grade is a railroad and certain crossings should be protected with gates.*

Indeed, on several new LRT lines operating on preexisting railroad ROW, gates were retained at crossings (e.g., Edmonton). The issue is not closed and arguments for and against the use of gates will be heard in many new LRT design programs. For the purpose of this discussion, traffic signals alone should be sufficient to control LRT intersections; only in response to regulatory or legal requirements or in unusual situations of high hazard should gates be considered.

When gates are to be used at an intersection, it is possible that confusion arising from the presence of both gates and traffic lights could result, which would degrade intersection safety. Another issue with respect to railroad gates is their location. In standard railroad practice, gates are located on either side of the median on the approaches to the tracks. With this arrangement, the gates hold the through crossing traffic but can be avoided by left turners (movement B in Figure 2-14).

*Proposed rules for the Design, Construction and Operation of LRT Systems Including Streetcar Operations (Draft July 20, 1977). California Public Utilities Commission.

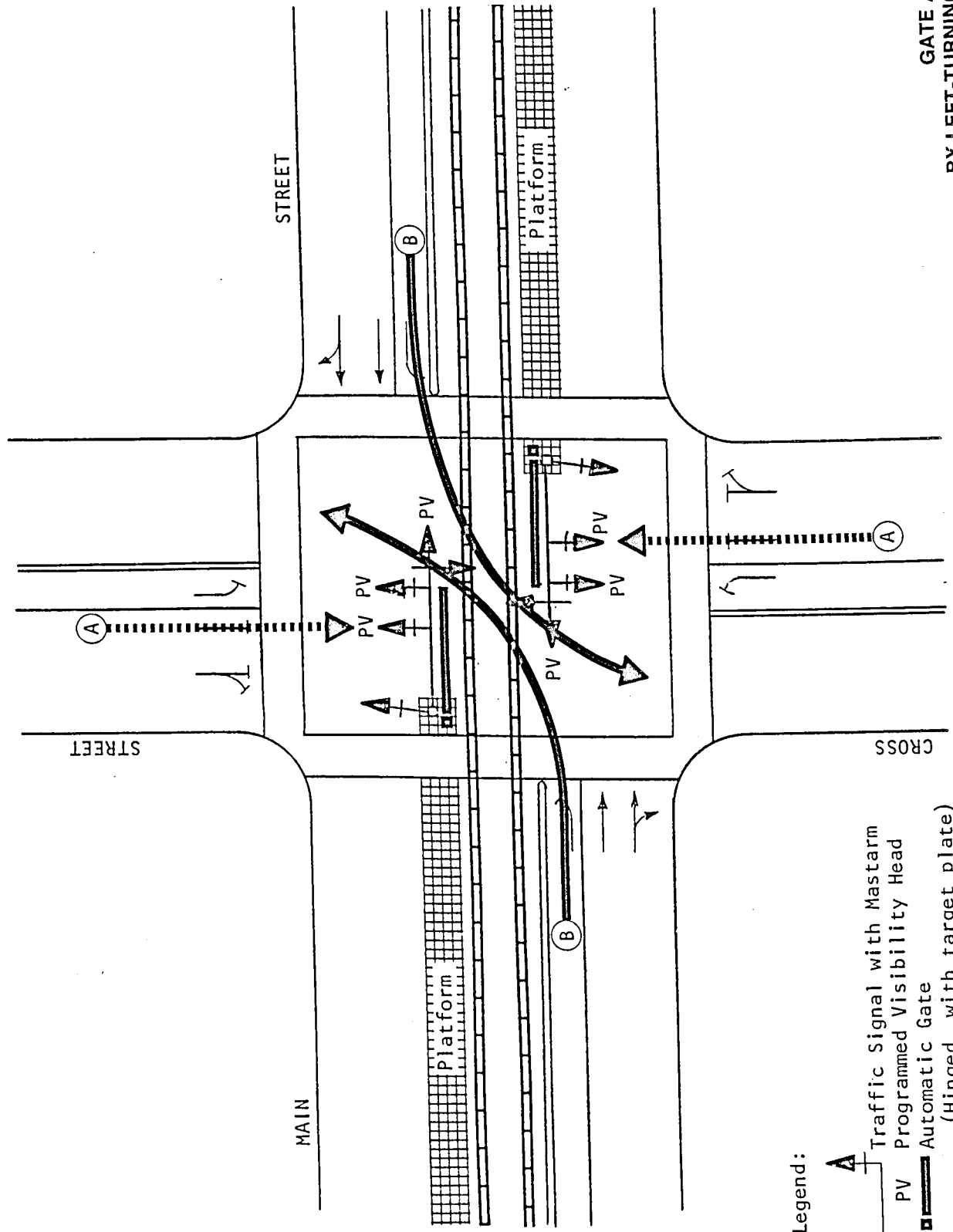
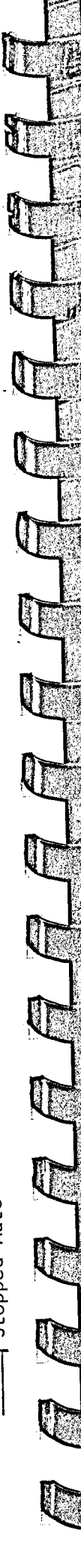


FIGURE 2-14
GATE AVOIDANCE
BY LEFT-TURNING VEHICLES

- Legend:
- Traffic Signal with Mastarm
 - Programmed Visibility Head
 - Automatic Gate
(Hinged, with target plate)
 - Moving Auto
 - Stopped Auto



To eliminate this problem, both sides of the LRT ROW should be completely gated, or each individual movement protected by a gate (Figure 2-15).

For this design, additional median width is needed. If near-side gates are used on the cross street approach, however, right turn on red (permissible in most states) may not be possible, thereby decreasing the available capacity of the intersection.

Figure 2-15 shows typical gate installations at an intersection. The gate can be placed on an island adjacent to station platforms (Location A), on the cross street approaches to the intersections (Location B), or at the end of the left-turn lanes (Location C). Each location has some advantages and disadvantages, as listed below:

Gates located on the cross street approach to the track (Location A):

- Form barriers for both through and cross-street traffic, as well as left-turning traffic from the main street; and
- Are located away from areas of high pedestrian concentrations. Tampering and vandalism are reduced.

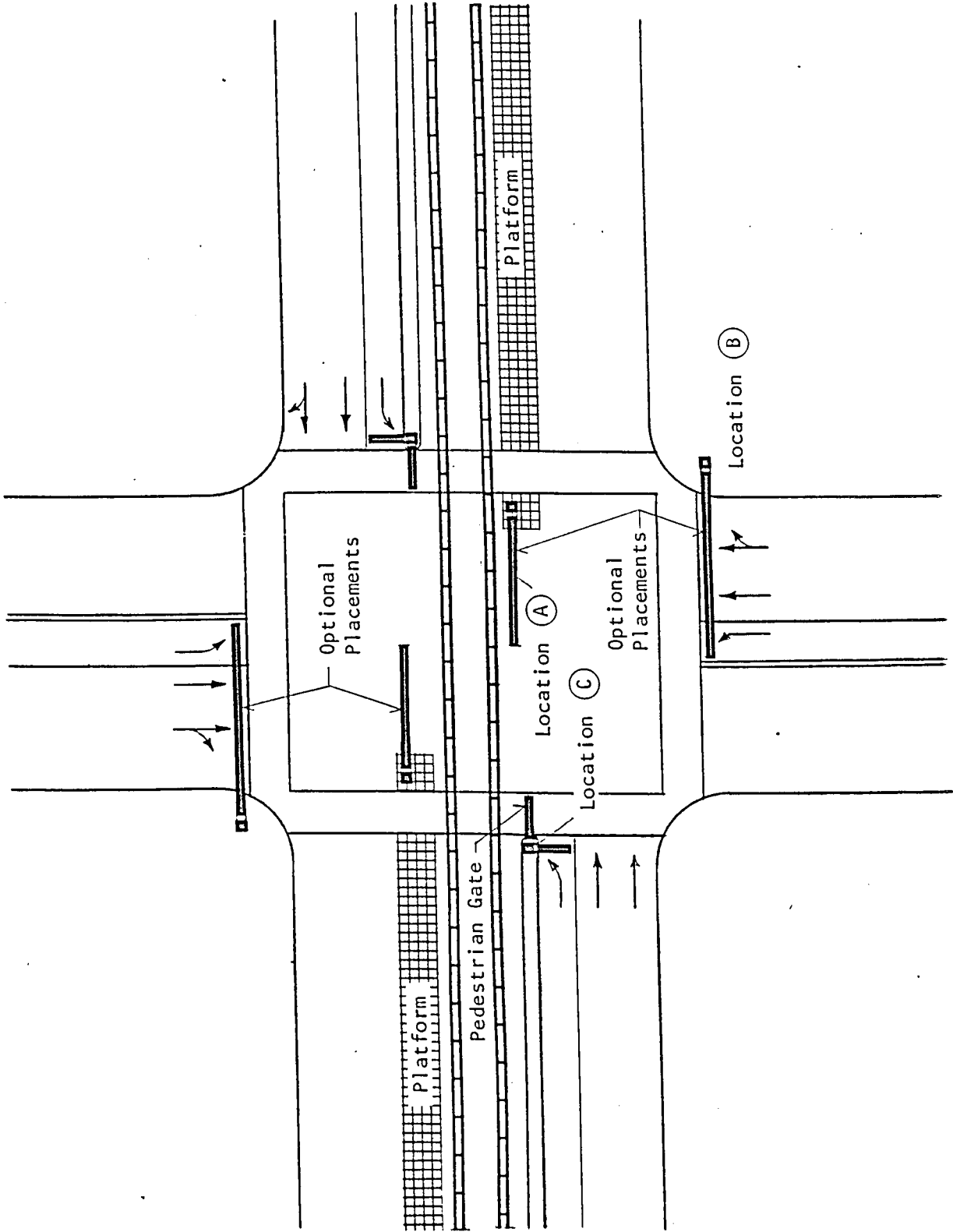


FIGURE 2-15
 PROVISION OF GATES
 FOR ALL MOVEMENTS

Legend:
 ■ Automatic Gate



On the negative side:

- Gates can easily be circumvented by motor vehicles turning left from the main street.
- Auto drivers may be confused since the gates are not located at the stop line.
- Left-turning vehicles from the cross streets could be trapped in the LRT ROW if they run a red light.
- Pedestrians are not controlled.

The first disadvantage of this gate location could be mitigated by the use of landscaping treatment around the tracks in the center of the intersection. This treatment, running gate-to-gate, might include on earth area for shrubs on each side and between the two LRT tracks.

Gates located at the near side location relative to cross street traffic (Location B):

- Are protected from damage by traffic on the main street.
- Can be mounted in tandem with pedestrian gates.

- Cannot trap any traffic movements.

On the negative side:

- Gates mounted on the sidewalk could disrupt pedestrian flow, be subject to vandalism, and could, in extreme cases, injure pedestrians.
- Only cross street traffic would be stopped. Left-turning vehicles on the main street would not be prevented from crossing the tracks.

Gates can be installed to control left turns from the main street (Location C) to complement gates at either Location A or B and provide a positive barrier to the left turns that could proceed with installations A or C. Advantages of this installation are:

- These gates can also be mounted in tandem with pedestrian gates.
- They can be used in combination with gates at either Location A or C.
- They are not located close to major traffic flows.
- Fast opening and closing of the gate is possible because of the short gate arm length.

On the negative side:

- . Location is difficult because street space is usually limited.
- . Pedestrians might be impacted by the proximity of the gate housing to the crosswalk.
- . Vehicles making sharp left turns from the major street could collide with the gate housing.

PREFERENTIAL CONTROL OF LRT SURFACE LINES

Introduction

The distinguishing feature of modern surface light rail lines is the specialized use of traffic control at crossings and intersetions to reduce transit delays. Modern traffic control techniques can enhance the operation of light rail considerably as compared to buses in mixed traffic or to the earlier streetcars. When a significant proportion of the LRT line is on reserved ROW where high speeds can be attained between stations, it is essential to minimize delays at crossings and intersections in order to maintain the otherwise achievable high levels of performance. This can be accomplished by adjustment of traffic

signals to provide preferential treatment to light rail. This can provide separate or extended green phases to transit while delaying traversing and left-turning automobile movements across the LRT tracks. In actual implementation of this strategy, the resulting gains in transit performance must be weighed against a range of resulting impacts on vehicular and pedestrian movements. Applications of preferential control, therefore, will be found to be attractive and implementable for certain ranges of traffic volumes at the intersection, when street geometrics are available, and when certain auxiliary traffic management measures can be adopted. In Chapter 3, the various conditions favorable to preferential control of LRT, and the impacts resulting from such application are explored for a range of potential intersection and crossing circumstances. It is important to note that the inability or unwillingness to realize the operational advantages achievable from preferential control can lead to one of three potential undesirable consequences: a) degraded operation on the line (i.e., slower speeds, longer headways, reduced transit capacity); b) relocation of the line to a less sensitive, and perhaps less effective patronage-producing alternate surface route; and c) costly grade separation at the intersection and perhaps elsewhere. Hence, the importance of careful predetermination of the feasibility and probable acceptance of preferential traffic control cannot be overstated. In particular, public agency attitudes and policies and public perception of the role of transit versus the role of the automobile in modern American cities will determine the

acceptance of the preferential control strategies in future LRT applications. Certainly, greater acceptance of preferential treatments will lead to more effective and low cost LRT installations in the United States.

A variety of preferential controls is employed in modern LRT technology; each is suited to particular circumstances on the LRT line. For example, special controls are used at some locations to permit immediate but sporadic LRT movements across traffic lanes at turnouts. On many LRT installations, preferential green signals are granted to transit as part of normal traffic signal cycles, even during peak periods. An important variant of this technique permits synchronization of LRT movements with auto movements on arterials having interconnected signals with a high speed green progression. The most effective form of preferential treatment for LRT is unconditional preemption of all vehicular traffic in favor of LRT movements. While this strategy may be used with success on low-volume crossing streets, it can lead to traffic congestion in the urban core or at high-volume crossings.

Technologically, the principles of preferential traffic control are simple, and analogous to preferential treatment for autos and buses. The arrival of the light rail vehicle at the intersection is detected by various means and, depending on traffic conditions and other factors related to the traffic control system, signal phases are adjusted to permit LRV passage or reduce delay to the LRV.

The devices used on most modern installations to detect the arrival of the LRVs and to activate preferential traffic cycles are conventional, proven, and reliable. Their capabilities are limited, however, when it is necessary to handle the more complex movements which sometimes occur during peak periods. To overcome these limitations, several new computerized control techniques are being employed experimentally at various locations in western Europe (see Appendices). Consequently, the LRT preferential control technology relies upon fairly conventional traffic control hardware.

A range of preferential traffic control techniques is reviewed in the following pages, and priority treatments for both intersections and midblock crossings are addressed. Many of the options discussed for LRT crossings at intersections will apply equally well for midblock crossings.

Types of Preferential Control

Two terms, priority and preemption, are used to describe the preferential treatment given to LRT at traffic signal controller intersections. Preemption implies that, consistent with safety, an immediate green is given to the arriving LRV regardless of traffic conditions. Priority implies that, in addition to safety, the relative condition of other vehicular and pedestrian movements is assessed before the signal is changed in favor of the arriving LRV. Because of the potentially severe

traffic congestion which might develop upon the unconditional granting of green to light rail (preemption), the technique is generally used only at minor crossings. It is possible to forecast the traffic congestion impacts of preemption, however, to show the "worst case" resulting congestion. If these impacts fall within an acceptable range, it follows that the actual impacts of less restrictive priority treatments would be less severe. In Chapter 3, this analytical technique is applied to establish the limits of acceptance of preferential control at a range of intersections and crossings.

In the most general sense there are five basic strategies for control of LRT crossings at intersections:

- . Conventional traffic signals without special phases for LRT
- . Traffic signal interconnect with progression speed favoring LRT
- . Traffic signals with special phases for LRT
- . Priority
- . Preemption

The first provides, of course, no preferential advantage to LRT. It is the standard streetcar traffic control technique and is useful in this review only in establishing a baseline against which the advantages and impacts of preferential control can be measured.

The next two strategies provide a measure of fixed but perhaps less effective preferential control: the LRT is given an advantage at fixed preset intervals, but any unexpected delays incurred in reaching the signals are not offset by special adjustments in signal phasing. The last two strategies progressively extend transit's operational advantage. In fact, the last strategy, preemption, has the potential of providing performance competitive with that of an exclusive guideway, if coupled with fully reserved surface ROW.

The following discussion focuses on preferential treatments for light rail in intersection medians. However, most of the alternative control strategies apply equally well, sometimes with minor modifications, to alternate types of LRT ROW. Some of the control methods cited are more applicable to a given geometric configuration and will be so noted.

LRT Subject To Conventional Traffic Control. This strategy provides no special signalization of phases for the movement of LRT. The signal cycle controlling the movement of motor vehicles is also used to control LRT movements. An LRV receives the same treatment as any other vehicle in the intersection and must obey the appropriate signals. On older

streetcar lines this is the common method of control. It is used in mixed flow or in median operations when traffic volumes are too high to permit the development of additional delays arising from preferential control. With conventional traffic control, the delays experienced by LRT are a function of signal phasing and street congestion. The latter does not directly contribute to delays for median operations but is important for mixed flow. Under congested conditions, LRT is delayed between intersections and, in addition, at intersections, because of increased opportunities for conflicts with turning and traversing vehicles. Particularly during peak periods, this method of operation can lead to schedule unreliability and low operating speeds in the range of 8-10 mph (13-16 kph). In modern application, this form of control should not be considered unless absolutely necessary. The signals used to control light rail in mixed flow are usually part of an overall city interconnected traffic signal control system operating on a fixed time basis or with computer control set to accommodate peak and off-peak traffic conditions. With interconnect, progression speeds in the 25-35 mph (40-55 kph) range are often used. Because the LRV periodically stops at stations, it cannot travel long distances at a constant speed. It is consequently unable to stay in the green band for a considerable length of time and incurs further delays.

In summary, use of conventional traffic control on LRT lines will, at best, maintain traffic speeds within the same range as for adjoining vehicular traffic. On low-volume streets (5000 vehicles per day or

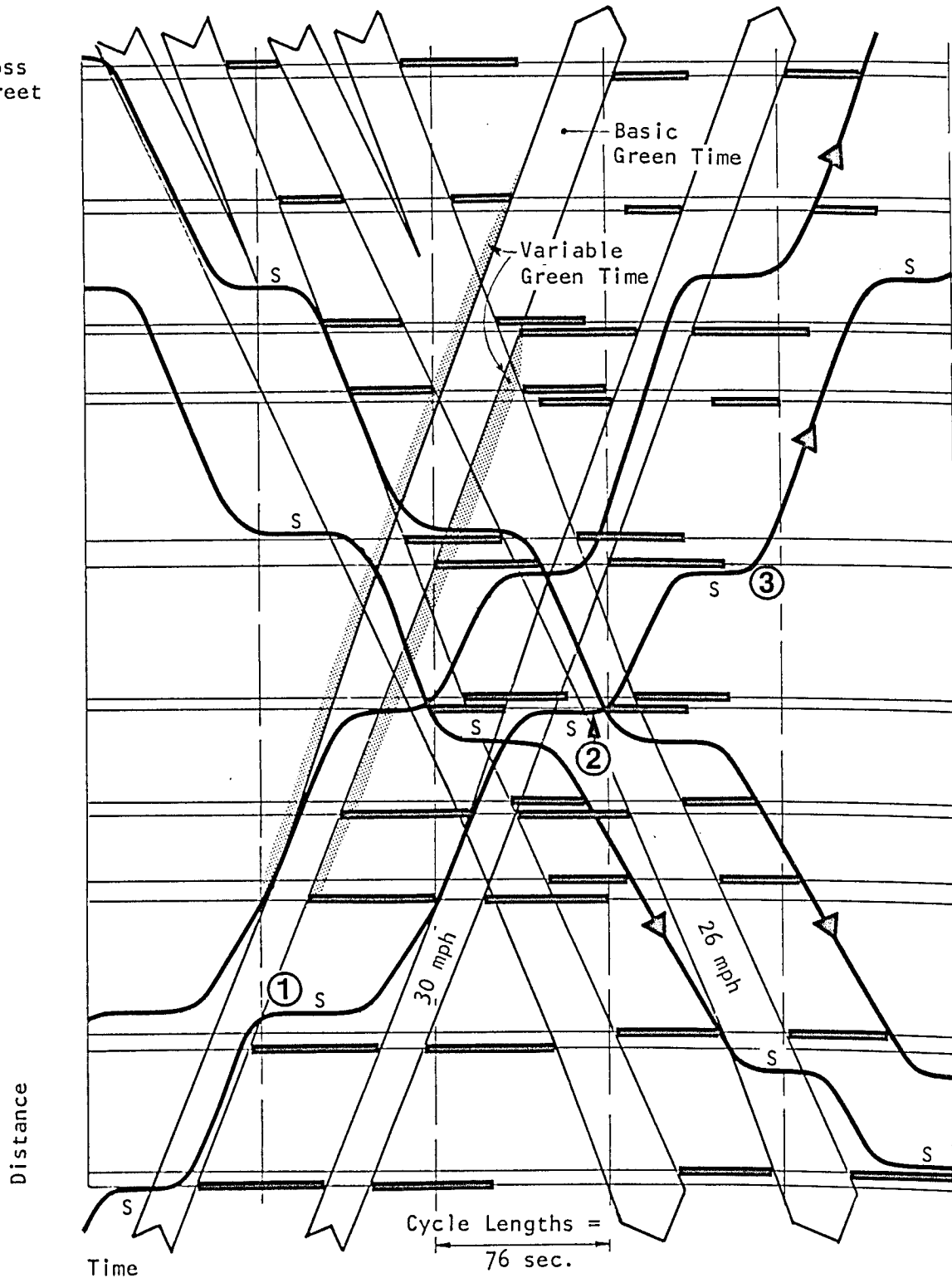
less) in mixed flow or on reserved ROW, or when running on medians, LRT peak speeds will approach (or even exceed at times) automobile speeds, but average speeds will be lower due to station stops. For these conditions and on lines with closely spaced stations, this form of control will not significantly degrade transit performance relative to even the more efficient operations on exclusive ROW since the cumulative effect of station delays can be substantially greater than that of intersection delays. Conversely, operation of LRT lines in mixed flow on high-volume streets with conventional traffic control will be degraded substantially, compared to what could be achieved by preferential control or on exclusive guideways. Consequently, new LRT lines will not often be located in mixed traffic on high traffic volume streets. Usually, locating the LRT line on such streets will result mainly from a conscious decision to trade off construction cost savings achieved from avoiding grade separation against traffic impacts. In several recent instances of LRT design, the adverse effects of mixed flow operation on selected lane segments have been circumvented by dedicating the streets to transit/pedestrian mall use only.

Interconnect with Progression Speed Favoring LRT. On LRT lines operating in reserved ROW on major streets where a traffic signal interconnect system is used, there are strategies which can be used to improve LRT performance.

In Figure 2-16 the operation of a traffic interconnect system is shown schematically in a time-versus-distance diagram. The traffic signal phases are coordinated to create green traffic signal indication bands moving in either direction at pre-selected speeds. By synchronizing the automobile speed with the speed of the green band, traffic can move fairly fast over considerable distances. In Figure 2-16, two bands of basic green time are shown in both directions.

Since light rail must make station stops, it cannot maintain the high speed of the adjoining automobile traffic and cannot operate within the basic band of green time, thereby further reducing its speed by forcing more stops at intersections where the LRV would encounter the red phase of the cycle. A simple strategy in such cases is to adjust the signal timing to more closely match the LRT average speed as determined by its delays at station stops. Thus, the likelihood of additional delays at intersections would be minimized to achieve this end. Progression speed along a given street could be reduced from, say, 25 mph (40 kph) to about 15 mph (25 kph) or less, but that is not always necessary for the success of the strategy. The lower transit speed would account for delays at passenger stops. LRT would be favored by reduction of the number of times that a transit vehicle would be stopped at a red light, but at the same time delays to motor vehicles would increase. Where alternate routes are available, some motor vehicle trips would be diverted to parallel routes. This diversion would reduce the likelihood of motor vehicle/LRT conflicts and also could improve safety along the LRT line.

Cross Street



Legend:

- LRV Movement
- S LRV Stop

FIGURE 2-16
TIME-SPACE DIAGRAM
SHOWING LRV TRAFFIC SIGNAL PROGRESSION

As an alternative, or in combination with the above, the travel speed of LRVs can be increased by selective placement of the platforms. Alternating platform locations from near-side to far-side at intersections achieves a more desirable progression speed. LRV station departure time would then nearly coincide with the arrival of the next green band, and the progression speed can be set to more closely coincide with auto travel speeds. A good example of this treatment can be found in Figure 2-16. The cycle length used was 76 seconds, with an average progression speed for autos (and for LRVs between stops) of about 30 mph in the off-peak direction of travel and 26 mph in the peak direction. Traffic phases do not coincide in both directions, as shown in the Figure. Following the progression of one LRV it can be seen, at (1), that the vehicle running in the peak direction is stopped at a platform on the far side, i.e., it departs while the phase is still red. For good combination of LRV speed and station spacing, the vehicle, after stopping on the near side, just crosses the intersection, at (2), before the end of the green phase. For this illustration it can be seen that at the next stop, at (3), the vehicle would encounter a red phase. Location of the platform again on the near side would allow the vehicle to make a station stop while the signal is red. This operating strategy will improve the operation of LRT only when the street geometrics and station spacings fit with the desired green band progression. Certain adjustments in LRV and progression speeds are obviously possible and the strategy will produce good results, but it should not be expected that it will be found applicable or successful in all cases.

In considering the applicability of this strategy to specific local conditions, the opportunities for locating station platforms on the far and near side of intersections should be considered. In addition, there are other concerns. During periods of light patronage demand (midday or evening hours), the dwell time at stops is likely to be shorter than during the peak hours. If the progression is not adjusted for off-peak traffic volumes, LRT movements would become unsynchronized and delays to LRT would result. The overall travel speed of light rail, however, is likely to be nearly the same with this treatment during peak and off-peak hours. Occasionally, the light rail vehicle will be able to travel with the normal vehicle platoon for considerable distances, particularly if operating procedures permit the skipping of station stops where no boarding or alighting is required.

A more sophisticated traffic signal progression concept may be possible, whereby the station dwell time variation throughout the day is reflected in the signal timing. This would reduce delays on a 24-hour basis and help LRT achieve superior operating speeds even during off-peak hours. Technical, cost, reliability and traffic aspects of such improvements would require further study before the improvements could be adopted.

Special Signal Phases for LRT. Special signal phases to favor LRT movements, such as blocking cross traffic while the LRV is allowed to move, may be provided during every signal cycle on a fixed time basis, or by actuation by approaching LRVs. This strategy is most applicable where LRVs make unusual movements which create conflicts with motor vehicles, such as at locations where light rail tracks leaving the center of the street turn into a cross street or enter a separate ROW. The primary purpose of the special signal phase is to hold the conflicting movements and therefore reduce the potential for accidents.

The special LRT signal phase could take the form of a preset, fixed advance or delay in the phasing for opposing automobile traffic. This condition is not desirable unless the conflicting LRT movements are very frequent or the impacted automobile traffic so light as not to justify the additional cost of equipment needed for LRT actuation of the signals. With LRT actuation of the special phase, however, green time would be taken away from one or more conflicting vehicular phases. If the frequency of the LRT movements at these special locations is low, delays to motor vehicle flows also are likely to be low.

Priority Treatment of LRT Movements. This strategy is somewhat similar to the bus priority traffic control strategies used in the United States and elsewhere. At intersections, preferential green is granted to LRVs on a conditional basis, i.e., only when the resulting disruption to

cross or turning vehicular traffic flow is minimal. Generally, LRT is not given a priority phase when a large moving platoon of vehicles would be disrupted, since there may be an available block of green time at the beginning and end of the cross street green phase that could be allocated to LRT. The granted green time can be of a fixed length or made a function of actual cross street traffic. For example, shorter greens would be available, if at all, depending on the volume of traffic delayed by granting the priority passage to LRT. However, considerable further development of traffic control technology is required before adapting this concept to general use at LRT crossings. A system of this type is being developed and tested for the Commonwealth Avenue segment of the Green Line in Boston.

Advanced design signal control systems are used with this strategy to detect traffic movements and locate vehicle platoons. A master controller predicts the arrival time of the platoons and of the LRV at the intersection(s) in question. If a transit vehicle is calculated to arrive prior to an approaching platoon, the LRV may be given a priority green indication. If both are to arrive simultaneously, the signal may be set to stop either the LRV or the platoon to allow the other to clear. This type of operation links the traffic controller and the

vehicle detectors located in the street system. A number of control parameters can be used to govern the degree of priority treatment LRV should receive. Control systems of this type are usually described as adaptive.*

The effectiveness of the priority control approach is also influenced by pedestrian crossing requirements. Where pedestrian crossings are permitted, traffic signals must be timed to provide sufficient walk time for pedestrians to cross. With fixed signal time phases, adequate timing for pedestrian crossings is provided during every phase. At many locations, pedestrian signals are actuated manually, and signal phases can be shorter than in fixed cycle configurations. Where pedestrian crossing intervals must be provided and minimum green is needed for

*In certain cases the traffic disruption caused by an "adaptive" control system actually may occur at a considerable distance away from the LRT intersection. Areawide control techniques may be required to maintain equity of movements to all modes. The flexibility of such control systems is limited by the amount of disruption deemed tolerable at adjacent intersections due to signal adjustments made to favor LRT movements. The technical and cost effectiveness of areawide adaptive controls would need to be established.

cross traffic, the green time available for LRT preferential treatment is limited. At locations where the signal cycle length is longer than that required to handle pedestrian movements, the signal timing can be adjusted significantly to favor LRT crossings.**

**For example, if a given intersection requires 30 seconds for each phase to clear pedestrians (for a total of 60 seconds per cycle) and the signal cycle is actually 70 seconds long, there remains a maximum of 10 seconds which might be utilized for LRT priority treatment. Whether this interval is allocated to LRT or not is a decision which depends on the extent of conflicting vehicular demand and the degree to which priority shall be given to transit. When the pedestrian phases are actuated manually, and no pedestrians are present, the cross street green time of 30 seconds can be shortened to the minimum time required to carry the bulk of the cross street traffic. Depending on traffic volumes, this could be anywhere from zero to 20 seconds. Such decisions are best made by some form of local computer control which measures the traffic volumes of conflicting movements, and relates them to available capacity and overall signal system operation. Computer installations controlling movements at one or more adjoining intersections along an LRT line are in existence, such as at Cologne, West Germany.

Preemption Treatments for LRT Movements. When this operational strategy is used, the LRT vehicles are allowed to cross the intersection by preemption of the green granted crossing or turning traffic. With this form of control, LRT operating speeds and operating characteristics, unless limited by other civil regulations, can approach those achieved by transit on grade separated routes. Because preemption is unconditional, the status of vehicular traffic is not used in establishing the exact traffic signal timing. Only the minimum time intervals needed to clear the intersection of crossing traffic and pedestrians are permitted before the signal changes to the LRT preemption phase.

Operationally, the preemption cycle can be initiated automatically or manually. In the first mode, automatic LRV detection and actuation of the preemption sequence guarantees that preemption occurs at the optimum time to ensure minimum disruption to preempted motor vehicle traffic. Under the automatic mode, depicted in Figure 2-17, an approaching LRV is detected a sufficient distance from the intersection to allow enough time to clear conflicting movements from the crossing. This must be accomplished prior to that point in time when the LRV reaches a safe stopping distance from the intersection. Before the LRV reaches the limit of its safe stopping distance, verification of preemption phase actuation occurs by means of a wayside signal or an automatically monitoring system. The safety devices signal the operator or automatically stop the LRV at its normal braking rate if the preemption phase has not been actuated. Preemption remains in effect until the LRV completes its traverse and is detected by a preemption release detector.

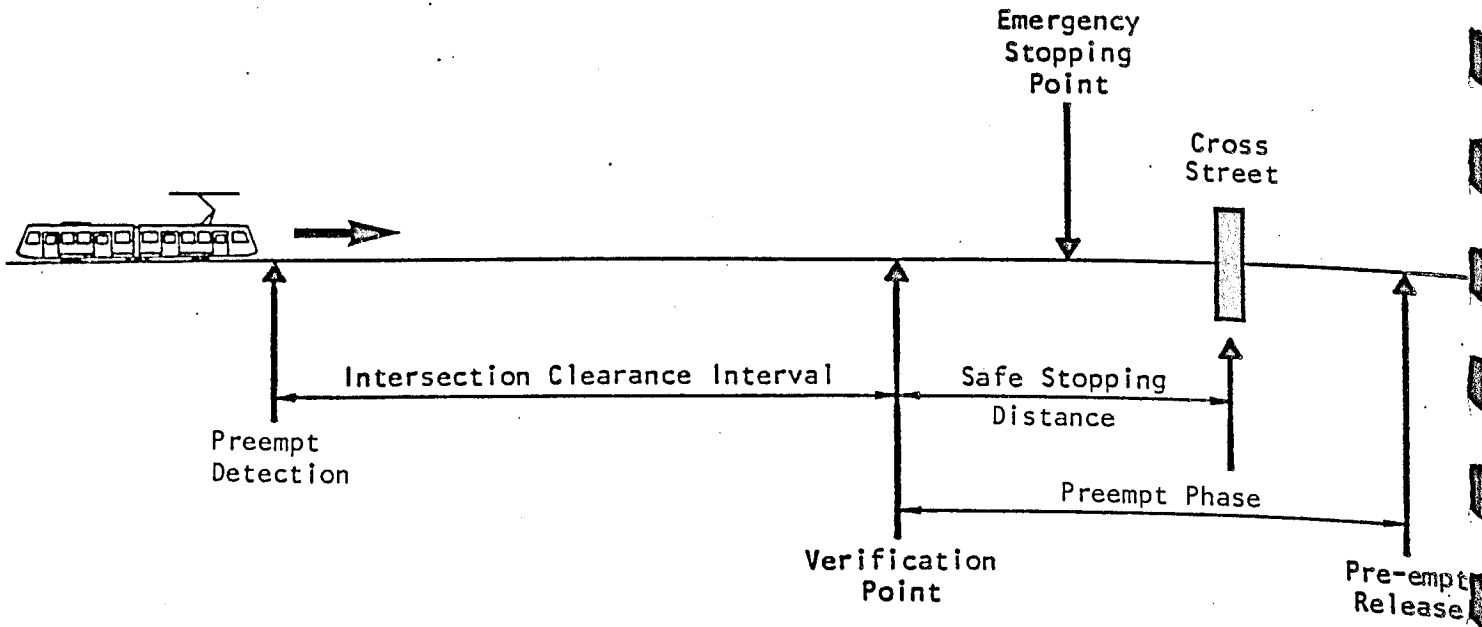


FIGURE 2-17
 AUTOMATIC PREEMPT SEQUENCE

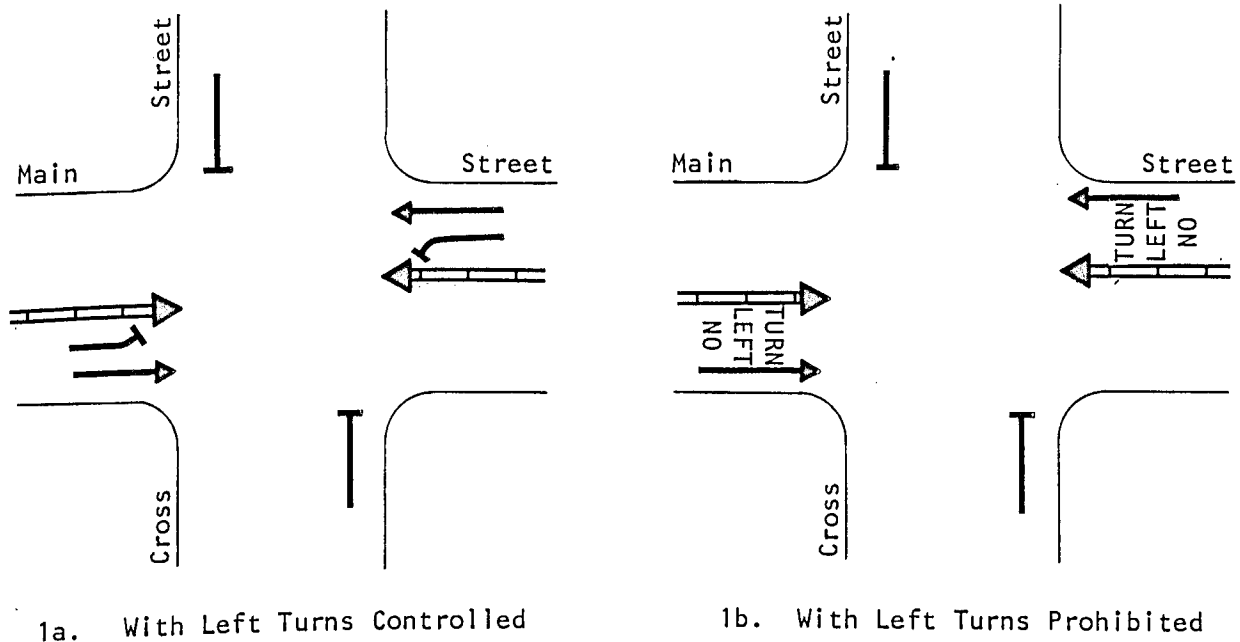
The second operating mode involves manual actuation of the preempt sequence by the train operator. In this case the LRV operator activates an onboard preemption transmitter prior to crossing the intersection. After the intersection is traversed, the preemption sequence is automatically terminated by a release detector or by a time clock. This approach is sometimes used at intersections with near-side station platforms where the operator can observe the condition of cross street traffic. In such cases, LRV station dwell time cannot always be predicted and driver discretion is provided for by allowing actuation of the preemption sequence in a manner which will minimize delay to motor vehicle traffic. This strategy is also sometimes used where LRT operates in mixed traffic. In cases where safety and speed are deemed to have paramount importance, the automatic preemption strategy is, however, more appropriate.

There are two basic types of traffic operational strategies that can be utilized for preemption of intersections by LRT. In one case, traffic which flows parallel to the LRT movement is permitted during the preemption phase. In the other case all traffic is stopped.

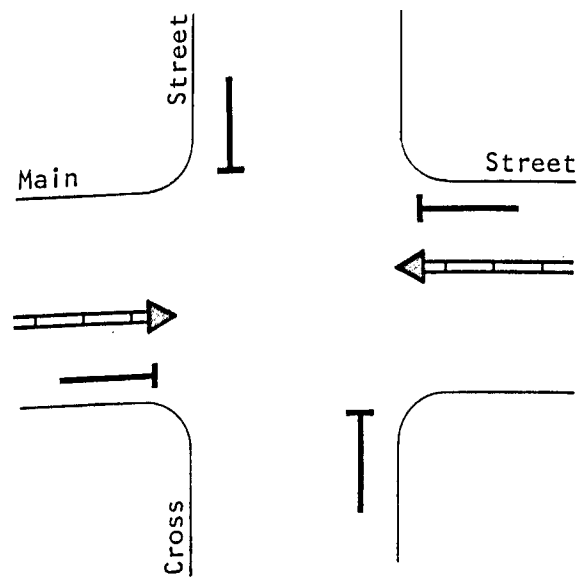
When parallel traffic flow is permitted during preemption, the LRV proceeds through the intersection and the crossing street receives a red indication. This strategy is possible where a separate traffic signal

phase is provided for the left turn lanes (Case 1A, Figure 2-18) or where left turns are prohibited (Case 1B). This would be a safe configuration because no conflicts would exist between moving traffic and the LRV. This phasing sequence, without preemption, is currently used in San Francisco, and, with preemption, on Boston's Green Line. This type of preemption phasing is more efficient because the least amount of green time is lost to motor vehicles, thereby minimizing potential congestion.

When traffic flow on all approaches is stopped during preemption (Strategy 2, Figure 2-18), traffic signals on all vehicular approaches show a red indication while the LRV proceeds. This is somewhat similar to existing railroad preemption signal phasing. The resulting amount of green time lost to motor vehicle traffic is significantly greater than when parallel traffic movements are permitted. This strategy is applicable at intersections where left turns from the parallel traffic lanes are normally allowed and where separate left-turn lanes or separate left-turn indications are not feasible. It is also applicable where LRT lines cross the intersection on the diagonal, turn from one street to another, or cross traffic to another ROW. An example of the application of this strategy is found in The Hague at a location where LRT tracks cross a roadway at a shallow angle. This method of operation provides maximum safety, but it maximizes congestion in comparison to other preemption strategies. It is most applicable at midblock crossings where stopping all vehicular traffic is essential for crossing safety.



STRATEGY 1 - Parallel Flow



- Legend:
- LRT Movement
 - Auto Movement
 - Auto Movement Stopped

STRATEGY 2 - All Stop

The preemption techniques used to control intersections can also be used at midblock crossings. However, midblock crossings are more easily controlled since turning movements are not present and the minimum crossing intervals for pedestrians (for clearance across the LRT tracks only) generally are much shorter than the time needed for traffic movements. The shortened clearance interval means greater flexibility in adjusting the signal timing to favor LRT. Where the midblock crossings are located far enough from nearby intersections, the degree of preemption can be made solely a function of cross street traffic and LRT headways. In recent studies of LRT deployments made at various locations in the United States, capacity calculations have shown that unconditional preemption is possible at isolated crossings of four-lane streets carrying traffic volumes as high as 25,000 vehicles per day for LRT headways as low as twice the minimum signal cycle time at the crossings.

For midblock crossing locations close to an intersection, the control strategy must also consider conditions at the adjacent intersections. Unconditional preemption could result in motor vehicle queues blocking the adjacent upstream intersections. In such cases it is therefore important that the traffic signal phasing be interconnected between the intersection and the midblock crossing. Care must be taken to provide for proper crossing clearance intervals to keep the street section between the LRT crossing and the adjacent intersection clear of motor vehicles. Clearance requirements, however, could restrict the degree of preemption afforded LRT at such crossings.

When traffic signals are interconnected and the street carries heavy flows crossing several major intersections on either side of the LRT tracks, the flow of vehicular platoons on the main street may have to be given priority over LRT. Light rail vehicle traverses may only be permitted during times when LRT can proceed through the crossing without major disruption to cross street traffic.

From the point of view of LRT operations, preemption strategies are obviously beneficial since they allow the highest level of service achievable at grade (as described by the speed and capacity achievable on a given line). It is also obvious that preemption strategies can have undesirable effects on automobile or pedestrian traffic. Since precise scheduling of LRT is much more difficult than scheduling for conventional rail transit, the LRVs often arrive randomly at intersections. With preemption, this may result either in providing excess and unusable green time for parallel traffic and/or in excessive delays to parallel or crossing traffic. Excess and unusable green time (Figure 2-19) will occur when the LRT preempt phase follows immediately after the main street green phase but before the next LRV has arrived at the station. Excess delays for parallel traffic occur when a platoon of vehicles is stopped during the LRT preempt phase and cannot reach the next downstream intersection at its preprogrammed time. Excessive delays to cross traffic would occur if the preempt phase is initiated just when a conflicting vehicle platoon arrives.

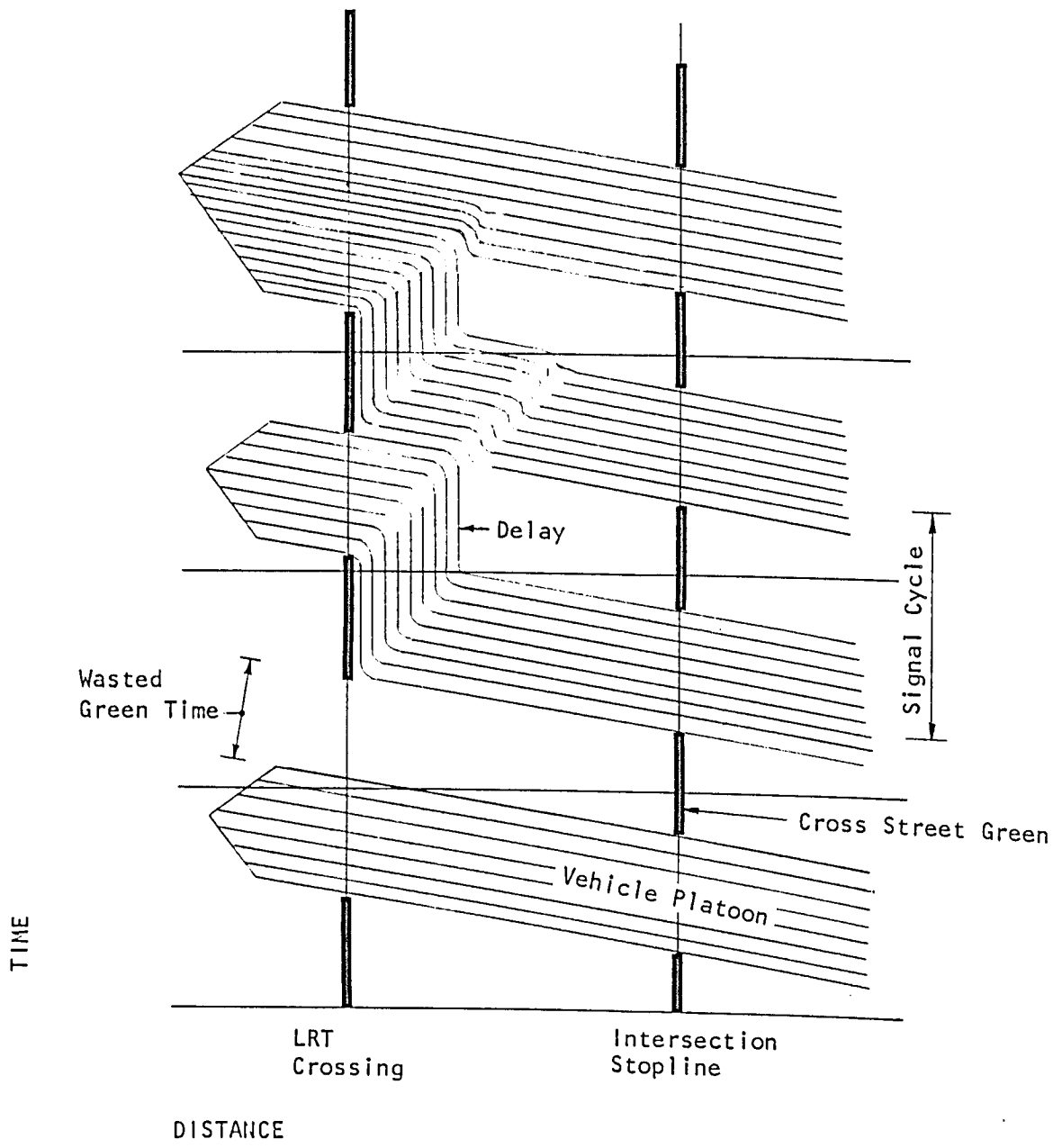


FIGURE 2-19
 DELAYS DUE TO RANDOM LRT PREEMPT

On streets with interconnected traffic signals, halting arriving vehicle queues through preemption can contribute to an increased incidence of rear end accidents since drivers would be forced to come to a sudden stop. However, reductions in the number of rear end accidents is one of the benefits usually cited when the decision is made to install traffic signal interconnection. If the street system in the vicinity of the crossing in question carried large volumes relative to its capacity, then the system has very little flexibility to recover from such disruptions. In that case, unconditional preemption for light rail could result in the formation of long vehicle queues, resulting in long vehicle delays. This could be deemed unacceptable by local agencies, businessmen, and residents. Generally, unconditional LRT preemption would have the least impact on traffic along isolated arterials or intersections. Use of a preempt strategy which does not prohibit parallel flow along a relatively isolated arterial that has interconnected signals would confine disruption primarily to traffic on the cross streets. Such disruptions would then be local in nature and may be more acceptable. Even at isolated intersections with relatively high volumes, the delay to motor vehicle traffic caused by preemption would be very local in nature, and often would represent less person-delay to motorists than no preemption would cause to light rail passengers. Finally, preemption is effective where station platforms are located on the far side of the intersection or where there are no platforms at all.

In all cases, use of unconditional preemption will result in some loss of intersection capacity for automobiles. The decrease in capacity is proportional to the frequency of LRT intersection crossings (LRT headways). It is also a function of the location and level of service of upstream intersections as well as of the particular preemption strategy used. Examples of this loss in capacity are shown in Chapter 3.

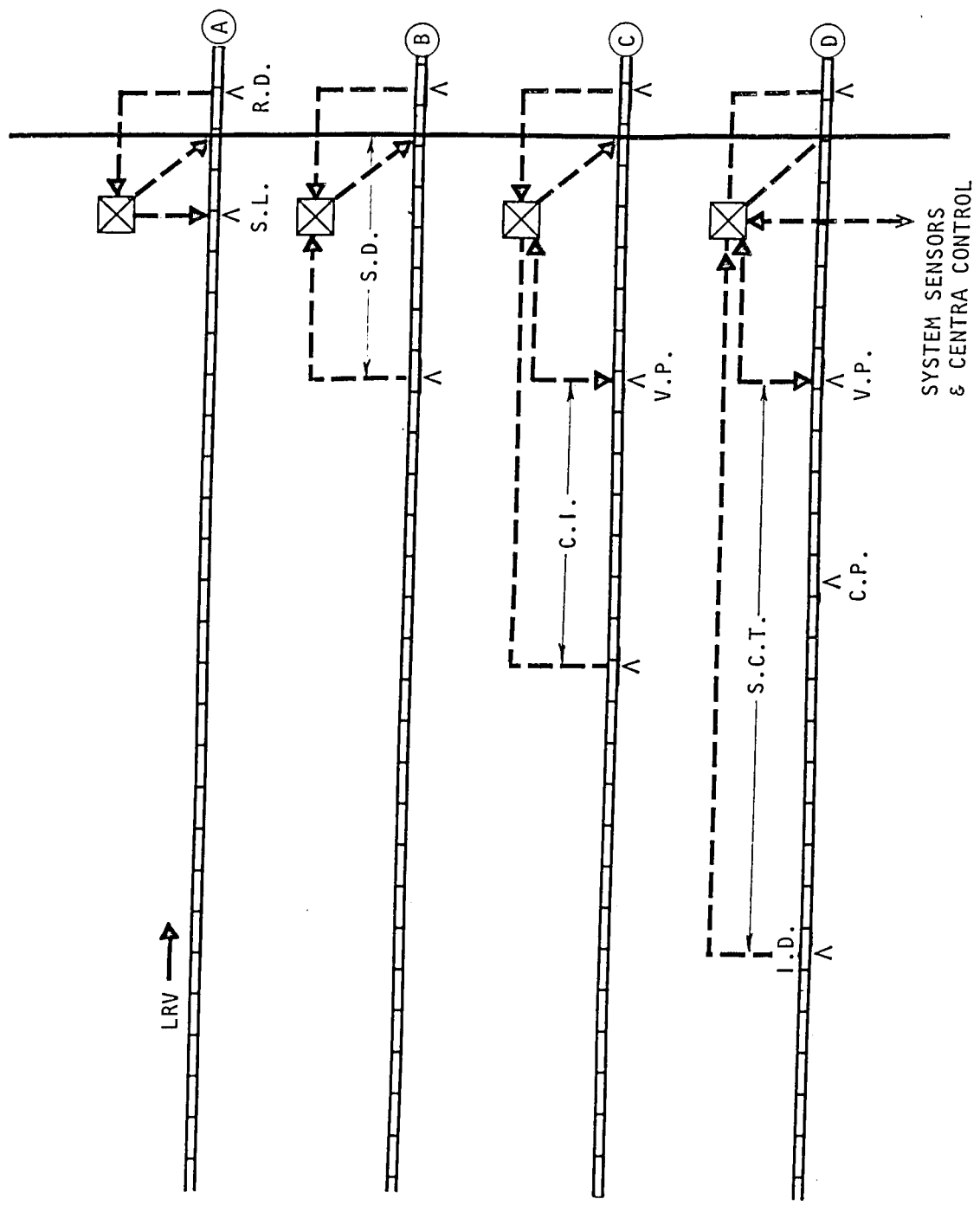
Detection. Proper and timely detection of arriving LRVs is an important element of preemption strategies. The safety and smooth operation of the LRT/vehicular street traffic system depends upon this detection.

Two basic types of detection are used to indicate the arrival of an LRV at an intersection. With onboard detection, a signal is sent by the LRV operator (or automatically by the vehicle) to a wayside sensor which connects to an intersection signal control device. The second method employs wayside detection of vehicles. Detector devices are located between the tracks or on the overhead wires. The position of detectors relative to the crossing is a function of the preemption strategy used. Where the LRV stops at the intersection prior to crossing, the detector is located near the stop line. This treatment is most applicable where near-side platforms are used and a special priority signal phase is provided. Detection locations upstream of the crossing are applicable to far-side platforms and are used to keep LRT delays to a minimum.

Types of LRV detectors are listed below, the first two being the most commonly used and the last two the most experimental. Locations where these devices may be found are provided in parentheses.

- . Magnetic detectors embedded in the trackbed (Boston's revamped Green Line)
- . Overhead catenary and/or mechanical switches (San Francisco)
- . Railroad train detectors using insulated track circuits (Philadelphia's Red Arrow Division)
- . Vetag (The Hague), SESAM (Zurich), or similar detection systems which communicate between vehicles and receivers located in the ROW
- . Radar or ultrasonic detectors mounted adjacent to the ROW
- . Onboard radio or optical systems such as Opticom, which send signals to remote receivers (used by bus transit systems in several U.S. cities)

Detection Strategies. Figure 2-20 illustrates four LRV detection strategies. Method A locates the detector just upstream of the cross street at the LRV stop line. After receipt of the signal from the LRV detector, the intersection signal control device can initiate the intersection clearance interval and actuate the LRT crossing phase.



Legend:

- △ Detector
- ⊠ Controller
- S.L. Stop Line
- R.D. Release Detector
- S.D. Stopping Distance
- V.P. Verification Point
- C.I. Clearance Interval
- I.D. Initial Detector
- S.C.T. System Computation Time
- C.P. Calibration Point



After the LRV has crossed, the release detector returns the intersection control to normal operation. This method is most applicable when an LRV must come to a stop upstream of the crossing, such as with a nearside platform. It has been used on the Red Arrow Division in suburban Philadelphia. LRT preferential treatment could range from a special phase to full preemption.

Method B involves detection of the LRV at the maximum safe stopping distance point upstream of the crossing. After detection, the control device immediately changes the signal to provide green time for the LRV. This type of control is applicable at crossings where a clearance interval is not required or is very short. Such may be the case at isolated midblock crossings where only an amber indication is required to clear the crossing, LRV headways are five minutes or longer, and cross traffic volumes are relatively low. A downstream release detector then returns the crossing to its normal operation.

Method C illustrates the use of upstream detection with a long clearance interval at the downstream intersection. This is similar to Method B with the exception that the detector has to be located at a distance upstream of the intersection equivalent to the safe stopping distance plus the clearance interval. After initial detection, the control device initiates an intersection clearance interval. Upon its completion, a signal is sent to the verification point. When the LRV passes that point, the LRV onboard control system or the light rail operator is

informed of the status of the downstream intersection signal. If the signal displays a red indication, it remains possible for the LRV to stop safely, either manually or automatically. With LRT preemption, the signal should normally display a green indication. The verification point can therefore be considered an emergency safety feature. A modified version of this method is in operation on the Skokie Line in Chicago.

Method D involves a more complicated system of advance detection which interacts with adjacent intersections or with an interconnected signal control system. The initial LRT detector is located a sufficient distance upstream to allow the master control device or computer, upon receiving an indication from an approaching LRV, to calculate the estimated LRV arrival time, measure existing motor vehicle traffic demand, calculate capacity, and adjust traffic signal settings. The control device can also verify LRV arrival time at the calibration point, and indicate the status of the traffic signals at the crossing downstream. The system involves extensive two-way communication between the detectors and the intersection control device, motor vehicle detectors, and the master control of the interconnect signal system. Signals at the intersection return to normal phasing after the LRV has cleared the intersection. This extremely elaborate and advanced method of detection is most applicable to intersections where the priority

given to light rail is a function of many conflicting traffic demands. It is being implemented on the Commonwealth Avenue segment of Boston's Green Line.

Equipment. A number of equipment alternatives are available for LRV detection. Different varieties of equipment provide a variety of functions and sensitivities that for some systems can even permit discrimination between different kinds of vehicles traversing an intersection. For some preemption strategies it is important that different control commands be given to different vehicles, e.g., turning or through LRVs, buses and LRVs, etc. Magnetic loops and similar devices, commonly used to detect motor vehicles, are not always usable because they cannot distinguish between LRVs and other vehicles. In mixed flow operation, motor vehicles may travel close enough to the LRT track to activate the detector; on LRT ROW shared with buses, distinction between vehicles would be difficult. Transmitters located onboard the transit vehicles have been developed to solve this identification problem, such as in Zurich, but these are not extensively used. Overhead detectors located on the catenary system are in common use. However, excessive wear of overhead detectors, especially resulting from older LRVs using trolley pole power pickup, has been reported. Common railroad track circuits are used on separate ROW sections.

Whichever detection method is selected, it is important that detectors be failsafe and of the highest reliability for safety reasons. Equally important, detectors must also be reliable to avoid LRT delays due to failure to activate the preferential signal and to avoid delays to motor vehicle traffic resulting from unwarranted extensions of the preempt phase.

Stations

Smooth movement of light rail on many arterials is the result of carefully designed intersections and well-planned station stop locations. Good coordination with signals can be achieved because locations can be selected to minimize signal delays. Station dwell times can be fairly constant even during peak hours since passengers can use all doors on each vehicle, up to five double-width doors, for both boarding and alighting, assuming self-service fare collection is used.

Three different issues must be addressed in planning LRT stops: their physical dimensions, their approximate average spacings, and the specific locations of stops along the line.

A number of design principles and dimensions useful to LRT line and stop design existed in the United States professional literature until the mid-1950s when the massive elimination of streetcars and most design

work shifted from urban streets to freeways and major arterials. Thus the "Traffic Engineering Handbook," second edition, published by the Institute of Traffic Engineers, 1950, included substantial material useful in the design of transit stops, islands, stop locations, and so forth. This material has not been updated since that time. Although there are presently no warrants or design standards in effect, planners and designers will find it useful to have at least the basic figures available for a general orientation. For this reason, main dimensional parameters are quoted here for old U.S. and contemporary European experience. They have been collected from various reports and technical papers. A recent comprehensive review of many data sources dealing with this subject has been published recently by Bandi, et. al. The numerical values quoted below should therefore be treated as guidelines; further work will be needed to develop more precise technical warrants and design standards.

It has been found that the length of a single light rail stop platform should be at least equal to the distance between the first and the last door of the longest train consist operating on the line, plus 10 feet (3m).

For a double stop, the additional length of the train plus 5 feet (1.5m) should be used. The width of the area for passenger waiting and boarding depends on the maximum expected passenger volume at the stop, but if

the area is on a median, the minimum width is 5 feet (1.5m), which allows a minimum safe distance from both LRT and highway vehicles. For large passenger volumes a wider area would be required.

To allow reasonably high travel speeds, transit stops should not be spaced too closely unless many of them are only on-call stops on lightly used line segments. Minimum distances between stations of 800 feet (250m) are suggested. Surveys of different cities show that stop spacings on existing LRT lines are usually in the range of 1000-1300 feet (300-400 m) in the central urban areas, but they average as long as 1600-2300 feet (500-700 m) in suburbs. Most lines have overall average spacings of 1300-1600 feet (400-500 m). For modern United States with only moderate density, the average station spacing likely could be much longer. For further discussion on transit stop spacings, see References 4 and 5.

There are three types of locations for LRT stops along streets:

- . Near-side, or at the intersection prior to crossing the street
- . Far-side, or at the intersection, past the cross street
- . Midblock, or away from intersections

Many cities adopt one type of stop location and use it throughout the city. Most commonly a near-side stop policy is used; far-side stops are used less frequently, while midblock stops are found only in special cases. However, uniformity of stop location is seldom justified.

Various other factors influence the choice of station location and there are considerable advantages to using different types, including both near-side and far-side, at different locations along the same route.

Major factors influencing the choice of stop locations are:

- . Timing of traffic signals
- . Vehicular and pedestrian traffic conditions
- . Passenger access
- . LRT priority treatments

As discussed previously, signal timing can be an important factor in choosing LRT stop locations. Generally, the average speed of LRVs (or buses, for that matter) is slower than automobiles on city streets because they must stop not only for traffic signals, but also to pick up and discharge passengers. However, operating speeds can be increased if

the need to stop for a red light can be combined with a passenger stop. At signalized intersections, with everything else considered equal, the stops should be located beyond the signal, i.e., far-side, so that vehicles can travel through the intersection if they arrive under the green phase.

On arterials with fully synchronized signals, the LRV periodically drops out of one progression band and must wait for the next one. The time lost should be utilized for stopping at one or two passenger stops. This is best achieved by use of alternating near-side and far-side stop locations. This method can effect time savings as high as 10 to 15 percent over operation on streets with all near-side or all far-side stops.

In some situations, there may be a particular sequence of near-side and far-side stops which yields an even higher operating speed than simply alternating them, since vehicle delays depend both on the frequency and duration of stopping for passengers and the signal synchronization pattern. However, two basic rules are always valid for equal block spacing:

- . When a near-side stop is followed by two or more progressively coordinated signals and the motor vehicle and LRT speeds are the same, the subsequent stop should be far-side.

- For any length of signal phases and length of delays at stops, alternating near-side and far-side stops are at least equal to and usually considerably better than all near-side and all far-side stop policies.

Traffic conditions must also be considered when determining the location of stops. It is desirable to locate LRT stops so as to minimize interference with other vehicular and pedestrian traffic. Stops should always be connected to both sides of the street by well-marked and signalized pedestrian crossings. Transfers to other transit lines should be provided via paths as direct as conditions permit.

The application of these design principles is discussed in further detail in the design examples contained in Chapter 3.

Safety Considerations

Introduction. Safety of at-grade crossings is one of the issues of greatest concern encountered in the planning and design of LRT lines. Safety problems associated with intersections and crossings can be mitigated greatly by proper design. Heightened public awareness can minimize hazards to pedestrians crossing the LRT ROW between intersections, as well as by planting shrubs in locations which make access difficult, by using Z-type crossings at selected locations, and, in

extreme cases, by using fencing. LRT experience in west European cities shows that some residual hazards along LRT lines cannot be completely eliminated but can be held to a minimum. In areas which have not recently had streetcar service, a massive program of public education would be required to generate the degree of public awareness and attendant good safety records found with LRT in European cities.

Planners must comprehend the operational issues which can arise at intersections and crossings and relate them to the use of the traffic control techniques discussed in the preceding sections. Most problems arise because LRVs are unable to evade vehicular or pedestrian obstructions, and severe consequences can arise due to the great momentum of an LRV.

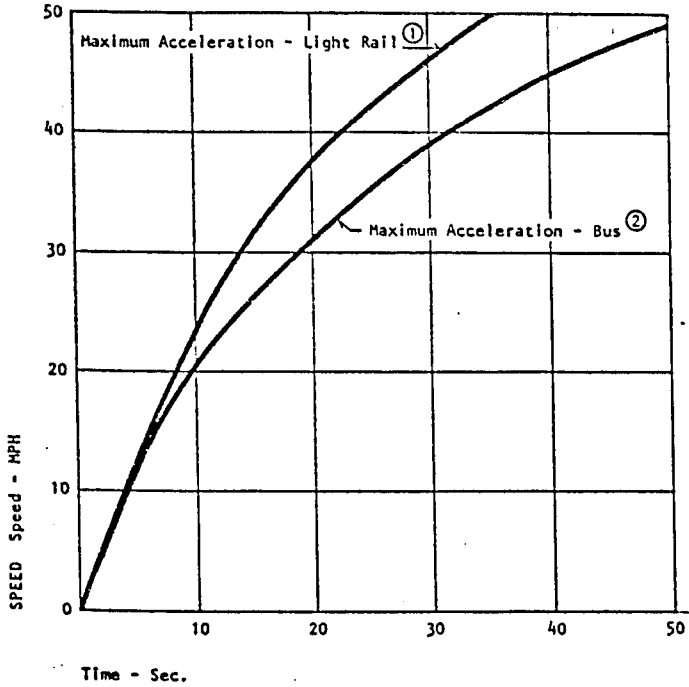
Not all of the safety concerns are founded on thorough understanding of the actual performance capabilities of LRVs, the flexibility available in the formulation of traffic control strategies, and the control of operations at intersections. The performance capabilities of modern LRVs (i.e., speed and braking abilities) are not inferior to other surface modes. On LRT lines, safe speeds actually can be higher than for traffic on parallel streets. LRV braking capabilities are equal to or better than those of rubber tire vehicles. Limits on speed and headway (promulgated by transit agency rule books and by automatic speed

control on more sophisticated installations) can provide adequate LRV stopping distances even in inclement weather, when adhesion on wet rails is reduced. In this sense LRV operation is not much different from that of heavy trucks or buses on surface streets.

The probability of collision can be minimized by assuring that route design provides maximum visibility to the LRV driver, and to pedestrians and motor vehicles at potential points of conflict. In addition, full utilization of the detection and warning capabilities of modern intersection traffic control systems (as discussed above) is necessary. Geometrics, equipment, and operation also must be designed with a safety-oriented philosophy. In other words, potential hazards must be identified and design decisions should be made with consideration given to system safety and cost-effectiveness. Should all feasible safety actions be undertaken, and the disparity between LRV and auto traffic speeds is still of concern, LRV speeds can be reduced at intersections to values which are considered to be "safe". If concern remains for pedestrians or vehicles becoming entrapped in the intersection, there is a wide body of experience that indicates these incidents do occur, but are quite rare, and seldom so severe as to justify the use of gates. In the following discussion, some of the major LRV crossing safety considerations are reviewed.

LRT Performance. The basic performance characteristics of light rail transit are similar to those of conventional transit buses. A comparison of braking and acceleration curves for LRT, buses and autos (Figure 2-21) shows that:

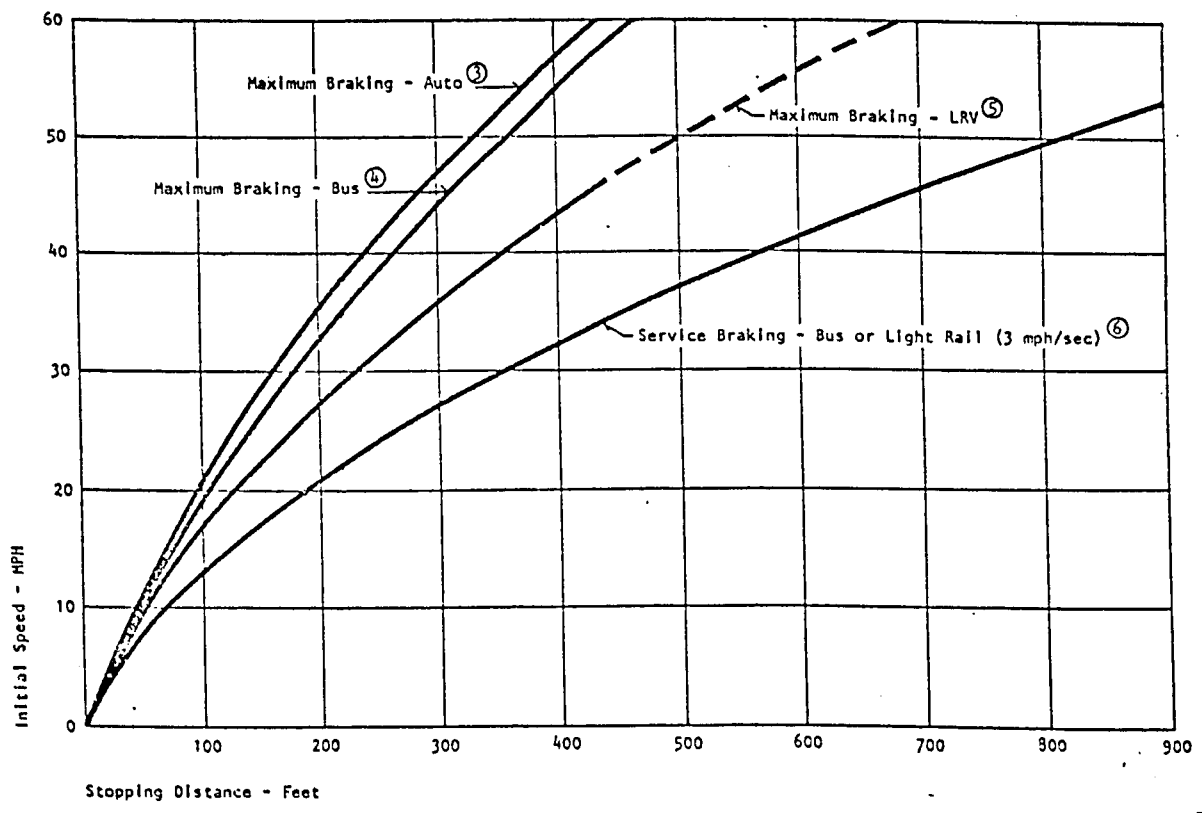
- Very high braking rates in transit vehicles are of limited practical application because they may cause more injuries to standing passengers than they avoid.
- LRV braking capabilities are better than buses under inclement weather conditions because of the all-weather efficiency of emergency track brakes.
- The stopping distance for most heavy trucks is longer (worse) than for either buses or light rail. In addition, tractor trailer combinations lack the lateral stability of LRVs under maximum braking. Traffic engineers and planners do not generally make special provisions in their design of urban roadways for trucks or buses with the exception of slightly wider lanes or turning roadways where turning radii are small. The similarity of operating and performance characteristics of LRVs to buses and trucks implies that LRT can be operated on-street without serious deterioration in the overall safety or flow pattern of the street system.



Notes:

- ① 1975 Boston Test Data for Boeing LRV with 102 passenger equivalent load. Source: Boeing Vertol Co.
- ② 40 foot G.M.C. Transit Bus with V8 engine - Model T8H 5307 A 66 passenger load, airconditioning on. Source: General Motors
- ③ Dry Pavement. Includes 2½ seconds reaction time. Source: Traffic Engineering Handbook, ITE 1965
- ④ Based on FHVSS 121 for dry pavement, Skld Number 75. Includes 2½ seconds reaction time
- ⑤ Based on VOV (80 Strab) requirement for light rail vehicles on dry rail. Includes 2½ seconds reaction time.
- ⑥ Limited by passenger safety and comfort consultations.

Acceleration



Braking

FIGURE 2-21
COMPARATIVE TRANSIT
PERFORMANCE CHARACTERISTICS

Collision Avoidance. Because LRT operates on fixed rails, collision avoidance depends on conflict control through implementation of traffic regulation techniques (as discussed above) and proper design. A number of design features and operations procedures provide for improved collision avoidance.

Avoidance of collisions between vehicles, pedestrians and LRVs is achieved primarily through good geometric route design, a minimum of decision points facing the vehicle drivers or pedestrians, and unobstructed sight distances for LRV and motor vehicle operators and pedestrians.

Sight Distance, Crossing Geometrics and Visibility. Provision of good sight distance is an important safety factor, particularly at higher speeds. Adequate safe stopping distance should be provided in all directions at possible conflict points (Figure 2-22). Motor vehicle drivers should see approaching LRVs at a distance at least equal to their vehicle's safe stopping distance; the same would apply to LRV operators and also to pedestrians.

Provision of adequate sight lines and stopping distance means that adjacent development and landscaping should be regulated to prohibit obstruction of the view of the intersection (further discussion of this point is found in Chapter 3). Frequently, safe sight distances can be

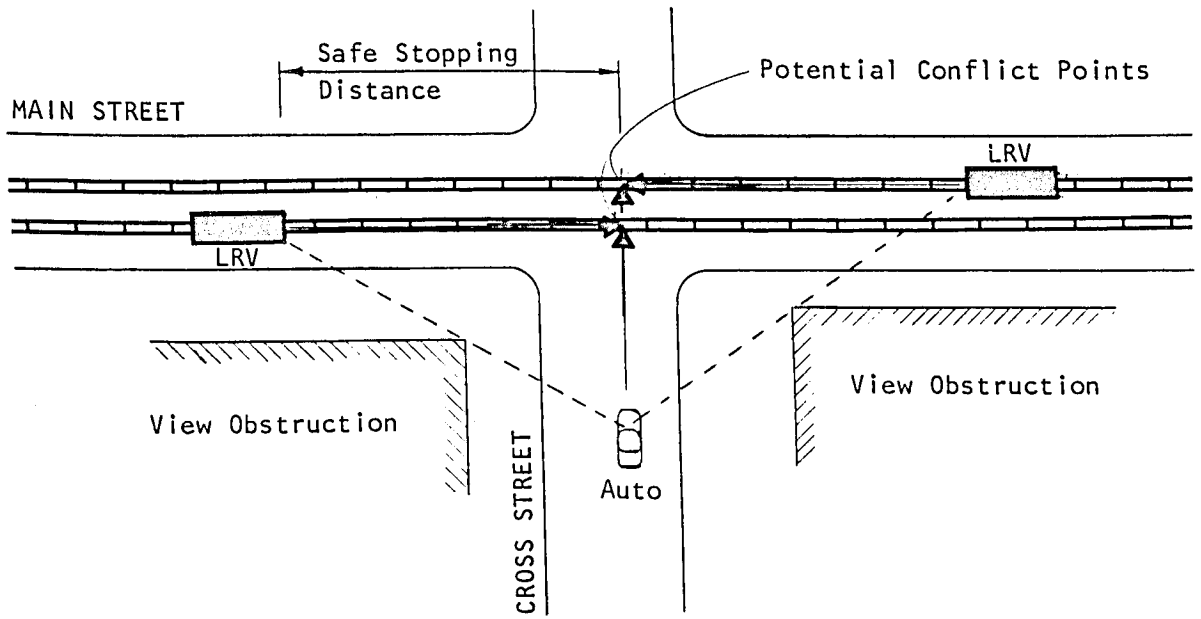


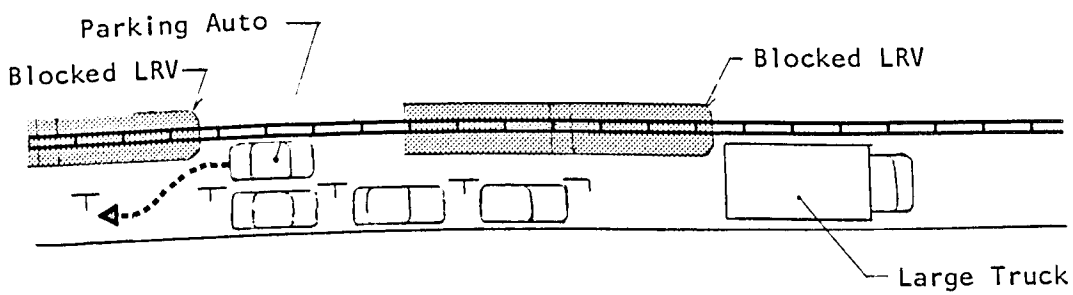
FIGURE 2-22
SIGHT DISTANCE CONSIDERATIONS

provided by proper grading and placement of structures. However, untrimmed plant growth is capable of significantly limiting sight distance, so all plantings in the vicinity of crossing points should consist of low ground cover or trees with high branches. Provision of proper sight distance is enhanced by avoidance of acute angle crossing geometrics. Where movements cross each other, they should, if at all possible, cross at angles between 90 and 180 degrees to maximize the awareness of each mode and consequently minimize the potential for blind side accidents.

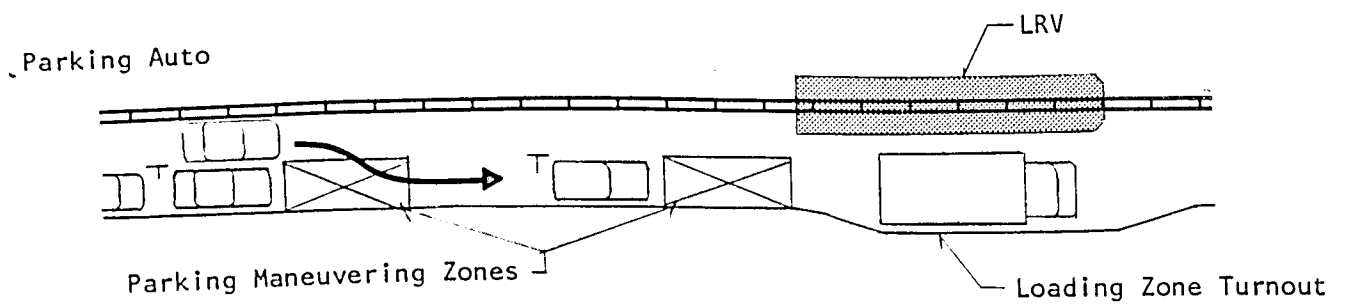
Collision avoidance is enhanced by the high good point of LRT operators. In the case of median operation, the placement of light rail in the center of a street gives the driver a vantage view of potential conflicts with pedestrians or autos on cross streets.

The LRT vehicle is large, which on one hand contributes to its conflict potential but on the other hand makes it highly visible to motor vehicle drivers and pedestrians. When LRVs are painted with a highly visible color, pedestrian and motor vehicle driver awareness is increased and accident potential reduced. This treatment was tried in Pittsburgh for esthetic rather than safety reasons, and it was found that the brightly colored vehicles did experience fewer accidents.

Avoidance of Track Obstructions. LRT vehicles cannot swerve to avoid obstructions. Consequently, proper clearances must be kept between conflicting vehicles, pedestrians and other obstructions. In malls where LRVs operate at slow speeds, clearances can be smaller and LRVs do not have the ability to circumvent traffic congestion or parked vehicles. A typical problem is shown on Figure 2-23. If a parking lane is adjacent to a light rail track in mixed flow operation on a narrow street, the side clearance may be low and result in blockage of the track should a large truck park in an auto space or loading zone. A similar situation could arise when a vehicle is double-parked on the tracks or is backing into a parking space. Occurrences of this type are common on the older streetcar lines, but can be avoided in modern LRT design. The frequency of delays due to route blockage is usually a function of land use. In residential areas, the parking turnover is usually low and the incidence of blockage rare. In commercial zones with short-term parking, the parking turnover rate and frequency of blockage could be large. Standard mitigation procedures are available. Special turnouts for trucks can be provided to avoid the first problem. Striping of tandem parking spaces with a maneuvering space between each pair of parking spaces reduces the parking maneuvering time for autos from an average of 35-40 seconds to less than 10 seconds, because backing maneuvers in the traffic lane are eliminated.



Problems



Solutions

FIGURE 2-23
BLOCKAGE OF LRV
IN MIXED FLOW

LRV Operating Speeds. Light rail operating speeds can vary from as high as about 55 mph to as low as 5 or 10 mph. The exact speed on a given line is based upon the physical and operating characteristics of the route and is usually specified in the system's operating rule book. The speeds required by the rule book can also be altered along any track section in response to changing conditions or developing accident patterns.

At midblock crossings, safety is dependent upon the speed of the transit vehicle and the driver's sight distance (Chapter 6). On streets where the transit vehicle operates at the motor vehicle traffic speed limit and adequate sight distance is provided, no particular safety problems can be experienced. Operation of transit vehicles at considerably higher speed limits than permitted for parallel automobile traffic can be considered in sections of the right-of-way where fencing is provided and where at-grade crossings do not exist. Technically, speeds of at least 10 mph over the traffic speed limit may be considered safe between at-grade crossings; however, local traffic conditions should be considered in establishing actual LRV speed limits at crossings.



CHAPTER 3

DESIGN ILLUSTRATIONS*

INTRODUCTION

Tremendous cost savings are possible by placing LRT at grade, rather than above or below the ground surface. This chapter is intended to assist the planner in applying the at-grade operational design concepts presented in Chapter 2 to site-specific conditions within a city. The purpose of this chapter is to:

- Identify potential surface right-of-way (ROW) opportunities for light rail transit.
- Determine where surface operation can be superior to underground operation.

*Material for this chapter has been provided by Messrs. H. Korve, R. Sauve, J. Hall, E.S. Diamant, and T.J. Stone.

- Show how to improve surface operation (for both LRT and traffic) to minimize performance problems and maximize the cost savings.

The presentation is focused around a series of prototypical urban configurations: LRT in existing roadway median, LRT in new median, LRT in mixed traffic, LRT in midblock crossing, LRT in pedestrian mall, contra-flow LRT operations, and bus on LRT right-of-way. Following presentation of the design cases, some general comparisons and conclusions are drawn.

The Art of Compromise

LRT rights-of-way could be liberally created at the expense of vehicular traffic flows, and unimpeded LRT movement could be instituted across all intersections. To do so, however, could interfere excessively with the mobility of other modes and in the accessibility of those activity centers bordering the line. There are, however, many techniques for integrating LRT with other modes and land use activities which will maximize LRT performance with little interference to other traffic. For instance, LRT rights-of-way could be placed in undesirable corridors and LRT movements subordinated to those of vehicular and pedestrian movements. To do so, however, could severely deteriorate LRT performance.

The challenge is to find those design solutions which result in the best LRT performance and yet result in acceptable impacts on vehicular and pedestrian movements and established land uses. The cost incentive for avoiding grade separation is considerable: a factor of two to ten less cost for a surface alignment than for a grade-separated one. The monetary savings, however, will be offset by some loss in the performance of all modes, public and otherwise, which would have to coexist within the narrow confines of the LRT corridor. It is a disappointing but true observation that the troubles of surface rail transit in the United States in the last four decades did not produce resourceful compromise design solutions, as they did elsewhere, for surface location of LRT lines or present strong quantified arguments supporting alternative design solutions. These alternative treatments could, in fact, provide real improvement to congested or modal conflict areas. For example, if light rail were to carry part of the person travel more efficiently, thereby increasing the overall person-carrying capacity of the intersection with little change in the level of congestion, then a significant net transportation gain can be achieved. Indeed, in most cases it can be demonstrated that any minor increase in delay imposed upon motorists is more than offset by time savings realized by transit passengers.

Needs of the Planner

Generally, the planner cannot directly transfer the experience of one location to another, whether it be the experience of a European city or a neighboring community. However, it is often possible to break a problem into component segments which can be reassembled by the planner to the whole to suit the needs of the particular situation. Utilizing the prototypical design illustrations in this chapter, the planner can come close to duplicating most situations. The incentive is certainly obvious, for if it is not possible to find a satisfactory at-grade solution, LRT must become grade-separated (elevated or underground) at costs that often eliminate it as an acceptable modal consideration. Modern fiscal restraints are such that minimizing capital cost is quickly becoming even more important.

Specifically, the planner's concerns focus on two key questions related to the application of LRT to a specific urban situation:

- What can the performance of the LRT line be in a corridor with particular geometrics, traffic patterns, and land use without intruding excessively on other modes? More specifically, how can a surface line, when forced to coexist within the constraining urban infrastructure, retain a high enough performance margin to justify its monetary and social costs?

- What will be the impacts on the other modes and on adjoining activity centers when street and intersection capacities and accessibilities are modified to accommodate the LRT line? More specifically, can these impacts be kept within acceptable limits to justify the support of the new transit installation?

To answer these questions, the planner should be able to both visualize the design solution within the specific urban context of his or her proposed light rail line and to quantify as many of the impacts as possible.

The Value of Prototypical Designs

To assist the planner or engineer in applying LRT design concepts to specific conditions in his or her community, a series of specific situations have been chosen representative of the range of conditions likely to be confronted by the planner. Particular emphasis is placed on geometric changes, on traffic control adjustments, and on related modifications to rights-of-way, flow patterns and accessibilities. Each design case was taken from an actual operating LRT system, although street names have been changed. Various traffic volumes and frequency of LRT movements have been calculated to show the limiting operating conditions for that specific LRT alignment.

The first two illustrations feature LRT located in a roadway median: first, an LRT line in an existing median; and second, creation of a new median for LRT operation within an existing street right-of-way.

The next three designs illustrate the operation of LRT in mixed traffic situations. In these examples, the maximum LRT speed is primarily dependent on the techniques used to handle vehicle and pedestrian movement at intersections and along the line. Here the LRT line would most likely add to congestion and require a significant adjustment to existing circulation and parking. Various geometric design and traffic control strategies are often possible to limit and even remove any negative effects. In the third case, the geometrics of the street do not permit reserving right-of-way for exclusive LRT use. Consequently the ROW is shared, at least temporarily, with other motor vehicles. This configuration is typical of streetcar lines in the older sections of cities, and sometimes even on modern LRT installations in those areas where the streets are narrow.

The fourth case features midblock LRT crossings. The fifth example addresses LRT operation along a pedestrian mall. These malls are popular in many western European cities and are becoming popular in many U.S. cities.

The design illustrations feature two special LRT applications: contra-flow LRT lane and shared LRT/bus right-of-way. These techniques may entail operational advantages not otherwise realizable for certain LRT segments of a urban transit system although opportunities for their application are limited.

The LRT route options described in this chapter cover only a few of the locational problems encountered in actual practice. Since site-specific street and right-of-way geometrics as well as local traffic and pedestrian patterns create many variations from the cases reviewed here, special treatments involving geometric redesign and application of traffic engineering principles will be necessary for each location if the best design is to be achieved. However, the design and traffic engineering principles applicable in these cases will generally be the same as those described here.

The prototypical light rail designs have not been optimized since local conditions vary so widely and non-technical and sometimes even unquantifiable factors often play a dominant role in deciding which concepts are best for a given situation. The design solutions presented are not complete: only the most salient features necessary to show how light rail can be applied in the urban context are presented. For instance, important design configurations such as street texturing and parking configuration are only briefly addressed.

The Importance of Quantification

Quantification of LRT performance is essential to a realistic evaluation of prototypical designs. Therefore, evaluation of prototypical designs have been simplified so as not to obscure the discussion of the design principles involved. Typical calculations are included to show the impact of intersection traffic control changes on various levels of automobile congestion. For example, the complexity of the traffic problem increases when one considers effects induced on intersections away from the LRT line. These comprehensive traffic effects of LRT are omitted here. Evaluation of LRT performance is equally complex and often can be viewed only in probabilistic terms since, unlike grade-separated rail transit, actual speeds and various delays enroute are not always predictable or controllable. Yet it is necessary to have a grasp of the achievable performance on a given LRT line configuration, if for no reason other than to understand the impacts on vehicular traffic.

Light rail's performance on a proposed line can be quantified in several ways, including increase in average operating speed, and travel time savings. The numerical values for a large number of parameters must be determined for evaluation: the station spacing, the number of intersections between stations, the station dwell time, the delays at intersections, the cruising speed, the acceleration and deceleration rates, and

the jerk rates (rate of increase or decrease of the acceleration). In practice, station spacing will vary; the number and length of intervening street blocks will vary; the delays at intersections could be non-uniform or even zero; and the light rail vehicle's operating characteristics may vary from assumptions contained in this chapter.

However, by utilizing the sample designs and calculations, the planner can quickly identify those corridors (or sections of corridors) where LRT can be installed with little interruption of other traffic and gain an understanding of where some degree of compromise by both LRT and other modes will be needed. The planner then will be able to make an evaluation of whether the improved mobility provided by light rail is worth the cost of a grade-separated interchange, as compared to some level of degradation of traffic, or at the extreme, whether an alternative route, or a compromise in light rail service, should be considered.

DESIGN ILLUSTRATION NO. 1

LRT SURFACE LINE LOCATED IN EXISTING MEDIAN

Introduction

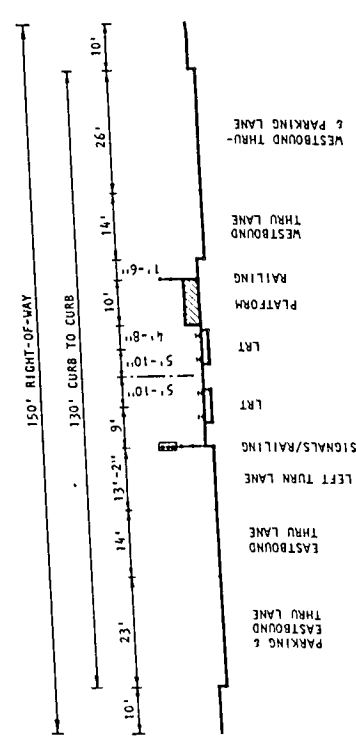
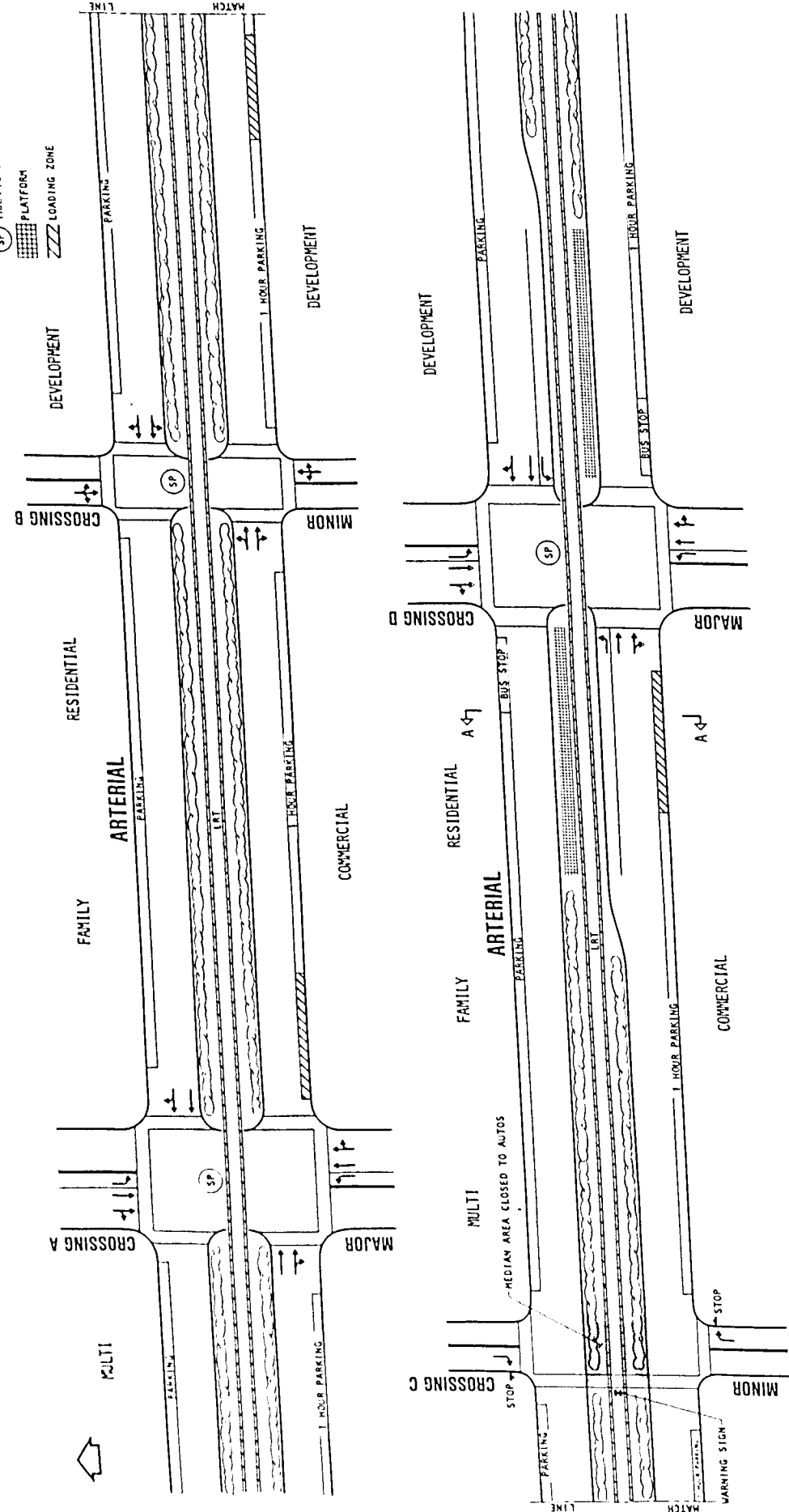
Light rail lines are frequently located in existing street medians. Median right-of-way often is available in suburban areas along well travelled roads with low cross traffic volumes. At these intersections, traffic control problems are usually simplified. Useable medians sometimes also are encountered on more centrally located arterials. Along these medians, greater volumes of through and cross traffic may require more complex control of vehicular and transit movements. In this design illustration, a two-track light rail line is placed into an existing median located in the center of a heavily travelled arterial. Several design variations are discussed to illustrate possible geometric changes in the location of motor vehicle traffic lanes required due to the additional right-of-way needed for station platforms. The handling of pedestrian crossings, curbside parking, and turning movements is also illustrated. Both low and heavy volume cross traffic situations are discussed, and the impacts in terms of traffic congestion due to traffic signal preemption in favor of the LRV are examined parametrically for a range of cross street vehicular volumes, various LRV headways, and different station platform locations. The consequences of installing rail-

road type gates at the intersection are also briefly examined. The analysis shows that a significant domain of operating conditions exists within which surface operation of LRT can be accommodated without excessive impacts on the movement of motor vehicles and pedestrians and on overall corridor accessibility. Obviously, however, since the findings and data shown with these design examples are only illustrative, the conclusions reached here cannot substitute for the locally specific judgments which are needed to establish the utility and acceptability of a proposed LRT installation.

Existing Conditions

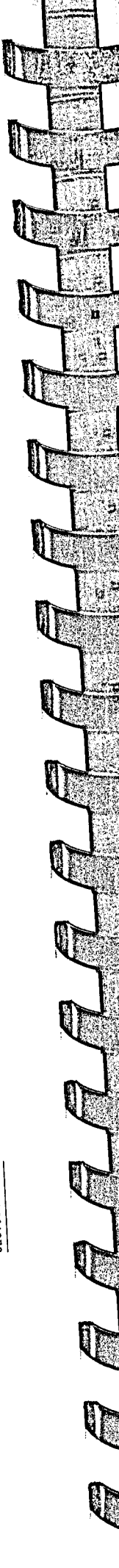
The light rail line would be accommodated in the existing 50-foot-wide median of a 130-foot-wide arterial. Because of the street's width, no substantial changes to the roadway would be contemplated for the arterial's two 40-foot-wide, one-way roadways. Two traffic lanes and one parking lane are assumed to exist. The prototypical arterial section shown in Figure 3-1 includes four intersections denoted by letters A through D, two of which (A and D) are formed by major cross streets. Traffic signals are assumed for each intersection. Left-turn bays exist at the major street crossing. The assumed land use on the north side of the arterial is multiple family dwelling units, primarily large apartment buildings. On the south side the assumed land use is primarily commercial with many small shops.

LEGEND: (SP) TRAFFIC SIGNAL WITH LRT PREEMPTION



SECTION A - A

FIGURE 3-1
LRT LOCATED IN EXISTING MEDIAN



Geometric Design

Figure 3-1 shows a light rail design option in which minor street crossing C is closed to motor vehicles but pedestrian crossing is permitted. Minor intersection B is left open to carry auto traffic across and onto the arterial. A third alternative would be to close both cross streets entirely, but this would have a negative impact on local circulation.

Figure 3-1 shows a configuration with station platforms located on the far side of the crossing, opposite left-turn lanes at intersection D. This arrangement permits optimum usage of the available street space. Special left-turn traffic signal phases would be provided at intersection D, but at major intersection A, left turns would proceed without a protected signal phase. Left turns would be prohibited at minor intersection C.

Figure 3-2 shows two alternative geometric designs for intersections C and D with the station platforms located on the near side of the intersection next to left-turn lanes. The first example shown in Figure 3-2 maintains the full width of the median, but parking is removed and the approach lanes are shifted toward the curbs to provide space for the left-turn lane. This would result in the loss of about 30 percent of the parking supply on one block for both station platforms.

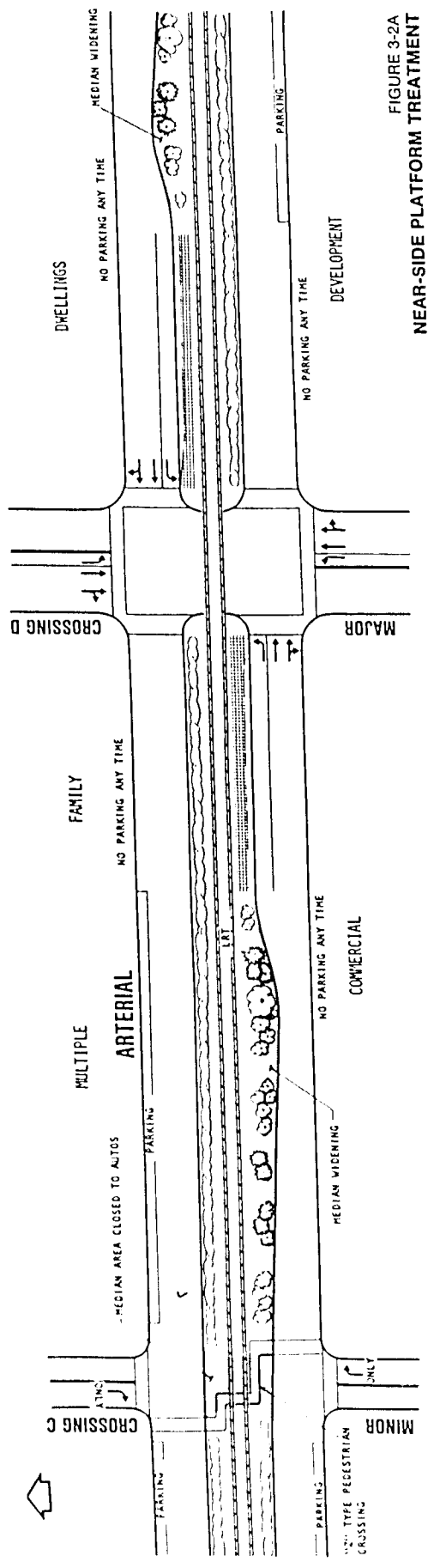


FIGURE 3-2A
NEAR-SIDE PLATFORM TREATMENT

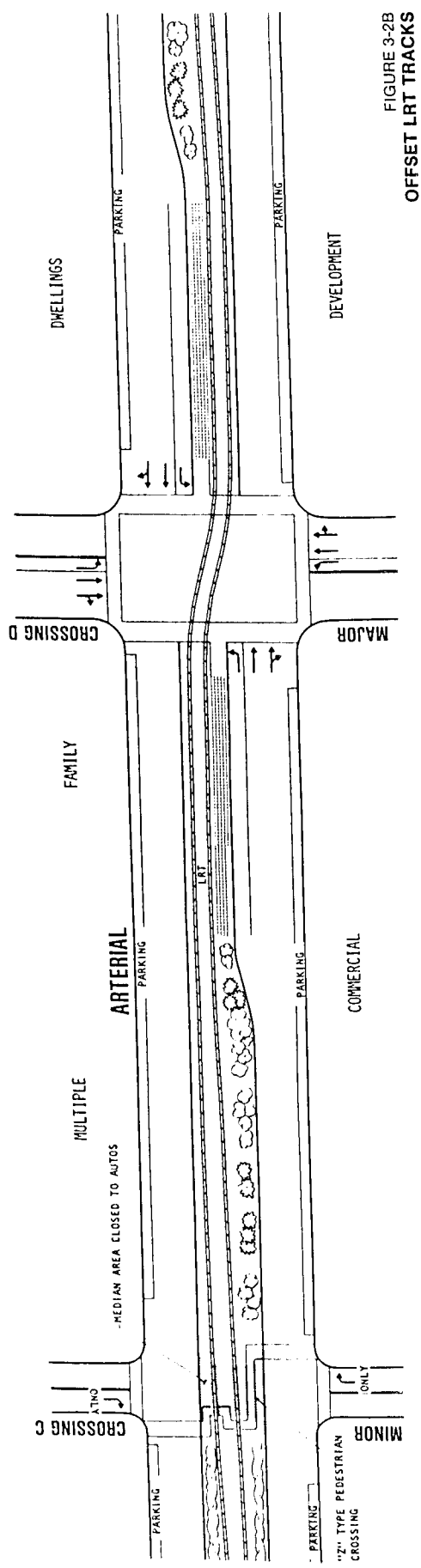


FIGURE 3-2B
OFFSET LRT TRACKS

FIGURE 3-2
NEAR-SIDE STATION ALTERNATIVES



The second example shown in Figure 3-2 varies the median width and shifts the alignment of the LRT track to provide space for a left-turn lane. This design would allow complete retention of the existing curb parking supply. The reverse curve of the LRT track can have a radius of about 1,500 feet with no spirals. This would permit a maximum LRT operating speed of about 30 mph through the curves.

Pedestrian crossings would be permitted at all intersections. These crossings could be protected by warning signs actuated by the LRV to indicate the approach of the vehicle (Figure 3-1). The warning signs would supplement standard pedestrian signals and would also indicate a safe crossing period when no light rail vehicles are present. Figure 3-2 also shows so-called alternative "Z" type pedestrian crossings. The configuration in 3-2B takes advantage of the increased width of the track spacing such that the crossing alignment is designed to allow pedestrians to face trains coming from either direction. With the "Z" design of 3-2A, pedestrians would have to turn to see an LRV approaching from the right on the second track.

Preferential Control of LRT Movements

Intersection traffic control would be provided by standard traffic signal indications, and LRV movements could be accommodated by any of the preferential control strategies discussed in the previous chapter.

Selection of the appropriate strategy is a function of the degree of transit priority deemed appropriate for light rail, the traffic volume and capacity of the intersection, the type of traffic signal system, and the intensity of LRV movements. Preferential movements would be provided for trains arriving from either or both directions depending on peak hour requirements. LRV detection, where required for a particular preempt strategy, could be accomplished via onboard or wayside detectors. The number and location of detectors would be determined by the LRV approach speed, intersection clearance time, platform location, and chosen preemption strategy.

Conflicts with pedestrians could be controlled by the existing pedestrian signals and/or could be supplemented by pedestrian signals mounted on the median on either side of the tracks. In addition, warning signs and/or audio signals could be placed on either side of the tracks to warn of approaching LRVs.

To illustrate the effect of at-grade light rail operation on different intersection configurations and traffic characteristics, detailed intersection capacity calculations were performed for each signalized intersection along the arterial using techniques outlined in the Highway Capacity Manual, 1965. Forecasts of traffic volumes are useful in obtaining an understanding of the general nature of traffic in an area or at an intersection, but do not by themselves indicate the ability of the street network to carry additional traffic nor the quality of service afforded by existing street facilities. For this, the concept of "level of service" has been developed, correlating traffic volumes and intersection capacity data with projected average travel speeds and subjective descriptions of travel performance. Table 3-1 shows the traffic service categories considered in this analysis, the corresponding intersection utilization factors, average travel speeds, and qualitative definitions of each category. The utilization factors indicate the percentage of theoretical capacity of the intersection that is being used. In an urban traffic design context, the "good operation" category is usually considered the design standard. A utilization factor of 85 percent of capacity is often the dividing line between good and poor traffic conditions, but local policies may alter this standard. What is acceptable at one intersection may not be so at another, and an acceptable standard in one community may not be another's. For the purpose of indicating the consequences of introducing light rail, the 85 percent

Table 3-1

INTERPRETATION OF LEVELS OF SERVICE FOR CITY STREETS

<u>Operation</u>	<u>Utilization Factor*</u>	<u>Interpretation** (During Peak Periods)</u>
Excellent	to - 50%	Relatively free flow, average speeds 30 mph (constrained only by roadway alignment and/or speed limits).
Very Good	50% - 75%	Stable flow, slight delay at key intersections, average travel speed 25+ mph.
Good	75% - 85%	Stable flow, occasional delay and intervehicular conflicts at many intersections, average speed reduced to 20+ mph.
Fair	85% - 95%	Approaching unstable flow, delays at critical intersections as long as two or more signal cycles, average speed as low as 15 mph.
Poor	95% - 100%	Unstable flow, continuous backups occur on the approaches to critical intersections, traffic from minor cross streets has difficulty entering or crossing main traffic stream, average speed likely to be at or below 15 mph.
Forced Flow	100% or Greater	Vehicles backup from critical downstream signal through upstream signalized intersections. Stop and go conditions. Average speed less than 15 mph.

*Percent of theoretical capacity

**As defined in the National Academy of Sciences Highway Capacity Manual, 1965.

point was adopted as an indicator of changes in vehicular operating conditions from "good" to "poor". Combinations of LRT operating frequencies and traffic volumes, which cause the utilization factor at an intersection to exceed 85 percent, are taken to indicate circumstances which may call for grade separation, alternate LRT routing, increase of LRV headways, or provision of alternative routings for motor vehicles. It also should be pointed out, however, that the change in utilization factor resulting from the introduction of light rail also should be considered by the planner, keeping in mind the overall increase in person-carrying capacity which will result.

Intersection utilization factors (or volume/capacity ratios) were calculated for a range of parameters, including many typical geometric and operational factors likely to be encountered in actual practice. The parameters considered are listed below:

- . Traffic volume on the arterial was assumed to be 20,000 vehicles per day.

- . Traffic volumes on the major cross streets, crossings A and D, were varied from 10,000 to 40,000 in increments of 10,000 vehicles per day.

- Traffic volumes on the minor cross streets, crossings B and C, were assumed to be 5,000 vehicles per day.

- It was assumed that the peak hour volumes were 10 percent of daily volumes. Peak direction vehicle volumes were assumed to be 60 percent of peak hour volumes.

- The geometrics and left-turn lane provisions assumed are shown in Figure 3-1.

- The configuration of the major cross streets included two approach lanes plus parking for traffic volumes of 10,000 to 20,000 vehicles per day. For cross street volumes of 30,000 to 40,000 vehicles per day, three approach lanes with no parking were assumed. This would correspond to a typical upgrading of capacity for an intersection as its traffic volume increased.

- Calculations were made only for the preemption control strategy. Under ideal LRT operating conditions the unconditional preemption results in the "worst case" impacts on auto traffic (but the "best case" for light rail). Further disruption of vehicular traffic would occur beyond that caused by the preemption policy described here when LRV movements are slow or delayed due to speed limits or

other conditions. For this reason, unconditional preemption is rarely used in practice. It was only chosen for this analysis because it defines the limits of vehicular disruption that could be induced by preferential control strategies. However, the analysis does not consider the nature of related changes in traffic movements at other traffic signal controlled intersections nor the impact of preemption strategies on traffic at intersections having interconnected signal networks. Site specific characteristics, such as street geometrics, traffic volumes, and control strategies heavily influence the feasibility of signal preemption, thereby rendering parametric analysis merely academic in many cases.

- . Preemption intervals of up to 20 seconds were used including time (2 1/2 seconds) for driver reaction and clearing the intersection of vehicles blocking the track. The signal cycle was assumed to be 60 seconds.

- . At the controlled intersection, utilization factors were calculated for three alternative operational strategies:
 1. left turns from the arterial onto the cross street (across the LRT tracks) controlled with a special signal phase

2. left turns prohibited from the arterial onto the cross street

3. all traffic stopped during LRV passage

- The utilization factors without LRV preemption are also included for comparison. In this case, the LRV would be subject to the same signal phasing as motor vehicle traffic on the arterial. When left turns across the track are permitted, the LRV would be given a red signal to clear the intersection for the motor vehicle left-turn phase.
- Pedestrian crossings of the arterial were assumed to take place in two steps: first, to the median on one signal cycle phase, and then to the opposite curb on the next phase. This is practical because of the protection afforded pedestrians by the wide median. Two cases were considered: pedestrian crossings allowed on each signal cycle and crossings allowed on every other cycle. Pedestrian crossings of the cross streets were assumed to require no more time than the green phase on the arterial and consequently would not affect the utilization factors.
- The LRV approach speed was assumed to be 40 mph; the LRV trains were assumed to be 200 feet long; and intersection crossings in either direction were assumed to be 1, 3, 5, and 10 minutes, i.e., 2-, 6-, 10-, and 20-minute light rail headways.

- The station platform was assumed to be on the far side of the major intersection. Utilization factors for intersections some distance from station platforms (such as intersection A in Figure 3-1) can be approximated with values calculated for a far-side platform location (as shown below in Table 3-2) since the duration of the preemption phase will be relatively insensitive to the LRV speed across the intersection. LRVs decelerating for a station stop on the far side of the intersection will require somewhat more time, however.

Utilization factors were not calculated for LRT operation with unconditional signal preemption and near-side platforms, because the impact of this type of operation is difficult to quantify. With near-side platforms, the time required to stop and serve passengers prior to crossing the preempted intersection is variable. With preemption it is necessary to compensate for this uncertainty by placing a light rail vehicle detector at the LRV stop line to detect when the vehicle begins to proceed. The variation in dwell time means that this detection, and hence, the initiation of the signal preemption sequence, could occur at any time within the signal cycle with near-side platforms. Consequently, the use of other control strategies (including conditional preemption strategies) is recommended if near-side platforms are to be used.

Table 3-2

EFFECT OF PREEMPTION ON PEAK HOUR UTILIZATION RATES AT AN
INTERSECTION WITH A MAJOR CROSS STREET
(Intersection D, Figure 3-1)

Preempt Strategy	Platform Location	Cross Street Volume	* LRT Headway (Minutes)				
			2	6	10	20	-
			Intersection Crossing Interval (Min.)				
			1	3	5	10	No LRT
A.							
Parallel Traffic							
Move with LRT	Far Side	10k ^b	82(76)	72(66)	70(64)	69(63)	67(62) ^d
Left Turns	or	20k ^b	92	81	78	77	76
Controlled	None	30k ^c	95	83	80	80	78
		40k ^c	110	97	93	92	91 ^e
B							
Parallel Traffic							
Moves with LRT	Far Side	10k ^b	77(82)	67(72)	65(70)	65(69)	63(67) ^d
No Left Turns	or	20k ^b	87	76	74	73	72
	None	30k ^c	90	79	76	75	74
		40k ^c	106	93	90	89	87 ^e

a Intersection crossing interval equals one half the headway operated in each direction

b 2 lanes plus parking

c 3 lanes no parking

d Assumed pedestrian actuation every other cross street phase

e Intersection utilization factor (volume/capacity ratio on most congested intersection approach or turn movement) in shaded area indicates congested conditions

* Average headway assumed to be twice the crossing interval

The utilization factors calculated for the major street intersections are shown in Table 3-2. The utilization factors are shown in column 5. Dividing lines drawn through the arrays of utilization rates show that the intersections become "congested" only for very heavy volumes on the cross street or heavy LRV volumes. The utilization rates already are 91 percent and 87 percent without LRT when cross street volumes are 40,000 vehicles per day. This high level of cross street traffic would most likely be encountered in the most dense travel corridors.

Table 3-2 also shows the effects of different LRV headways and left-turn prohibition at different levels of cross street traffic. When LRV headways are two minutes in each direction (one vehicle crossing the intersection every minute in the worst situation), only the lightest cross street volumes (10,000 vehicles daily) can be accommodated without some congestion developing. For this level of cross traffic, the utilization factors which would result if pedestrian crossings are restricted to every other traffic signal cycle are also shown in parentheses. When LRV crossings of the intersection occur no more frequently than every five minutes (10-minute headways on each line), left turns can be allowed without exceeding the 85 percent level, but again only at the same low volume on the cross street.

At six-minute LRV headways (a crossing every 3 minutes), high cross street volumes (up to 30,000 vehicles per day) could be tolerated without congestion if left turns were prohibited. Conditions on the higher volume cross streets are less affected by pedestrian cycles than they are under lower volume situations because the cross street signal phase becomes long enough for pedestrians to cross.

A different geometric design situation which would require all traffic to stop during LRT passage was investigated for the situation shown in Figure 3-3. It was assumed that a reserved right-of-way would be available for light rail after passing through the intersection. For LRT tracks turning from an arterial onto a median or reserved ROW in the cross street, this analysis would be somewhat conservative since some motor vehicle movements could continue during LRT passage. For example, the all-stop requirement could be relaxed for the turning case illustrated in Figure 3-3 where light rail enters the median, but would be mandatory for the diagonal crossing. The resulting utilization factors are for the situation in Figure 3-3 shown in Table 3-3. Utilization rates are about five percent higher than those in the previous situation (Table 3-2) when crossing intervals are three minutes or more. Far-side platform locations result in higher intersection utilization factors than do locations with no platforms. When LRV crossing intervals equal the signal cycle length (in this case one minute), strategy 2 preemption

Table 3-3

EFFECT OF PREEMPTION ON PEAK HOUR CAPACITY:
LRT INTERSECTION WITH A MAJOR CROSS STREET

(Preempt Strategy Requiring All Vehicles to Stop During LRV Passage)

Platform Location	Cross Street Volume	Intersection	Crossing Interval (Minutes)				
			1	3	5	10	No LRT
Far Side	10k ^a	c	76(70)	72(66)	70(64)	67(62)	d
	20k ^a		86	81	78	76	
	30k ^b		88	83	80	78	
	40k ^b		102	97	93	91	e
None	10k ^a	c	75(73)	72(66)	70(64)	67(62)	d
	20k ^a		85	81	78	76	
	30k ^b		87	83	80	78	
	40k ^b		101	97	93	91	e

- a 2 lanes plus parking
- b 3 lanes no parking
- c Minimum LRV crossing interval 1 minute
- d Assume pedestrian actuation every other cycle
- e Intersection utilization rates (volume/capacity ratio on most congested intersection approach or turn movement) within the shaded area indicates congested condition

Note

LRV approach speed 20 MPH

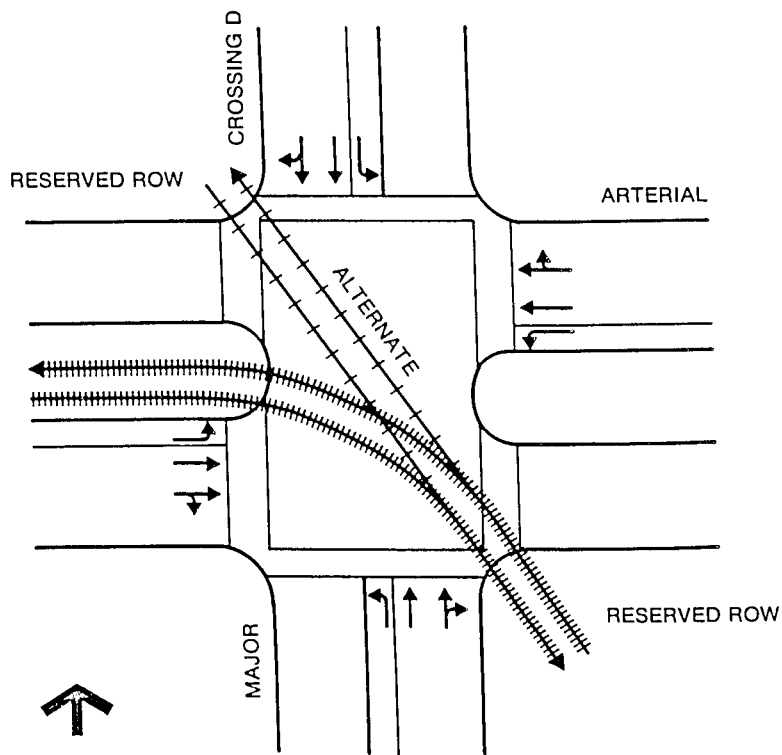


FIGURE 3-3
TURNING AND DIAGONAL CROSSING

would occur almost continuously. This would not allow sufficient signal green time for vehicular and pedestrian demand. Therefore, LRV crossings at intervals equal to or less than the signal cycle length could not be permitted, and values are not shown for those cases. Three- or five-minute LRV crossing intervals would provide fair to good traffic operation for all but the highest volume level, regardless of platform location. Ten-minute LRV crossing intervals would provide at least fair traffic service for all platform locations and traffic volume levels.

At an intersection with a minor cross street, such as Intersection B in Figure 3-1, the effects of preemption are considerably less severe. The utilization factors shown in Table 3-4 were calculated using the same assumptions used for the major cross street with the following exceptions:

- a. Volumes on the cross street were 5,000 vehicles per day.
- b. Pedestrian activity at the intersection was assumed to be minimal so that pedestrian demands would not overshadow those of motor vehicles on the cross streets.

Table 3-4

EFFECT OF PREEMPTION ON PEAK HOUR UTILIZATION
 RATES AT AN INTERSECTION WITH A MINOR CROSS STREET

<u>Preempt Strategy</u>	<u>Platform</u>	<u>Cross Street Volume</u>	<u>LRT Headways* (Minutes)</u>				
			<u>2</u>	<u>6</u>	<u>10</u>	<u>20</u>	<u> </u>
			<u>Intersection Crossing Interval (Min.)</u>				
			<u>1</u>	<u>3</u>	<u>5</u>	<u>10</u>	<u>No LRT</u>
A							
Parallel Traffic Moves	Far Side	5,000	78	68	66	65	62
	None	5,000	78	68	66	65	62
B							
Parallel Traffic Moves	Far Side	5,000	68	60	58	57	56
No Left Turns	None	5,000	68	60	58	57	56

*Average headway assumed to be twice the crossing interval.

The increase in utilization factors due to preemption is nominal when compared with the pre-LRT rates (column 6) for either left-turn strategy and with a station platform on the far side of the intersection. It can be concluded, therefore, that prohibiting through traffic on the cross street (e.g., crossing C in Figure 3-1) would not be necessary to alleviate congestion; it would, however, remove the need for signalization except for pedestrian crossings.

In summary, this illustration has shown that when light rail operates in a preexisting median and always has priority over motor vehicle traffic, fairly high cross street traffic volumes can be accommodated if LRV headways are large. With higher cross street volumes (above 30,000 vehicles per day), more frequent LRT service results in some deterioration of traffic flow. The obvious remedy for the resulting congestion would be grade separation. Major traffic engineering improvements such as roadway widening or turn prohibitions also may be considered. However, diversion of some automobile traffic to transit or to alternate routes, or even acceptance of the resulting congestion is also possible. When considering grade separation, it is important to remember that inclusion of light rail dramatically increases the overall person-carrying capacity of the intersection, even if there is some degradation of the traffic level of service. For example, a three-vehicle light rail train operating on five-minute headways could carry about 6,000 people in each direction. Thus, unless the induced congestion were severe enough to either block light rail operations or create severe congestion at adjacent intersections, it may be appropriate to accept

some additional delay to motorists in exchange for the higher volume of transit riders who would not be delayed. Such decisions are site-specific, and depend upon local attitudes toward public transit, and should be made only after evaluating the trade-off of motorist delay versus transit user delay.

Auto Circulation

The impact on automobile traffic on the parallel arterial of LRT operating in a wide median would be relatively minor. Some impact would occur where minor cross street intersections were closed to cross traffic. Traffic at major intersections could be maintained at nearly the same levels existing before implementation of light rail. Of course, prohibiting left turns as a selective traffic control strategy would affect vehicle movements. Some traffic diversion might result, thereby increasing volumes on other nearby streets and increasing left-turn and U-turn demand at those intersections where left turns are permitted.

Pedestrian Circulation

Pedestrian crossings of the arterial, because of its 130-foot width, would have to be signal controlled. Movements would occur in two phases: pedestrians would cross from one curb to the central median in

one traffic signal cycle; they would cross from the median to the opposite curb on the next cycle. Special traffic signal phases and pedestrian (WALK/DON'T WALK) signal heads would be necessary to properly effect this two-phase crossing.

Pedestrian crossings between intersections would have to be restricted. Where cross walks would be maintained, special devices would need to be used to warn pedestrians of approaching LRVs, including audible tones, flashing lights, or flashing warning signs. Alternatively, a "Z" type crossing such as that shown in Figures 3-1 and 3-2 could be installed. Crossing of the arterial would be controlled by standard WALK/DON'T WALK pedestrian signal heads. These signals would be actuated by pushbutton to assure that delays to auto traffic on the arterial would be minimized. Pedestrians could be prevented from crossing the LRT tracks at unauthorized locations by fences or barriers placed between the street and the track on both sides of the track. Care should be taken not to close existing pedestrian crossings because inconvenienced pedestrians will usually climb a fence or barrier erected at such locations.

Conflicts

Conflicts between motor vehicles and LRVs could be avoided by the raised medians, use of different materials which are uncomfortable or noisy for auto travel, curbs, plants, and so on. The median which uses these

treatments provides an operational separation as well as a physical barrier against encroachment and is the preferred form of separation in both North America and Europe. However, most medians can be crossed, if necessary, by emergency vehicles. Conflicts between LRVs, pedestrians and motor vehicles at intersections are all controlled by traffic signals. Certain situations may require special treatment, but conflicts can be minimized. An example of a special treatment is the left turn at Crossing B in Figure 3-1. Where left turns across the LRT track are permitted, a special signal phase and special signing and striping are needed to assure that automobiles do not conflict with the LRVs. Alternatively, an all-red preemption strategy could be employed; this would preclude conflicts while LRVs are crossing. Other alternatives would be illuminated "No Left Turn" signs or barrier gates, employed together or separately. Other left turns from the arterial that could cross the LRT tracks are either prohibited as shown at Crossing A in Figure 3-1 or controlled by the traffic signal phasing as indicated for Crossing D. For all preemption strategies the left turn across the LRT tracks would be given a red indication during LRV approach and passage through the intersection.

Gates

Railroad crossing gates could be installed at each intersection to provide additional protection for motor vehicle or pedestrian traffic. Gates would be a redundant traffic control device and would add little

additional safety to the operation of the intersection. Installation of gates to control an LRT crossing would increase the total time of the preemption phase. This would cause greater delays for crossing and turning traffic at such intersections, thereby increasing the minimum distance between streets crossing the LRT tracks.

The gate must be closed prior to the LRV reaching the verification point (the last point at which the gates must indeed be closed or the light rail vehicle begins an emergency stop). The added time lost per train due to this type of gate operation is about four seconds for preemption strategies A and B and eight seconds for the all-stop strategy. Table 3-5 shows intersection utilization rates for preemption strategy 1A, with and without gates. The Table indicates that using gates can increase the intersection utilization factors by as much as 20 percent. Consequently, using gates would require that LRV headways be longer for all situations in order to achieve the same utilization factors as realized without gates. The conclusion is that gates are best used only at midblock crossings where normal street traffic flow will not be affected, or preferably, only at high speed isolated crossings in suburban or rural locations.

Table 3-5

INTERSECTION UTILIZATION FACTORS*
 Comparison With and Without Gates

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>No LRT</u>
Without Gates	79	69	68	66	65	63
With Gates	95	75	70	68	67	63
Percent Increase Due to Gates	20%	9%	3%	3%	3%	-

Assumes:

- * Far-side or no platform, 40 mph LRT approach speeds, major urban intersection (35,000 vehicles per day enter intersection)
 Preempt Strategy 1A

Parking and Land Use

The treatment shown in Figure 3-1 involves no parking loss. Land use impacts for the LRT and street configuration considered here would be minimal because the width of the combined street and median is so great (130 feet curb to curb). One major impact which would occur for the special case shown in Figure 3-2 would be the loss of parking where the near-side LRT station platform is adjacent to a left-turn lane. In this case up to 30 percent of the total parking supply in the example is lost. Removal of parking space could make deliveries and passenger loading difficult in the vicinity of the intersection. However, commercial loading zones could be displaced to side streets or further down the cross streets and the other parking areas could compensate for this loss of parking.

However, if parking indeed can be removed, then greater overall intersection capacities can be achieved at lesser interruption to cross traffic. This may be feasible for two reasons. First, light rail itself could increase accessibility to local businesses, thereby decreasing the need for parking. Second, the implementation of light rail may be accompanied by a desire to increase the intensity of land uses in the vicinity of stations. Such intensification often is compatible with removal of parking and other automobile disincentives in an effort to

enhance transit use and devote more land to development rather than to the auto. This should not be taken to imply, however, that removal of parking would be achieved easily. Indeed, merchants and property owners often tend to resist parking removal quite vehemently.

No intersection widening is required in this treatment. The median was used to develop left-turn lanes in the manner shown in Figures 3-1 and 3-2. This has minimum impact on the surrounding area because it improves circulation and does not remove parking. However, it may require relocation of some median plantings.

It is possible that the LRT stop itself would increase parking demand in suburban areas for "park-and-ride" and "kiss-and-ride" trips. This would exacerbate the effect of potential parking loss or displacement in such locales.

DESIGN ILLUSTRATION NO. 2

LRT SURFACE LINE LOCATED IN NEW MEDIAN

Introduction

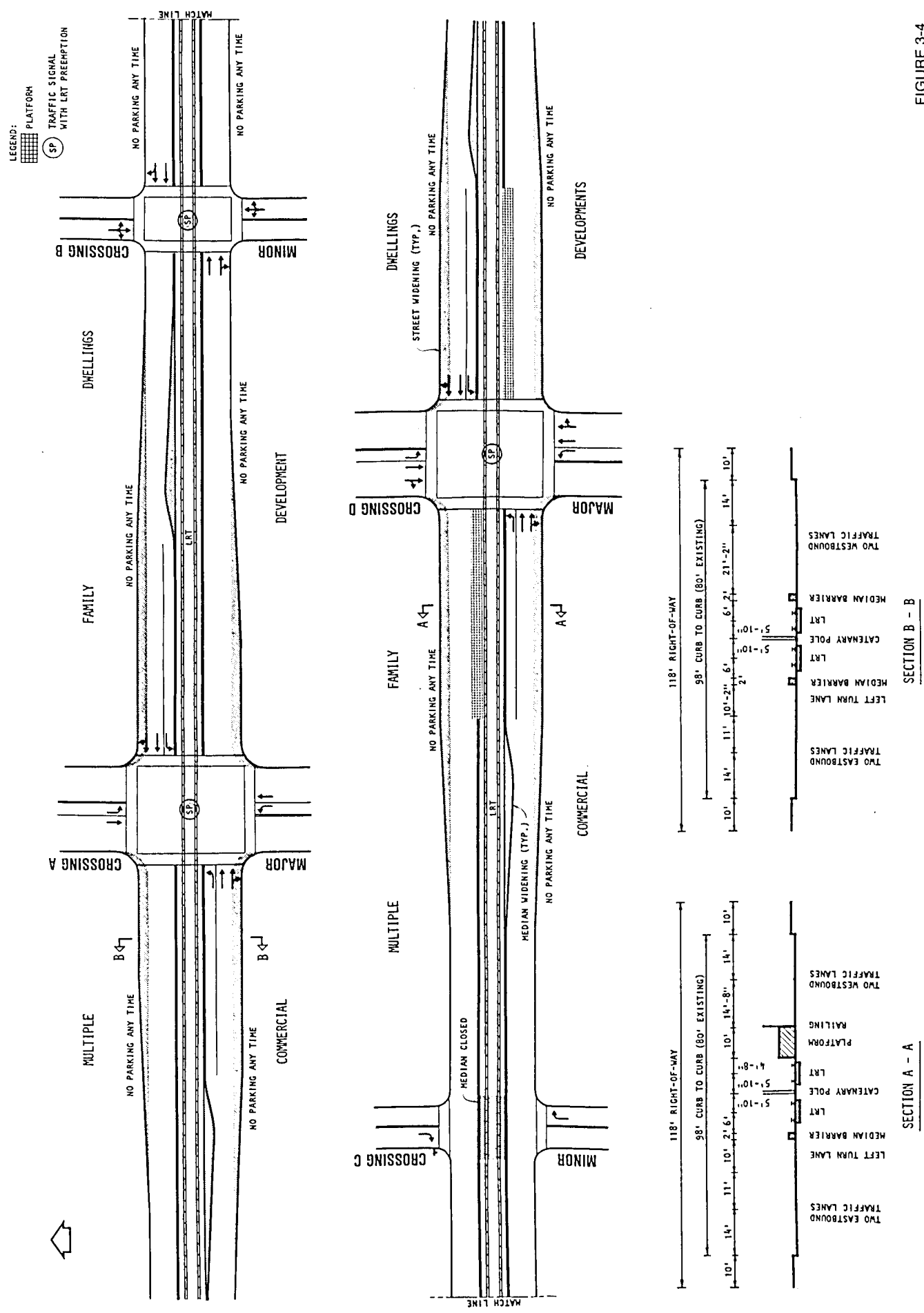
Where existing medians or private ROW are not available, surface segments of LRT routes can be accommodated in undivided streets. Wherever possible, however, a reserved ROW should be provided to achieve most effective use of light rail's capabilities. This design illustration explores the consequences of providing a reserved ROW along an arterial by constructing a curbed median that would accommodate the LRT line. The construction could cause loss of traffic lanes, parking, or both. In this illustration, the traffic lanes were simply shifted and parking was curtailed. In other cases, depending on traffic volumes and the number of available lanes, different design decisions may be made. To accommodate left-turn lanes, installation of the median requires some street widening at intersection approaches. Depending on existing land use, widening may be carried out if impacts on existing structures are acceptable. Alternatively, turns may be prohibited (rather than widening the street) if adverse impacts of widening on the community are greater than impacts of altering preexisting traffic patterns. Construction of the median could bring about significant traffic and land use changes along the route, so the design process must be quite concerned with the local conditions.

The diagrams in Figure 3-4 imply that it is possible that installation of high performance LRT operations could have serious congestion impacts unless preexisting traffic volumes are rather low. Operating LRT at lower levels of performance by employing only a moderate preferential treatment strategy would have less impact on traffic. A striped or curbed median, rather than a raised median, could accommodate motor vehicle traffic. This would severely reduce LRT performance and would mitigate effects of the new median on traffic flow. In other words, a range of options are available, depending upon the degree to which light rail can be favored at the expense of traffic impact.

Existing Conditions

The street in which the new median for the LRT line would be located is assumed to be an 80-foot-wide arterial with four traffic lanes, parking on each side, and left-turn lanes at each intersection. In this illustration the line would cross four streets, two of which are major streets designated as crossings A and D in Figure 3-4, and two of which are minor streets designated as crossings B and C. Traffic signals at the major streets are assumed to have separate left-turn phases, with simple, two-phase operation at the minor cross streets. The land use on the north side of the arterial was assumed to be multi-family residential with commercial on the south side.

FIGURE 3-4
CONSTRUCT MEDIAN



SECTION A - A

SECTION B - B

Modifications to Accommodate LRT

Placing the new median in the street makes it necessary to eliminate parking from both sides of the street and to widen the arterial street approaches at the major intersections. The new median was assumed to be 27 feet 8 inches wide and located in the center of the street, separated from traffic by raised curbs 2 feet wide. To accommodate the new median, the eastbound and westbound traffic lanes were assumed to be shifted north and south and all parking eliminated. The arterial was assumed to be widened by nine feet on both sides of the street at all approaches to major street intersections to provide left-turn lanes. The median at minor street crossing C was assumed to be closed to all cross traffic, including pedestrians. The approaches of minor street C were made right-turn only. At minor street crossing B, the median was left open to provide for pedestrian and vehicle crossings and left-turn access to the arterial. All intersections with an open LRT median would be signal controlled. Preemption could be provided for each intersection by any of the methods discussed in Chapter 2.

There is a station with platforms located on the far side of major crossing D. The left-turn lanes for arterial traffic at this crossing are located in "shadow" of the station platforms, on the opposite side of the LRT tracks from the station platform. This design permits good usage of the available street space.

If platforms were located on the "near-side" of the intersection, the design would be as shown in Figure 3-5. In this situation the station platform occupies the space used for the left-turn lane in Figure 3-4. Left turns would be prohibited on both approaches because the reduced street width available is not sufficient to provide for left-turn lanes. Left-turn lanes could be provided with the near-side platform if the arterial approaches would be widened 11 feet in addition to the 9-foot widening for the right-turn lane. With the near-side platforms, the same preemption and operation pattern would be used as for the situation with a preexisting median (Design Illustration 1).

Preferential Control of LRT Movements

The effect of LRT operation with unconditional preemption is illustrated by intersection capacity analyses for each signalized intersection along the street in the design illustration. The procedure outlined in Design Illustration 1 was used to interpret the results of the capacity analysis. In general the same assumptions were used except as follows:

- . The "all stop" strategy described in Design Illustration 1 was not included in this analysis. The same trends in utilization rates can be expected for both Design Illustrations 1 and 2.

- . Pedestrians would be allowed to cross the arterial only on every other cycle.

LEGEND:
 (SP) TRAFFIC SIGNAL WITH LRT PREEMPTION
 WIDENING
 PLATFORM

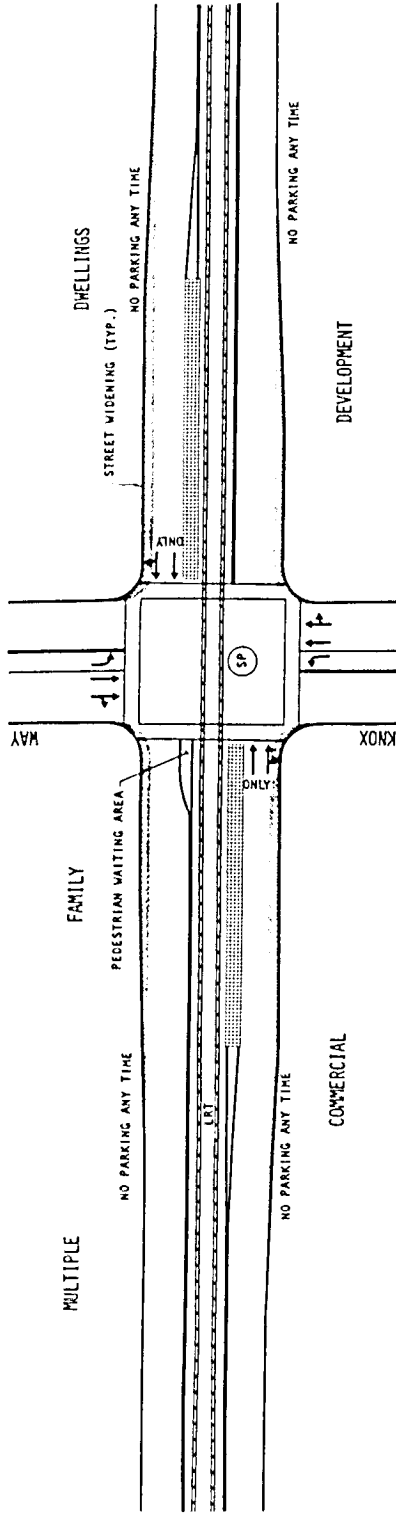


FIGURE 3-5
 NEAR-SIDE PLATFORMS



- The LRT operating speed would be reduced to 20 mph because of the proximity of automobile lanes to the LRT tracks. (This speed reduction conceivably could be avoided if the median were to be equipped with Jersey barrier-type curbing.)

Table 3-6 shows utilization rates for an intersection with a major cross street for pre-LRT conditions and as a result of installing the new LRT median. Congestion would occur even without the LRT median if 30,000 vehicles per day used the cross street and left turns were not prohibited. With the median in place and left turns permitted, congestion can be avoided only for the cross street volumes of up to 30,000 and headways of 10 minutes or more. If left turns are prohibited, traffic would remain uncongested with cross street volumes of up to 30,000 vehicles per day if LRT headways are greater than 6 minutes. These results are applicable for the geometrics shown in Figure 3-4. Without widening the arterial and eliminating street parking, congestion would develop for nearly all conditions where light rail operates on fairly frequent service.

Table 3-7 shows utilization rates for a minor street crossing, such as crossing B in Figure 3-4. The pre-LRT traffic conditions change little when the median is constructed, indicating the feasibility of the overall preemption strategy when cross street volumes are equal to or less than 5000 vehicles per day.

Table 3-6

EFFECT OF PREEMPTION ON PEAK HOUR RATES AT AN INTERSECTION
WITH A MAJOR CROSS STREET

Preempt Strategy	Platform Location	Cross Street Volume	(LRT Headways (minutes))				
			LRT Intersection Crossing Interval (Min.)				
			2	6	10	20	No LRT
A Parallel Traffic Moves with LRT Left Turns Controlled	Far Side or	10k ^a	87	76	74	73	72
		20k ^a	97	85	83	82	80 c
	None	30k ^b	99	87	84	83	81
		40k ^b	109	96	92	91	89
B Parallel Traffic Moves with LRT No Left Turns	Far Side or	10k ^a	79	70	67	67	65
		20k ^a	90	79	76	75	74
	None	30k ^b	91	80	77	76	75 c
		40k ^b	104	91	88	87	85

a - 2 Lanes plus Parking
b - 3 Lanes no Parking

c - Utilization Rates below the line indicate congested conditions.

* Average headways assumed to be twice the crossing interval.

Table 3-7

EFFECTS OF PREEMPTION ON PEAK HOUR RATES AT AN INTERSECTION
WITH A MINOR CROSS STREET

<u>Preempt Strategy</u>	<u>Platform Location</u>	<u>Cross Street Volume</u>	<u>LRT Intersection Crossing Interval (Min.)</u>				
			<u>1</u>	<u>3</u>	<u>5</u>	<u>10</u>	<u>No LRT</u>
A Parallel Move Left Turns Controlled	Far Side	5,000	78	68	66	65	63
	or None						
B Parallel Move No Left Turn	Far Side	5,000	68	60	58	57	55
	or None						

No pedestrian crossing signals were assumed at this intersection.

It is important to note that the utilization factors shown in Tables 3-6 and 3-7 are based on unconditional preemption. All of the other preemption types would have less impact on intersection operation, although lower LRT travel speeds also would result. Capacity calculations were not developed for preemption and near-side platforms because that strategy is not recommended for reasons explained in the discussion of Design Illustration 1.

Pedestrian movements at each of the example intersections would be fully protected in both the normal traffic signal and LRT preemption cases. Adequate pedestrian clearances would always be given before arrival of the LRT. The timing of pedestrian phases would be critical for major street intersections A and D. For this reason, the capacity analysis for those intersections assumed that pedestrian movement across the arterial would be accommodated in alternate traffic signal cycles. Table 3-8 shows the comparison of intersection utilization rates at intersection D for pedestrian crossings during every signal cycle and in alternate signal cycles. Although utilization rates were calculated only for cross street traffic of 10,000 vehicles per day, it is clear that permitting pedestrian crossings more often than on alternate cycles would cause congestion at all LRT headways if LRT signal preemption is operative. Restricting pedestrian crossings to alternate signal cycles would require that pedestrian waiting areas be provided on the median as shown in Figure 3-5. An alternative would be to provide for pedestrian crossings with a pedestrian overpass.

Table 3-8

EFFECT OF PEDESTRIAN CROSSING INTERVAL
ON PEAK HOUR UTILIZATION FACTORS
AT A MAJOR INTERSECTION

<u>Pedestrian Crossing Interval</u>	LRT Intersection Crossing Interval (Minutes)				
	<u>1</u>	<u>3</u>	<u>5</u>	<u>10</u>	<u>No LRT</u>
Every Signal Cycle	105	92	89	88	86
Every Other Signal Cycle	87	76	74	73	72

Cross street volume 10,000 vehicles per day

Supplemental warning devices such as flashing lights and/or audible tones could be used to warn of the danger of crossing the tracks when an LRV is approaching.

Auto Circulation

Traffic movement along the arterial and on cross streets would be affected by the new median. The major effects would be at intersections closed to motor vehicle crossings. The street closure and prohibition of left turns would reduce traffic on the closed cross street, but traffic would increase on minor streets that remained open. This could increase traffic on some nearby residential neighborhood streets. Some autos would make U-turns at nearby intersections, and others would use local streets to reach an open crossing. Large trucks, which would have serious difficulties making turns on narrow local streets or U-turns at major intersections, might have to alter their routings in order to reach properties along cross streets that were formerly accessed by left turns. Certain truck movements, such as backing into a loading bay, require a large street area that can only be provided by allowing movement across the center line. Problems of this nature have led some transit agencies to consider mountable curbing light rail medians in order to allow trucks to encroach on the median for access and maneuvering.

Pedestrian Circulation

Pedestrian circulation would be more restricted by the median than would auto traffic. A pedestrian crossing which could be provided across the median is shown in Figure 3-2 at Intersection C. Pedestrian circulation at all other intersections would not be restricted. Midblock crossings of the LRT median by pedestrians could be discouraged by use of fences along the edge of the median or between the tracks. However, locations with established pedestrian crossing patterns should be provided with some kind of safe pedestrian crossing and not completely closed.

Pedestrian circulation would be affected by widening the major approaches at each major intersection. Pedestrians would have to cross 18 additional feet of roadway on the arterial; this would add approximately 5 seconds to the average pedestrian's crossing time and would increase their potential exposure to collision.

Conflicts

Midblock conflicts between motor vehicles and the LRT line would be avoided by the use of a raised median. Conflicts with pedestrians along the right-of-way can be reduced by using fences and allowing sufficient opportunity for pedestrian crossings.

At intersections, motor vehicles and pedestrians are controlled by traffic signals, and potential conflicts are minimized. Motor vehicle left turns across the LRT tracks from the arterial may be treated in the following fashion:

- . Provide a special left-turn phase in the traffic signal cycle, with a red indication given when a light rail vehicle crosses the intersection.
- . Prohibit left turns when an LRV crosses by using actuated signs.
- . Prohibit left turns at all times.

Installation of gates to control median crossings was discussed previously, and the same arguments against their use apply in this situation.

Parking

A primary impact of installation of the LRT median in the example arterial would be the loss of all curb parking. Approximately 100 curb parking places would be lost between crossings A and D. Loss of this parking would have varying impacts on adjacent land uses. The impact on multiple family dwellings would be minimal if sufficient off-street parking exists to satisfy their demands. Otherwise there would be demand for on-street parking, especially during evening hours. It is conceivable that this demand would be diverted to the side streets.

The short impact of the loss of parking on adjacent commercial development could be negative. Often small commercial establishments and businesses do not have either the space or the resources to provide off-street parking and rely primarily on curb parking. Parking meter revenue would be reduced, and demand for parking space dedicated to commercial purposes would increase. The LRT stations would attract "park-and-ride" and "kiss-and-ride" LRT patrons who may wish to park nearby. Over the long term, however, the light rail line would make the businesses more accessible to many more people, and this actually could strengthen the commercial establishments. Often, the intensity of strip commercial development is limited by the automobile and its need for space. Over the long run, light rail implementation could stimulate a transition to a more intense development pattern.

The loss of on-street parking for both residential and commercial activities could be mitigated somewhat by developing off-street parking or by allowing curbside parking during off-peak hours.

For development of off-street parking facilities, a comprehensive parking survey would have to be undertaken throughout the area close to the LRT line to determine the demand for parking facilities, the availability of parking in other nearby off-street facilities or on side streets, and the potential funding sources for construction and operation of such improvements. If vacant property for parking lots were not available,

small, local businessmen might object because they would feel customers would be discouraged by the difficulty of finding parking and the long walking distances from distant lots. It is conceivable, however, that the influx of new potential customers from light rail could more than offset this effect. The problem may turn out to be one of perception rather than actuality.

Restricting parking to off-peak hours has the advantage of providing maximum traffic carrying capacity when it is needed most and providing parking for local commercial and residential needs when they are their greatest. Restrictions are often necessary in only one direction during each peak period. Morning parking restrictions are usually easy to achieve in commercial areas since few of the establishments are open during early morning hours. In residential areas, early morning curb parking restrictions may be difficult to achieve because many residents would not leave for work before 7:00 a.m. Evening restrictions are more difficult to achieve in commercial areas because the restriction conflicts with convenience shopping patterns.

Curb parking control is closely related to the required street usage during the day and has certain inherent enforcement problems during peak periods. Detailed traffic analysis would be necessary to determine the feasibility of tow-away enforcement in any particular location. Directional peak hour parking restrictions would provide the existing parking supply during off-peak hours and up to 50 percent of that supply during peak hours.

Removal of parking would make deliveries and passenger loading along the arterial more difficult. Commercial loading zones could be displaced to side streets, or loading could occur during the evening hours when it would not seriously conflict with traffic movements. Night deliveries would be a problem because many stores would be closed, and driver unions might object to the hours. Passenger loading and unloading on the curb side would also be generally prohibited. These impacts would be most pronounced for commercial establishments which rely on curb-side deliveries of goods as well as curbside drop-off and pick-up of customers. These could be moved to off-street or side street locations to minimize the impact on local commercial establishments. The impact on multiple or single family dwellings would be minimal because they usually have driveways or internal circulation roadways which provide space for delivery and pick-up of passengers and freight.

Street Widening

Widening of the arterial on each side to provide space for the LRT median could require up to 18 feet of additional right-of-way if parking is to be maintained. Depending on the building setbacks, it could become necessary to purchase additional property and raze structures that are close to the street. Should this be required, building removal could be minimized by locating the full amount of widening on one side of the street. Building demolition also could involve relocation costs,

a reduction in the local tax base, and likely opposition by the community. If widening is unacceptable, then other strategies for handling LRT which might be investigated include:

- Provide "S" curve track alignment through intersections and prohibition of left turns (see Figure 3-2).
- Reduce the number of through-travel lanes; this could produce a significant diversion of auto trips to parallel routes.
- Eliminate left-turn lanes at intersections; this would increase auto travel on adjacent cross streets.
- Provide a shared LRT median, possibly with left-turn lanes on the tracks.
- Construct the LRT median but without passenger loading platforms, providing only "signal" platforms to protect passengers.
- Widen streets only in areas where it can be done to provide extra parking.

The above alternatives involve some compromise in LRT level of service, passenger safety, or auto capacity. A careful analysis of all viable alternatives must be undertaken at each location in question prior to adoption of a specific design solution.

DESIGN ILLUSTRATION NO. 3

LRT SURFACE LINE OPERATING ON STREETS IN MIXED TRAFFIC

Introduction

The operation of light rail vehicles on streets in mixed traffic may at times be an option for short segments of new LRT lines. Often in the CBD, streets are too narrow or traffic volumes are too high to permit reserving separate ROW for exclusive use by light rail. Sharing short portions of the ROW with other motor vehicles is an alternative to costly grade separation or rerouting of the line. Historically, street-car operations in heavy street traffic have been found objectionable and have led to their removal. However, it is often possible to keep vehicular traffic moving reasonably well and still maintain LRT operations by applying various modern traffic management techniques. Some of the problems of mixed traffic operations can be alleviated by closing side streets to through traffic, prohibiting left turns at intersections and restructuring on-street parking. Also, LRT operating in mixed traffic can often move ahead of other traffic at intersections by preemptive traffic control and/or queue jumping techniques. Traffic signals also may be used to enhance the safety of LRT passengers on station platforms by holding motor vehicles out of station access lanes before and while

an LRV is stopped. This design illustration addresses a number of possible solutions for locating and operating a two-track LRT line on a four-lane arterial street. Locating LRT facilities in a busy street will cause additional congestion and delay but the design solutions presented here can reduce these impacts to acceptable levels.

Aside from congestion, the operation of LRT in mixed traffic also affects the safety of motor vehicles, especially at intersections. This problem is less critical along the LRT line because the presence of LRT tracks itself is a constant reminder to drivers of motor vehicles to be more cautious. In much the same way, the presence of the tracks provides a warning to motor vehicle drivers who must turn or cross the tracks. At intersections, preemptive traffic control can be used to reduce the risk of collision between LRT and motor vehicles. It has been found in western Europe that unpredictable signal timing (signal preemption activated only when an LRV is near) tends to keep drivers more alert and to reduce the severity of collisions.

Even though impacts to motor vehicle traffic can be minimized by these design measures, operation of LRT in mixed traffic is often thought to be subjected to such large delays as to justify grade separation. As discussed in the introduction to this chapter, much of the travel time advantage of the exclusive, grade-separated ROW is lost when stations

are close together, as in the CBD, and the high speed potential of operating the LRT on an exclusive guideway cannot be realized. It is important in planning new LRT lines in the CBD to realistically assess the benefits of LRT surface operations since the grade separation alternative is not only costly but also potentially of little advantage in the reduction of travel times.

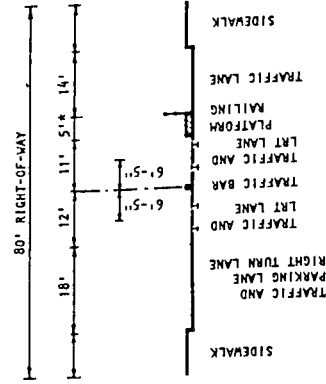
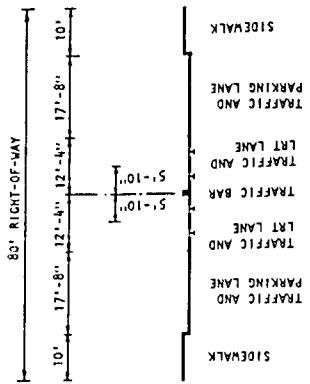
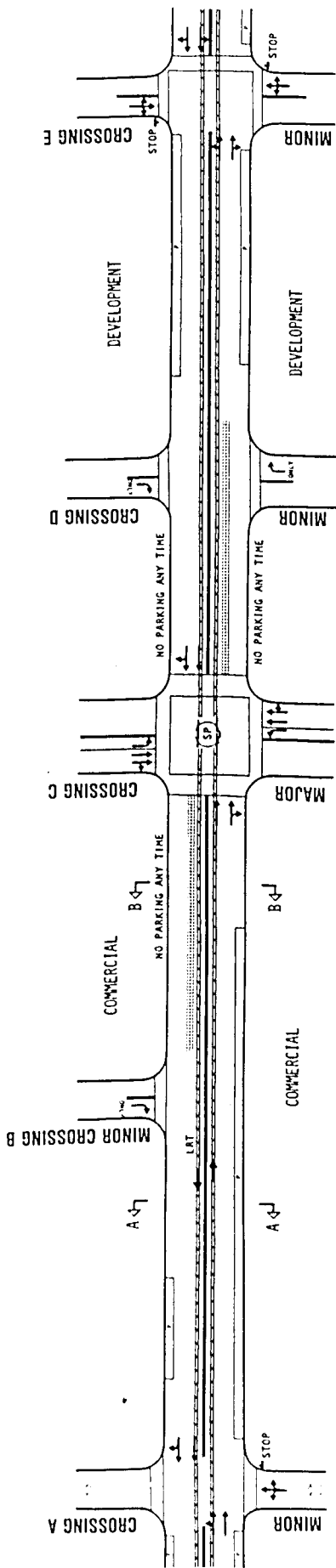
Existing Conditions

An example of how an LRT line might be designed to operate in mixed traffic on an arterial is shown in Figure 3-6. The new LRT line is shown on a 60-foot-wide, four-lane arterial with parking along both sides except at the approach to the major intersection. Left turns can be made both to and from the LRT arterial at each intersection. One major and four minor streets intersect the arterial. The land use along the arterial in the design example is commercial. There are many driveways onto the arterial used by both automobiles and trucks.

Modifications to Accommodate LRT

Traffic Flow Modifications. As shown in Figure 3-6, there would be two LRT tracks, each located in one of the traffic lanes. There would be no change to the two existing traffic lanes in each direction, but left

- LEGEND:
- SP TRAFFIC SIGNAL WITH LRT PREEMPTION
 - TRAFFIC SIGNAL WITH LRT PREEMPTION
 - PLATFORM
 - TRAFFIC BAR
 - P PARKING

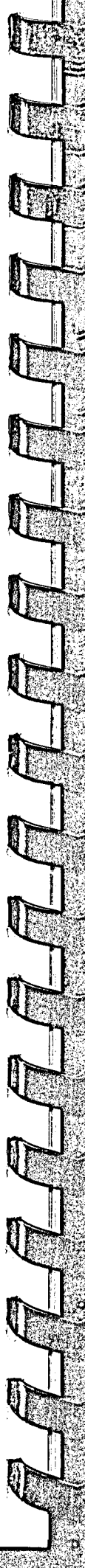


SECTION A - A

SECTION B - B

* FURTHER WIDENING OF PLATFORM REQUIRES ADDITIONAL STREET WIDENING

FIGURE 3-6
MIXED FLOW



turns from the arterial would be prohibited. Left turns into the arterial would be permitted at only two intersections. This restriction would be imposed to reduce blockage of the tracks by left-turning vehicles. One of the minor streets would be changed to one-way traffic to reduce intersection conflicts.

Typical street cross sections (A-A and B-B) for segments of the arterial with and without platforms are shown in Figure 3-6. Both sections have a curb-to-curb width of 60 feet and feature raised traffic bars along the centerline of the street to prevent left turns. The LRT tracks are located in the two inside traffic lanes, adjacent to the street centerline. The remainder of the street would contain a traffic and a parking lane at locations where there is no LRT station platform. Adjacent to platforms, parking would be eliminated.

The parking modifications near station platforms could affect access for deliveries by eliminating loading zones. Such loading zones could be shifted to space previously dedicated to regular parking, but sidewalk distances between loading zones and delivery points would increase.

Another effect could result from prohibiting left turns to and from minor cross streets. Drivers wanting to make left turns would generally have to follow a more circuitous route on streets adjacent to the LRT

arterial in order to attain their desired travel direction. These movements could be easily made by autos, but they could be more difficult for large trucks. Such circuitous travel would be time-consuming and would increase traffic on the streets used.

Converting some of the cross-streets to one-way operation could reduce intersection conflicts if adjacent streets would carry traffic in alternating directions (one-way pairs). Left turns across the LRT line might then be permitted at every other intersection.

Station Platforms. The 5-foot-wide station platform would be located between the inside traffic/LRT lane and the curb lane. A platform wider than 5 feet would require widening the street. These platforms should be at least long enough to accommodate a two-car light rail train. Adjacent to the platform, the curb lane would be used for right turns, and curbside parking and delivery space would be lost. To compensate for lost on-street parking, off-street parking could be developed if space were available. However, the presence of the light rail stop would certainly provide sufficient accessibility to the businesses to more than compensate for the loss in parking.

As an alternative, the station platforms could be eliminated by having passengers load and unload from the street (see Figure 3-7). Passengers would wait for the LRV on the sidewalk and cross to the boarding point when the LRV has stopped. Passengers must be prohibited from waiting in the street, due to the danger of moving traffic. This situation can lead to safety problems for passengers crossing to or from the LRV unless motor vehicle traffic is stopped before it reaches the station platform when the LRV is stopped at the platform. This could be effected by installing a traffic signal actuated by the LRV to stop the motor vehicles before they reach the passenger crossing. This solution is utilized in several western European LRT systems. On many existing LRT and streetcar lines in the United States and Europe, having no passenger loading platforms is common. Both the San Francisco MUNI and Philadelphia SEPTA systems operate many lines without passenger platforms, and they report few problems with the safety of this treatment when used on low volume and/or narrow streets.

Preferential Control of LRV Movements

In most of the situations where LRT is operating in mixed traffic in the CBD, it will be running on streets operating near capacity, at least in the peak hour. Traffic on major cross streets is likely to be as heavy as traffic running parallel to the LRT line. For such conditions and



FIGURE 3-7
IN-STREET PASSENGER LOADING

when LRV intersection crossing intervals are well above the traffic signal cycle length, the reduction in intersection capacity due to LRT signal preemption is almost totally independent of the method of preferential operation of the LRT. In other words, the addition of LRT doesn't necessarily greatly decrease capacity except for the lanes it removes. The changes in capacity would not be significant for preemption as opposed to normal signaling because parallel traffic would flow during the LRT preemption period. Since intersections are operating with nearly equivalent through and cross traffic volumes, the green time for parallel traffic during the preemption cycle would seldom be wasted. It is possible after each preemption to rebalance the intersection green time by giving the cross streets longer green intervals. This situation will not prevail if LRT crossing intervals are at or near the traffic signal cycle length because queues would be likely to form. It follows that the traffic management measures discussed previously (street closings, prevention of left turns, etc.) are as important as any signaling strategy for creating a suitable traffic environment for both LRT and motor vehicle flows. Because local characteristics (specific traffic volumes and patterns, specific street geometrics, etc.) are so important to these situations, it is difficult to draw general conclusions from prototypical design illustrations. Nonetheless, some quantification of traffic effects can help to provide an understanding of the effects likely to be encountered with LRT operation in mixed traffic.

Accordingly, an intersection capacity analysis was carried out for the intersection of the arterial and the major cross street in Figure 3-6. The calculation procedure used in the preceding illustrations was adjusted to account for the presence of LRT vehicles in the traffic stream. No data are available to indicate the effect of LRT vehicles on vehicular traffic capacity, so an approximate method was developed based on methods recommended in the 1965 Highway Capacity Manual for handling buses in mixed flow. LRT trains were prorated to local transit buses based on relative length, (for example, a 200-foot-long LRT train was considered equivalent to five 40-foot-long buses).

The capacity was calculated for two peak hour traffic volume assumptions: 20,000 and 27,000 vehicles per day on the LRT arterial and 17,000 and 19,000 vehicles per day on the major cross street. A signal cycle length of 60 seconds was used; LRT headways between 2 and 10 minutes were considered; and LRT consists ranging from 1 to 4 cars were included. The results are shown in Table 3-9.

For the preexisting conditions (without LRT) the intersection would operate well at 20,000 vehicles per day on the arterial but would experience significant delays at 27,000 vehicles per day. For the highest frequency of LRT operations (two-minute headways) conditions would be appreciably worse. All situations involving LRT operation would be

Table 3-9

INTERSECTION UTILIZATION FACTORS DURING PEAK HOUR
IN MIXED FLOW AT A MAJOR INTERSECTION

A) Arterial Volume 20,000 vehicles/day; cross street volume 17,000 vehicles per day

LRT Intersection Crossing Interval (Minutes)	Number of LRT Cars in Each Train				
	1	2	3	4	
1	89	101	118	165	Forced Flow Operation
2	84	89	93	100	
3	83	85	88	91	
4	83	84	86	88	
5	82	83	85	87	
Existing Conditions		80			

B) Arterial Volume 27,000 vehicles/day; cross street volume 19,000 vehicles per day

LRT Intersection Crossing Interval (Minutes)	Number of LRT Cars in Each Train				
	1	2	3	4	
1	104	116	136	187	Forced Flow Operation
2	98	103	108	115	
3	97	99	102	106	
4	96	98	100	102	
5	96	97	99	-	
Existing Conditions		93			

worse than what was considered acceptable in the previous design illustrations, i.e., utilization factors less than 85 percent. For several conditions of long trains and short headways the intersection would become saturated (i.e., utilization over 100 percent). The effects were especially severe for the heavier traffic volume condition with saturation occurring for nearly all situations.

At utilization rates at or above 100 percent, serious congestion conditions will occur, with forced flow traffic experiencing long delays. Once utilization reaches 100 percent, additional traffic will be delayed until it can be accommodated at a later time. Traffic queues could reach downstream to other intersections and block them. The LRT vehicles would also be affected by the congestion since autos would block the tracks.

Two factors must be considered when examining these results, however. First, installation of a light rail line on such a street could very well be replacing existing bus service along the street which itself was greatly affecting traffic operations. For example, if the street were carrying 60 buses per peak hour in each direction, this service could be replaced by about ten 2-car light rail vehicles per hour. The impact of this change upon traffic operations very likely would be positive. The second point to consider is that the traffic level of service does not

in itself present the full picture. Indeed, the installation of light rail would reduce the vehicle-carrying capability of the street, but it would greatly increase its person-carrying capacity. For example, for the sample intersection carrying 20,000 autos per day, installation of light rail service on only six-minute headways with two-car trains could at least triple that street's person-carrying capability. The challenge, therefore, is to determine methods for avoiding blockage of the tracks to facilitate the movement of this larger number of people.

LRT operations in mixed traffic may also interact with automobile traffic in other ways. For example, where station platforms are located between the traffic lanes, an LRV stopped at a platform will completely stop the inner traffic lane. With a near-side or midblock platform location, this results in a stopped queue of motor vehicles.

In summary, it appears that LRT operating in mixed traffic could be subjected to significant delay if traffic volumes are large. However, the mixed traffic option should be retained because it allows usage of existing street facilities, provides maximum routing selection, and allows use of varying preemption techniques without seriously reducing roadway capacity along moderately travelled arterials. This seems to be a useful technique on relatively short sections of streets where traffic volumes or width restrictions preclude development of a median, where

excess street capacity is available and slow LRT operating speeds can be tolerated. The associated changes in vehicular congestion and the required changes in preexisting traffic operations do not appear to significantly differ from the consequences of many proposed TSM techniques for providing priority treatment to buses.

DESIGN ILLUSTRATION NO. 4

LRT SURFACE LINE LOCATED IN MIDBLOCK CROSSING

Introduction

One traffic operations problem which occasionally arises concerns street crossings of LRT lines which run on private easements, such as railroad or private, reserved rights-of-way. These crossings are similar to railroad grade crossings. These crossings have unique design requirements because of potential adverse impacts on street traffic (for high LRT operating frequencies) and potential degradation of LRT performance due to stringent safety-related traffic control regulations.

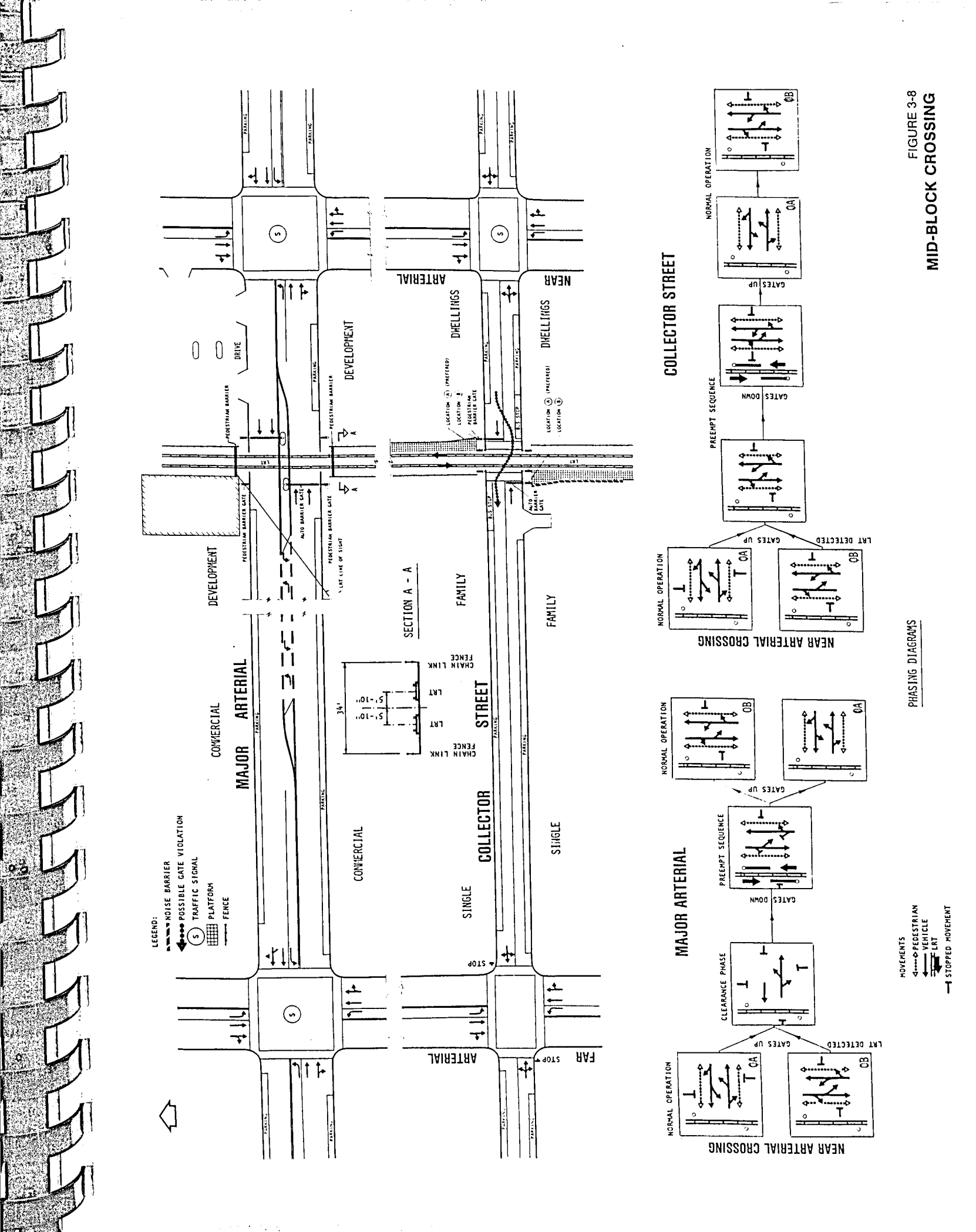
In this situation, the control of motor vehicles which cross the LRT tracks is usually the key design issue. Special control techniques are required for LRV and motor vehicle movements at these crossings if high levels of LRT performance are to be achieved. Control strategies which might be suitable for regulating infrequent and high speed railroad movements may be inadequate for the operational effectiveness demanded of modern LRT. This design example illustrates the application of geometric design and traffic engineering principles to enable high speed, uninterrupted operation of LRT at a midblock crossing.

The analysis highlights the significance of site specific characteristics. In particular, this analysis demonstrates how the proximity of street intersections influences the control of movements at LRT crossings. The illustrative route segment chosen for this analysis shows that preferential treatment of LRT movement does not significantly increase traffic congestion. Since midblock LRT crossings do not usually involve motor vehicle turning movements, the effects of preemption on the utilization factor are less severe than at street intersections. Traffic flow and congestion at the midblock crossing could be significantly impacted by the propagation of effects to and from nearby intersections.

The analysis projects the effects of various crossing control strategies for high LRT approach speeds. In general, the stringency of control measures required at midblock crossings is likely to decrease for lower crossing speeds.

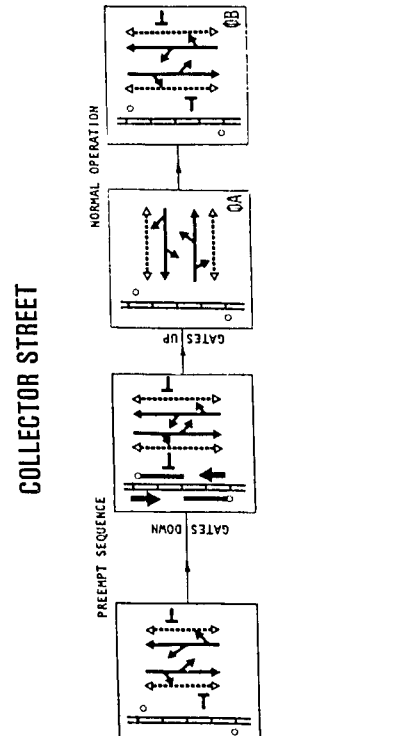
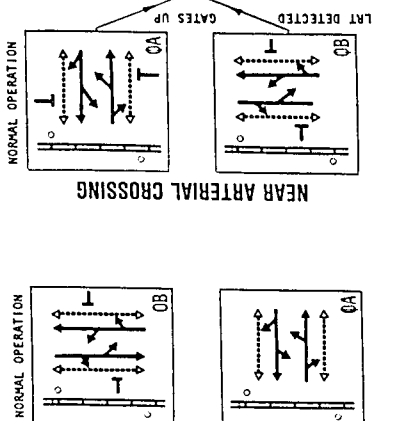
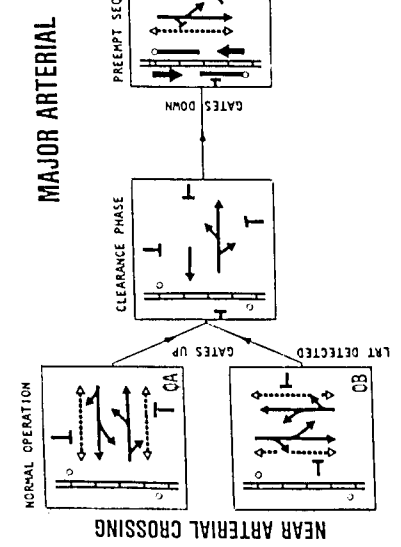
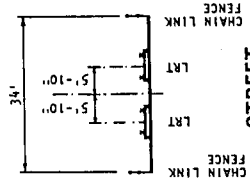
Existing Conditions

The illustrative street configuration for this example is shown in Figure 3-8. The LRT line is shown crossing a major arterial and a collector street. The major arterial has four travel lanes and an opposing left turn lane. The collector street has two travel lanes.



LEGEND:

- NOISE BARRIER
- POSSIBLE GATE VIOLATION
- TRAFFIC SIGNAL
- PLATFORM
- FENCE



MOVEMENTS

- PEDESTRIAN
- VEHICLE
- LRT
- STOPPED MOVEMENT

PHASING DIAGRAMS

FIGURE 3-8
MID-BLOCK CROSSING

Both the arterial and the collector have parking on both sides of the street. An LRT station platform is located at the collector street crossing. Two major arterial streets run parallel to the LRT tracks at the ends of the block bisected by the LRT ROW. One of these arterials is approximately 200 feet from the LRT crossing, illustrating the effect of adjacent intersection control. The LRT ROW was assumed to be 34 feet wide, carrying two tracks, and fenced between street crossings.

To illustrate the impact of an LRT crossing on different land uses, commercial properties and single family dwelling units were assumed to be located along the streets. Buildings were assumed to be located near the LRT track crossings of the arterial to illustrate sight distance restrictions.

It is assumed that along the prototypical streets, the intersections with major arterials would be controlled by traffic signals which are interconnected with progression favoring the peak traffic direction. The AM peak traffic direction on the major arterial is assumed to be westbound. During the PM peak, it is possible that the eastbound vehicle queue at the "near" arterial intersection could extend far enough back to block the LRT track.

Figure 3-9 illustrates a schematic time-space diagram of traffic signal progression along the major arterial. The wider band is the peak direction flow. The diagram shows that traffic from the upstream intersection would be discharged in platoons. Traffic between platoons would generally be vehicles that turned onto the arterial. This will usually be a lighter volume of traffic.

Traffic Control at Midblock Crossings

There are essentially five possible crossing control strategies for controlling LRVs and motor vehicle movements at a midblock crossing. Four of these use stop signs, traffic signals, or flashing lights. The fifth uses gates, backed up with traffic signals or flashing lights and audio devices.

LRT Stop Control. This strategy is applicable on low speed, large headway LRT lines crossing streets with very low traffic volumes. The operating rules would require LRVs to stop at the crossing and visually inspect the crossroad for traffic before proceeding. All LRVs would be delayed, regardless of available gaps in traffic, and adequate motor vehicle stopping sight distance would have to be available to the LRV operator. If it is assumed that traffic on the street operates at 30 mph, then the clear line of sight from the LRV would have to be at least

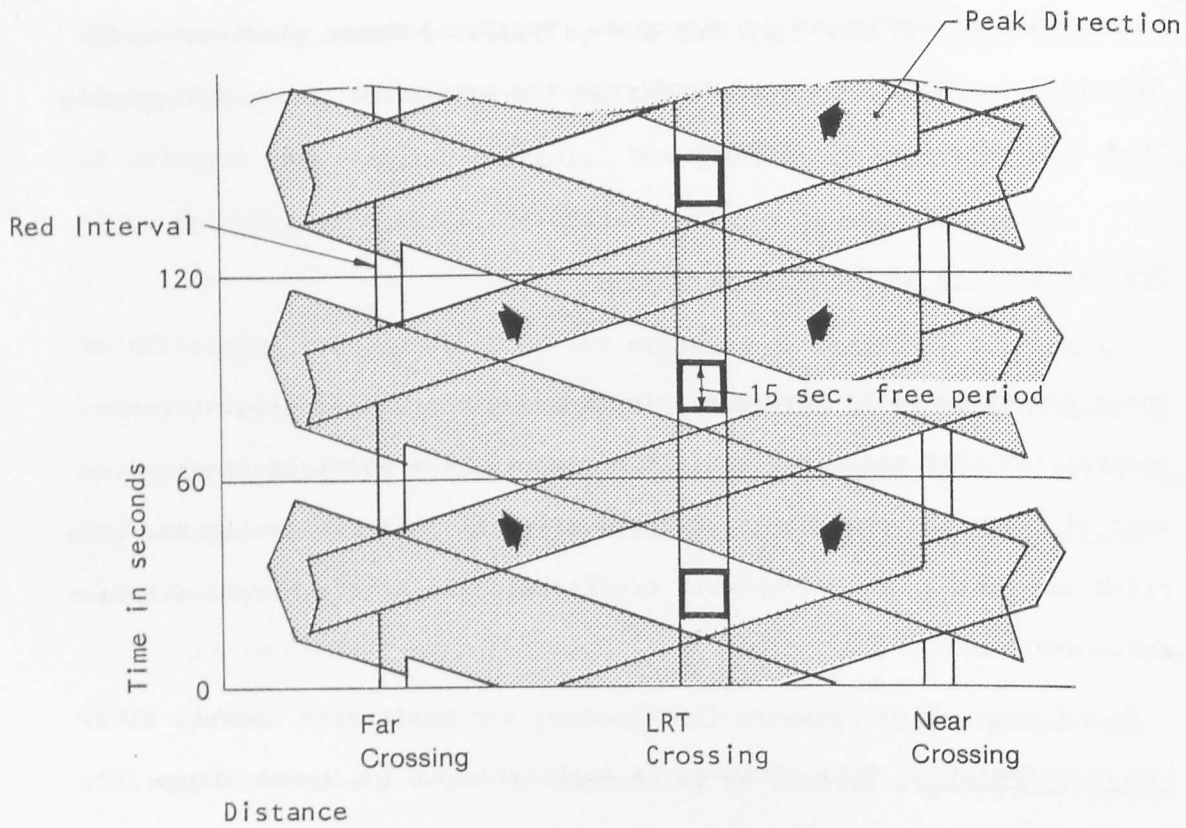


FIGURE 3-9
CROSS STREET SIGNAL PROGRESSION

200 feet to ensure adequate auto-stopping distance. In the illustration in Figure 3-8, the most restrictive sight distance occurs for southbound LRVs due to the presence of structures. The location of the structures restricts the sight distance to approximately 80 feet, which is below the stopping sight distance required for auto traffic. Consequently, this could be a hazardous location.

The four-lane arterial is approximately 100 feet wide; crossing it with a LRV train about 200 feet long would require about 13 seconds. This means a gap in the traffic of at least that many seconds would have to be available for the LRV to cross safely. An examination of the time space diagram in the previous figure indicates that for the assumed traffic signal pattern, a gap of only 15 seconds is available between vehicle platoons. On well-traveled streets, left- and right-turning vehicles plus leaders or stragglers of the platoon could reduce this gap to less than 10 seconds. This situation emphasizes the importance of providing adequate sight distance. Consequently, this strategy is unsuitable for the illustrative case discussed here unless the obstructing structures were removed. For the narrower two-lane cross street with very light traffic (1,000-2,000 vehicles per day), this crossing control strategy might be feasible. The required LRT crossing time would be shorter, about nine seconds, and sufficiently long gaps in traffic would be more frequent.

All Stop Control. A more stringent control strategy would require that all LRVs and motor vehicles stop at the LRT crossing in the same manner as at a four-way stop, with alternate vehicles taking turns to go through the intersection. With this control strategy, the need for long stopping sight distance is eliminated, but all vehicles are delayed. The crossing may be expected to operate reasonably well with motor vehicle volumes up to 1,000 vehicles per hour on the cross street; higher volumes will probably cause vehicle queues that may block street intersections close to the LRT crossing.

The "all stop" strategy is practical only at crossings with narrow (two-lane) streets carrying relatively low volumes of less than 5,000 vehicles per day. Wider streets require a longer time for an LRV to cross, and this could lead to confusion and accidents. A further complication is that infrequent LRV crossings could result in driver disregard of the stop sign control.

Traffic Signal Control. A third strategy would control the crossing with standard traffic signals operated as part of an interconnected signal system and/or when activated by LRVs or automobiles. Preferential treatment for light rail could be achieved with preemption by the LRT or by providing a dedicated LRT phase in the signal cycle. Which of these

control methods is chosen would depend on the motor vehicle traffic volumes on the arterial, the ability of the arterial to absorb disruptions to flow, the frequency of LRT crossings, the width of the crossing, and the extent to which light rail will be granted priority. Because preemption of signals at a midblock location does not penalize cross or turning traffic, the impact on utilization factors is far less than in the previous illustrations for street intersections, as shown in the following example.

Utilization factors were calculated for the LRT crossing the major arterial at headways varying from 2 to 10 minutes, assuming a heavy traffic volume of 27,000 vehicles per day and preemption of motor vehicle flows for up to 20 seconds. The 20-second preemption is long enough to permit passage of the LRV at speeds between 20 and 40 mph. The results of this analysis are displayed in Table 3-10. They show that preemption increases the utilization factor to between 40 and 53 percent if there is no station platform near the crossing. If a station platform is located near the crossing, the utilization rate would increase to a maximum of 66 percent for the same conditions due to the need for pedestrian crossing signal phases.

Table 3-10

MIDBLOCK CROSSING UTILIZATION FACTORS

	<u>Light Rail Intersection Crossing Intervals (min.)</u>				
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Near-Side Platform	66	47	43	42	41
No Platform	53	44	41	40	40

This calculation does not account for the effect of adjacent intersections upon light rail. To prevent excessive traffic queuing, the upstream intersection should ideally operate at about the same utilization rate as the LRT crossing. If traffic signals at the LRT crossing are not interconnected with signals at nearby intersections, westbound vehicle platoons could be stopped at the LRT crossing a short distance from the closest intersection, possibly leading to rear end collisions. A platoon longer than the 200 feet between the cross street and the LRT crossing could also result if the signals were not interconnected. Table 3-11 shows the anticipated queue length of such a platoon for various approach volumes. For approach volumes of more than 250 vehicles per lane per hour, the queue length would be longer than the distance between the LRT crossing and the closest street intersection, and the intersection could be blocked. To avoid such an occurrence, either restrictions on LRT preemption would be necessary for traffic volumes greater than 250 vehicles per hour, or the upstream intersections would need to be interconnected to the crossing.

A less stringent preemption strategy would allow preemption only in the off-peak traffic direction. This would disrupt less of the vehicular traffic but at the expense of delay to LRVs. This would make the traffic control system somewhat more complex. Interconnection between the traffic signal controller and the controller at the LRT crossing would

Table 3-11

REQUIRED VEHICLE STORAGE

<u>Hourly Volume Per Lane</u>	<u>Required Storage Distance Per Lane (Feet)*</u>
200	160
300	250
400	350
500	400
600	500

* Assumes 60-second cycle, no trucks

be required at the nearby intersection. In addition, to compensate for short sight distance, a signal would be needed to inform the LRT operator whether he has the ROW. An automatic trip signal could be installed upstream of the crossing to stop the LRT should the operator fail to see the stop signal. If computer control is available, the crossing control could be continuously varied to minimize delay at the crossing.

For those situations in which LRV delay is less important than traffic delay, a third control strategy could be used. The LRVs would be allowed to cross only during the so-called "free" period on the cross street. This is the period when the crossing is usually unoccupied by motor vehicles, as shown in the unshaded area in Figure 3-9. This is a period of about 15 seconds occurring once during every 60-second cycle. On the average, an LRV would be delayed 20 to 25 seconds waiting for this free period. This strategy operates best at crossings controlled by traffic signals which are part of an interconnected signal network.

The use of traffic signals alone at midblock crossings must be approached with caution. Since traffic signals are used almost exclusively to control street intersections, the unfamiliar situation of an uncurbed, midblock LRT crossing could cause confusion and non-compliance. The longer the LRT headways, the greater the chance that auto drivers would encounter a signal which is green. This could pose a particular hazard during midday or late night periods when drivers might fail to react to an infrequently activated signal.

Standard Railroad Automatic Flashing Signal. A fourth and much more common method of controlling midblock crossing could utilize standard railroad flashing lights. The flashing signal would stop all cross traffic for an LRV crossing.

Railroad Gates. The last control strategy would stop vehicular traffic during LRV passage with standard railroad crossing gates, supplemented with automatic flashing railroad lights or standard traffic signals as needed. The use of gates has a psychological affect on everyone concerned; they seem to signify secure control of the crossing. However experience with the Skokie Swift in the Chicago area has shown that gate arms at crossings are frequently knocked down by motor vehicles. Gate arms are somewhat fragile, enabling a vehicle to enter the crossing after breaking it. Gates take time to be lowered and raised and therefore increase the time that the crossing is closed to traffic by 8 to 10 seconds. This of course adds to motor vehicle delay and reduces the capacity of the crossing. To illustrate this point, the crossing utilization factors which were shown in Table 3-10 would increase to 85 percent due to the time required for gate operation.

This research has uncovered no agencies in the United States with LRT operating experience using standard traffic signals rather than conventional flashing lights in conjunction with gates. In Duisburg,

West Germany, a constant red indication is being used experimentally at railroad crossings with an amber signal preceding the red indication. This appears to have a more emphatic meaning to motor vehicle drivers than a flashing red signal. An experimental test and evaluation of this type of signal in the United States would be useful.

Activation of gates by the LRT operator is possible at crossings of low traffic volume streets with platforms located on the near side of the crossing. The operator would activate the signals just prior to departure from the platform. This is tantamount to unconditional preemption, which would permit passage of the LRV as soon as adequate clearance intervals have occurred or when traffic flow would not be interrupted.

Upstream detection would provide for unconditional preemption and be suitable for midblock crossings without station platforms or with the platform located just beyond the crossing (see Figure 3-8). If the approach speed of the LRV is known, detectors could be placed at a point which would allow for a safe crossing clearance interval and safe stopping of street traffic. The LRV would then receive permission to pass by the time it gets to the crossing.

The third method would operate in a similar way, but the preemption would be made conditional by a master traffic controller which would evaluate traffic demands, the current status of the traffic signal(s), and the position of the LRV. Detectors and controllers of this type are still in the developmental stage and should be used with caution. An operational system of this third type could function in the following way. Should the LRV arrive at the crossing during a major traffic movement, the LRV would be delayed. Otherwise, the LRV arrival would cause shortening of the operating signal cycle in order to provide clearance at the crossing in favor of the LRV. Detection of the LRV would have to occur at two places, one located 100 to 150 seconds upstream of the crossing and the second just upstream of the safe stopping sight distance. The first detection would allow the computer sufficient time to calculate the impact of an LRV preemption on traffic and to decide when to preempt. The second detection would verify the arrival time of the LRV and transmit the "go" or "no go" command to the LRV via wayside signals. This and even more "think" types of dynamic signals are being developed primarily as a result of the recent break-throughs in computer technology.

Pedestrian Protection

Because of restricted lines of sight, pedestrian awareness of LRV movements may be quite limited at midblock crossings. Unless special precautions are taken to prevent pedestrians from stepping into the path of the moving LRV, safety would depend largely on the pedestrian's alertness and ability to see and hear approaching LRVs. Traffic control at midblock crossings must therefore include measures to safeguard pedestrians at the crossing, entering or leaving station platforms, or making transfers from buses. Several techniques commonly used to protect pedestrians at midblock crossings are briefly reviewed below.

The most commonly used warning devices are signals and gates. These devices may be used singly or in combination, depending on pedestrian volumes, frequency of LRT movements, and concerns about visual impact. In order to guarantee safety, pedestrian protection could be required whether or not the LRT stops before proceeding. Unfortunately, visible and audible signals (i.e., lighted stop signs, red or flashing lights and horns, bells, and other sound makers) do not provide positive crossing protection. Pedestrians frequently ignore crossing signals at intersections to a degree that is closely related to the perceived hazard and the level of enforcement in the particular jurisdiction.

Barrier gates are a more positive means of pedestrian protection, but even gates are not foolproof. Gates could be activated at the same time as vehicular gates, or they could be used in conjunction with signal controls for motor vehicles. Pedestrians, especially children, have been known to crawl under gate arms to cross tracks. It a common practice in Europe to prevent this by suspending steel mesh screens from the gates; when the gate is raised the mesh collapses into itself presenting the same profile as an unmeshed gate. However, the meshed gates would have the disadvantage of increasing the possibility of pedestrians being trapped on the LRT right-of-way if caught on the crossing while the gates are closing.

Providing a refuge area would obviate this deficiency. Since warning lights and/or audible signals usually precede gate closing, the likelihood of pedestrians being trapped between gates would be minimal.

Pedestrian protection is increased by placing barrier gates near station platforms, between the platform and the nearest LRT track. This location will discourage but not prevent pedestrians from rushing across the tracks to the platform in front of the arriving LRVs. Two potential gate locations were shown on Figure 3-8; location A is more effective.

If there is a bus serving the LRV stop on the street crossed, special pedestrian access requirements and safety problems must be addressed. The bus stops should be located on the downstream side of the LRT tracks to avoid blocking the crossing signals and gates. Bus passengers would have to cross behind the bus in view of all approaching LRVs, thereby reducing the potential for accidents. As shown in Figure 3-8, crosswalks could be provided across the collector street to connect the bus stops with the station platforms. To provide positive protection from motor vehicles, the crosswalks could be located between the vehicular gate and the LRT tracks; pedestrian crossing should be controlled by pedestrian signals.

A common problem of LRT on separate right-of-way is pedestrian activity on the right-of-way itself. This activity could be discouraged by fencing the right-of-way and placing a pedestrian barrier at the entrances to the right-of-way at crossings as shown on Figure 3-8. To prevent injury to pedestrians that do stray on the right-of-way, the right-of-way should be wide enough to provide a safe refuge area on either side of the tracks. Pedestrian crossings across the fenced ROW should be provided where demand justifies them. The "Z" type crossings shown in Figure 3-2 could be used to assure that crossing pedestrians face the approaching train. A standard crosswalk treatment with pedestrian signals or an uncontrolled crossing may be sufficient if proper sight distance is available.

Traffic Circulation

The impact of a midblock crossing on adjoining commercial zones would be relatively small. During brief periods when the gates are closed, the traffic queues would somewhat restrict traffic movement on arterials in front of the stores.

Parking

Parking would have to be restricted the last 50 feet on either side of the LRT crossing to provide adequate sight distance and to prevent vehicles from entering the tracks when parking. This encroachment could occur at parking spaces downstream from the LRT track, where drivers could inadvertently back onto the track. A potentially greater negative effect could result due to an increase in parking demand at the LRT stop.

Land Use

Left turns into commercial establishments in the immediate vicinity of the LRT crossing may have to be restricted due to the placement of gates. Station platforms located close to residences could produce some negative noise and visual effects. However, these could be mitigated by

planting shrubbery to mask the sound and the view of the platform. Construction of a sound barrier such as a brick wall may more effectively reduce the noise impact, but care should be taken lest these remedies restrict sight distances.

DESIGN ILLUSTRATION NO. 5

LRT SURFACE LINE LOCATED IN PEDESTRIAN MALL

Introduction

Light rail transit malls have been successfully developed in many European cities.* In the United States, Buffalo is presently constructing an LRT/pedestrian mall, and in Portland, Oregon, a bus mall is being considered for eventual conversion to operation by light rail. Placing the LRT tracks in a mall serves several purposes: a means is provided for bringing LRT riders close to the activities concentrated in the mall; an intra-mall circulation system is provided; and, where the mall is made auto-free, the LRT can provide quiet and pollution-free transportation. The LRV is one of several options that may be considered for transportation in malls, among which are conventional buses, electric trolleys, small battery powered buses, and people movers. Sharing the


*European cities with LRT/pedestrian malls include Hannover, Frankfurt, Mannheim, Dortmund, Cologne, Bremen, Kassel, Amsterdam, Geneva, and Zurich.

mall ROW among two or more modes is also a possible option. Each mode has certain special advantages and disadvantages. LRT offers the advantages of potential construction cost reductions, elimination of the penalty of a transfer from the line haul portion of the trip to the collector/distributor portion, and improved safety relative to buses and automobiles.

The LRT in a pedestrian mall poses unique design and operational challenges resulting mainly from the need to separate movements of the LRT and pedestrians in the interest of safety. This design illustration addresses some of the possible ways to deal with these challenges.

Mall Configuration

A typical LRT configuration in a mall is shown in Figure 3-10. Only two blocks of the mall are shown, but the mall can be several blocks long. A typical mall might be 80 feet wide with two LRT tracks occupying about 24 feet of that width. Separation between the clearance area for the LRT tracks and pedestrian walkways can be delineated by texturized pavement and/or a small difference in elevation as shown on Sections A-A of the Figure. Certain blocks of the mall might be restricted to pedestrians and LRT while other transit modes or motor vehicles might be permitted in some places.

LEGEND:
 TRAFFIC SIGNAL

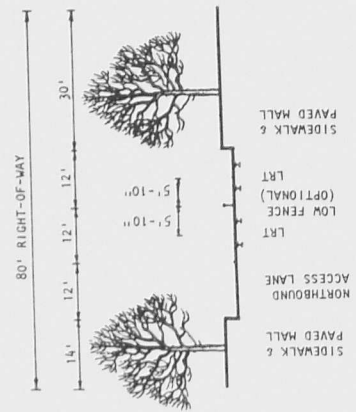
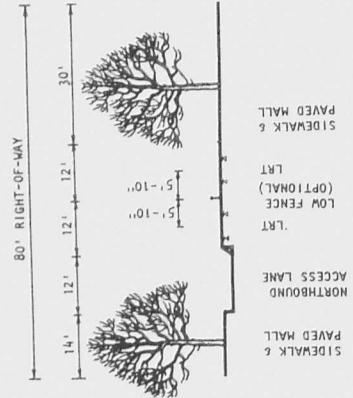
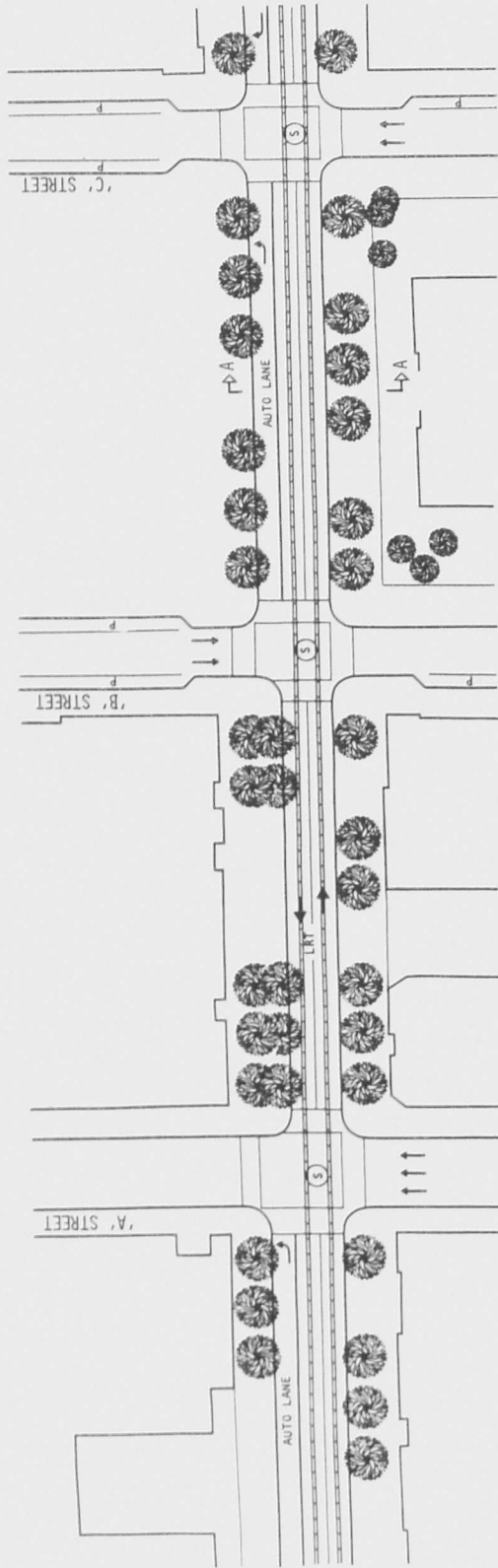


FIGURE 3-10
 LRT MALL

If absolutely necessary to provide access to fronting properties, existing parking structures, major traffic generators, and for around-the-block circulation, a traffic lane could be included. Local motor vehicle traffic would be required to turn off the mall at the end of each block; through traffic in consecutive blocks would not be permitted by the manner of design. The traffic lanes would be one-way and turns would be restricted so that vehicles entering or leaving the mall would not cross the LRT tracks. LRT conflicts would be limited to those with cross traffic at intersections. The motor vehicle lanes would be separated from the LRT by a narrow median barrier. However, most European LRT malls do not include auto lanes, thereby enhancing their pedestrian environment.

A number of mall design features are necessary to reduce the potential for pedestrian accidents. Two alternative mall cross sections are shown in Figure 3-10. The first section shows LRT tracks at a slightly lower elevation than the mall pedestrian way, thereby effecting a curbed separation from pedestrian traffic. This elevation differential serves as a warning and reminder that the LRT tracks are near. The second section shows the LRT tracks flush with the mall sidewalks. An access roadway is also shown on one side of the tracks at a different level and separated from the track by a mountable curb. In lieu of curbing, striping can be used to distinguish the LRT ROW, or different textured materials such as cobblestones or brick pavers could be used to define the LRT track area. The use of different textures and colors for this delineation has proven quite satisfactory in European malls.

Another method of keeping pedestrians off the LRT tracks between intersections is with a low fence or plantings between the tracks. However, this treatment discourages full pedestrian circulation within the mall.

Nonetheless, the fencing would reduce the potential for pedestrians to walk around the end of a light rail vehicle that was either parked or moving and, due to the large size of the LRV, to be blocked from view of an LRV coming from the opposite direction. Use of fencing would limit dual use of the right-of-way by buses because bus turns would be restricted and passing would be impossible if the ROW between the fencing were as narrow as 12 feet. Many of the European LRT malls do not use fences, but rather rely upon a combination of texturing the LRV running surface, bells on the vehicles, and the relatively slow operating speeds to ensure pedestrian safety.

LRT Operations in the Mall

In mall operations, LRVs cannot operate faster than pedestrian interference will allow. In most cases, control of the LRT system would be maintained by traffic signals at each intersection, and preemption would not be used. Station platforms would not be necessary; passengers could board the LRT at any point which is designated as a stop. However, permanent shelters could be provided to provide relief from inclement weather, and to encourage patrons to wait in the designated area rather than blocking storefront entrances.

The most important safety feature along a mall is the LRV's relatively slow operating speed. Depending on pedestrian activity and other factors, this could be about 10 to 15 mph (16 to 24 kph). At these low speeds the safe stopping distances of LRVs are similar to those for autos and buses, i.e., 70 to 110 feet (21 to 34 m). Operators of LRVs would ride high enough to have a good view of pedestrians on the mall, and no obstructions should limit their field of vision along the right-of-way. The potential for collision with vehicles or pedestrians at the cross streets can be minimized with traffic signals controlling all conflicting auto movements. However, in comparison to subway configurations, for relatively short malls, these slow speeds do not cause undue delay to pedestrians. This is true because the passenger has direct access to the vehicles, and is not subjected to the delays inherent in reaching the subway (stairs, elevators, and escalators).

The LRT configuration in Figure 3-10 would operate in two directions on its own right-of-way. Alternatively, the operating scheme might include bus operations as well.

However, joint use of the LRT ROW by buses can have serious drawbacks. The primary disadvantages would include conflicts between the buses and LRVs, increased noise and air pollution, and reduced space for pedestrians to allow for bus passing and turning movements. The conflicts and

passing restrictions could reduce transit capacity and cause delay and schedule unreliability. Rubber tire traction and braking capability of buses on the steel rails would be poor in inclement weather, causing further safety problems. For safety, vehicles could not operate close to one another, further reducing capacity. A progressive fixed time traffic signal system that would provide good travel speeds along the mall for buses and LRT would be difficult to devise. Access to property along the mall would be reduced with bus use if access by other traffic were restricted as a result. However, the new LRT/bus transit mall on 7th Street in Calgary is now in operation, and appears to be successful.

Traffic Control in the Mall

A standard two-phase traffic signal installation with WALK/DON'T WALK pedestrian indications could be used along the mall at each intersection. All LRV movements would be controlled by the same traffic signals. Preemption generally would not be practical or needed since the LRVs move slowly and stop frequently. Preemption would be difficult to implement and detrimental to cross street motor vehicle and pedestrian traffic. Since CBD traffic signals are usually interconnected, preemption at mall intersections would disrupt the progressive traffic movements that cross the mall, thereby causing congestion. Maintaining a capacity balance on CBD streets is important in order to avoid overloading them for long periods of time. The mall environment and the

close spacing of traffic signals could allow use of the existing CBD signal system. Signal timing could be adjusted to favor progression of the LRVs. The traffic signals could be synchronized, accounting for the average LRV dwell times, speed, acceleration and deceleration rates, platform locations, and the level of interference from mixed flow bus traffic so as to minimize delays to the LRVs. Operation of a one-way mall would make it easier to achieve good signal progression.

The theoretical capacity of light rail in a pedestrian mall could greatly exceed the circulation needs of the public. Up to 45 two-car LRT trains per hour would be theoretically possible in each direction with coordinated signals operating on 60- to 70-second cycles and stops located every three blocks. It is doubtful that this high level of service would be needed for most applications, but the capacity for high volume operation exists. The experience in pedestrian/LRT malls in cities like Zurich indicates that frequent service can be provided and is useful because shoppers' waiting times are kept low. Pedestrian movements among the closely spaced LRVs do not seem to be particularly impeded. Distances between LRVs tend to adjust to the pedestrian volumes on the mall.

Access to Establishments on the Mall

With private vehicles excluded from large stretches of the mall, motor vehicle access to establishments fronting on the mall is of prime concern. Service access could be maintained in various ways. For instance, truck deliveries could still be permitted during the day from a parallel motor vehicle lane. Access for portions of the mall which do not have such lanes could be provided by any of these three methods:

- properly paving the LRT roadbed to accommodate heavy delivery trucks and permitting delivery vehicles to enter the LRT right-of-way during selected hours.
- developing a flush paved mall and restricting mall furniture and landscaping to provide a clear travel lane partially or totally on the sidewalk.
- for CBD's with extensive parallel alleyways, restricting deliveries to the alleys.

For malls with heavy LRT traffic, deliveries could generally be restricted to evening hours. Permitting access for truck deliveries would also assure emergency and maintenance vehicle access. Obviously,

the access problem is simplified when the arterials selected for conversion to a mall have alleys and cross streets available for auto and service vehicle access.

The selection of the most appropriate street for conversion to a light rail mall is a complex matter requiring detailed field investigations. Site-specific access requirements, pedestrian movements, proximity to major attractions, traffic volumes and turning movements, and parking and loading requirements all must be considered. Further, the potential for opposition to arise to such a conversion must be dealt with. One major difficulty is that as yet there is no "role model" in the United States for planners to point toward. It can be difficult for business and civic leaders to envision a light rail mall operating effectively. Consequently, a major challenge for transit planners and engineers is to devise methods for demonstrating the effectiveness of the mall alternative.

DESIGN ILLUSTRATION NO. 6

SPECIAL APPLICATIONS - LRT AND BUS CONTRAFLOW OPERATIONS
ON LRT RIGHT-OF-WAY

LRT Contraflow

Contraflow LRT operations are not generally found in North America or Europe. However, contraflow bus lanes operate in roadways in many American cities such as Chicago, Los Angeles, Honolulu, and San Antonio, and in several European cities, including Rome, Milan, Paris, London, and Marseilles. Many of the advantages of contraflow lanes that have been realized in bus operations could also apply to LRT: travel time saving, separation from other traffic where reserved ROW cannot be provided otherwise, self enforcement, and direct routing and creation of transit identity and image. Contraflow operations allow passenger boarding directly to the sidewalks and can function with progressive traffic signalization. However, contraflow operation is not without drawbacks. It may disrupt access to adjacent development, reduce auto capacity, increase conflicts with opposing traffic, decrease safety, and disrupt signal progression for opposing traffic.

Contraflow Configuration

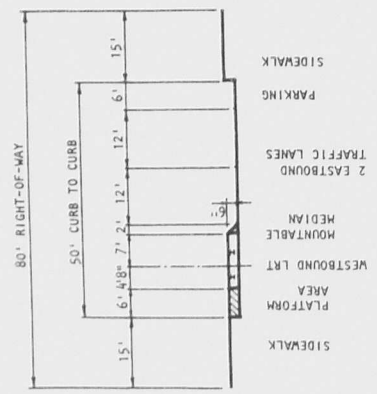
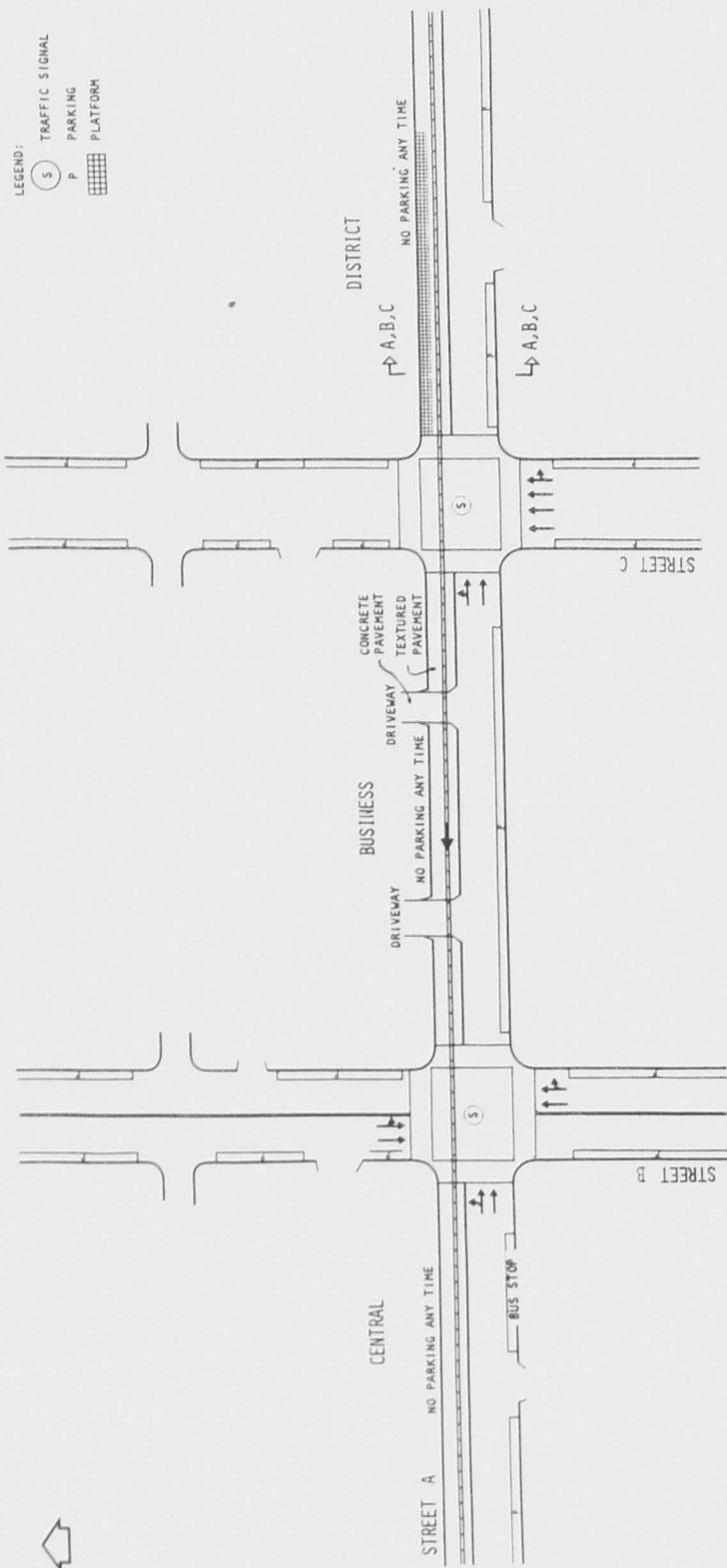
The prototypical design illustration for this discussion is shown in Figure 3-11. The track would be located in the northernmost lane of the one-way, three-lane street. The LRVs would run in the direction opposite to motor vehicle traffic. The cross streets would remain unchanged except for required grade adjustments to cross LRT tracks at intersections. No motor vehicle traffic would use the LRT lane.

Various cross sections could be developed for the contraflow alignment. Three such alternative cross-sections are shown on Figure 3-11.

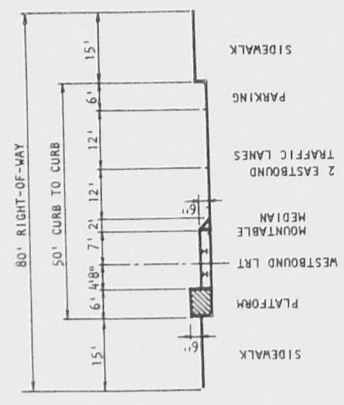
A-A The top of the LRT rails and platform would be level with the adjacent sidewalk, and motor vehicle traffic lanes would be 6 inches below the sidewalk height. The center line of the LRT track would be 10 feet 8 inches from the sidewalk to allow room for a 6-foot-wide platform.

B-B This section is similar to A-A but with the station platform raised 6 inches above the sidewalk to reduce passenger stepping distance to and from light rail vehicles.

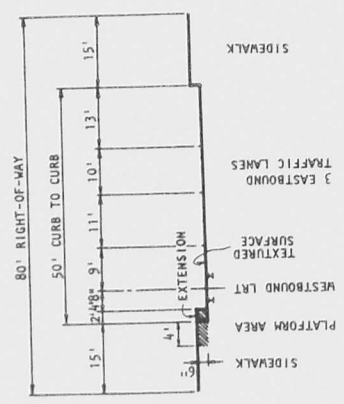
- LEGEND:
- (S) TRAFFIC SIGNAL
 - (P) PARKING
 - (Hatched Box) PLATFORM



SECTION A - A



SECTION B - B



SECTION C - C

FIGURE 3-11
CBD CONTRA-FLOW LANE

C-C The top of the LRT rails would be level with the existing street. The LRT track would be 4 feet closer to the sidewalk than in Sections A-A or B-B. A portion of the sidewalk plus an extension of 2 feet would make up the platform area. At locations away from the platform, the 2-foot extension of the sidewalk would not be used, but would provide clearance between LRVs and pedestrians. Textured pavement and/or traffic bars would separate opposing LRV and motor vehicle flows. The roadway width would allow striping of three through lanes with no parking.

For Sections A-A and B-B, the passenger platform would be 6 feet wide and would extend from the sidewalk at sidewalk height. The LRT roadbed would be elevated from the auto traffic lanes by 6 inches, and a 2-foot-wide mountable median would allow vehicle access from traffic lanes across the track. The station platforms would be located so they do not block existing driveways. For Section C-C, the track would be closer to the sidewalk, and the sidewalk would be used as a platform. This treatment would also leave more street area for motor vehicle use than the other two cross sections.

For each of these treatments, textured pavement could be used for paving the LRT roadbed. Paving could allow the roadbed to be used by emergency vehicles. Texturing would provide a means of visual and tactile differentiation between the LRT roadbed and adjacent sidewalk and street uses.

A key aspect of the texturing would be extending any driveways which must remain open across the LRT tracks using standard concrete. This would provide clear identification of the driveway location for both motor vehicle and LRV drivers. Colored pavement could also be used to identify station platform areas. Paving materials to be considered for the LRT right-of-way include rough white or black asphalt, rough concrete, brick, or cobblestones. Platform paving materials might include brick or exposed aggregate concrete. For the sidewalk and driveways across the LRT track, conventional concrete would probably be the most suitable material. In all cases the materials chosen for the different purposes must contrast and look and feel different.

Contraflow Operations

With cross sections A-A or B-B, one parking and one travel lane would be removed. Some auto queuing would result behind left-turning vehicles waiting for opposing LRT trains to clear. The combination of the travel lane reduction and the left-turn conflicts would reduce the roadway motor vehicle capacity by about 40 percent. For cross section C-C, three travel lanes would be maintained and all on-street parking would be removed. Roadway capacity would be reduced by approximately 15 percent due to narrowing of the travel lanes and of left-turn conflicts.

If left turns were eliminated or accommodated in left-turn lanes, the street capacity would be improved by at least 5 percent. Providing a left-turn lane would require some street widening.

A detailed traffic study for any proposed contraflow lane would have to be performed to determine the exact mix of parking supply and traffic capacity needed along the subject street and in general in the CBD area. Other factors that would influence selection of the cross section include availability of sidewalk space for queuing passengers, adequacy of other routes to absorb diverted traffic, local parking needs, vehicle delivery needs, and access requirements of fronting properties.

The LRT contraflow lane would not significantly restrict circulation in the CBD area. All vehicle turning movements would be allowed. The potential for LRT/auto head-on accidents would be introduced by the contraflow operation but would be reduced by the clearance between the tracks and traffic lanes, and should be, at worst, no more critical than that between contraflow bus lanes and autos. For cross sections A-A and B-B, the mountable median would alert motor vehicle traffic leaving the traffic lanes and also provide adequate recovery distance. Both motor vehicle and LRV drivers would have good, unobstructed visibility. With LRV speeds less than 20 mph and good braking characteristics, the potential for accidents would be further decreased.

Conventional traffic signals would be used to regulate LRV, automobile and pedestrian movements. Some of the potential LRV/auto conflicts at the intersections can be controlled by traffic signals. For example, conflicts with traffic on cross street C can be kept to a minimum. Motor vehicles making right turns on red onto street A from northbound street C or street B would not conflict with LRVs. However, southbound traffic on street B turning left or different orientations of one-way traffic on cross streets could lead to potential conflicts.

The primary conflicts between LRVs and motor vehicles would be caused by left turns across the LRT track if not protected by a left-turn signal phase. These are conflicts directly attributable to the contraflow operation. Some queuing and delays would result. The potential for left-turning auto/LRV accidents would exist, but the discreet nature of the LRV crossings and their size and easy recognizability coupled with slow LRV speeds and LRV drivers' superior forward vision minimize chances of any serious accidents.

Traffic Signal Progression

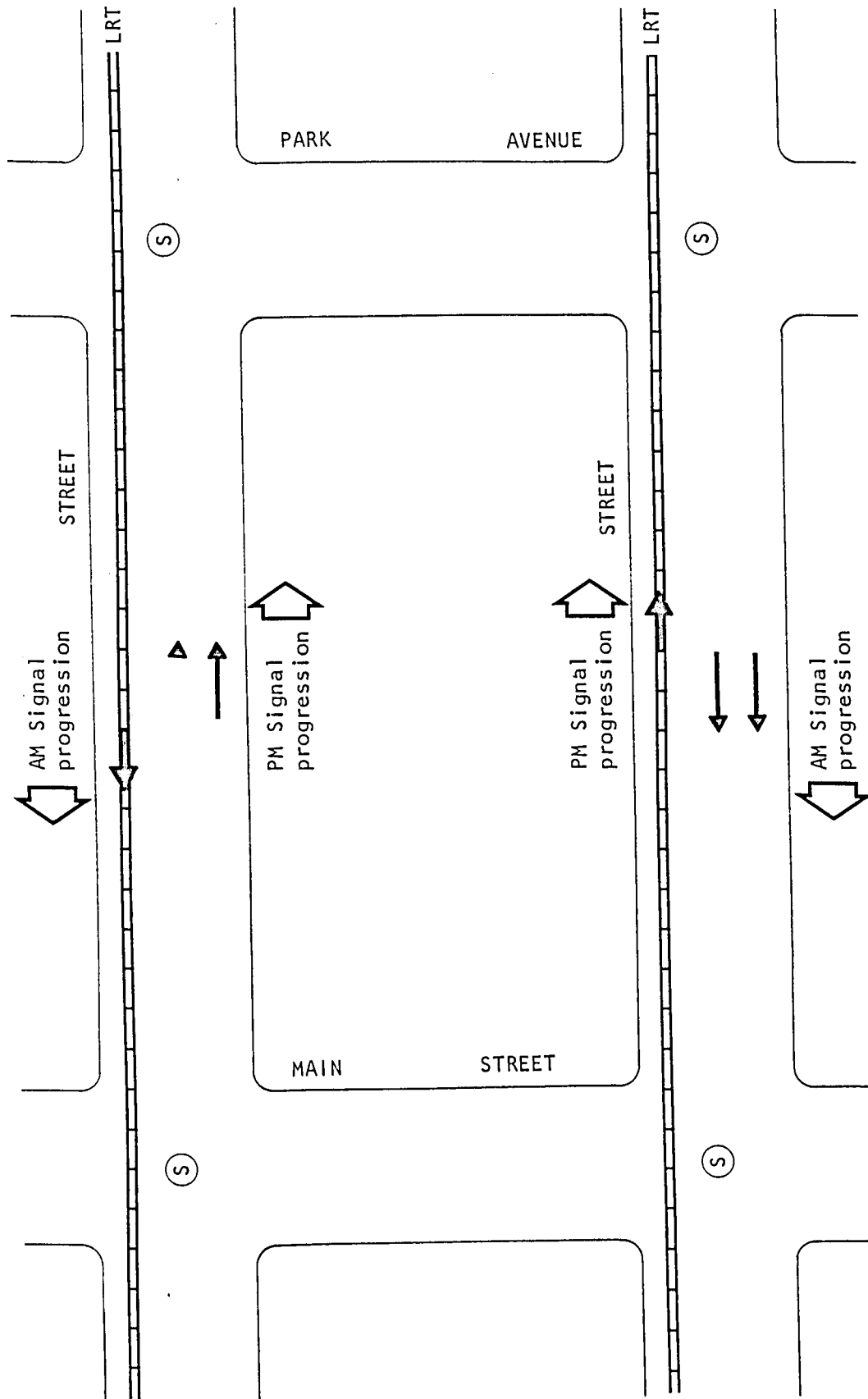
Traffic signal progressions which yield optimum flow of both LRV and motor vehicles may not be possible. Various options can be considered to provide an acceptable level of traffic movement through interconnected signals. Whether LRV or motor vehicle are given preference would depend on the relative importance of delays to the vehicles (as

well as on block length, traffic flow, LRT characteristics, and stop locations). Careful study will be required of exact requirements for the signal system, and installations should be "fine tuned" to provide optimum performance. Flexibility to change the operational parameters of the system should be built into the system from the start in order to handle changes in traffic flows.

The following are five possible traffic signal system progression strategies for contraflow LRT:

1. Develop good progression for motor vehicles and let the LRVs operate as best they can. This may only be acceptable for short sections of LRT track or with LRVs operating on long headways.
2. Develop a progressive signal system that optimizes both directions of traffic flow (both modes). Some delays to both modes will probably result. This type of progressive system is difficult to devise due to differences in distances between lights and LRT operations that require frequent stops.
3. Give all progression priority to the LRT, and let motor vehicle traffic filter through the system as best it can. This strategy may not gain acceptance in many CBD situations, except where most of the persons traveling along the street would use light rail.

4. Combine elements of the first and third strategies, based on the fact that most urban arterials exhibit distinct peaking characteristics: the traffic flow is much heavier in one direction during the AM peak period and in the other direction during the PM peak period. The contraflow LRT concept implicitly assumes that for two-way LRT flow, two adjacent one-way arterials would be converted to contraflow LRT operations. For the design illustration, an arterial parallel to street A would provide eastbound LRT traffic flow. Under these assumptions, suitable traffic progression could be developed for each pair of contraflow streets, favoring both LRT and motor vehicle traffic during their respective peak periods. Figure 3-12 illustrates this concept. The AM peak travel direction was assumed to be westbound for both LRT and motor vehicle passengers. Therefore, LRT on A street and motor vehicle traffic on D street in the westbound direction would receive progression preference during the AM peak period. Similarly during the PM peak period, eastbound LRT on D street and eastbound motor vehicle traffic on A street would receive optimum progression. During off-peak hours a compromise signal timing strategy could be employed. This strategy would maximize person flow and would only inconvenience travel in non-peak directions. This alternative appears to have strong potential for application in CBD areas which have directional travel orientations.



LEGEND:

(S) Traffic Signal

← LRV Movement

→ Motor Vehicle Traffic Movement

5. In this alternative, the LRT vehicles would preempt each traffic signal or series of traffic signals by either on- or off-board vehicle presence signaling. For example, when stopped for passengers at a near-side station platform, the presence of an LRV could be detected by a sensor embedded in the roadbed. A signal of the presence of the LRV would be sent to the traffic signal controllers at the intersections ahead. After a suitable clearance interval, green signals would be given to the LRV to proceed through the two intersections to its next station stop. The preemption interval could be ended either by activation of a preemption release detector or it could be designed to terminate after a fixed time interval had elapsed. The preemption would disrupt the normal motor vehicle progression only when an LRV is present. For this reason, this technique would be most appropriate for LRT operation at headways of about four to five minutes or greater. Lower headways would leave little recovery time for autos, and headways in the one- to two-minute range would cause the traffic progression to be permanently disrupted during peak periods. However, this could be acceptable for a low-volume street.

All of the above techniques are operationally safe because a failure of the interconnection or preemption system would leave each intersection under its own fixed signal control. Both LRT and vehicular traffic

could still move if the traffic signals are operating in a non-sequential manner. These techniques could be implemented incrementally in response to buildup of LRV volumes.

Bus Operation on LRT Right-of-Way

The operation of buses on LRT right-of-way might be considered to supplement scheduled service or to act as a backup in case of outages on the LRT system such as power failures, LRV accidents, or operator strikes.

In planning for dual use of the LRT ROW, several design and operational matters should be considered:

1. To allow bus operation on the LRT roadbed, all sections of the LRT right-of-way must be fully paved. This means no open trackage or unpaved sections can be allowed.
2. To the auto driver, paved roadbed looks more like a street than unpaved trackage. Care must be exercised in curbing the ROW, signing, and placement of striping or other warning devices to prevent trespassing by automobiles.

3. Design criteria for horizontal and vertical alignment apply equally well to LRT and buses. Both vehicles operate with essentially the same parameters. Therefore, no special alignment modifications have to be made during design of LRT systems to permit bus operation.

4. Buses need greater lateral clearances than LRVs. At least 12-foot-wide lanes are needed to provide adequate clearance. Less clearance would inhibit operations, lead to slower speeds, and increased collision potential. The increased side clearance requirement implies that the typical minimum LRT cross section would not be generally acceptable for dual operation. Figure 3-13 illustrates the typical lane widths used for LRT operations with and without center poles. Generally, the minimum width for LRT is somewhat too narrow for satisfactory bus operation. In addition, center poles pose a potential safety hazard for buses. In a bus/LRT ROW, center poles should be avoided.

5. Detection equipment for traffic activation and/or traffic signal preemption would have to be modified to accommodate bus activation if bus preemption were desirable. Catenary mounted detectors would have to be supplemented with wayside detectors activated by on-board vehicle transponders or appropriate roadway mounted detectors.

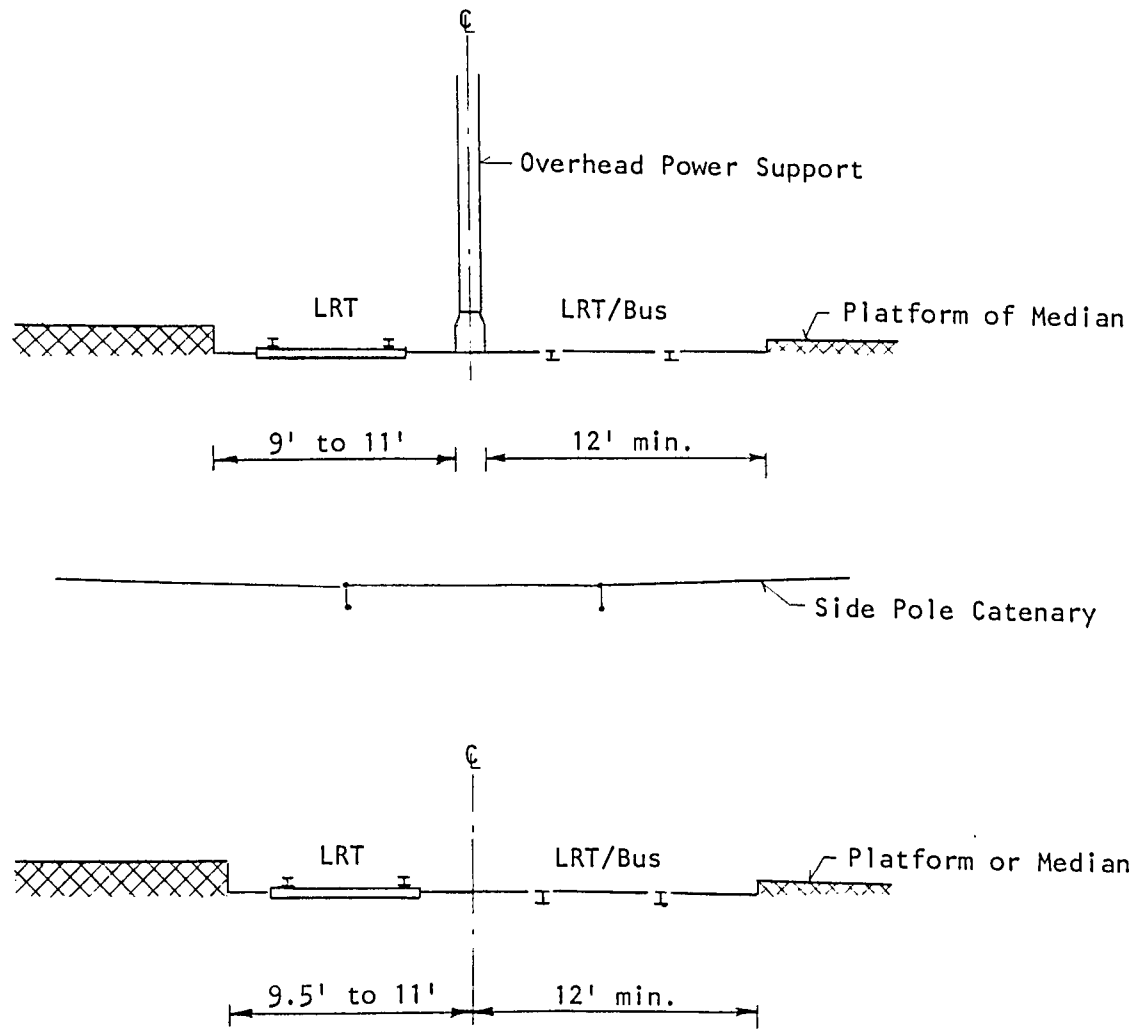


FIGURE 3-13
 BUS/LRT LANE WIDTH COMPARISON

6. The 6-inch high platforms used for LRV stops would not be suitable for buses; split high/low platforms would be required with the buses stopping at the low end of the platform as illustrated in Figure 3-14. This design would lengthen the platform and add to the cost. Currently a similar split platform is being considered by the MUNI system in San Francisco. With a suitably designed LRV door and step, the front doors, and possibly the middle doors, could be located at the low end of the platform, with the rear doors at the high end of the platform. The low platform should accommodate the first two LRV doors in order to fit the dimensions of a standard bus.

7. Joint operation buses in a separate median with LRT should result in an increase in bus operating speed since median operations are generally faster than mixed flow curbside operation. These benefits could accrue as long as headways were long enough so that transit vehicles would not interfere with each other.

8. Joint median operation of buses and LRT could result in higher concentrations of passengers loading/unloading in the middle of the street at platforms. This could increase the exposure to collisions with motor vehicles for pedestrians that have to cross traffic lanes. Fencing of the traffic side of the platforms and proper vehicle/pedestrian signals could alleviate this problem.

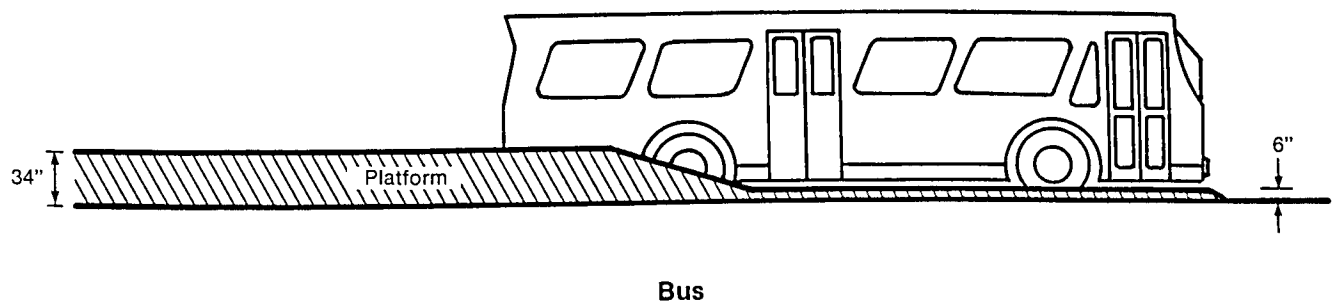
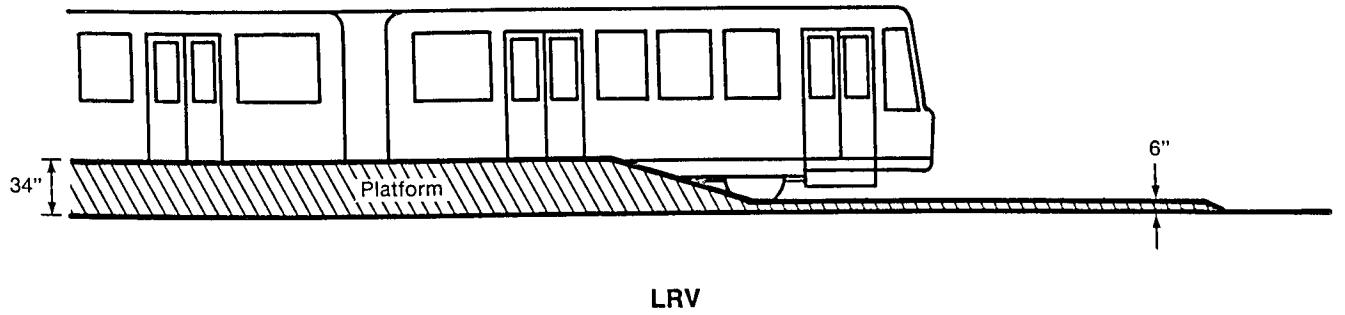


FIGURE 3-14
SPLIT HIGH/LOW PLATFORMS

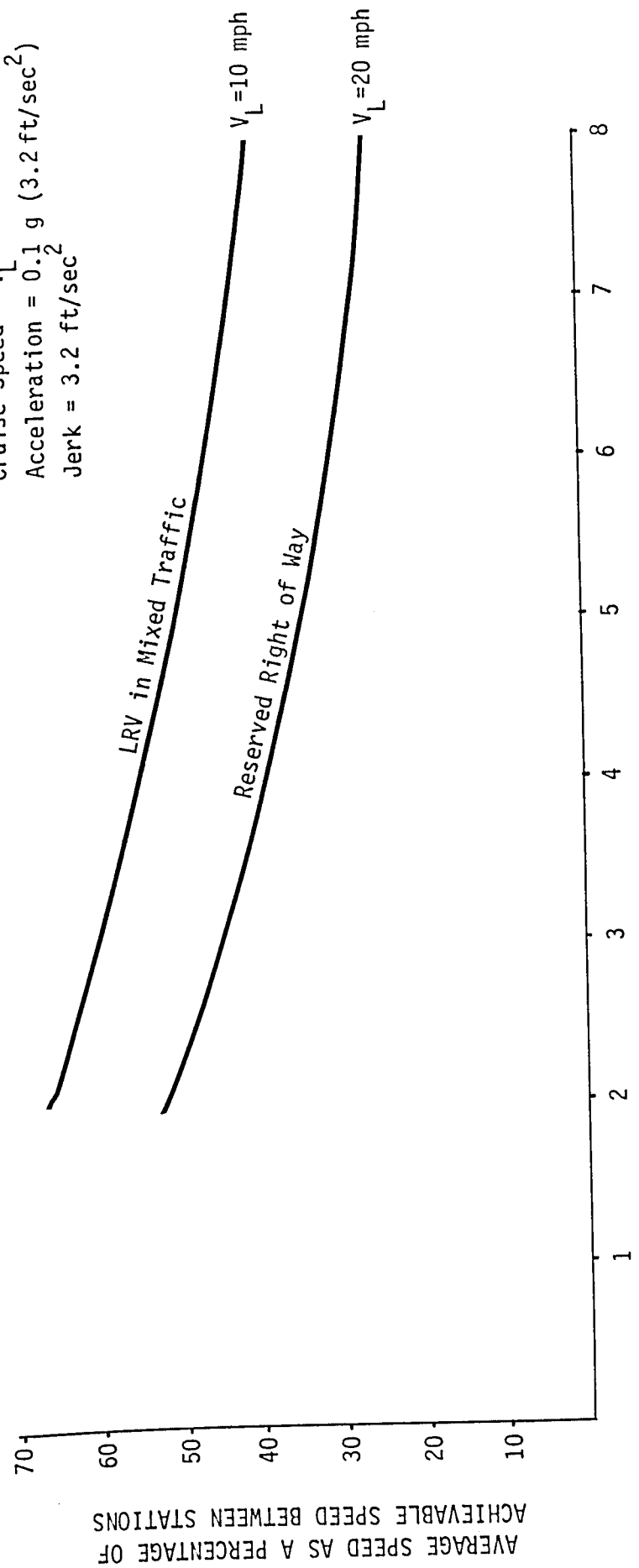
PERFORMANCE COMPARISON OF LRT DESIGNS

Speed and Travel Time

Figure 3-15 compares average speed of LRT in separate right-of-way with speed in mixed traffic, accounting for varying degrees of intersection signal delay. Average speed in Figure 3-15 is expressed as a percentage of maximum theoretical speed. Under the idealized conditions presented,* average speed is more adversely affected by intersection delay than by midblock delay due to operation in mixed traffic. This is typically the case where there are a substantial number of signalized intersections. Reducing the number of intersections where delays occur from eight to two improves the performance of the reserved ROW light rail by a factor of two (average speed increases from 26 to 52 percent of the maximum speed).

*Calculation details are found in an Appendix to this Chapter. Further clarification can be obtained by comparing the time savings resulting from LRV speeds of 10 and 20 mph (the latter more closely represent LRV speeds - Figure 3-17). The time savings under these conditions are still impressive for the 0.5-mile station spacing, but they are even less significant than for the previous case with closer station spacing. A maximum reduction in travel time of roughly three minutes is achieved when the number of crossings is reduced from four to two.

Distance between Stations =
 $D_S = 0.5$ miles
 Station Dwell = 20 seconds
 Intersection Delay = 30 seconds
 Cruise Speed = V_L
 Acceleration = $0.1 g$ (3.2 ft/sec^2)
 Jerk = 3.2 ft/sec^2



NUMBER OF INTERSECTIONS BETWEEN STATIONS

FIGURE 3-15
 EFFECT OF INTERSECTION STOPS
 ON AVERAGE LRT SPEED

Expressing performance changes in absolute numbers rather than percentages is often more meaningful for decision-making. The same data displayed in Figure 3-15 are shown in a different form in Figures 3-16 and 3-17. These graphics show the absolute travel time increase due to delays of 30 and 60 seconds at each intermediate intersection for two LRV speeds, 10 and 20 mph, and two station spacings, 0.5 and 0.25 miles. Several observations are apparent. The most important is the significance of intersection delay. For 10 mph, which is typical of operations in mixed traffic, and for intersection stops of 30 seconds, reducing the number of intersection stops from eight to two reduces the travel time from over 10 minutes to slightly more than 3 minutes, a saving of 7 minutes. With high volume intersections where delays may approach 60 seconds, the improvement would yield a saving of approximately 12 minutes from the previous 15 minutes. A second factor to consider is the importance of station spacing. For example, if the station spacing is decreased to 0.25 miles, the travel time improvements achieved by reducing the number of intersection stops from four to two are not so dramatic: approximately four minutes reduction for a trip which previously required eight minutes at cruise speed of 10 mph. These numbers indicate that the return for unimpeded surface operations diminishes rapidly as the station spacing decreases. This further implies that the travel time advantages of subways over surface alignments decrease when stations are close together. This has important implications for light rail transit, in that low cost surface treatments can be competitive with subways in dense urban centers with respect to travel time.

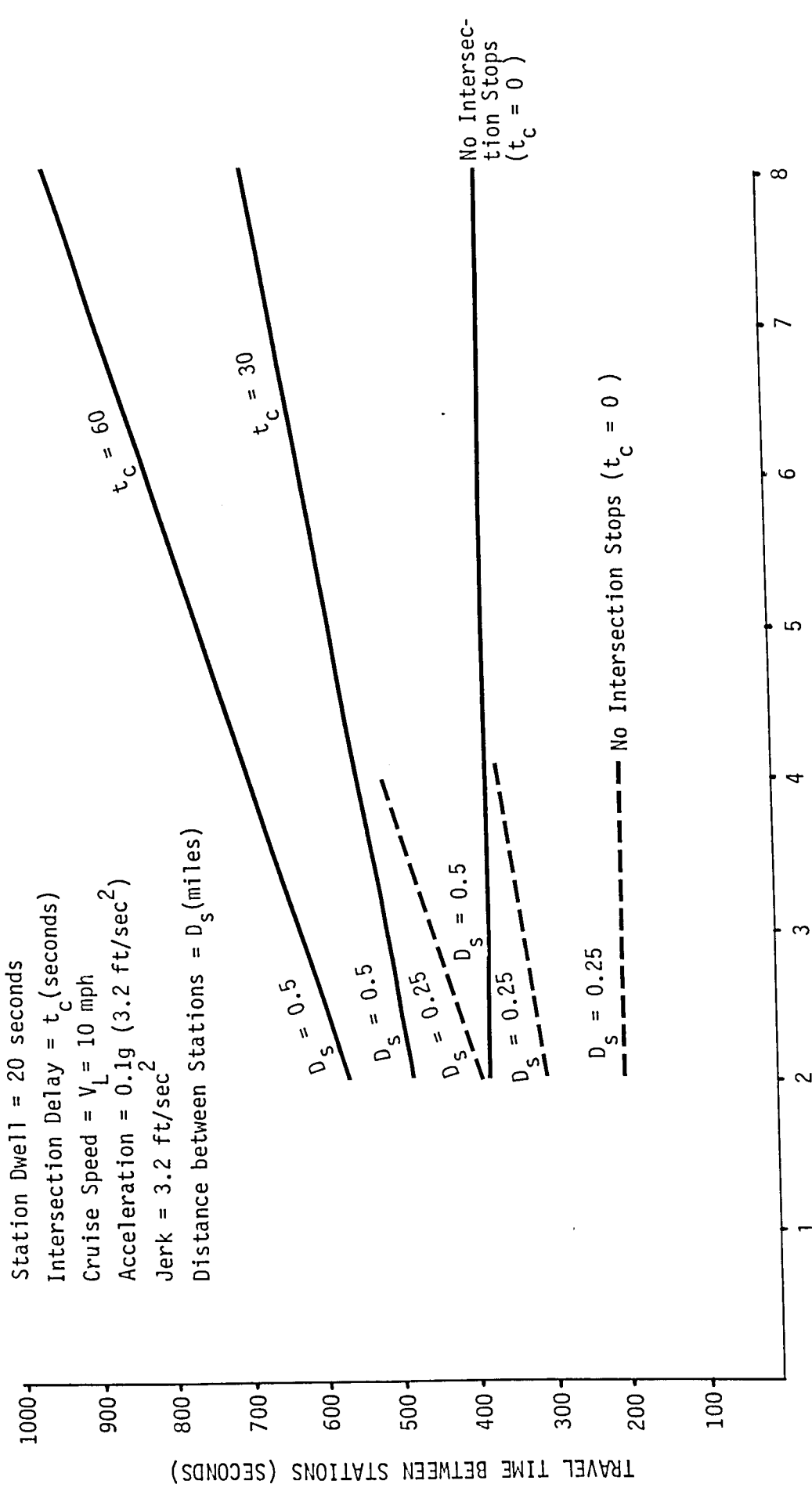


FIGURE 3-16
 EFFECT OF INTERSECTION STOPS
 ON TRAVEL TIME; CRUISE SPEED 10 MPH

NUMBER OF INTERSECTIONS BETWEEN STATIONS

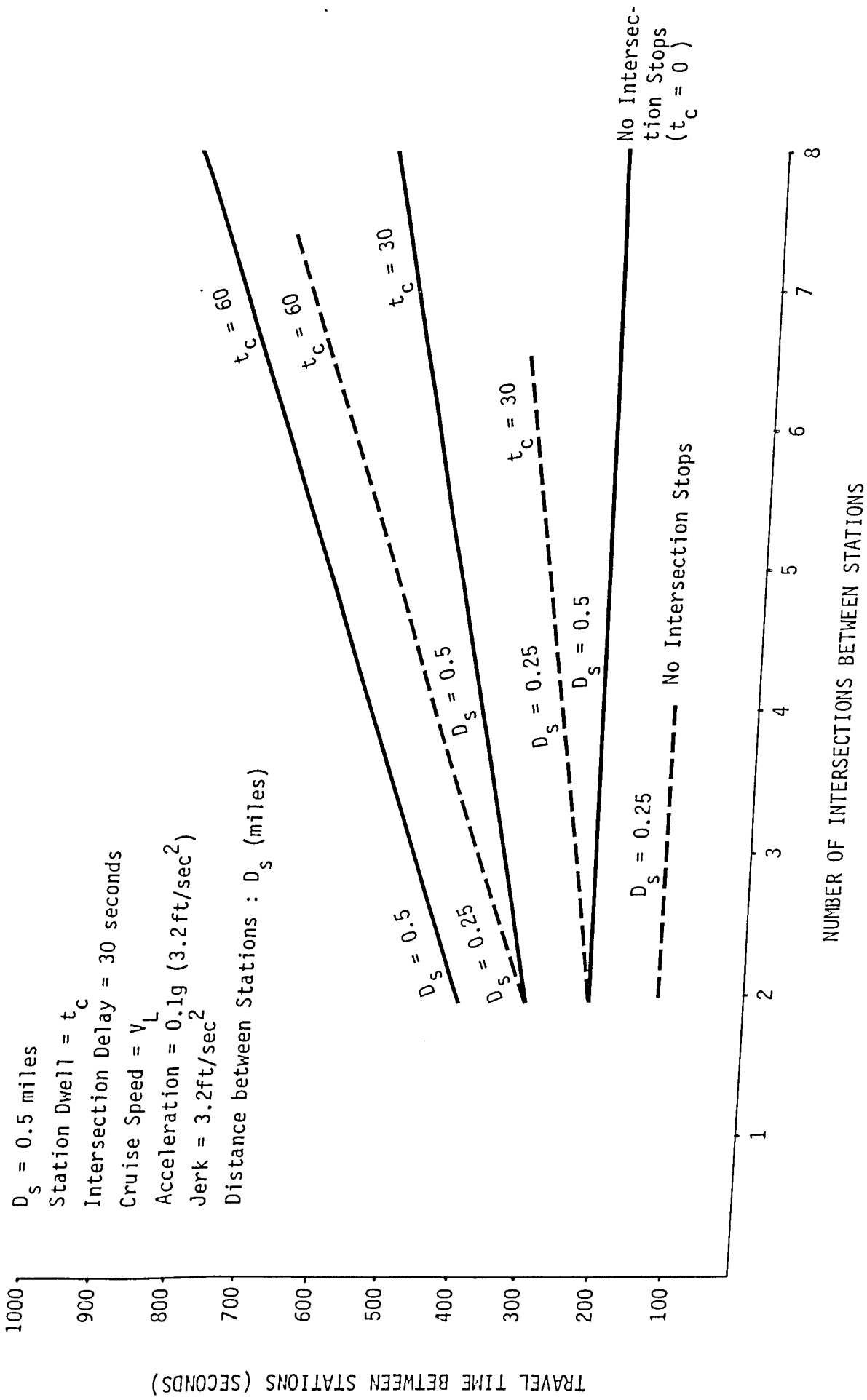


FIGURE 3-17
 EFFECT OF INTERSECTION STOPS
 ON TRAVEL TIME; CRUISE SPEED 20 MPH

General Conclusions

Some simple rules of thumb are suggested by these very idealized calculations:

- Time savings which can be achieved by preventing cross traffic (when minor crossings are closed) or by traffic signal preemption for LRVs are not so significant as station spacing decreases. In other words, in dense urban corridors such as in CBD where stations are likely to be spaced close to one another, preempting traffic signals in favor of LRT or closing streets will have little effect on LRT performance. However, such operational strategies may have major consequences to automobile traffic.
- Time savings due to any of the strategies discussed above increase significantly as the duration of probable delays at intersections increases. In other words, the performance of LRT can be severely degraded if it must operate under normal street traffic control without preferential treatment at high volume intersections.
- Grade separation of LRT lines in dense urban corridors often will yield relatively little improvement in LRT travel time and may therefore be difficult to justify. Avoiding the disruption of local traffic patterns in dense urban corridors may provide a stronger justification for costly grade separations. Underground-

ing part of the LRT lines in western European cities (see Appendix) and more recently in North America, e.g., Edmonton, Buffalo, has been justified on this basis more than on the basis of time savings.

- Reduction in intersection delay to LRVs through priority treatments and provision of reserved rights-of-way where stations are widely separated (i.e., away from the dense urban core) greatly improves the performance of LRT.
- Mixing operational strategies on the same line as suggested above, i.e., mixed operations on some parts of the line and preferentially controlled operations on others, may have undesirable operational consequences during peak hours. This conclusion is not immediately obvious from the preceding discussion but may be inferred in the following way.

To design an LRT line for absolute minimum cost, preferential traffic control or other related measures may be proposed on the outlying portion, while maintaining operations in mixed traffic on the central portion of the line. Construction costs would be minimal and the performance only marginally worse compared to that achievable with full preferential traffic control at all intersections. Preferential control tends to enhance schedule reliability because the likelihood of unforeseen and random delays is reduced since fewer (if any) intersection delays are encountered.

Thus, on the peripheral part of the line, reasonably good schedule adherence could be maintained, and in peak hours high frequency service could operate with fairly reliable headways. On the central part of the line, however, failure to enforce similar preferential control strategies at intersections will result in high schedule variability. The calculations displayed in Figures 3-16 and 3-17 suggest that wide fluctuations could be expected in interstation travel time depending on how many intersection stops are encountered and on how long each stop is. Consequently, schedule reliability would be poor, and during peak periods, bunching of LRVs could be expected with widely varying headways between successive vehicles. Eventually the irregular distribution of vehicles would be reflected on the peripheral part of the line. As a corollary, crowding on some vehicles and extra delays at some stations are likely to occur. For this reason, mixed traffic solutions are being avoided and priority treatments are being implemented in most western European cities.

APPENDIX TO CHAPTER 3

The Effect of Intersection Stops on LRT Speed and Travel Time

The equation for the travel time t_s between two stations is given by*

$$t_s = \frac{V_L}{a} + \frac{D_S}{V_L} + t_d \quad (\text{sec}) \quad (1)$$

Where:

V_L = peak speed (ft/sec)

a = acceleration (ft/sec²)

D_S = distance between stations (ft)

t_d = station dwell time (sec)

For N equally spaced crossings between stations

$$D_C = \frac{D_S}{n+1} \quad (2)$$

Where:

D_C = distance between crossings (ft)

and for the travel time t_s' , if equally long stops of t_c seconds are experienced at each crossing, the equation

$$t_s' = (nt_i) \left(\frac{V_L}{a} + t_c \right) + \left(\frac{D_S}{V_L} + t_s \right) \quad (3)$$

The average LRT speed is

$$V'_{AV} = \frac{D_S}{t_s'} \quad (4)$$

The ratio

$$R_1 = \frac{V'_{AV}}{V_{AV}} = \frac{t_s}{t_s'} \quad (5)$$

The travel time with crossing stops K_S' is plotted in Figures 3-2 and 3-5 for the shown two values of V_L , the shown values of D_S and t_c .

*J. Edward Anderson Transit Systems Theory, Lexington Books, 1977.

Chapter 4

FARE COLLECTION FOR LIGHT RAIL SYSTEMS*

INTRODUCTION

The method of fare collection employed by operators of transit systems throughout the world fall into three generic categories: conventional barrier collection, conventional North American fare box collection, and self-service barrier-free collection (SSBF).

The conventional barrier collection method is typical of North American rapid transit systems such as in New York, Chicago, Atlanta, Washington D.C., and San Francisco. This method requires controlled access to the station platform by means of turnstiles or automatic gates. The passenger gains access to the paid area and to the platform by paying his or her fare to an attendant or depositing a coin or token at the turnstile or gate. Most modern systems (BART, Washington D.C., Atlanta) accept magnetic coded tickets that allow the use of zone-assigned fares. In most cases, an attendant is employed at each station to provide information, to assist in case of equipment malfunction, and to deter fare evasion (easily accomplished by jumping over the gates).

*Material for this chapter was provided by T. Stone and is based on material prepared for the Regional Transportation District of Denver, Colorado, by De Leuw, Cather & Company and Heisler-Granzow Associates, Inc.

Because access to the platform must be controlled, the Conventional Barrier System is most adaptable to elevated and subway stations. At-grade stations require the construction of fences to impede access to the track side of the platforms, which further requires larger capital and operating costs for the stations. For a light rail system utilizing low level on-street platforms, as projected for many downtown applications in North America, barriers would be difficult to install and esthetically undesirable.

The conventional North American fare box collection method is the method commonly used in North America for fare collection in buses and streetcar systems. The operator of the vehicle collects the fare and all patrons normally enter the vehicle through only one door. When multiple-unit trains are run, the operator in the front car both drives the train and collects fares; all the other cars also must each be provided with one operator to collect fares and operate the doors. Access to each car again must be through one door. In some cities, fare collection during peak evening hours is done as the passengers exit, thus facilitating loading to the vehicles by use of all doors.

Self-service barrier-free collection is used by most transit systems in western Europe. There are no barriers such as turnstiles or gates at stations, nor is any fare payment required upon boarding the vehicle.

Each passenger is responsible for obtaining or being in possession of a valid ticket when on the vehicle. Fare payment is accomplished by the purchase of special passes (monthly, weekly, etc.), multi-ride, or single-ride tickets from outlets or machines located on or off the stations. These tickets must be validated (except for special passes) when entering a station or vehicle by inserting them into a validating machine which imprints the location, time, and date. The machine usually clips a portion off the ticket to prevent reuse.

To deter evasion, a system of ticket inspection is employed by roving uniformed or plain-clothes inspectors. When a passenger is found without a valid ticket or pass, penalties are usually applied. Passes and multi-ride tickets (normally with discounts of 10 to 50 percent) are purchased by mail or in person from transit offices, banks, and stores. Multi- and single-ride tickets are bought from machines located at transit stations. Several systems utilize the operator to accept cash fares or sell tickets to passengers boarding through the front door of a train. Charges are slightly higher than from the outlets to deter frequent use of driver transacting.

For further detail, the reader is referred to the UMTA-funded research prepared by MITRE Corporation on Self-Service Fare Collection.

EXPERIENCE WITH SELF-SERVICE FARE COLLECTION

European Experience

For approximately 15 years, European transit systems have developed and successfully implemented self-service fare collection methods.

Although the original reason for introducing self-service, the severe labor shortage experienced in Europe during the 1960s, is no longer relevant in today's excess labor market, European properties continue to adopt and expand self-service operations partly because of labor costs, but primarily because of the opportunities to:

- Integrate transit modes and local operations into regional networks providing a common fare structure and "through ticketing."
- Increase revenue through the implementation of fare structures more closely reflecting the cost and value of the service received.
- Increase transit ridership by offering a diverse fare structure with a variety of incentives and discounts designed to appeal to broader segments of the population.
- Improve service productivity and facilitate the use of high-capacity vehicles through the streamlining of passenger boarding.

Analysis of the European SSBF systems has also revealed that their success is not derived from development of a certain set of operational procedures and employment of appropriate hardware alone. European SSBF systems have been successful because they have been highly responsive to passenger requirements for ease of use, convenience, efficiency and economy, and because the development, implementation, and continuing operation of these system have been conducted in terms of these requirements.

European systems' use of systematic spot checking and penalty assessment by teams of special enforcement personnel has proved to be a satisfactory substitute for driver, conductor, or automatic equipment enforcement. Fare evasion in Europe, as reported from inspection statistics, ranges from as low as 1 percent of ridership in Geneva to as high as 8 percent in Milan, while an average might be on the order of 2 percent. The percentage of non-pass-holders who evade the fare is significantly higher than the percentage of pass-holders. For this reason, transit operators aggressively market special discount passes. The lowest reported fraud rates occur in places where the penalties are higher (e.g., Geneva and Munich).

Inspection staff varies from a low of one inspector for each 30 vehicles (e.g., Milan) to about one for each 7 vehicles (e.g., Munich). Most European systems, however, base their inspection force on the number required to check a given percentage of ridership, with this percentage based on estimated fare evasion and the amount of penalty.

These findings suggest that the SSBF concept has considerable potential for enhancing the quality and quantity of local public transportation in the United States by allowing more flexible fare structures to be adopted by U.S. transit systems, and through its positive effects on service productivity.

Self-Service Collection in North America

There have been no self-service collection methods in operation for a long period of time in North American mass transit systems, except for the Burrard Inlet Rapid Transit Ferry between downtown Vancouver and a cross harbor suburb. Volumes of up to 22,000 passengers per day are carried in this system. Passengers buy tickets from coin-operated machines and inspection is by ferry personnel on a time-available basis. Detected evasion rate is about 1 percent.

San Francisco's Light Rail (MUNI) utilizes conventional barrier collection at their subway stations where attendants and coin-operated turnstiles are provided. Collection for at-grade street stops is done by the driver in the conventional way. MUNI cars are operating only as single cars at the present time.

The new light rail systems entering revenue service in San Diego, California, and Calgary, Canada have implemented self-service collection methods. The San Diego system provides on-vehicle and off-vehicle ticket vendors, and on-vehicle ticket cancelers/validators. Fare collection machinery accommodates a six-value tariff: 2 classes of basic fare by 3 zones. The Calgary system utilizes a simple self-service collection structure: ticket issuing machines are provided at all stations and exact change will be necessary to obtain single-ride tickets. There will be no zone fare or pay by distance tariff except for a free-fare CBD zone. Proof of payment is required when riding a vehicle; this may be a bus transfer, a ticket, or a special pass. Visible inspectors supervise with at-random checks; the staff of inspectors is estimated to consist of about 6 inspectors per shift, which amounts to one for each 4 vehicles in operation.

Portland, Oregon is planning a demonstration project on their bus system to convert their present conventional fare box system to a self-service system. Under their proposed full self-service method, passengers would enter or exit through all doors on vehicles. Self-service could be used primarily on articulated buses and light rail vehicles. Fare payments would be by passes, multi-trip tickets, and single-trip tickets. Multi-ride tickets would require validation before each trip.

The fare structure would be adjusted to encourage pass use and to discourage cash payment into the farebox. Fare collection would be enforced by fare inspectors who would check tickets on a random basis and would be empowered to issue citations to violators.

ADVANTAGES AND DISADVANTAGES OF EACH METHOD

Obviously, each method of collection implies certain advantages and disadvantages, as summarized below.

The primary advantages of conventional barrier collection include:

- . Patron must pay to ride (unless he jumps the barrier), so violation rate may be low.
- . Frees vehicle operator from fare collection duties, yielding only one operator per train and saving operating labor.
- . Reduces boarding time (hence, increases average speed).

The disadvantages are:

- . Costly construction required at stations.
- . Automated ticket machines can be unreliable.

The key advantages of conventional North American light rail collection are:

- Simple to implement and administer.
- Compatible with exact cash, passes, multiple-ride tickets, tokens.
- Compatible with manual transfers.
- Operation on each car provides a feeling of security.

The disadvantages include:

- Zone fares become inconvenient.
- Station dwell times are longer and average speeds decrease because passengers board at one door.
- High labor cost because more than one operator per train is required.
- Increases operator's work load.

The key advantages of self-service collection are:

- . Reduces operator workload.
- . Compatible with short-term passes, special user discounts, multiple-ride tickets, off-peak differentials, etc.
- . Reduces dwell times and increases average speed because passengers can board through all doors.
- . Reduces complexity (and cost) of stations.
- . Requires only one operator per train, thus saving operating labor.
- . No on-vehicle equipment requirements, so no vehicle downtime due to fare collection equipment malfunction (if validation is done wayside rather than on-board).

The key disadvantages are:

- . Requires purchase and maintenance of ticket vending and validating machines.
- . Machines accessible to weather and vandalism damage.

- Requires inspection to ensure compliance, and legal implications, therefore, not yet fully explored.
- Possible higher violation rate and loss of revenue.

It is shown in this chapter that the cost and operational advantages of self-service fare collection can be overwhelming. Indeed, in order to take full advantage of the efficiencies inherent in surface operations of light rail transit, self-service fare collection is a necessity. It becomes the transit planner's responsibility, then, to plan for self-service fare collection just as comprehensively as he or she designs traffic engineering solutions to facilitate light rail surface operations. Along these lines, this chapter concludes with a discussion of the major implications of combining a self-service light rail fare collection system with an existing conventional fare collection bus system.

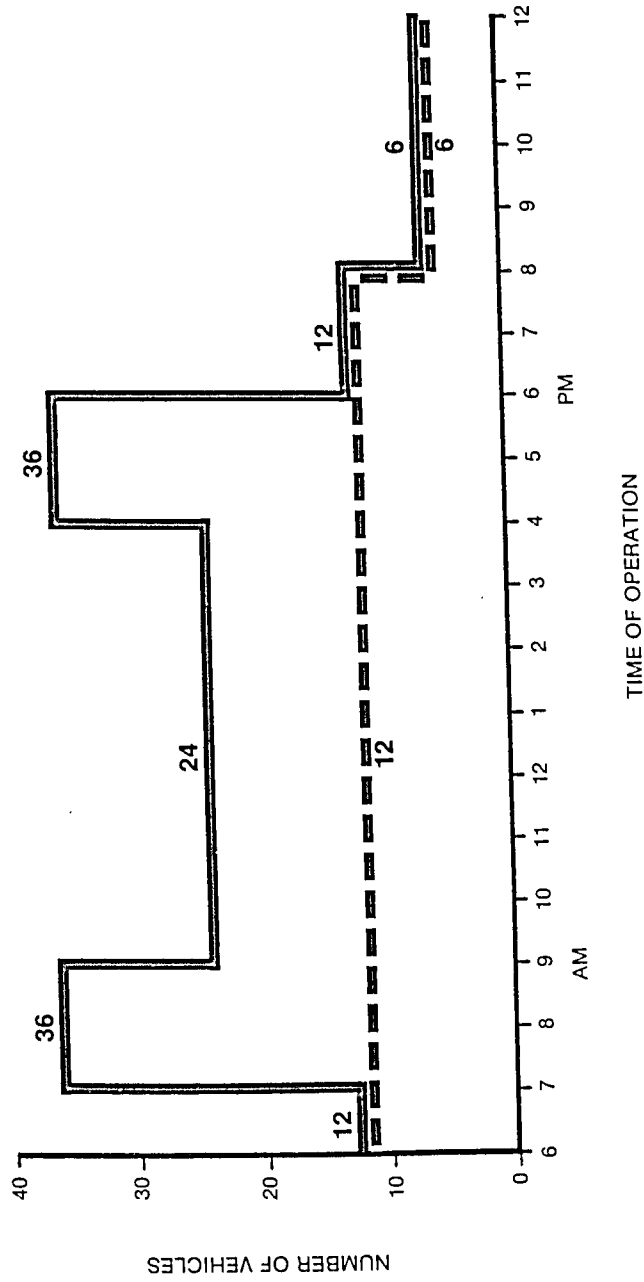
COST COMPARISON OF CONVENTIONAL FARE BOX VERSUS SELF-SERVICE COLLECTION

In order to establish estimated acquisition costs for equipment, construction costs of station additions, and labor costs for operation and maintenance of the collection system, the number and type of equipment and the number of operators and inspectors must be estimated for each of the two collection systems under consideration. This analysis does not consider the capital cost savings which accrue in stations. These can be quite large, but are highly site-specific.

Assumptions For Implementation of Each Method

Cost estimates are based on constant 1980 dollars for application to a hypothetical 15-mile light rail line. It is estimated that 36 vehicles in trains of three cars would operate in the peak morning and evening hours. Each vehicle is assumed to have three doors per side. The estimated number of vehicles and drivers per each hour of operation are shown in Figure 4-1. For a conventional fare box collection system, one operator will be required for each vehicle in operation so the maximum number of operators at peak hours will be 36. For the self-service system, the maximum number of operators reaches 12. It is assumed that the system will operate from 6:00 a.m. to 12:00 p.m. with a two-hour peak period in the morning and in the evening.

The self-service collection system is assumed to provide several fare configurations including special passes, discount tickets, multi-ride and single-ride tickets. Inspection is assumed to be performed at random by a total staff of six inspectors, which averages one inspector for each 12 vehicles during the peak hour (or one for 4 trains). A summary of staff and equipment requirements for each collection system is indicated in Table 4-1, assuming part-time operators and split shifts are feasible. Estimated annual salaries, including fringe benefits (30 percent) for operating and maintenance staff, are as follows:



LEGEND

- NUMBER OF VEHICLES
- - - NUMBER OF OPERATORS FOR CONVENTIONAL SERVICE
- ... NUMBER OF OPERATORS FOR SELF-SERVICE
- NUMBER OF OPERATORS FOR CONVENTIONAL SERVICE

FIGURE 4-1
 VEHICLE AND OPERATOR REQUIREMENTS:
 CONVENTIONAL VS. SELF-SERVICE

Table 4-1

EQUIPMENT AND PERSONNEL REQUIREMENTS
(36 Vehicles Total Fleet Active)

<u>Collection Method</u>	<u>Hardware Required</u>	<u>Personnel Required (Typical Weekday Operation)</u>
Conventional North-American Fare Box Collection	1 Fare Box for each vehicle, total = 36	3 shifts of 12 full-time operators, one 4-hour shift of 6 operators, 1 split shift of 12 operators, total = 51 man-days per weekday Maintenance personnel, total = 1 man-day; revenue collectors = 1 man-day
Self-Service Collection	2 Ticket machines at each station, total = 40 2 validators at each station, 1 validator on each vehicle, total = 76	2 shifts of 12 operators, one 4-hour shift of 6 operators, total = 30 man-days per weekday Inspectors - 2 shifts of 3 each, total = 6 man-days Personnel for revenue collection and maintenance of equipment = 2 man-days Maintenance personnel = 2 man-days Additional personnel for administration and enforcement = 1 man-day

Operators = \$25,000

Inspectors, Money Collectors = \$20,000

Maintenance Personnel = \$26,000

Supervisors, Administrative

Staff = \$31,000

Cost Estimates for Conventional Fare Box Collection

For purposes of estimating annualized costs of fare collection, it is assumed that operators under both collection methods would receive the same average pay and that driver's expenses are attributable entirely to transportation costs. That is, even though drivers under the conventional method do most of the collection, only the additional operators are considered to contribute to the fare collection operating costs.

The conventional fare collection method requires 21 additional man-days of operators per day than the self-service method. An approximate breakdown of capital and O&M costs is as follows:

Capital Costs

36 Fare boxes @ \$1200 each = \$43,200

Annualized capital costs = \$ 4,300

O&M Costs per Year

(Assume that 50 percent of
weekday personnel will
be required on weekends)

Additional Operators = $[21 + 1/2 (21) (2/5)] \times \$25,000 = \$630,000$

Revenue Collectors = $[2 + 1/2 (2) (2/5)] \times \$20,000 = \$ 48,000$

Maintenance Personnel = $1 \times \$26,000 = \underline{\$ 26,000}$

Total Annualized Capital & O&M Costs \$708,300

Cost Estimates for Self-Service Fare Collection

The self-service fare collection system requires more sophisticated hardware (increasing capital costs) and a staff of inspectors to reduce fraud. For the hypothetical line, this would total six inspectors, two persons for money collection and maintenance of the ticketing equipment, and one additional person for administration and enforcement of the system (processing fines and handling complaints). Thus, the total number of additional personnel for implementation of the

self-service system is estimated at nine persons. This represents an average of one person per 4 vehicles. This compares favorably with existing European systems, as can be seen from the information shown in Table 4-2.

Table 4-2

SELF-SERVICE COLLECTION STAFF REQUIREMENTS

<u>City</u>	<u>No. of Inspectors</u>	<u>No. of Maintenance</u>	<u>Additional Personnel</u>	<u>Total Personnel</u>	<u>Total No. Per Vehicle</u>
Milan	100	35	5	140	1:21
Bern	12	10	2	24	1:9
Cologne	85	25	5	115	1:6
Geneva	12	13	4	29	1:11
Munich	135	50	10	195	1:5

The estimated cost of the equipment used in self-service collection (ticketing and validating machines) has been based on the acquisition costs experienced for the new San Diego LRT line plus 25 percent to allow for installation and inflation.

Capital Costs:

40 Ticketing Machines @ \$20,000	=	\$ 800,000
76 Validating Machines @ \$1,000	=	<u>76,000</u>
Total Equipment Costs	=	<u>\$ 876,000</u>
Annualized Capital Costs	=	\$ 87,600

O&M Costs:

Inspectors = $6 + 1/2 (6) (2/5) \times \$20,000$	=	\$ 144,000
Collectors = $2 + 1/2 (2) (2/5) \times \$20,000$	=	48,000
Maint. Personnel = $2 \times \$26,000$	=	52,000
Adm. Personnel = $1 \times \$31,000$	=	<u>31,000</u>
Total Annualized Capital & O&M Costs	=	\$ 275,000
Loss of Revenue from violators (2 percent of total revenue of \$5.0M)	=	<u>\$ 100,000</u>
Annual Collection Costs	=	\$ 375,000

Cost Comparisons

As can be seen from the previous cost analysis, the self-service fare collection method would provide direct cost savings on the order of \$333 thousand per year. If we assume an estimated 20 million passenger-trips per year for the line, this represents almost \$0.02 per trip, or perhaps 8 percent of the average fare.

It should be noted here that a conventional fare collection system also experiences fraud, perhaps at least 2 percent.

We have assumed that 2 percent of the fraud rate for self-service is recuperated through fines and the other 2 percent as revenue losses. Even with a 4 percent revenue loss, however, the savings of employing a self-service barrier-free collection method still would be significant.

Operational Comparisons

There are other, even more important factors to consider when comparing the two methods of fare collection. Time savings per trip due to shorter dwell time are quite significant when a self-service collection method is used. For example, passengers boarding at each station require much more time to load the vehicles when using conventional fare box collection as compared to self-service collection.

It has been estimated, based upon observations made throughout the country, that passengers boarding and paying to the operator will average roughly 2.5 seconds per person and that passengers entering vehicles without paying (self-service) will average roughly 2.0 seconds each. An additional time allowance of about 15 percent during peak hours for trains having several doors is appropriate for imbalance occurring during loading. Average time for opening and closing doors may be estimated at 2.0 seconds.

• Estimates of dwell times:

For Conventional Fare Box Collection, assuming 75 passengers maximum boarding load per stop during peak hour for a three-car train:

Number of passengers entering per door = 25

Dwell time $(25 \times 2.5) + 2$ = 65 seconds

For Self-Service Collection:

Number of passengers entering per door,

assuming 3 doors per car = 8.3

Dwell time $1.15 (8.3 \times 2) + 2$ = 21 seconds

With the assumption of an average of 75 persons boarding per station per stop at peak periods, it will take six stations to load the train. If stations are spaced only about one mile apart toward the end of the line, the travel time and total trip time in such a segment would be as follows:

Travel time between stations	=	120 seconds
Dwell time (conventional collection)	=	65 seconds
Dwell time (self-service collection)	=	21 seconds
Trip time using conventional collection	=	19 minutes
Trip time using self-service collection	=	14 minutes
Average speed using conventional collection	=	24 mph
Average speed using self-service collection	=	32 mph

It can be seen that on an average 10- to 15-mile trip in the peak period, the self-service collection method could produce trip time savings of at least 5 minutes. This time saving will be less during off-peak hours, but proportionately even greater in sections where stations are closely spaced. This, in turn, will result in lower capital and operating costs for the system because fewer vehicles need to be purchased and operated. These savings in operating costs have not been quantified and therefore are not included in the O&M costs estimated in the previous section. However, more than dollars saved, a most important result will be improved operation and potential for greater ridership due to the time savings.

Another important factor to consider is the capability for fare policy flexibility. Self-service permits zone fare in a much simpler manner than conventional operator collection. In addition, ticket inspection by roving inspectors provides a feeling of security. The system

requires no change to fare collection practice on the bus system although some variation may need to be implemented to facilitate transfer from buses to light rail vehicles. This is discussed further in a subsequent section.

Legal and Labor Implications of Self-Service Fare

Every transit system must have legal authority to enforce fare payment under a self-monitoring SSBF collection system. The power to inspect and to fine, however, is not usually sufficient by itself to ensure an effective fare enforcement program. The power to enforce payment of fines and other penalties through court action is also desirable. Most transit systems in Europe provide for enforcement in the courts.

One-the-spot fining, citations, and court processing are common and central elements for fare evasion control in most European systems. However, it is doubtful that these elements could be readily implemented in the United States because at the present time, the necessary enforcement powers lie outside the transit authority and would have to be established by either municipal ordinance or state legislation.

Several U.S. cities have established special legislation to prosecute fare evaders (New York, Boston, Chicago). The experience in Europe indicates that in those systems where fines and enforcement are greatest (Geneva and Munich, for example) the rates of fraud are lowest.

Successful implementation of the SSBF collection method in the United States can require implementation of new ordinances to effectively prosecute fare violators.

Self-service fare collection would undoubtedly effect changes in the areas of job security, working environment and worker remuneration. Even though self-service collection implies fewer operators and operating staff in general, this does not appear to be a major concern in cities proposing a completely new light rail transit system where new employment would be provided, as opposed to changing collection methods where the existing labor force would be reduced.

The personal security of drivers and inspectors in a self-service operation is a potential area of concern. Under conventional fare box collection methods, drivers not only monitor fare payment but also boarding passengers. A degree of control of who is in the vehicle is thus maintained by the driver. However, with self-service the driver can only monitor passengers entering through the front door. Such unsupervised access could lead to increased crime within the transit system. The security of passengers as well as operators is thus at stake. Another element of risk is added when inspectors are authorized to issue citations or fines to passengers without a valid ticket. Many European systems have found that the most effective way to minimize inspector security problems is to operate inspections in teams.

Another factor of concern is liability. The transit property could be held responsible for accidents involving its off-board equipment. Unrestricted boarding through all doors might create new liability problems. Liability may also increase in the area of ticket inspection and fining of evaders. On the other hand, the opportunity to reduce liability might occur when drivers, freed from their roles of watching the fare box, are able to devote greater concentration to traffic conditions, and the number of accidents are thus reduced.

Analysis of Self-Service Fare Policy Options

To select the most appropriate equipment for a self-service fare collection system for a new light rail line, several operational issues regarding fare policy need to be considered. The selected fare policy must be made compatible with the existing fare policy and structure of the bus system. This is important because fare policy affects ridership, revenue, equipment costs and complexity as well as user convenience. Fare policy also affects the functional and performance requirements for self-service fare collection hardware. To demonstrate the impacts of alternative fare policies, three options were selected for analysis. These options are:

- continuation of a current flat fare policy and extension of those policies to self-service fare collection on light rail;

- adoption of a zoned fare structure for light rail only; and,
- adoption of a systemwide zoned fare structure

Each of these options and their major impacts are summarized in the following sections.

CONTINUATION OF AN EXISTING FLAT FARE POLICY FOR LIGHT RAIL

Under this option, an existing flat fare structure would be continued with light rail transit classified as another type of service. Peak/off-peak pricing would also be applied to light rail to encourage off-peak ridership. The fare for light rail could be set at a rate commensurate with fares for other types of service. For both cash fares and monthly passes, the same fare classifications would be maintained. The only modification that may be required would be an alteration of off-peak fares for handicapped persons to reduce the number of fare classifications or fare increments required on automatic ticket vendors.

Cash fares, tokens, and monthly passes would continue to be accepted on all buses. Light rail vehicles would require a pre-purchased and validated ticket as proof of fare payment. If it were necessary to eliminate the need for on-board validation equipment, one option would be to provide single-trip ticket vendors with capabilities for validating

multi-ride tickets at all light rail stops. Single-ride tickets would be validated upon issuance and patrons with multi-ride tickets would validate their tickets prior to boarding. Additional validators or vendors could be provided at high-volume stops. The ticket vendors could be designed to vend tickets in different increments such as \$.25, \$.50, \$.75 and \$1.00. This would allow for peak and off-peak pricing without having to specify fare classifications. Instructions on the vendor would indicate the fare required by fare classification for peak and off-peak service. The vendor would vend tickets for whatever amount inserted by the patron. This type of vendor would also facilitate the implementation of fare increases, as only the instructions on the vendors would need to be changed (as opposed to the acceptable coin combinations for each ticket type).

Multi-ride tickets could be sold at transit agency offices, retail establishments such as banks and stores, and by mail. Multi-ride tickets could also be structured on an incremental fare basis so that they could be used for both peak and off-peak time periods. For example, if the peak fare for light rail were to be set at twice the amount of an off-peak fare, each increment on the multi-ride ticket would be worth one off-peak fare. To utilize the ticket for peak hour service, a patron would have to validate two rides on the ticket. As an alternative to this type of ticket structure, separate peak and off-peak

multi-ride tickets could be sold. Multi-ride tickets could also be sold for different fare classifications. These classifications could be color-coded for easy identification by fare inspectors.

Monthly passes for light rail transit could be made available through current procedures, with discount monthly pass rates for senior citizens, handicapped persons, and students. Patrons utilizing monthly passes would not be required to validate them as the pass would serve as proof of fare payment. To utilize a less expensive monthly pass on light rail, the pass could be supplemented by purchasing a ticket for the appropriate increment from a wayside ticket vendor.

Transfers

An existing free transfer policy could be continued under this option. Transfers from buses to light rail would be handled in the same manner as transfers from lower to higher priced service. To transfer from a feeder bus to light rail, a patron could pay the fare for the feeder bus, obtain a transfer, and supplement the transfer with an appropriate amount from a light rail wayside ticket vendor, if it were determined that light rail's fare needed to be higher. Multi-ride tickets would be handled in a different manner. One option would be to install on-board validators on the feeder buses that serve light rail to allow passengers with multi-ride tickets to validate a portion or the

entire journey at the beginning of the trip. For example, the patron could validate the entire light rail fare on the feeder bus, and this would serve as proof of payment for the bus and the light rail trip. Alternatively, the fare increments on the multi-ride ticket could be set low enough so that a patron could validate the feeder bus portion of the trip on the bus, and validate the light rail portion of the trip at the light rail stop. Another option, which San Diego is implementing, is to have the bus driver punch the multi-ride ticket as the passenger boards, and to require the patron to validate the ticket at the light rail stop. In all cases, no supplemental enforcement of fare payment on the buses would be required. Provision of a validator at the front door only would minimize equipment costs and allow the driver to monitor validation.

Major Implications

Equity. The fare is independent of trip length and could be viewed as inequitable by passengers who make short light rail trips.

Equipment Requirements. A flat fare structure with a minimum of fare increments would not require highly complex equipment. In addition, this option utilizes minimal hardware, so equipment capital, operating and maintenance costs would not be extensive. Equipment options such as change-making facilities, electronic or magnetic code recognition

capabilities for ticket validation, and bill acceptance facilities would increase equipment capital costs. Operating and maintenance costs would also increase due to the increased equipment complexity (increased labor and spare parts inventory).

Location of the automatic ticket vendors at light rail stops would require the equipment to withstand environmental conditions such as heat, rain, snow, wind and ice loading, salt spray, sand and dust, fuels, solvents and fumes, and humidity. In addition, all vendor functions should be contained in one enclosure to prevent vandalism and ensure ticket and revenue security. The security aspects are particularly important since the machines may contain a substantial amount of money if change-making facilities (self-replenishing) are not provided.

Flexibility. Ticket vendors which issue tickets based on fare increments would be easily adaptable to fare changes. Instructions on new fares could be provided on all machines and no modifications to the acceptable coin combinations by ticket type would be required. If the fare increments were selected at appropriate levels, this type of vendor could also be adapted to a zoned fare structure. Instructions on the cost per zone via a system map on the vendors would indicate the fare required for each trip. Multi-ride tickets could be sold which were valid for travel in a certain number of zones.

Data Capture. Detailed statistics on the number of tickets sold by fare classification would not be feasible under this option. The vendors would probably be capable of providing total ticket counts and total money accepted, possibly by peak and off-peak time periods. Counts on the number of tickets sold by fare classification would not be possible as patrons would be utilizing the vendors to supplement transfers and monthly passes for other service types. However, if the vendors were designed to vend tickets by fare classification and peak/off-peak period to obtain better fare reporting statistics, several problems would result. First, transfers would become a problem since the patron would either have to pay full fare on both modes, or would have to determine which fare classification and period of service matched the incremental fare required for a transfer. In this case, passenger convenience would be decreased, and the statistics produced by the machine would not be accurate. For example, if a patron required an incremental fare equal to a senior citizen off-peak fare and purchased this ticket as a supplement, the vendor would inaccurately represent the number of senior citizen tickets actually utilized by senior citizens.

Property Implementation/Operation. This option would not require a substantial education campaign to instruct patrons on how to use the system. The current fare structure and transfer procedures would not be changed substantially. Only instructions on self-service fare collection procedures would need to be provided. Current fiscal reporting

procedures would be comparable, and no major modifications to the fare and transfer policies would be required. Roving maintenance personnel to repair coin and ticket jams would be required as would teams of personnel to collect money from the vendors on a scheduled basis. No additional driver involvement would be necessary unless drivers on feeder buses were required to punch/validate multi-ride light rail tickets.

Additional provisions for the sale of multi-ride tickets via stores, banks and other commercial outlets may be desirable to encourage prepayment of fares. This may create the need for expanded accounting capabilities in terms of monitoring ticket distribution and revenue collection, as well as require the negotiation of commissions with the commercial outlets. The number of different types of multi-ride tickets required would be dependent upon whether separate tickets for peak and off-peak service and different fare classifications were provided. The lowest cost alternative would be to provide tickets with fare increments that would adapt to all possible combinations of ridership. Costs and accounting requirements would increase if multiple ticket types were offered. However, passenger convenience would be increased if different ticket types were offered. This would decrease the number of calculations a passenger would have to make regarding how many fare increments to validate, and decrease the number of multi-ride tickets a patron would have to purchase for a given time period.

Revenue Capture. A flat fare structure may not recoup an adequate proportion of the costs of providing light rail service. This is especially true when the system is large and longer distance trips are provided. The fare per unit of distance traveled would decrease with increased trip length.

Passenger Convenience. A flat fare structure with similar transfer procedures is easy for patrons to memorize and use. It provides for easy transfers between modes and maintains a common systemwide fare structure. The only problem initially may be in determining the incremental fare required, if any, when transferring from bus to light rail service. If the equipment reliability is high and adequate provisions for the sale of multi-ride tickets and passes are made, the users should benefit from faster boarding procedures, resulting in shorter travel times.

Inspection and Enforcement. A group of roving inspectors would be required to randomly check fare payment on light rail vehicles. Since ticket validation would take place at light rail stops, the problem of passengers waiting to validate their ticket on-board until they saw an inspector would be avoided. If tickets only displayed different combinations of validated fare increments, fare inspection would be more complex for the ticket inspectors. Tickets coded by fare classification and/or time period would simplify the fare inspection process. The use

of coded stripes on the reverse side of a ticket could potentially decrease fare evasion. The stripes would prevent passengers from validating multi-ride tickets with no remaining rides. However, this type of coding appears to be more useful when the validators are located on the vehicles since an alarm would signal the driver of an attempt to use an invalid ticket. The transit agency's statutory authority to enforce fare payment via fines would have to be investigated, and special legislation might be required to allow the authority to inspect and enforce fare payment.

ADOPTION OF A ZONED FARE STRUCTURE FOR LIGHT RAIL ONLY

Under this option, an existing flat fare structure would be continued for all bus modes, and a zoned fare structure would be implemented for light rail service. The zoned fare structure could consist of concentric rings around the central business district, with each ring constituting a zone, or increase in fare. Alternatively, each alignment could be zoned or divided into stages, with each stage constituting an incremental fare increase. Peak and off-peak pricing could also be applied to light rail service to encourage off-peak ridership. The zones could be set at key areas delineated by natural boundaries such as rivers or major streets. The zones would have to be carefully planned, based on patron boardings, so a great number of short trips did not cross zone boundaries. Otherwise, these short trips would be charged a much higher

amount per mile than long trips, which would defeat the purpose of a zoned fare structure. Fare increments between zones should also be set in convenient amounts to facilitate passenger usage.

The current fare classifications under this option could be maintained for purposes of public acceptability. However, these fare classifications, in addition to zone and peak/off-peak service pricing, could complicate fare calculations for passengers. An alternative to maintaining the current fare classifications would be to discontinue fare classifications for ticket fare only and continue to offer discounted rates for monthly passes. This would be consistent with a policy to promote the sales and use of monthly passes.

Cash fares, tokens, and monthly passes would continue to be accepted on all bus service. Light rail service would require a pre-purchased and validated ticket for the number of zones to be traveled. Similar to the configuration proposed for a flat fare, single-ride vendors with validation capabilities could be located at light rail stops.

If the vendors were designed to vend tickets in monetary increments, detailed instructions on the vendor would be required for patron usage. The instructions would consist of a system map showing the zone boundaries and the amount of fare required for each fare classification for peak and off-peak service by number of zones. This information could be

presented in matrix format. This type of ticket vending process would require substantial user education, but would be readily adaptable to fare changes (only the instructions to the users would require updating).

An alternative to fare increment vendors would be to have vendors with separate selection buttons for each fare classification and number of zones. To further simplify patron usage, the vendors would be programmed to change the required fares for peak and off-peak service. The user would then only be required to determine the correct number of zones and the appropriate fare classification. This alternative may require more complex equipment.

Multi-ride tickets could be sold in the same manner as suggested for the flat fare option, with each ticket valid for a set number of zones. Alternatively, they could be structured on an incremental fare basis. Other options include providing multi-ride tickets by fare classification and by number of zones for peak or off-peak service. Different combinations of these options are also possible. Monthly passes for a certain number of zones by fare classification and peak/off-peak service could also be sold. The major problem with specifying the number of zones on either multi-ride tickets or monthly passes is user convenience. A patron who purchased a multi-ride ticket or monthly pass for a specific number of zones would be limited to utilizing these tickets for

certain types of trips. This may discourage patrons from using the system for non-work trips as they would have to purchase additional fare increments; or it may lead to increased fare evasion. This would be avoided if a fare increment multi-ride ticket was utilized and the fare increment for each zone was equal. However, the fare increment tickets would create greater demands on the patrons in terms of fare calculation and validation procedures. For example, if an increment on a multi-ride ticket was equal to one zone's worth of fare, a passenger travelling three zones would have to validate three fare increments on a multi-ride ticket. This may discourage the use of multi-ride tickets as they would be inconvenient to use and quickly exhausted by patrons who traveled many zones on a daily basis. In addition, if passengers were discouraged from using fare increment-based multi-ride tickets or passes, the demand on ticket vendors would increase. To service these increased demands, additional equipment and equipment maintenance would be necessary.

Transfers

Under this option, a separate transfer system could be created for light rail. This system could consist of the following elements. Feeder bus to light rail transfers would be allowed. Feeder buses would be designated as a separate type of service with the fare equal to one zone of light rail service. Passengers could pay a cash fare on the feeder bus,

obtain a transfer, and purchase the remaining zones of travel at the light rail stop. For example, if a patron were travelling three zones on light rail, the feeder bus would count as one zone, and the passenger would only have to purchase a ticket for two zones. The transfer plus the ticket would serve as proof of payment. For multi-ride tickets, the passenger could validate a portion or all of the ticket upon boarding the bus. This could be accomplished by on-board automatic vendors or by a driver ticket punch. For monthly light rail passes, the pass would serve as a transfer to all equally priced or less-expensive types of service. (Monthly passes may be designated for a specific number of zones so this option would dictate the nature of the transfers.) All validated single and multi-ride light rail tickets could be valid as transfers to all bus service types or alternatively, to those equally priced or less expensive. All other bus system to light rail transfers would cost the full amount for each mode. The current transfer policies and procedures for bus system transfers would remain the same.

One alternative to the above proposed transfer policy would be to establish parity between light rail zone fares (single and multiple) and the fares for other types of bus service. For example, a local bus fare would be set equal to one zone of light rail, an express bus fare equal to two zones, and a regional bus fare equal to three zones. This would allow passengers to transfer to and from all modes and service types by supplementing tickets, transfers, or passes with an appropriate fare

increment. The viability of this alternative would be contingent upon the ability to achieve zone/bus service type pricing structure parity. Some modifications in the pricing of different fare classifications may be required to facilitate this transfer policy. The complexity of this transfer policy would require substantial user education.

Major Implications

Equity. The fare charged for light rail trips would be proportional to the distance traveled. This could be viewed as a more equitable fare structure for light rail than the flat fare alternative. However, depending upon the type of transfer policy selected, public acceptance of light rail fares versus fares for other types of service may be variable. If the feeder-bus-to-light-rail transfer option were selected, patrons may view this arrangement as unfair since all other bus-to-light-rail transfers would cost the full amount for both trips. If zone/bus service pricing parity were selected, public acceptance would probably be contingent upon the relative costs and availability of the different types of service. For example, if two areas were equidistant from downtown and one area had light rail service and the other did not, it is conceivable that the light rail patrons would pay more for the same trip length. The provision of alternative services to various areas would have to be carefully planned and priced to maintain public acceptance of the fare policy.

Equipment Requirements. Equipment requirements for this option would be dependent upon the number of fare classifications and zones selected, as well as the type of vending capabilities required for the ticket-issuing machines. The lowest cost alternative would consist of vendors which sold tickets in various monetary increments. Provision of single-ride ticket vendors at light rail stops with capabilities for validating multi-ride tickets would require minimal hardware. Again, change-making, bill acceptance and electronic code recognition capabilities would increase equipment complexity and costs. More complex equipment may require additional hardware due to potential problems associated with reliability.

Vendors which sold tickets by fare classification and number of zones would require more complex subassemblies. If the vendors were programmed to change fare levels for peak and off-peak service, this would also increase equipment complexity. The costs for this type of equipment would vary by the combined number of zones and fare classifications to be provided. Other options such as change-making would also increase costs.

The advantages of locating vending and validation equipment at light rail stops increase in a zoned fare structure. The advantages relate to driver involvement and equipment requirements. When all validation equipment is located at stops instead of on-board the vehicle, the zone

location of each machine is fixed. This means that drivers do not have to change the zone indication on the validators (via a remote control unit on the dashboard) every time a zone boundary is crossed. For example, if a passenger boarded a vehicle in zone two, this would be indicated on the validation stamp from a wayside validator. If the validator were located on the vehicle, it would be the driver's responsibility to ensure that the zone indication on the validator actually reflected the correct zone. If a driver forgot to change the zone or changed it too late, a passenger could have paid the correct fare, but have the incorrect zone stamped on the ticket. A ticket inspector could then erroneously fine a patron for inadequate fare payment. Location of validators at light rail stops would eliminate this situation, reduce driver responsibility, and decrease equipment costs (no remote control units would be required).

As discussed in the section on flat fare policy, wayside vendors and validators would have to be designed to function under various environmental conditions and to prevent vandalism and ensure revenue and ticket security.

Flexibility. Ticket vendors which issue tickets based on fare increments would be easily adaptable to fare changes. Only the instructions for fare payment on the vendors would need to be altered. Fare changes for ticket vendors which issue tickets on the basis of fare classifications and number of zones could require hardware modifications regarding

the acceptable coin combinations for each ticket type, and possible (depending on the specific model) modifications to the printing mechanism which indicates the amount of fare paid on each ticket. Ticket vendors which issue tickets based on zones and/or fare classifications would have to be carefully selected to allow for potential system expansion such as an increase in the number of zones. If potential expansion is not considered, the equipment could become obsolete as the system network grows.

Data Capture. For ticket vendors which issue tickets based on fare increments, detailed statistics on the number of tickets sold by fare classification and number of zones would not be feasible. For ticket vendors which issue tickets based on zones and/or fare classifications, statistics would be available within certain limitations. The limitations would be a function of the reporting capabilities of each equipment model. However, most vendors would be capable of providing information on the total number of tickets sold and the total money accepted.

Property Implementation/Operation. User education requirements would be greater for the ticket increment option than the ticket classification option. With the ticket increment system, users would have to be instructed on how to determine fares for the number of zones, type of fare classification, and the time period of service. The ticket classification option would only require a determination of the number of

zones and the appropriate fare classification. The vendor would perform the actual fare calculations. Maintenance requirements in terms of personnel and parts may be greater for the ticket classification option due to greater equipment complexity.

Fare enforcement would be more complex for ticket inspectors under a zoned fare structure due to fare increments for zones, fare classifications, and service periods. Both transfer policies would encourage patrons to ride the bus to the light rail stops. This would decrease parking requirements at stops. The fully integrated light rail/bus transfer policy would produce the greatest savings in terms of light rail stop auto parking requirements. Both transfer policies would place more demands on bus drivers as they would have to determine the validity of transfer and/or the additional fare required on a greater number and types of tickets and passes.

Multi-ride tickets could be provided as suggested in the flat fare option. A similar expansion of accounting capabilities could be required for monitoring ticket distribution and revenue collection. The number of multi-ride ticket types offered in terms of fare classifications, number of zones, and peak/off-peak service will influence ticket costs and accounting requirements. These costs would have to be compared to user convenience and the impact on the use of single-ride versus multi-ride tickets.

Revenue Capture. A zoned fare structure could recoup a greater proportion of the costs of light rail service than a flat fare. While the zones would have to be carefully designed not to penalize short cross zone boundary trips, the fare per unit of distance traveled would increase with trip length. Other revenue sources would be dependent upon the transfer policy selected.

Passenger Convenience. A zoned fare structure is more difficult than a flat fare structure for passengers to memorize and use. If the ticket increment option is utilized, users would require instructions on how to calculate fares. The ticket classification option would only require passengers to determine the number of zones to be traveled and to push the appropriate selector button. The feeder-bus-to-light-rail-only transfer policy would be easier for passengers to use than the all-bus-to-light-rail transfer policy. However, user costs on the feeder-bus-to-light-rail transfer policy would increase for certain bus-to-light-rail transfers. The all-bus-to-light-rail transfer policy would be more difficult for passengers to learn, but it would encourage systemwide travel due to reduced transfer costs. The latter transfer policy would also facilitate the implementation of a systemwide zone fare structure if it was desired at some time in the future.

Inspection and Enforcement. This option would require an inspection team and procedures similar to those required for a flat structure. Fare inspection would be more involved for ticket inspectors because they would have to determine if the required fare increments for the zones, fare classifications, and period of service matched the amount on the ticket. In addition, both transfer policies would complicate fare inspection due to similar determinations of the combined fare values of transfers, tickets, and passes. The feeder-bus-to-light-rail-only transfer policy would reduce the number and types of transfers inspectors would be required to examine. All inspection procedures would be simplified by coding tickets for fare classification and/or time period.

ADOPTION OF A SYSTEMWIDE ZONED FARE STRUCTURE

The fare structure in this option would involve application of a zoned fare structure to the entire transit system. Zones could consist of concentric circles around the central business district. Each zone traveled by a patron would require an incremental fare amount above the base fare. The base fare would be set at one zone of travel. The same zone structure would be applied to all modes, and the service types for bus travel would no longer exist. Peak and off-peak pricing could be maintained to encourage systemwide off-peak ridership. Zones would have to be carefully planned so a great number of short trips do not cross zone boundaries.

Existing fare classifications could be maintained under this option. Since this would complicate fare calculation for patrons and drivers, an alternative would be to offer fare classification discounts for monthly passes only.

Fare payment under this option would be more complex than under either of the two previous options. Light rail service would require a pre-purchased and validated ticket for the number of zones to be traveled. Similar to the two previous options, single-ride vendors with validation capabilities could be located at light rail stops. Vendors could be designed to issue tickets by fare classification and number of zones, and could be programmed to change the fare required for peak and off-peak service. This design would be preferable to vending tickets in monetary increments as the tickets could be used as transfers to bus service. A zone indication on the tickets would facilitate transfer procedures as well as fare inspection. Since all types of service would have the same fare structure, a zone indication on the tickets would facilitate passenger usage by promoting uniformity in ticket receipts.

Multi-ride tickets could be sold through various government and retail outlets, and would be valid for a set number of zones (with or without coding for fare classifications). Monthly passes could also be issued for a certain number of zones. To promote multi-ride ticket and monthly pass usage, zones could be grouped on the media. For example, a multi-ride ticket could be sold for one to two zones of travel and so on.

For bus service fare payment, several alternatives are available. For all alternatives, cash fares, tokens, and monthly passes would continue to be accepted for all bus travel. Three alternatives for bus service fare payment are listed below.

Driver-Monitored Fare Payment

This alternative would require bus drivers to ask for each passenger's destination (zone number), indicate the amount of fare required, and monitor the payment of this amount. This alternative would increase driver involvement and slow down boarding times. Its success in terms of fare evasion would depend on passenger honesty and driver ability to enforce the correct fare. Drivers could issue transfers coded for the number of zones purchased. These transfers could be utilized on all modes for travel in a similar number of zones. Transfers from fewer to a greater number of zones could be supplemented by an appropriate fare increment.

Pay-Enter/Pay-Leave

This alternative would only be feasible on radial routes, or under the assumption that most trips are downtown-oriented. Passengers would pay a fare upon entering the bus for all inbound trips. This fare would be determined by the zone in which they boarded. Passengers would pay

their fares upon exiting for all outbound trips. This fare would be determined by the zone in which the passenger exited. The pay-leave situation may create passenger inconvenience on vehicles that are crowded as they would have to make their way to the front of the bus to pay their fares. It may also increase vehicle dwell time at stops, and thus total travel time. This alternative would also create problems for cross-town trips. Transfers could be coded for the number of zones purchased, and could be utilized on all modes for travel in a similar number of zones. Transfers to additional zones of travel could be supplemented by an appropriate fare increment.

Honor System

This alternative would require passengers to pay the appropriate fare for the number of zones to be traveled. Passengers would be issued a receipt which indicated the zone, date, and time of boarding. This receipt could also be used as a transfer if the number of zones purchased was indicated on the receipt. Current transfers could be modified slightly by coding them for the number of zones and used as receipts since they already contain all relevant information. This alternative would avoid problems associated with the pay-enter/pay-leave alternative, but would require periodic inspection of ticket receipts to monitor fare evasion. Ticket inspectors employed to monitor fare payment on light rail service could be utilized periodically to check fare evasion on bus service.

Transfers

Transfer policies under this option would be easier to implement than those for a light-rail-only zoned fare structure. Transfers between modes would be allowed, with the number of zones purchased as the criteria for requiring additional fare increments. For example, a two-zone bus transfer would be valid for two zones of light rail service. The bus transfer would serve as proof of payment on the light rail trip. If a passenger had a two-zone bus transfer, and wanted to travel three zones on light rail, the patron would be required to purchase one additional zone's worth of travel from a wayside vendor. This single-ride ticket plus the transfer would serve as proof of fare payment. Transfers from bus service to other bus service, or to light rail would be obtained from the vehicle driver. For transfers from light rail to bus service, a validated single or multi-ride ticket would serve as a transfer to an equal number of zones. If a passenger had a two-zone light rail ticket, and wanted to travel three zones on a bus, the patron would be required to show the light rail ticket to the driver, and deposit the additional zone's worth of fare in the farebox. Non-validated multi-ride tickets could not be utilized as transfers or fares on buses unless all buses were equipped with validators, or drivers could validate the tickets by means of a punch. This latter form of driver validation would be desirable to allow patrons to transfer from feeder buses to

light rail. All monthly passes would be valid on all modes, with the number of zones purchased as the criteria for determining whether additional fare payment would be required.

Major Implications

Equity. The fares charged for all trips would be proportional to the distance traveled. Since the zone structure would be uniformly applied to all modes of service, this may be viewed by passengers as the most equitable way of charging fares.

Equipment Requirements. Equipment requirements for light rail self-service fare collection would be similar to those discussed for the fare classification/zone option. Vendors would issue single-ride tickets for a certain number of zones, and would validate multi-ride tickets. The complexity of the equipment in terms of the number of zones and fare classification and/or peak/off-peak pricing would dictate equipment capital and operating costs.

Other equipment requirements would be dependent upon the type of fare payment alternative selected for bus service. For the driver-monitored and pay-enter/pay-leave alternatives, no additional equipment would be required. Equipment such as an automatic transfer-issuing machine is optional, but may be cost-justified only if a large number of zones

exist. For the honor system alternative, an automatic ticket-issuing machine may be required to decrease driver involvement. However, current transfers could be utilized as receipts if space was provided on the tickets for the driver to punch the number of zones purchased. Validators could be provided on buses to validate multi-ride tickets, although it may be less expensive to have drivers punch the ticket. The capital and operating costs of providing the validators would have to be compared to the additional driver labor costs associated with the additional fare collection involvement.

Flexibility. The flexibility of the vendors would be dependent upon their expansion capabilities for adding zones. Fare price changes may require some hardware modifications to change acceptable coin combinations for each ticket type and printwheel adjustments for fare prices. A systemwide zone structure would facilitate patron transfers between modes due to uniformity in pricing.

Data Capture. Data capture possibilities for ticket vendors would be limited to the reporting capabilities of each equipment model. Most vendors would be capable of providing total ticket counts and totals of the cash accepted. Current fare box reporting procedures (driver-based) could be supplemented for cash fares only if ticket/receipt issuing machines were utilized on buses. The ticket/receipt-issuing machines would be able to provide information on the number of passengers purchasing fares for each number of zones. However, the machines would not

be able to record transfers or passes, so their utility in terms of reporting capabilities would be limited.

Property Implementation/Operation. User education requirements for this option would be substantial. Users would have to be instructed on how to utilize the self-service portion of fare payment, how to determine fares for the entire system, what types of fare payment media were available, and how transfers could be made. Since the transit authority might need to restructure the entire fare system, current monthly passes and transfers would have to be reprinted with zone information.

Increased involvement of drivers resulting from issuance of multiple zone transfers and/or receipts could require modifications to existing union labor agreements.

Fare enforcement would be more complex for ticket inspectors under a zoned structure than a flat fare structure. However, a systemwide zone structure would be easier to monitor than a light-rail-only zoned structure. Since all tickets, passes and transfers would have the number of zones indicated on them, inspectors would not have to perform as many calculations to assess the validity of each ticket, or combination of media.

Revenue Capture. A well-designed systemwide zoned fare structure could provide the opportunity to recoup a greater portion of operating costs than either of the two options. This is due to the ability to apply a more realistic fare to longer-distance trips.

Passenger Convenience. A zoned fare structure is more difficult to learn and use than a flat fare. However, a systemwide zone structure would be more convenient for passengers than a light-rail-only zoned structure. This is because passengers would not have to memorize and apply two different fare structures. Transfers between modes would be easier than the previous option due to uniformity in the cost of travel for a given number of zones.

Inspection and Enforcement. This option would require an inspection team and procedures similar to those outlined for a flat fare structure. In addition, if the honor system fare payment alternative was selected for bus service, additional inspectors would be required. Fare inspection would be less involved than the light-rail-only zone structure because the tickets, passes, and transfers would all have the number of zones indicated on them.

SUMMARY

Table 4-3 qualitatively summarizes the major implications of these fare policy options. There are some significant equity and revenue capture advantages to the systemwide zone fare alternative, but these are offset to a degree by the relative simplicity to the user and to the transit operator of a flat fare system. There appear to be few, if any, significant advantages of the hybrid flat/zone option relative to either the full zone or full flat fare alternative.

Table 4-3

MAJOR IMPLICATIONS OF FARE POLICY OPTIONS

<u>Fare Policy Options</u>	<u>Equity</u>	<u>Equipment Complexity</u>	<u>Expansion Potential</u>	<u>Data Capture Opportunities</u>	<u>Ease of Property Implementation/Operation</u>	<u>Revenue Capture</u>	<u>Passenger Convenience</u>	<u>Complexity of Inspection and Enforcement</u>	<u>Ease of Transfer</u>
1. Flat Fare	Poor	Low	Low	High	Good	Poor	Good	Low	Good
2. Zoned Fare - Light Rail Only	Good	Medium to High	High	Low	Poor	Good	Poor	High	Poor
3. Zoned Fare - System-wide	Excellent	High	High	Low	Poor	Excellent	Acceptable to Good	Medium to High	Good

