job well done. Instructors must spend 15 min/d walking between stations in the subway. This serves several functions. The likelihood that an instructor may appear anytime and anywhere helps keep operators on their toes. In addition, instructors assist the Facilities Department by spotting and reporting out-of-order equipment, evidence of vandalism, and other problems. Finally, many breakdowns or delays are quickly cleared because an instructor was handy.

Besides working to assist operators, instructors run various checks of compliance with operating rules. The subway's block signals do not have trips, since an arrangement such as that used on the Shaker Heights PCC cars cannot be employed on street-running trolleys. Operators are sometimes tempted to lose respect for red signals, especially on time-zone lights. To minimize safety violations of this type, instructors periodically conduct signal checks during which the signal is held at red until the operator comes to a complete stop. Violators are suspended for a day for the first offense, and progressively stricter discipline is exercised thereafter. The possibility is being discussed of equipping new cars and the tunnel with an inductive-coil trip system such as that used in Belgium.

Our rules require operators to come to a complete stop at all facing point switches (except the air-brake-operated double-point switch in the subway) and to ensure that the switch is properly set before proceeding. Instructors conduct frequent switch checks. Interlocking switch and signal plants are possible accident sites, and operator adherence to safety rules at our one such location is reinforced by the use of a graphic recorder that can pinpoint signal or switch violations. This recorder in the 34th Street Tower is monitored by a signal maintainer.

The subway-surface system has only one railroad crossing; this is also frequently checked by instructors to see that operators stop and look before proceeding. The overhead wire at the crossing has a conductive net guard to catch the pole if a dewirement occurs. This allows the car to clear the crossing before the pole is rewired. Other safety aids are installed where needed, such as signs to warn of slippery rail. There is also a mirror at the portal so that an inbound trolley operator can watch in the mirror for automobiles behind outbound cars.

None of these efforts in itself will ensure accident-free operation but together they are very effective. SEPTA's greatly improved safety record attests to this.

SUPPORT ACTIVITIES

There are many activities and facilities necessary to support a subway-surface system, so I will mention only a few. Because our private right-of-way precludes the use of automotive vehicles to string or repair overhead wire, a tower car is employed. This car is also essential for repairs in the subway. Trash removal from the tunnel is facilitated by use of a work car. Other maintenance and repair functions dictate the need for crane and flatbed work motors. Car maintenance itself is accomplished at Callowhill Depot for Route 10 and at Woodland Depot for the other routes. A disastrous fire in late 1975 destroyed the Woodland Shop; we must now make do with a temporary prefabricated structure.

The future of the five subway-surface lines is assured. Specifications are being prepared for new light-rail vehicles to replace the tired fleet of PCC cars. A new depot and major maintenance facility have been designed to replace the antiquated Woodland Shop. Together these efforts will begin a new era in efficient transportation for the people of West Philadelphia. By then the joint efforts of the city and SEPTA to provide better security on the system for passengers and operators, eliminate graffitti, and in general raise the quality of service will have gone far forward.

RECOMMENDATIONS FOR NEW SYSTEMS

1. Use preemptive signals liberally for street running or private right-of-way with cross traffic, especially where turns are involved.
2. Plan the subway alignment to exclude or minimize curves; unavoidable curves should be made as gradual as possible.
3. Provide for transitional lighting where operators enter and leave the tunnel.
4. Provide uniform lighting levels throughout both stations and tunnel sections.
5. At terminal stations use sliding gates to increase loading and unloading capacity during peak hours.
6. Plan for the strategic, uniform placement in the tunnel of such items as telephones, extinguishers, fire alarms, and emergency tools.
7. Use arrows to indicate the shortest distance to such emergency equipment and make sure the tunnel has a concrete walkway for operator use and emergency evacuation of passengers.
8. Buy double-ended cars or cars with back-up controllers and place crossovers at frequent intervals in the trackage.
9. Provide for diversion of routes since even the most well-designed system will suffer blockages; it would be especially wise to include a loop at tunnel entrances if cars are single ended.
10. Ensure safety with simple block signals and car trips.

Traffic Engineering for Light-Rail Transit

Hans W. Korve, De Leuw, Cather and Company, San Francisco

The development of safe and operationally effective designs for at-grade intersections and crossings for light-rail transit (LRT) is an issue central to the future deployment of the mode. This paper describes a design approach based on the performance characteristics of light-rail vehicles (LRVs) and the application of conventional traffic engineering hardware and design practice. At-grade operation of LRT introduces potential conflicts with motor vehicles and pedestrians at intersections, in streets between intersections, and at mid-block crossings. These conflicts are a source of delay and accidents for LRVs. Application of the appropriate conflict-control techniques must consider that modern LRVs have performance characteristics essentially similar to those of transit buses. There are four strategies available to the traffic engineer to eliminate or

control points of conflict among LRVs, motor vehicles, and pedestrians: at-grade separation of traffic flows in space, vertical separation of traffic flows in space, separation of traffic flows in time, and reduction in the number of traffic approaches.

A rail transit system is classified as light-rail transit (LRT) if it has the capability to operate safely and effectively through at-grade conflict points. LRT is being increasingly considered as a mass transit alternative in many medium- to large-sized cities all over the world. While LRT has many of the characteristics of heavy-rail transit (HRT) systems, such as the ability to operate at high speeds on exclusive right-of-way or to couple vehicles into trains, it has the additional capability to operate on steeper grades and negotiate sharper curves than conventional HRT systems. Most importantly, it has the capability to operate at grade. The development of safe, simple, and operationally effective designs for at-grade intersections and crossings for LRT is an issue central to the future deployment of the mode.

At-grade operation of LRT introduces potential conflicts with vehicles and pedestrians at intersections, at mid-block crossings, and in street operations between intersections. Various traffic engineering techniques exist for reducing delay to LRT and controlling conflict between light-rail vehicles (LRVs) and other vehicles and pedestrians. Vast improvements to LRVs, primarily in braking, enable them to operate more like modern transit buses than like railroad vehicles (Figure 1).

The level of sophistication of traffic-control methods should be commensurate with the level of activity at the conflict point. In areas where LRV headways are long and conflicting motor vehicle volumes are low, only limited measures need be taken to control conflict. Where LRV headways are short and conflicting motor vehicle or pedestrian volumes are high, sophisticated measures (such as traffic signals with LRT priority, channelization, and turn prohibitions) may be appropriate.

CONFLICT CONTROL

In improving the traffic flow and safety of existing LRT systems and in designing new LRT systems, the traffic engineer should consider the LRV in relation to traffic movement and not treat it as if it were a railroad. This traffic movement, when accommodated on an at-grade alignment, will introduce new conflicts with motor vehicles and with pedestrians. These conflicts can be a safety hazard as well as a source of delay to LRT. The number of persons carried by the LRV must be considered in determining priorities between conflicting movements.

These conflicts will occur both at intersections and at mid-block locations. The highest number of conflicts among vehicles, pedestrians, and LRVs occurs at a multileg intersection that has branching LRT lines. The number of potential conflicts is lowered if the number of intersection approaches or LRT lines is reduced or if one or more traffic movements is prohibited. The lowest number of conflicts occurs at an LRT mid-block crossing.

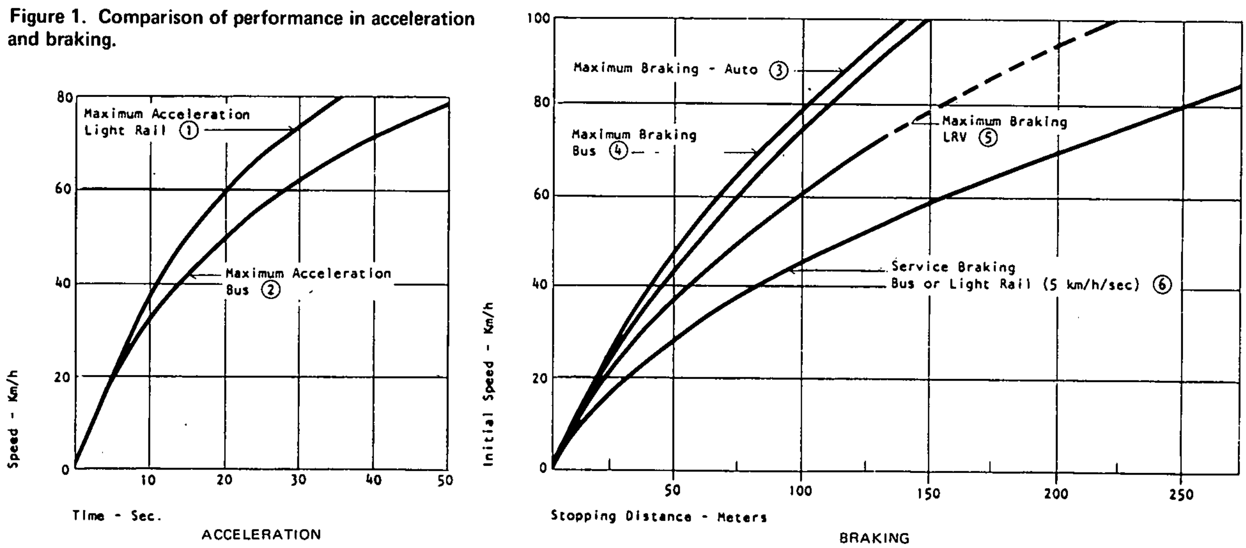
CONTROL STRATEGIES

There are four strategies available to the traffic engineer to eliminate or reduce LRT conflict points at intersections or mid-block crossings: at-grade separation of traffic flows in space, vertical separation of traffic flows in space, separation of traffic flows in time, and reduction in the number of traffic approaches. Within each of these strategies many different techniques are available.

At-Grade Separation of Traffic Flows in Space

Traffic flows can be separated at grade by developing separate traffic lanes for each movement, by developing medians, or by prohibiting or diverting certain movements. Development of special lanes, such as through lanes or right-turn lanes serves to compartmentalize

Figure 1. Comparison of performance in acceleration and braking.



Note: 1 km = 0.6 mile; 1 m = 3.3 ft.

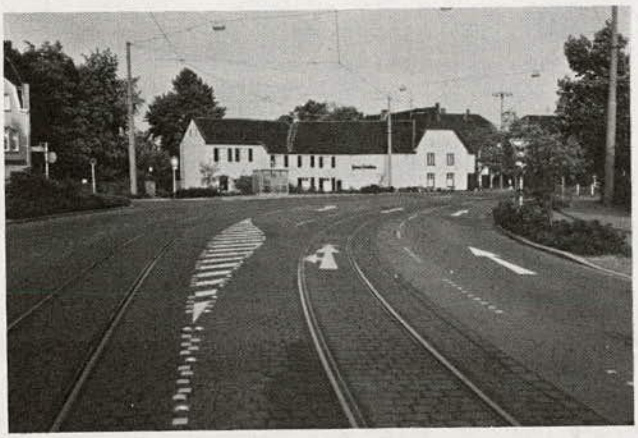
1. 1975 Boston test data for Boeing Vertol LRV with 102-passenger equivalent load.
2. 12-m (40-ft) General Motors transit bus with V8 engine (model T8H 5307), 66-passenger load, and air-conditioning on.
3. Dry pavement, including 2.5 s reaction time.
4. Based on Federal Motor Vehicle Safety Standard No. 121 for dry pavement, skid number 75, including 2.5 s reaction time.
5. Based on the German federal standard for LRVs on dry rail, including 2.5 s reaction time.
6. Limited by considerations of passenger safety and comfort.

the traffic movements, and this reduces potential conflicts at a given intersection approach. Figure 2 illustrates the use of a left-turn lane between the LRT tracks to improve traffic flow. A more positive means of separating LRT from motor vehicle traffic would be to separate the two movements by using a median. Such a treatment, which is found in most LRT systems, would restrict crossings to specific locations, and special design measures can be undertaken at these locations to safely separate the movements. Such a median would provide opportunities for landscaping, placement of traffic signs and signals, platforms, a refuge area for crossing pedestrians, and space for left-turn lanes.

Prohibition of certain traffic movements can also result in a reduction of the number of conflicts. Examples of this would be prohibition of left turns or through movements from a cross street. Such a prohibition could also apply to a pedestrian crossing.

Diversion of conflicting motor vehicle movements to parallel routes would reduce conflicts and the delay to LRT. This could be done by reducing the progression speed along the arterial that carries the LRT to the average travel speed of the LRV, including stops. Parallel arterials may then become more attractive for the motorist to travel on. Such an approach is being considered in Philadelphia.

Figure 2. Use of left-turn lane with LRT in mixed traffic (Krefeld, West Germany).



Vertical Separation of Traffic Flows in Space

Traffic flows can be separated vertically so that conflicts are totally eliminated. Examples of this treatment are pedestrian overpasses and underpasses and railroad or highway grade separations. When the LRT is separated from all motor vehicle and pedestrian conflict, it becomes a rapid transit system. Capital cost considerations usually dictate that this form of conflict control for LRT should only be used when all other traffic engineering measures have failed. Grade separations of critical conflict points are often a last step in an overall improvement program of a portion of an LRT line. A good example of such a program in the United States is the coming LRT subway in downtown San Francisco.

Separation of Traffic Flows in Time

The separation of traffic flows in time is one of the most heavily used traffic engineering techniques; it is usually accomplished by the use of traffic-control signs or traffic signals.

At locations with a relatively low volume of traffic, stop or yield signs are used to define the right-of-way of specific movements. This technique may be adequate at the outer ends of LRT lines, where cross-street traffic may be low (less than 5000 vehicles/d) and the LRT headway high (greater than 5 min).

At higher volume intersections or crossings, traffic signal control can be used to positively assign right-of-way to conflicting movements. Standard traffic-signal warrants must be met before installation of such a device is considered. Figure 3 illustrates the use of traffic signals to control conflicts between LRVs, motor vehicles, and pedestrians. Two-phase signal control would

Figure 3. Typical use of traffic signals at intersection.

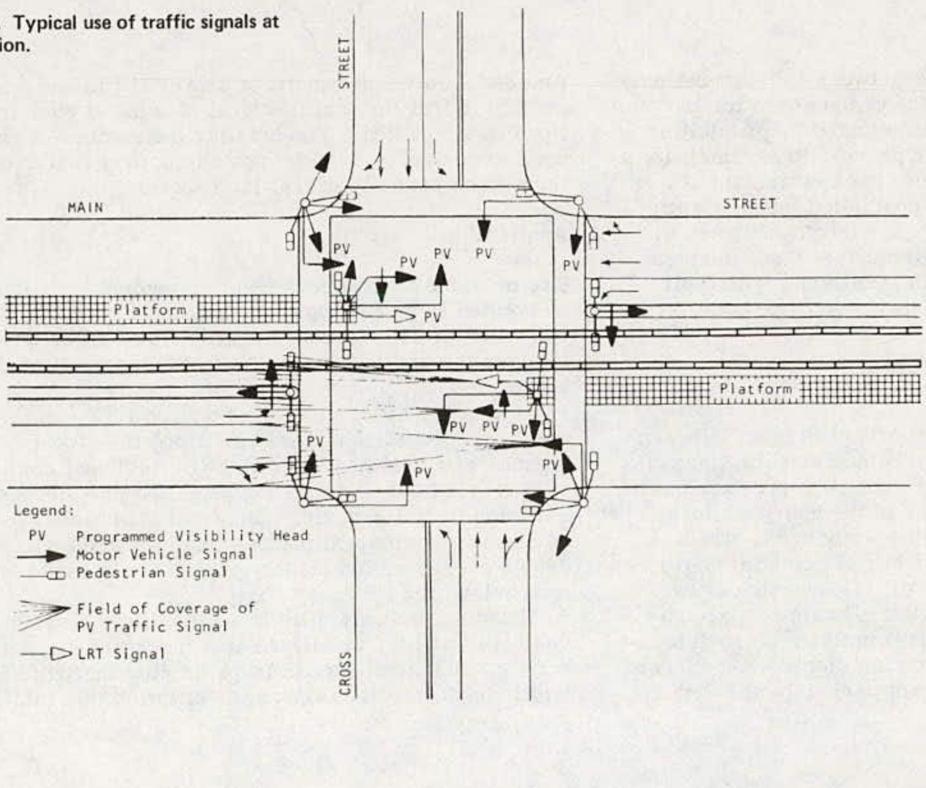
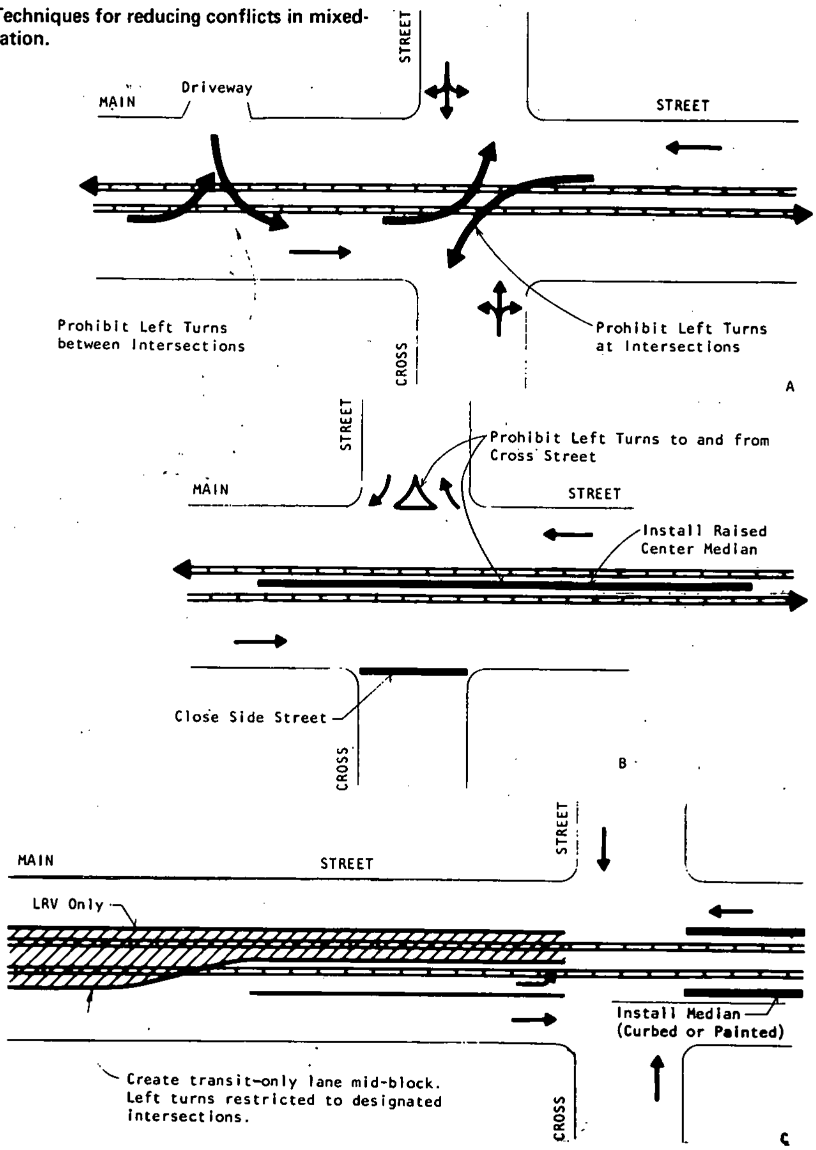


Figure 4. Techniques for reducing conflicts in mixed-traffic operation.



create a potential for conflicts between left-turning motor vehicles and LRT during the green phase for the main street. This conflict can be eliminated by prohibiting left turns or adding a left-turn phase. Programmed visibility traffic-signal heads allow each movement at a multiphase intersection to be controlled independently of all other movements. They are frequently used to control left-turn phases. As the use of these devices has increased and drivers gain familiarity with their use, acceptance by the public has been quite good.

Reduction of the Number of Traffic Approaches

A reduction of the number of approaches to an intersection or mid-block crossing can be achieved by converting one or both of the crossing streets to one-way operation or by closing one or more of the approach legs. For example, conversion of a two-way cross street to one-way operation cuts the number of potential conflicts at the intersection almost in half. Conversion of two-way streets to one-way operation is easiest to accomplish where there is a grid street pattern. In such locations, one-way couplets can be established, and access to private property is usually not seriously affected.

Another significant benefit of converting to one-way operation is that the traffic-signal phasing at such intersections is simplified. The smaller the number of phases used to control a given intersection, the greater the throughput capacity of that intersection.

Application

One or more of the above conflict-control techniques can be applied to provide fast and safe operation of LRT. The operation of LRT in mixed-traffic flow will be used to illustrate the application of some of these conflict-control techniques.

In mixed traffic, conflicts between LRT, motor vehicles, and pedestrians occur all along the street. The sharing of a common travel lane by LRT and motor vehicles creates the potential for rear-end and side-swipe collisions. Motor vehicle queues at approaches to intersections, vehicles waiting to make left turns, and vehicles double parked or too closely parked could cause significant delays for LRT.

Possible methods of reducing conflicts between motor vehicles and LRT are illustrated in Figure 4. Left turns between intersections can be prohibited through signing, traffic bars, median islands, or creation of a mid-block transit-only lane. Any of these prohibitions would eliminate most mid-block LRT delay. Alternate access routes to adjacent properties must be available if this technique is to be used. In San Francisco, such a design is planned for the outer ends of the N Line and is in operation on Market Street. Left turns at intersections can be prohibited by installing signs or channelization islands. The sign prohibition could be in force during peak periods or all day, depending on the accident history and the nature of the delay. Installation of center channelization islands on the cross-street approaches or between the LRT tracks would eliminate cross-street through and left-turn movements and main-street left turns. An example of this treatment can be found on Huntington Avenue in Boston. This technique would be highly effective in increasing safety and reducing delay to LRT, but it would impair local circulation. This treatment is most appropriate for low-volume local streets and collector cross streets. Elimination of the cross-street through movement would cause diversion of traffic to other streets. Residents along the streets that attract diverted traffic may oppose such a treatment.

An outgrowth of the previous step could be to close the side street to motor vehicle traffic as shown in Figure 4B. This treatment would primarily benefit pedestrians, since the pedestrian-vehicle conflicts would also be eliminated.

The most positive means of reducing mid-block vehicle-LRT conflicts and controlling pedestrian-LRT conflicts would be to convert the inside lane from mixed-flow operation to transit only and separate the two lanes with a painted or raised median (Figure 4C). It could mean loss of a travel lane on the arterial, and this could significantly reduce its traffic-carrying capacity. On narrow streets such a median could have mountable curbs to allow emergency vehicles or turning vehicles to use the median. An example of such a treatment can be found on a portion of the N Line in San Francisco.

On arterials carrying large amounts of automobile traffic, this treatment could result in serious congestion or significant diversions of traffic to other routes. For this reason, this treatment is best used where parallel routes are available to handle the diverted traffic or where traffic demands are low enough that they can be satisfied by the remaining traffic lanes. Alternatively, the street could be widened to provide equivalent automobile capacity. A study of Vermont Avenue in Los Angeles (1) revealed that the conversion of a portion of that street from two travel lanes in each direction to one travel lane and one LRT lane in each direction could result in significant congestion on Vermont Avenue and diversion of at least 30 percent of the 19 000 vehicles/d that use that street to parallel streets.

Placing transit stops in areas of mixed flow creates potential vehicle-LRT conflicts. These conflicts can be mitigated by a variety of traffic engineering techniques. If LRT platforms are installed in mixed-flow operations, motor vehicle traffic must pass on either side of them. This introduces a potentially serious vehicle conflict between the automobiles and the platforms. Designs that require a change in the direction of the travel lane contribute to collisions with the platforms by automobiles. On a section of the K Line on Ocean Avenue in San Francisco, as many as 10 vehicle collisions/platform were recorded in a single year. Most occurred at night, and none involved waiting passengers. This could indicate that the poor visibility of the platforms, which are 15 cm (6 in) high, was a significant causal factor. Gentle transition areas, a median with far-side platforms and near-side left-turn lanes, crash barriers on the upstream side of the platform, or left-hand loading from a platform located in the median between the LRT tracks (as is used in Mexico City) can mitigate this potential safety problem. The use of center-platform loading allows use of a narrower median and avoids the need for widening the intersection approach to provide space for platforms. In addition, if the median is confined to the area between the tracks, left turns can be allowed from the track lane at selected locations. The use of leading green arrows will minimize delay of LRT.

TRANSIT PRIORITY

The success of the LRT system in attracting patronage is to a large degree a function of its travel time in relation to that of other modes. Shorter travel time can be achieved either by extensive use of grade separation (a costly alternative) or by use of traffic engineering strategies to control conflicts and reduce delay. At traffic signals this involves granting LRT priority over conflicting movements. This discussion will focus on median operation of LRT at intersections and on mid-block crossings by LRT. Most of the alternative control strategies apply equally well, sometimes with minor modifications, to alternate LRT alignments.

For the purposes of this discussion, the terms priority and preemption both refer to preferential treatment given to LRT at traffic signals to minimize delays to LRT caused by the traffic signals or by other vehicles in the traffic stream. Preemption is intended to imply as immediate a response as is consistent with safety, whereas priority is intended to imply that, in addition to safety considerations, the needs of other movements, primarily vehicular, will be evaluated before deciding whether to grant preference to LRT. There are four types of preferential treatments that could be used to control the LRT crossings at intersections.

Progression Speed Favoring LRT

In an interconnecting traffic-signal system, the signal timing can be adjusted to favor transit. This usually means reducing the progression speed along a given street, e.g., from 40 to 48 km/h (25 to 30 mph) or about 24 km/h (15 mph). The lower progression speed would include average dwell time at passenger stops (see Figure 5). Such a change in travel speed would favor transit by reducing the number of times that an LRV would get caught at a red light, but at the same time it would increase delay to motor vehicles. Such increased delay usually has the added benefit of diverting some of the motor vehicle trips to parallel routes. This diversion will reduce motor vehicle-LRT conflicts and thereby could improve the safety aspects of that LRT line.

As an alternative, or in combination with the above, travel speed of LRT can be increased by selective placement of the platforms. Alternating platforms from near-side to far-side locations achieves a more desirable progression speed. The end of the LRV's dwell time would then nearly coincide with the arrival of the next motor vehicle platoon traveling in the green band. The progression speed can then be set to more closely coincide with automobile travel speed. A good example of this treatment, shown in Figure 6, can be found in Dusseldorf, West Germany.

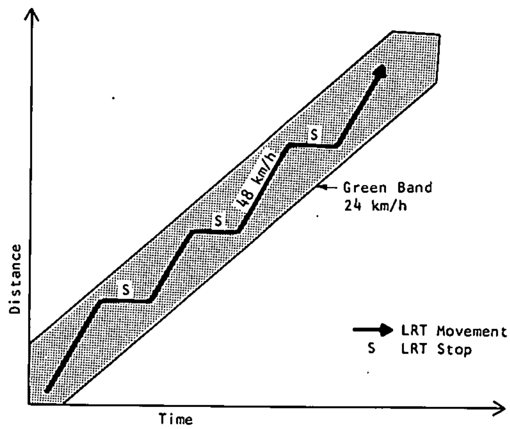
Since this treatment provides higher progression speeds for motor vehicles, it would not achieve the same degree of traffic diversion as that achieved with low progression speeds that favor transit. During periods of light patronage demand, e.g., midday or evening hours, the LRV may travel with the normal vehicle platoon for considerable distances if it is able to skip station stops.

Special Signal Phases for LRT

A second method of intersection control features the use of a special phase to control the movement of an LRV. This special phase may appear during every signal cycle on a fixed basis, or it may be actuated by an approaching LRV, which places a call to the controller and waits for the phase to appear. This would involve no preferential treatment for LRT, and therefore an LRV would suffer delay.

This treatment is most useful where an LRV comes into unusual conflict with motor vehicles to create the potential for collisions. Such cases exist where light-rail tracks leave the center of the street and turn into a cross street or enter a separate right-of-way. Figure 7 illustrates this situation in Mannheim.

Figure 5. Alteration of progression speed to favor LRT.



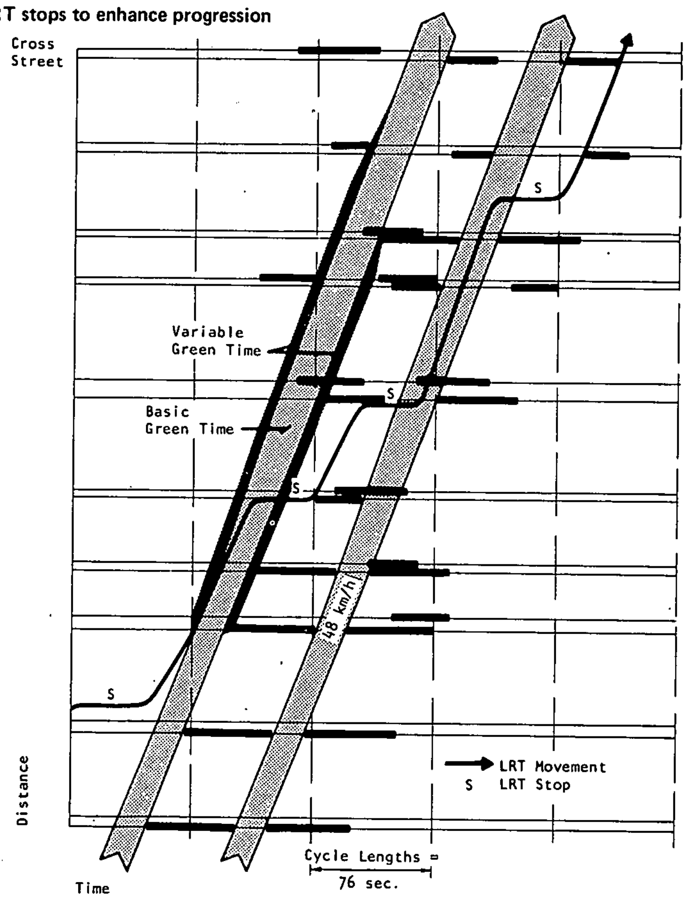
Preemption of Traffic Signals

A third form of intersection control would provide unconditional preemption for LRVs at conflict points. This means that the crossing-control signals will display a green LRT indication by the time an LRV arrives at the preempted intersection. This method most closely resembles the operating speeds and operating characteristics of grade separation. If far-side platforms are also used, an LRV will always clear the crossing and avoid a double stop. Because the preemption is unconditional, vehicular demands are not used to establish the exact traffic-signal timing. After an arriving LRV is detected, only the minimum intersection-clearance intervals are timed out before the signal switches to the LRT preemption phase. Clearance intervals are usually set by the safe-crossing requirements for pedestrian rather than vehicular demand.

Use of the unconditional preempt will result in some loss in intersection capacity. This loss is proportional to the LRT headway and is also a function of upstream intersections and the particular preemption strategy used. For example, at a standard intersection where all other traffic must stop to let the LRV pass, as shown in Figure 8, about 10 percent of the available signal time would be lost if preemption occurred every 3 min.

To illustrate the effect of LRT preemption at a standard intersection, I calculated intersection capacity for a range of vehicular and LRT demand. The main-street traffic volume was assumed to be constant at 20 000 vehicles/d and the cross-street volume was varied from 10 000 to 20 000 vehicles/d. The intersection configura-

Figure 6. Selective placement of LRT stops to enhance progression speed.



tion is that shown in Figure 3. It was found that a multiphase traffic signal makes LRT preemption feasible in every third signal cycle. If simple two-phase signals are used and left turns are prohibited, LRT preemption in every second signal cycle is feasible.

Similar capacity calculations performed for a mid-block crossing of a four-lane arterial by LRT showed that preemption is feasible as often as every 2 min for traffic volumes as high as 25 000 vehicles/d. In both cases the Highway Capacity Manual's level of service D (2) was used to determine the maximum congestion level.

Figure 7. LRV entering private right-of-way (Mannheim, West Germany).

Figure 8. Preemption of all traffic for crossing by LRV (the Hague, the Netherlands).

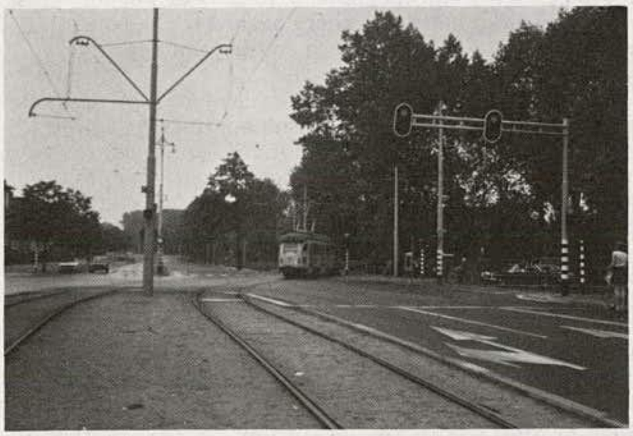
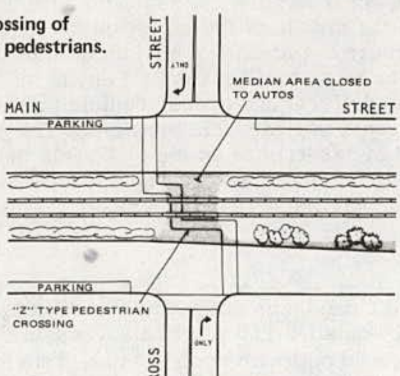


Figure 9. Z-crossing of LRT tracks for pedestrians.



In a dense traffic-signal network, frequent preemptions could disrupt vehicular traffic flows, result in unused green time at downstream intersections, and result in increased incidence of rear-end accidents if a vehicle platoon is preempted just as it arrives at a given intersection. For these reasons this method is best applied in less busy locations. This treatment should be combined with far-side LRT stops, since the accurate prediction of the arrival time of an LRV at a given intersection, which is impossible in the case of near-side stops, is important to the efficient timing of the preemption phase.

Priority

When the needs of conflicting vehicular or transit demands must also be met, then conditional preemption or priority techniques should be used. This would call for detectors to measure the conflicting traffic demand and locate arriving vehicle platoons and LRVs. A master controller would then predict the arrival time of those platoons and the LRV at the intersections in question and assign green signal time to the movement predicted to arrive first. If both are to arrive simultaneously, then the signal may be set to favor the movement carrying the greatest number of people.

This type of control would involve an extensive feedback between the controller (probably a computer) and vehicle detectors located in the street system. A number of control parameters could be fed into the computer to set the degree of priority treatment that LRT should receive. The flexibility of this approach is limited to the requirements of pedestrians, the amount of disruptions tolerable at adjacent intersections as signal adjustments are made to favor LRT movements, and the needs of conflicting transit movements. The degree of priority afforded conflicting transit movements must be a function of relative delay to people. Such a system is currently being installed along Commonwealth Avenue in Boston.

PEDESTRIAN CONFLICTS

Pedestrian conflict occurs when a pedestrian must cross LRT tracks, either at an intersection or mid-block, or when a pedestrian is boarding or alighting from an LRV. Crossings of LRT tracks at intersections are treated like crossings of a street that does not carry LRT. If possible, pedestrian signals should be used. Streets that have wide medians can carry supplementary indications in the median to aid pedestrians in crossing and to allow shorter pedestrian crossing time. This allows a shorter signal cycle and, where vehicular green-time demand is less than pedestrian demand, increases the level of service (capacity) of an intersection.

At mid-block crossings, the pedestrian-LRT conflict is relatively simple to control. Since LRT movements are usually fewer than vehicular movements, the primary problem a traffic engineer faces is to make sure the pedestrian is aware of the arriving LRV. Provision of good sight distance all along the LRT right-of-way is a key to solving this problem.

On median or private right-of-way operation, fencing should be used to establish specific crossing locations. These locations must be chosen on the basis of both pedestrian demand and such safety considerations as adequate sight distance. To increase the pedestrian's awareness of an approaching LRV, a Z-barrier can be installed. Such a barrier, illustrated in Figure 9, makes sure the crossing pedestrian faces toward the nearest approaching LRV and prevents him or her from blindly dashing straight across the tracks.

Figure 10. Signal island to protect pedestrians.

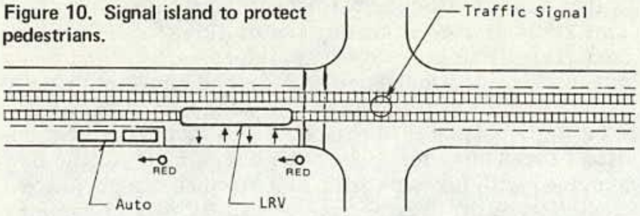


Figure 11. Fenced platform for passenger boarding (San Francisco).

At transit stops the problem gets more complicated because queuing space must be provided to handle boarding and alighting passengers. In mixed-flow center operation without platforms, passengers must enter the roadway to board a vehicle. This is acceptable only when the street is narrow and automobiles cannot pass the LRV on the right. On wider streets, a signal island can be provided. Such a treatment, illustrated in Figure 10, is used in Dusseldorf. An arriving LRV actuates a traffic signal located at the programmed stop. When this signal turns red, it stops approaching motor vehicle traffic upstream of this transit stop. Such a signal must be coordinated with a nearby downstream traffic signal to avoid blockage of the LRT tracks by motor vehicles stopped at the next intersection.

Alternatively, a raised platform can be provided in the street. If motor vehicle traffic is allowed to pass on either side of the platform or must change direction of travel in order to avoid striking the platform, the potential for accidents exists. Experience with such island platforms on Ocean Avenue in San Francisco shows that motor vehicles strike them an average of 10 times/year. Luckily these accidents usually occur when no passengers are waiting on the platform. To protect waiting passengers, transit systems have installed crash barriers on the upstream side of the raised platforms.

To prevent passengers from crossing behind waiting LRVs and from dashing into adjacent automobile lanes, fencing between the tracks as well as between the platform and the automobile lane can be quite effective, as illustrated in Figure 11. Alternatively, the platform can be located on a median between the tracks. If the LRVs have left-hand doors, the passengers can board from the median. This technique, used in Mexico City, has the added benefit of not forcing a change in direction by the motorist; this reduces the likelihood of a collision with the median.

BUS OPERATION ON LRT RIGHT-OF-WAY

Generally speaking, it is feasible to operate buses on the LRT right-of-way. This operation can be undertaken either to supplement scheduled service or to act as a backup in case of outages on the LRT system due to power failures or accidents. Joint operation of buses and LRT in a separate median, which is used in such cities as New Orleans, Chicago, and Hamburg, should result in an increase in bus operating speed since median operation is generally faster than mixed-flow curbside operation because there are fewer conflicts. These benefits could accrue as long as headways were long enough so that transit vehicles would not interfere with each other.

If bus operation on LRT right-of-way is to be implemented, all sections of the LRT right-of-way must be paved to full strength. This means no open trackage of ballast or other unpaved or thinly paved sections can be allowed. The general design criteria regarding grades and horizontal and vertical curvatures apply equally well to both modes; therefore no special alignment modifications would have to be made during the design of an LRT system to permit bus operation. However, the inability of a bus to track entails greater lateral clearances for a bus than for an LRV. Buses should have at least a 3.7-m (12-ft) lane to provide adequate side clearance. Less clearance would inhibit their use and would lead to slower operating speeds and increased potential for collisions. A good example of low-speed operation is found in the Mount Washington tunnel in Pittsburgh, which was designed for LRVs and is now shared by buses. The buses operate at about 16 km/h (10 mph) because of the narrowness of the travel lanes. Generally, the minimum width for LRT is 0.3 to 1.0 m (1 to 3 ft) narrower than is satisfactory for bus operations. In addition, center poles could present a potential safety hazard to the buses. If an LRT system is being designed for joint operation, center poles should not be used.

Basically, the same traffic engineering principles that govern control of LRT movements apply to buses. However, the detection equipment for traffic-signal actuation or traffic-signal priority treatments would have to be modified to respond to bus actuation and bus operating characteristics.

Joint operation could result in several operational and safety problems. Paved trackage looks more like a street to the automobile driver than does unpaved track. Since buses would be operating on the LRT right-of-way, automobile drivers, thinking that the buses are traveling in an automobile lane, might enter the LRT right-of-way. Care must be exercised in placing proper signing and other warning devices at openings to the right-of-way to prevent trespassing by automobiles.

Joint median operation for buses and LRT would increase the concentration of passengers loading and unloading in the middle of the street on the platform. This could increase the hazard of accidents to pedestrians who have to cross traffic lanes. Fencing of the traffic side of the platform and proper vehicle and pedestrian signaling could mitigate this problem. The greater concentration of passengers on the platforms may also require that these platforms be wider and possibly longer to accommodate more than one transit vehicle at a time.

SUMMARY

Modern LRT can be an attractive transit alternative to heavy-rail transit. The key to a successfully operating LRT system is optimum control of at-grade conflicts. It requires very little imagination but a lot of dollars to build a grade separation for LRT. On the other hand, it requires a lot of imagination to build and operate a fast, efficient, safe, and inexpensive at-grade LRT system. To achieve optimum operation a community must be willing to sacrifice some of the conveniences of the automobile for the benefit of LRT. Most importantly, the various jurisdictions governing transportation, such as transit planning, operations, design, traffic engineering, and police, must work together in designing, operating, and maintaining the traffic-control system for an at-grade LRT system.

REFERENCES

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Control of Light-Rail Transit Operations in Edmonton

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The first line of Edmonton's light-rail transit (LRT) system is currently being completed. The underground portion of the line in the downtown area connects to a surface portion that shares its corridor with a major railway line. Interactions between the railway, LRT, and other transportation modes have created problems in the areas of safety, roadway capacity, and regularity of service. This paper describes the approach taken in Edmonton to overcome these problems. The new transportation management system, which is in its initial stages of implementation, is a major tool in minimizing the negative impacts of LRT. The system focuses on the establishment of LRT controls that, in addition to the categoric requirements of safety, must guarantee optimum use of the LRT tunnel, which in turn depends greatly on the regularity of service on surface portions of the LRT line, and integration with other transportation modes in terms of safety, coordination of scheduling between LRT and buses, and minimization of disruption to all modes at the nine grade crossings. In general, the flexibility of LRT operations and the implementation of an integrated transportation management system has enabled cost-effective solutions to be developed.

In 1974, the city of Edmonton formally adopted a transportation philosophy that had as a basic objective an increased reliance on public transportation and the development of techniques to use more fully the capacity of the existing transportation network. This led to the development of a new transit concept plan for Edmonton and the development of a transportation management system (TMS).

The transit concept relies on the new light-rail transit (LRT) system and a restructured bus system for provision of improved public transit service. The TMS will integrate the management of all transportation resources of the city and will use advanced surveillance and monitoring techniques to provide better utilization of the transportation infrastructure. Both systems are now in a first stage of implementation. The implementation of the Northeast LRT line provided the first opportunity to apply some of the TMS features to a real-life situation.

PUBLIC TRANSIT IN EDMONTON

Public transit in Edmonton is an important component of the urban transportation system. It carries about 20 percent of all daily work trips and about 35 percent of the peak-period trips to the central area of Edmonton. During the past 15 years the proportion of central-area trips made by transit has been increasing steadily. A second major function of the transit system is the provision of transportation services for people who cannot use an automobile for travel.

An overall public transit plan for Edmonton is set out conceptually in Part 1 of the city's Transportation Plan (1). Figure 1 illustrates the general pattern of transit service proposed in this plan. A main feature of this concept is the development of transit centers in the outlying sectors of the city. Local feeder-bus routes serving the surrounding areas meet at the transit centers, and then most routes continue to the downtown area. This plan provides direct service to the downtown area, and passenger transfers between different bus routes are provided at the transit centers; this permits reasonably direct trips between outlying origins and destinations.

In the northeast sector of the city, the first LRT line is now in the last stage of construction. This facility will provide a high-capacity transit line to the downtown. The three outlying stations will serve as transit centers for LRT, buses, and private vehicles (Figure 2). At these transit centers, off-street bus stations and parking areas will be provided, along with pedestrian connections to the station. An example of a typical outlying station is shown in Figure 3. These stations will also offer transit services during special events along the corridor. Near the middle of the Northeast Line, a new stadium with a capacity of 40 000 is being built for the 1978 Commonwealth Games. Further to the northeast, the Edmonton Coliseum attracts regular audiences of more than 15 000 people. Finally, in the same neighborhood, the Northlands horse-racing track and Edmonton Exhibition Grounds draw very large daily crowds during major events, such as Klondike Days. Since all of these facilities are in developed areas, parking space is limited.

The other two stations on the Northeast Line are in the downtown area. One of these stations is a through station; the other will serve as a temporary terminus until the line is extended through the downtown.

The line is 7.2 km long; about 1.6 km are in the downtown tunnel, and 5.6 km are at grade along the Canadian National Railways (CNR) right-of-way. While this corridor provided a readily available route for LRT, it re-