Investigating the Potential for Street Operation of Light-Rail Transit

John Taber and Jerome Lutin, Department of Civil Engineering, Princeton University

This paper examines the potential for light-rail transit (LRT) operations in the street with mixed traffic. It is hypothesized that street operation of LRT is possible, and in some areas desirable, for both cost reduction and service improvement. It is believed that the potential cost savings in construction should lead planners to consider using LRT in streets. However, little work has been done in analyzing the problems associated with street operation. This paper attempts to establish a systematic framework for investigating the potential for a shared street environment and to stimulate a discussion among LRT planners about the role of street operations in proposed systems. The methodology used in this study has two phases: the identification and investigation of the associated problems and the analysis of various design elements and strategies. Several possibilities for street operation are discussed and the generic problems of street running and traffic conflicts are analyzed. The approach is based on existing data from Toronto.

Many current light-rail transit (LRT) planning studies for North American cities have emphasized the use of private right-of-way. However, an important advantage of LRT is its ability to serve downtown areas by running through city streets where exclusive right-of-way, usually a subway, is prohibitively expensive. Little current research has been devoted to analyzing the potentials and problems associated with a shared street environment.

In general, planners have considered using street right-of-way for LRT operation only where a center median strip is available to separate LRT operations from automobile and pedestrian traffic. Although private right-of-way will undoubtedly be necessary to achieve high running speed, the degrees of reservation that are possible range from an exclusive median for LRT (full reservation) to fully integrated street running in vehicular traffic. Some of the alternatives are listed below.

1. Suburban collectors—In some medium-density suburban areas, street running with stops at corners may provide residential access times superior to those found in conventional line-haul, pedestrian- and automobile-feeder transit systems.
2. Downtown distributor—In central business districts (CBDs) LRT street operation may be a feasible way to provide distribution service in conjunction with high-speed routes running on segregated rights-of-way between the suburban areas and the urban core. Adequate levels of service can thus be provided while the high costs of CBD subway construction are avoided.
3. Limited-traffic streets—Certain streets can be used by LRT at speeds that compare favorably with separated running if measures are taken to reduce competing vehicular traffic. These measures may include contraflow lanes, in which LRT vehicles operate in a direction opposite to that of automobile traffic; traffic restraints; transit priority signals; and diversion of traffic to adjacent streets.
4. Automobile-free zones—Pedestrian malls and transitways in downtown areas can be used for LRT without compromising transit service and can enhance these areas.

Historically, rail transit was placed in the centers of streets. Gradually, as the availability and popularity of the automobile grew, motor vehicle traffic began to interfere with streetcar operation. This produced an increase in the streetcar's travel time and made the service less attractive. In the period following World War II, streetcars in the United States were regarded as inhibitors in the urban streets. The removal of streetcars followed two basic trends. In most cases, tracks were removed and service discontinued. Where the streetcar lines were retained, every effort was made to separate them from automobile traffic. Some larger cities turned to heavy-rail transit or elevated systems or (as in Philadelphia and Boston) placed the most congested portions of the existing streetcar operation underground. San Francisco is now preparing to run its Market Street Streetcars in a subway one level above the Bay Area Rapid Transit line.

Today, in the face of escalating costs for rail rapid transit, North America is experiencing a resurgence of interest in LRT. Concurrently, federal transportation policy has placed emphasis on transportation system management to improve the efficiency of all modes and increase the effective capacity of streets to move people as well as automobiles. In this context, reinstitution of LRT street operation can be feasible if new strategies are developed to create a suitable shared street environment. The increased emphasis on planning for pedestrian malls and large-scale automobile-restricted zones can give LRT street operation a major role in providing distribution and collector service throughout these areas. The ability to operate at grade with closely spaced stops and to conveniently serve shopping areas is a highly desirable characteristic for LRT operations in pedestrian zones. The problems of conducting street operations in heavy automobile and truck traffic may be insurmountable, but LRT operation may be possible in less dense traffic or in conjunction with more advanced traffic control and signal strategies.

Modern LRT street operations exist throughout Europe; several cities (Amsterdam, the Hague, and Zurich) have added new street trackage. Many European cities have instituted transit priority schemes, generally in the form of reserved transit lanes. Other priority techniques found throughout Europe include the exemption of transit vehicles from barred turns, signal priority, and various regulations that give transit vehicles the right-of-way over other vehicles. While many successful European mixed-traffic techniques may be adopted in North America, one must be careful in comparing European street systems and those in North American cities because of the differing social and driving characteristics. A survey of European transit systems by R. Bennett and C. Elmberg (1) showed that observance of transit priorities by the motoring public depended on the type of priority. Observance of physical or operational priorities was generally satisfactory there, but North American drivers are less likely to abide by such regulations. Both Toronto and Philadelphia have experienced major problems because motor vehicles have used reserved streetcar lanes.

Although several North American cities, including Boston, New Orleans, Philadelphia, Pittsburgh, San Francisco, and Toronto, currently operate on-street

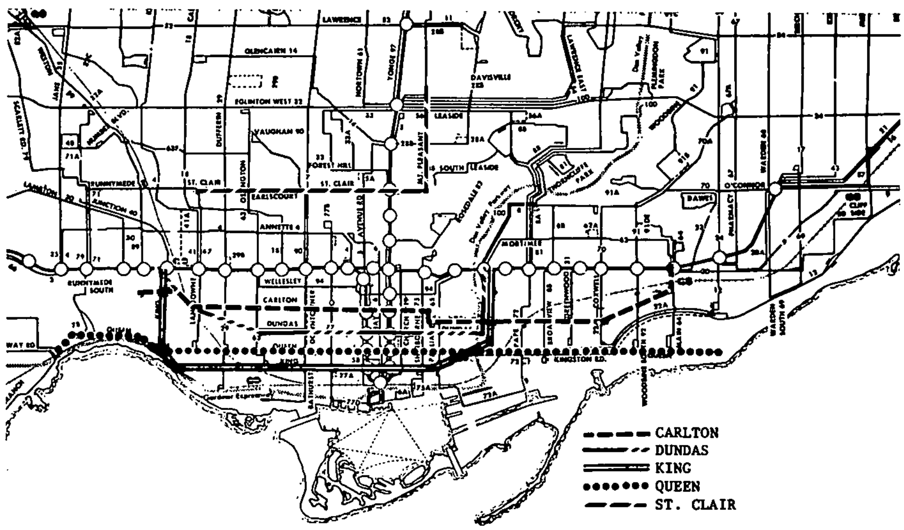


Figure 1. Routes of five streetcar lines in Toronto.

LRT lines, there is little information transmitted to the planning community on the degree of operating success of these streetcar systems or on the potential for improving their performance. Most often, one hears only criticism, which is probably justified, of mixed-street operations because of their slow running times and undependable service as a result of interference from congested vehicular traffic.

We believe, however, that the potential cost savings in construction should lead to consideration of using LRT in streets. Exclusive transit lanes should be preferred, but these are not always possible. This leads to the alternative of mixed-traffic street operation.

As the first step in this study, we defined and identified the major causes of street operating delay. In searching for current streetcar information, we found that a great deal of data had been accumulated on several LRT routes in Toronto (2). Toronto is a growing North American city that has a strong streetcar orientation in its public transit system. We feel that problems of LRT operation in Toronto are similar to those that would occur in any new or existing mixed-traffic LRT system in the United States or Canada. Five LRT routes in Toronto have therefore been examined closely in regard to the problems and potential that must be determined before new LRT systems in a shared street environment are recommended or implemented.

BACKGROUND

Metropolitan Toronto encompasses an area of 624 km^2 (240 $miles^2$) and a population of 2 300 000; it is the fifteenth largest city in North America. Toronto is a city oriented toward public transportation; some 70 percent of peak-hour travelers use mass transit (3). All LRT operations are under the jurisdiction of the Toronto Transit Commission (TTC), a fully integrated public transit agency.

The streetcar system currently has a total of 11 routes covering 74 km (46 miles) and has 338 light-rail vehicles (LRVs). Virtually all routes use mixed-traffic street operations. Basically, the streetcar routes run in an east-west direction; most routes converge in the major downtown sector. The streetcar lines constitute the major mode of surface transit serving the central city. They carry 4000 to 9000 passengers/h/direction in the rush hour.

Due to the city's development pattern, the streetcar routes pass through areas of each of the basic land uses: residential, light commercial, heavy commercial, and industrial (3).

ROUTE DESCRIPTION

This analysis examines the five routes—Carlton, Dundas, King, Queen, and St. Clair—shown in Figure 1. The first four are primarily downtown routes although they extend into dense residential areas. The Carlton route runs past the University of Toronto and the Ontario Parliament buildings. The King, Queen, and Dundas routes traverse the major office district of the city; the King route extends through the major manufacturing sector. The St. Clair route runs through a major shopping district surrounded by residential streets whose population ranges from middle to upper middle class. All five routes run east-west, have double tracks, and run in the center of their respective streets. A short stretch of the Queen route, located on the outskirts of the city, runs in a segregated median strip along a major artery. The St. Clair line had diagonal striping across the pavement to separate automobile and transit traffic. However, objections to the striping were made by motormen, who complained of headaches. The striping is now being allowed to fade.

DATA COLLECTION

During 1973, TCC accumulated data on various delays encountered by streetcars. Little more was done with this study because of budget constraints, although left turns were eliminated at several intersections. Observations were collected by a full-time traffic checker.

Data were collected for delays in eastbound and westbound directions for four different time periods in the morning peak, midday off-peak hours, afternoon peak, and evening. Routes were divided into 12 to 16 segments on the basis of important intersections and stops. Each delay was assigned to one of 12 categories:

1. Passenger service time,
2. Other delays due to TTC operations,
3. Traffic signal,
4. Left or right turn,
5. Accident,
6. Traffic congestion,
7. Yield and merge,
8. Pedestrian crosswalk,
9. Parked automobiles,

Figure 2. Total operating delays.

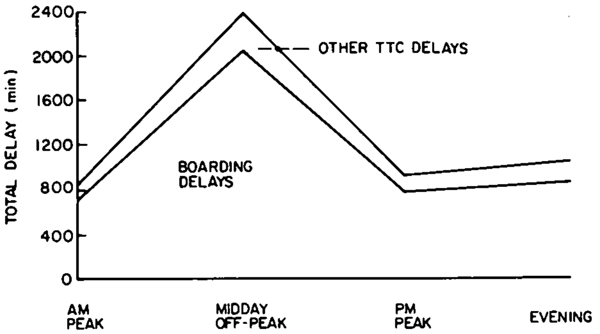
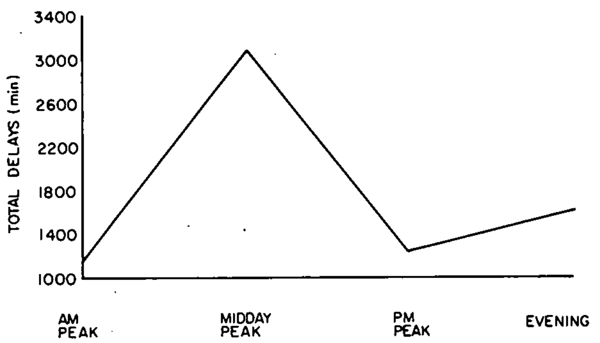


Figure 3. Street delays for all routes.



10. Traffic officer,
11. Construction, or
12. Miscellaneous delays.

Guidelines were established for what constituted a delay, and all delays were recorded in minutes. We conducted a preliminary investigation of the data; our findings are given below.

OPERATING DELAYS

Operating delays were those attributed to passenger service time (boarding delays) and those caused by TTC operations (i.e., operator lag or other transit vehicles ahead). All other delays were considered street delay. For all routes, operating delays accounted for about 40 to 45 percent of the total delay, as shown below (1 km = 0.6 mile).

Route	Round-Trip Distance (km)	Operating Delay (%)	Street Delay (%)
Carlton	29.8	41.7	58.3
Dundas	21.1	41.4	58.6
King	25.6	41.6	58.4
Queen	33.6	41.6	58.4
St. Clair	19.4	46.9	53.1

Operating delays, adjusted for the length of route, were greatest for the Dundas and St. Clair lines. However, the St. Clair line experienced large delays at the transfer station with the Yonge Street subway, since streetcars must await connections with the subway. For all routes, delays caused by TTC operations remained approximately 10 to 15 percent of the total operating delays (0 to 10 percent of the total delay incurred).

On most routes, boarding is done in the center of the street with no special passenger provisions. Along St. Clair Street, there are boarding platforms that offer the passenger refuge from the surrounding street traffic. At the time the data were collected, Toronto had a conventional fare system, and the operators made change. The TTC has since switched to exact-fare collection, which has probably resulted in a reduction of boarding delays.

The data indicated that all routes except St. Clair had boarding delays ranging from 85 to 90 percent of the total operating delays (35 to 40 percent of total delay incurred). Boarding delays along the St. Clair line made up a much lower percentage of the total operating delay and averaged only 27 percent of the total delay incurred; this indicates that protected passenger platforms may reduce scheduled running times by 10 percent. Further analysis showed that boarding delays were greatest for midday off-peak hours and approximately equal for other hours of the day (Figure 2). This may be because passengers who use the transit system during off-peak hours tend to be senior citizens or shoppers with packages, both of whom can be expected to board more slowly.

STREET DELAY

The most obvious effects of LRT operation in a shared street environment were found in the street delay categories: traffic signals, left or right turns by motor vehicles, accidents, traffic congestion, locations where traffic must yield and merge, pedestrian crosswalks, parked automobiles, traffic officers, construction, and other miscellaneous traffic delays. Throughout the Toronto system, street delays accounted for 55 to 60 percent of all delays incurred. They were found to be highest during the midday off-peak period (Figure 3). This may be because traffic lights are more effectively synchronized during the peak periods to ease the traffic flow along arterial roads. The LRVs are thus able to take advantage of the extended green cycle.

The length of street delays varied among routes and among segments of each route. Several variables were analyzed to account for the significant range in delay. The variables were land use, volume of motor vehicle traffic, roadway width, and number of intersections.

Land use was divided into four types: residential, light commercial, heavy commercial or office district, and industrial. Correlation between these categories and street delay proved to be virtually nonexistent. Minutes of delay ranged from 11.0 for light commercial to 15.23 for residential. However, it must be noted that, since all streetcar lines in Toronto serve the nucleus of the city, the densities for each type of land use do not vary significantly in the area studied.

Traffic volume, roadway width, number of intersections, and traffic volume per roadway width were all tested for correlation with total street delay time. In each case, the correlation proved to be not significant. Among the variables examined, the number of intersections had the largest effect on street delay.

The overwhelming cause of street delay was traffic signals, which accounted for 86.9 percent of all street delays and remained approximately constant across all routes and times of day. The second largest cause of delay was traffic congestion, which made up 5.7 percent of street delay. All other causes of street delay were relatively insignificant.

An understanding of street delay can be gained from the route-delay profiles of the Toronto streetcar lines (Figures 4 to 8). Several patterns of delay can be distinguished. The Dundas line exhibited major traffic congestion along the Jarvis-Parliament segment, where there is a circular bend in the road. The King route had significant delays on the segment where the line turns from King Street onto Broadview Avenue.

IMPLICATIONS

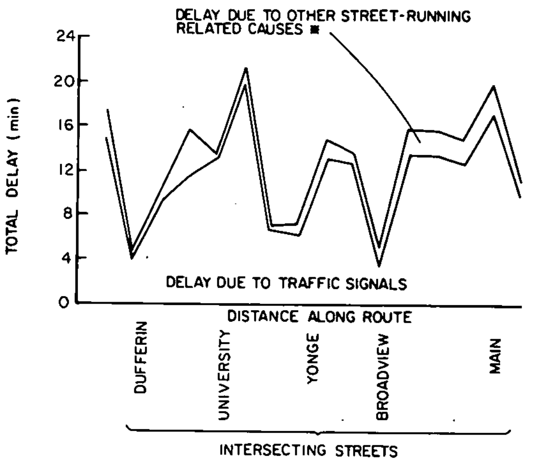
The analysis of the Toronto streetcar delay data reveals that delays caused by boarding passengers and by traffic signals together account for 90 percent of all delays incurred—boarding delays make up 40 percent of the total and traffic signals the remaining 50 percent. Efforts to reduce streetcar delay should therefore be directed to improving these two major elements.

Boarding delays could be reduced by providing platforms (preferably high-level platforms) that offer the passenger a refuge in the street center. The installation of low-level platforms along the St. Clair route has substantially reduced boarding delays and has not created any major traffic problems. Contrary to the fears of many planners, pedestrian access to the street-island platforms has not produced any significant problems.

Installation of traffic signal preemption capability for LRT street operation can drastically reduce delays. In the case of Toronto, it appears that total delays could be reduced 50 percent if LRVs were given 100 percent priority. An example of the large time savings possible is shown for the Carlton route in Figure 9 and for all routes in the table below (1 km = 0.6 mile).

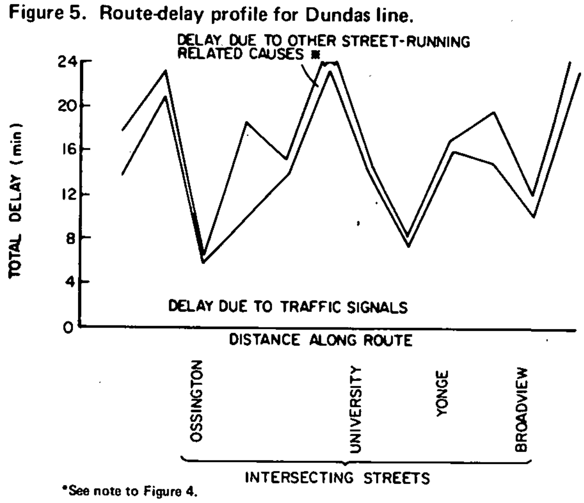
Route	Average Speed (km/h) Existing	Average Speed (km/h) With Preemption
Carlton	16.5	22.7
Dundas	14.9	22.2
King	16.8	22.7
Queen	18.1	21.3
St. Clair	15.2	22.4

Figure 4. Route-delay profile for Carlton line.



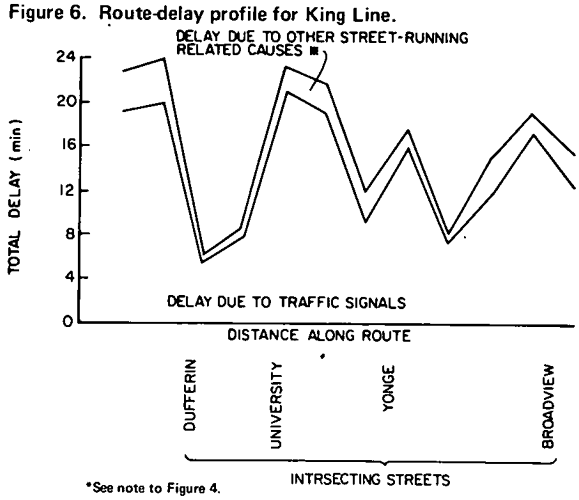
*Left or right turns by motor vehicles, accidents, traffic congestion, yield and merge, pedestrian crosswalks, parked automobiles, traffic officers, construction, and miscellaneous delays.

Figure 5. Route-delay profile for Dundas line.



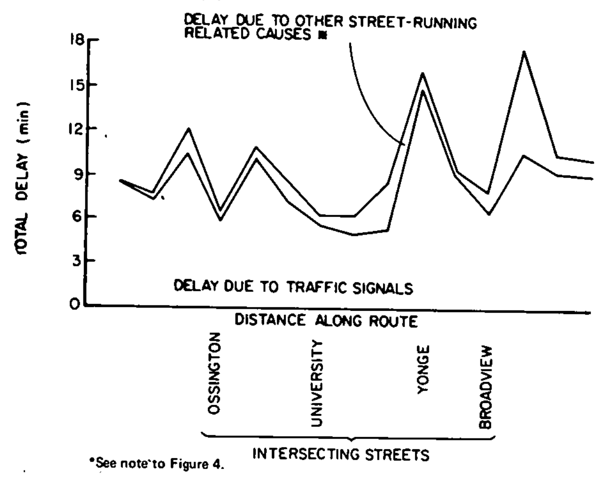
*See note to Figure 4.

Figure 6. Route-delay profile for King Line.



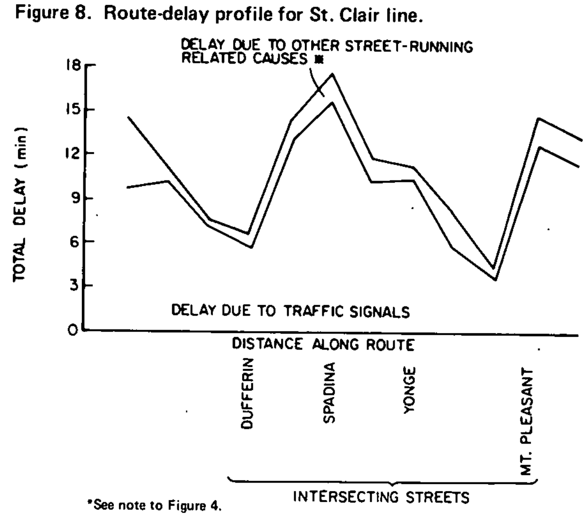
*See note to Figure 4.

Figure 7. Route-delay profile for Queen line.



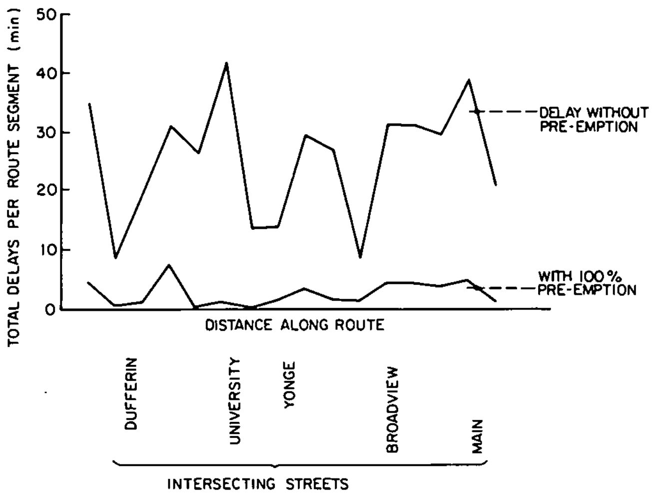
*See note to Figure 4.

Figure 8. Route-delay profile for St. Clair line.



*See note to Figure 4.

Figure 9. Effect of signal preemption on street delays along Carlton line.



The Dundas route would benefit the most; its average speeds could increase from 14.9 to 22.2 km/h (9.3 to 13.9 mph), a 50 percent improvement in average speed (4). The routes' average speed would rise from 16 to 22.4 km/h (10 to 14 mph), a 40 percent increase.

Surprisingly, streetcar delay due to traffic congestion was extremely low; it accounted for only 3.3 percent of the total delay. This finding seems to refute some of the criticisms leveled against street running of transit vehicles, i.e., that conflict between transit and motor vehicles is the major cause of delay. Of course, it must be noted that schedule speeds are based on the average speed that can be attained in mixed traffic.

Although improvements may be instituted to reduce the delays in the other categories mentioned, the data from Toronto's operations indicate that these variables are relatively unimportant in regard to transit travel time. In fact, the eight other categories of street delay account for a mere 4.2 percent of all delays incurred as is shown below.

Type of Street Delay	Percentage of Total Delay	Type of Street Delay	Percentage of Total Delay
Traffic signals	49.97	Pedestrian crosswalk	0.67
Left or right turns	0.98	Parked automobiles	0.10
Accidents	0.32	Traffic officer	0.12
Traffic congestion	3.30	Construction	0.76
Yield and merge	0.84	Miscellaneous	0.43

Thus far, Toronto has instituted several measures, such as banning left turns by motor vehicles, to alleviate delay at specific intersections. The TTC is currently exploring the use of signal preemption.

CONCLUSIONS

As the experience of the TTC has shown, LRT operation in streets can provide a workable solution for some urban transport problems. The advantages of street operation are greatly reduced capital costs in construction, faster construction time, and less environmental disturbance. Since urban real estate costs are climbing, LRT street operation is a relatively low-cost solution to providing a widespread, line-haul transit system capable of transporting large volumes of passengers. The subway-surface LRT lines in West Philadelphia and San Francisco are also excellent examples of the street operation of widespread collectors for LRT systems.

These exceptions notwithstanding, street operations have been deemed largely impractical for LRT systems in North America. However, there are many dimensions to the problem, and trade-offs are possible. While the past 50 years has seen a diminishing of streetcar priority in street traffic, there is no reason that priorities cannot be changed in the interest of moving people, rather than motor vehicles, more efficiently.

The data from Toronto indicate that improvements in two areas, boarding and signal preemption, can significantly reduce running times. Boarding delays can be lessened by the installation of platforms, as was shown by the St. Clair route. Island platforms have been used successfully, both in Toronto and in Philadelphia. The plans for a new LRT line in Calgary include high-level island platforms that are accessible from the street and from overhead walkways.

The other area in which significant gains in transit speed can be made is in traffic signal preemption. The technology of traffic signal control systems is becoming less and less expensive as sophisticated low-cost microprocessors are becoming more readily available. Several cities in Europe have installed modified forms of signal preemption. The LRT systems in Berne and Glasgow use traffic signal synchronization that is based on transit speeds rather than motor vehicle speeds. Berne has included a provision for longer green cycles for LRVs that is actuated by overhead contacts. The city of Melbourne has also instituted a signal priority system that can be actuated by overhead wire contacts, loop detectors, or push buttons on the transit vehicle. The institution of such transit priority measures in Europe and Melbourne has resulted in patronage gains.

However, systemwide signal preemption is still relatively untried in the United States. Many opportunities for the implementation of such control systems exist throughout the United States. Recent decisions to rehabilitate LRT lines with street trackage (as in Pittsburgh) may provide an ideal opportunity to test the effectiveness of transit priority measures.

It appears that signal preemption strategies, if they are successfully implemented, can produce significant increases in running speed—almost enough to make street running comparable to running in private right-of-way in which the stops are closely spaced. Moderate traffic density and traffic signal controls may make street operation an optimal strategy for LRT systems.

Various other traffic control measures can be promoted, such as legally restricting parking at transit stops. However, as the Toronto data show, these measures will have little effect on reducing the overall delay. In addition, observance of this type of regulation in Europe has been poor (1).

The results from Toronto indicate a strong potential for street operation of LRT. Significant reductions in delay time can be achieved by means of improvements that will yield benefits in the form of improved service levels and better utilization of the two most costly transit resources: labor and car fleet.

ACKNOWLEDGMENTS

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