Improving Light Rail Transit Performance in Street Operations: Toronto Case Study

R. M. Topp
Planning Branch, Toronto Transit Commission
Toronto, Ontario, Canada

The Municipality of Metropolitan Toronto consists of six local municipalities. It covers an area of some 244 mi^2 and, with a population of nearly 2.5 million people, is the ninth largest city in North America.

As shown in Figure 1, the Toronto Transit Commission (TTC) operates 35 mi of full subway integrated within an extensive surface system and in March of this year opened a 4-mi, elevated rapid transit line. Last year the system carried about 428 million revenue passengers, more than any other transit property in North America with the exception of the New York Transit Authority. However, with a 1984 per capita ridership of about 200, it was second to none in that category.

During the morning rush-hour period a total of 1,630 surface vehicles are scheduled for operation. Of that total 231, or 14 percent, are streetcars. The remainder of the surface fleet is comprised of diesel buses and electric trolley coaches.

Streetcars go back a long way in Toronto's history. The first electrically powered revenue vehicles were introduced in 1912. The current streetcar system is shown on Figure 2 and the nine routes indicated represent approximately 7 percent of the 134 surface routes in the existing system.

In metropolitan Toronto the streetcar network has an east-west downtown orientation, mainly for historic and cost reasons. Some 119 of the 129 total streetcar route miles are centrally located within the city of Toronto, with all but two of the 9 routes intersecting the Yonge-University-Spadina subway in or near the central business district. These routes play a major two-way role in distributing subway patrons among local downtown destinations, as well as feeding the Yonge-University-Spadina subway for the reverse movement.

With one exception at the west end of the Queen route where streetcars run in an exclusive at-grade right-of-way for approximately 1.7 mi, all these operations are conventional in nature in the sense that the streetcars run in mixed traffic generally on streets with four-lane cross sections. Some 90 percent of the streetcar stops function without

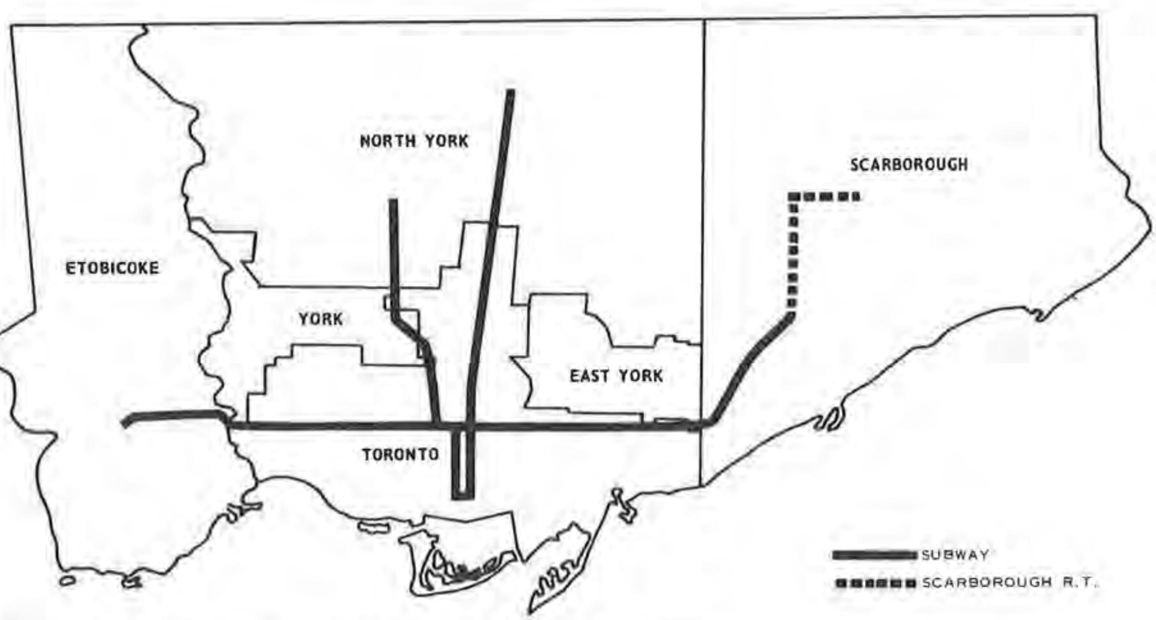

FIGURE 1 TTC subway and rapid transit alignments in metropolitan Toronto.

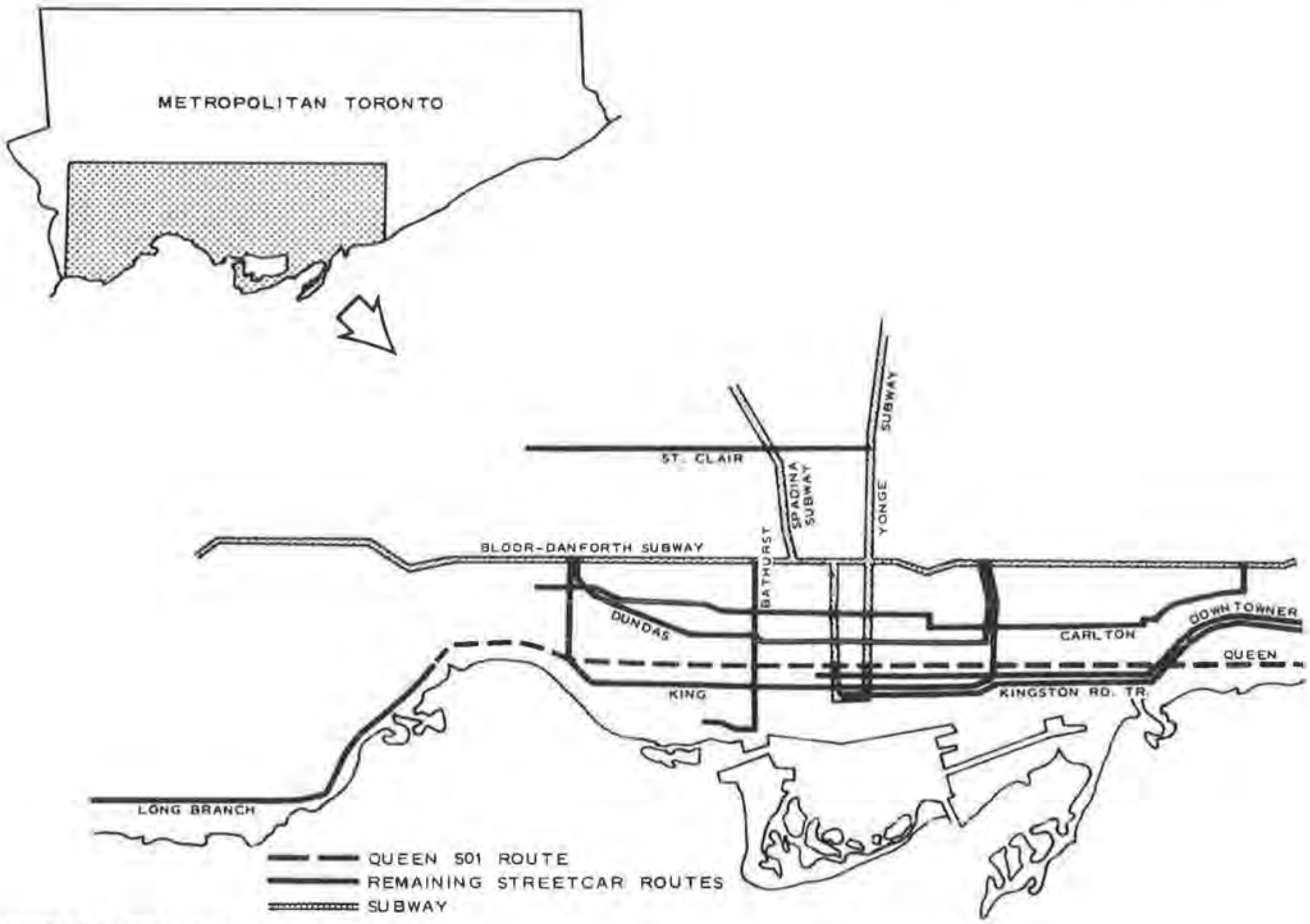

FIGURE 2 TTC existing streetcar network.

passenger safety islands, and in these cases following automobile traffic is required by legislation to stop behind streetcar doors when patrons are boarding or alighting at designated stop locations. One particular route, St. Clair, is atypical because of the unusually wide street (six lanes in some locations) and the preponderance of safety islands at stop locations, which allow following automobiles to pass by stopped streetcars in a free-flow manner.

Two types of vehicles are presently in use: the older Presidents' Conference Committee (PCC) car and the newer Canadian Light Rail Vehicle (CLRV).

EVALUATION OF QUEEN STREETCAR OPERATIONS

Background

All public transit operating in mixed traffic on surface routes is subject to delay and schedule irregularity due to interference from other traffic and pedestrians. The causes of such delay are usually obvious and include above-average stop dwell time for surge passenger loading, general traffic congestion at intersections, left-turning automobiles blocking the path of the transit vehicle, accidents, and such obstructions as road maintenance or illegally parked vehicles.

When en route delays are sufficient to cause excessive gaps in frequency of service, passenger waiting times at stops increase and vehicle overcrowding often becomes a problem. For streetcar operation, where vehicle movement is restricted by the location of the track, there are fewer means available to compensate for unanticipated service irregularities than there are for conventional buses; a following bus can overtake a delayed bus and make up lost time. For this reason, on long routes such as the Queen streetcar, intermediate turnaround facilities, called "short-turn" facilities, are used to gradually eliminate or minimize excessive gaps between successive vehicles.

Operational Problems

Recently, considerable public attention has been directed to the operational problems associated with the Queen streetcar line.

The Queen line, with a round-trip distance of almost 21 mi, is the longest and most heavily traveled route in the streetcar network. (A second streetcar route, the Downtowner, overlaps approximately 40 percent of the Queen route and is considered an integral part of the Queen line. Hence "the Queen line" is assumed by many to mean both services.)

With some 75,000 passengers carried daily, this combined line has the highest ridership in the entire TTC surface route system as well as the second largest complement of peak scheduled vehicles (57 at present). Consequently, reliable and effective route operation is extremely important.

Queen route streetcars are scheduled to operate directly from one end of the line to the other with scheduled headways of 2 min 33 sec and 2 min 40 sec in the morning and evening peak periods, respectively. On that portion of the line overlapped by the Downtowner, the combined headway decreases to 1 min 56 sec in both peak periods.

For many years, however, transit patrons using the Queen streetcar route have complained about irregular service and, in particular, unscheduled short-turning of streetcars, especially during the evening peak period. When the direction of a streetcar is reversed at a location away from the end of the line, passengers on the vehicle must alight and wait for a following streetcar. Although it goes without saying that this procedure is unpopular with affected passengers, it is employed to close gaps in service that, if left unchecked, would continually worsen.

Short-turns are generally initiated only at the judgment and instruction of a route inspector, whose decision is based on the need to restore regular and evenly spaced service over the entire route, in response to any number of possible emergency or delay situations. Short-turns require inconveniencing a few for the general benefit of riders as a whole but, not surprisingly, this "general benefit" is seldom the subject of consumer comments.

Until the completion of a recent study, the precise reasons for the deterioration of headway regularity on Queen Street were not fully understood. However, it was suspected that there was no single cause but instead an interaction of factors that compounded to the point where a significant gap was created on the line. The traditional strategy used to counter this problem has been short-turning streetcars to fill gaps.

Evaluation of Queen Streetcar Service

The TTC is looking into the Queen Street operational problems in considerable depth and has undertaken two special studies, both of which are intended to develop methods to improve the situation on Queen Street and are expected to allow greater insight into similar operational problems on other routes.

The first, a "Transit Priority Study," is a municipal interagency long-range project involving transit and traffic engineering officials. This detailed study is concerned strictly with those areas that are beyond the control of the TTC and involves the investigation of traffic signal optimization measures and, alternatively, transit-actuated signal priorities as ways of easing transit congestion on Queen Street.

The second study has been conducted by an independent consultant retained by TTC. In this study the emphasis is placed on investigating corrective transit operating strategies as opposed to traffic engineering measures. Because this consultant study has recently been completed, it is discussed first and a general overview of the major findings and recommendations is included.

EVALUATION OF QUEEN STREETCAR OPERATIONS--CONSULTANT'S STUDY

In August 1984 TTC retained the University of Toronto/York University Joint Program in Transportation to serve as consultant for this project. The role of the consultant in this project, as defined in the project terms of reference (1), was to provide a fresh and independent assessment of the overall operation of the Queen streetcar line. Through extensive data collection and a passenger attitudinal survey the consultant was expected to evaluate the existing quality of service on Queen Street and to diagnose the cause or causes of short-turning streetcars on Queen Street as well as comment on the appropriateness of the short-turning strategies currently being applied. Specific, as well as generalized, solutions to the short-turning problems were to be identified.

This project was initiated to provide TTC management with a clearer understanding of the reasons behind service irregularity problems and the need to short-turn streetcars. This independent opinion was intended to assist TTC in pursuing the most effective ways of minimizing unscheduled short-turning.

Principal Objectives of the Study

The first objective of the study was to measure the quality of streetcar service currently available on the Queen streetcar service and determine

- Major causes of the need for short-turns,
- Magnitude of inconvenience to passengers affected by short-turns, and
- Effectiveness of current procedures used to exercise short-turn options.

The second objective was to recommend changes or modifications to existing procedures that might be implemented over the short term and be likely to

- Reduce the degree of passenger inconvenience and dissatisfaction associated with short-turns and
- Improve the effectiveness of short-turn operations from the standpoint of TTC and its operating labor.

The third and final objective of the study was to address longer term options for reducing service irregularity on the Queen streetcar route.

It was emphasized that the final project report was to present a practical picture of the situation, formed around a comprehensive information base. The consultant was requested to provide a clear presentation of the operating conditions on Queen Street and to present a creative yet practical approach to remedying the short-turning problem.

The consultant completed most of the work on this study during the fall of 1984 and presented an interim staff report in January 1985 and the final report (2) to the Toronto Transit Commission in March 1985.

Study Approach

The consultant's task centered primarily around the evaluation of the trade-off between the inconvenience to passengers forced to leave a short-turning vehicle and the improvements in service regularity for downstream passengers. Also, with this trade-off in mind, changes were to be formulated that would improve the effectiveness of the short-turn procedures. This involved a process of observation, field measurement, diagnosis of primary problem sources, and assessment of the effectiveness of current procedures.

The project was approached with a four-phase work program:

Phase 1. Documentation of procedures and performance, diagnosis of primary problem sources:

- Review existing data and establish additional data requirements and
- Satisfy data requirements through passenger attitude survey, various operational field studies, and interviews with key operational personnel (TTC management, route inspectors, and operators);

Phase 2. Diagnosis of problem sources, assessment of current performance;

Phase 3. Formulation of alternate methods for improving performance and development of methods of analysis to evaluate the range of alternatives; and

Phase 4. Evaluation of the range of alternatives identified in Phase 3.

The project was based on a firm foundation of operating data reflecting current procedures and operating performance on the Queen line. Combined with this was a grass-roots understanding of the "subtleties" that affect service on Queen Street, gained from various interviews with TTC staff as well as the consultant's own field observations.

The study approach thus led to final conclusions and recommendations with respect to short-term changes to existing methods and procedures that will provide interim solutions until longer term, more extensive modifications can be implemented.

Major Study Findings

The consultant concluded that "on a long route, characterized by heavy passenger volumes and congested traffic conditions, short-turns represent the only effective means of compensating for large irregularities in streetcar service that result from factors beyond the control of the TTC," and that "overall service on Queen Street would clearly deteriorate significantly if short-turns were to be discontinued." Some specific results of the consultant's investigation are summarized in the following sections.

Current Short-Turn Characteristics

- During the period September 1983 to September 1984 there were approximately 2,000 reported short-turns per month but there was, surprisingly, no clear seasonal variation.
- There was a wide variation in the number of short-turns by day of the week with a daily average of 63, a weekday average of 71, and a maximum of 95 on the average Friday.
- On weekdays the number of short-turns is highly concentrated in the period between 3 p.m. and 6 p.m. with 50 to 60 percent of daily short-turns made during that time.
- Analysis of vehicle riding data shows an average of 7.1 persons per vehicle are required to leave a short-turning car and the criterion of a maximum of 15 persons is exceeded about 15 to 20 percent of the time.
- It is estimated that approximately 300 persons daily are unexpectedly off-loaded from short-turned cars in the evening peak period and about 2,700 persons wait slightly longer times at the end of the line.
- Approximately 5,000 persons share directly in substantial waiting time and vehicle load distribution benefits from short-turning in the evening peak period.

Service Delays

- Passenger service time is the largest component of delay (i.e., reduction in actual running time) and comprises approximately 12 to 18 percent of total travel time.
- Signal plus queue delays are also significant, comprising about 13 to 15 percent of total travel time.
- Time running free (total time less all delays) is remarkably consistent by location, direction, and time, as is signal plus queue delay.
- Variations by time and direction are primarily the result of inconsistencies in passenger service time.

Passenger Attitudes

A passenger attitude survey, conducted to gain some insight into the passengers' perceptions of the Queen streetcar service in general and the short-turning issue in particular, was conducted from September 10 to September 12, 1984. Sampling was based on passenger boarding counts by time period so as to be representative of the entire route ridership. A total of 654 interviews were conducted and therefore the overall survey results can be viewed as accurate within ±5 percent, or 19 times out of 20.

Some specific findings were

- Approximately 25 percent of those surveyed were dissatisfied with the Queen service; 15 percent of the respondents stated they were dissatisfied with TTC service in general.
- Twenty-eight percent of the passengers perceived their morning wait time to be greater than 5 min; 55 percent estimated their afternoon wait time at greater than 5 min.
- Of those passengers who estimated their wait time to be less than 5 min, approximately 17 percent were dissatisfied with the Queen streetcar service, and 34 percent of those with time estimates of more than 5 min expressed dissatisfaction.
- Approximately 80 percent indicated that they checked to see if the vehicle was signed for a short-turn and 90 percent stated it would be helpful if short-turn vehicles were signed.
- During the week before the survey (four-day week), 32 percent of the passengers experienced at least one short-turn, and approximately 30 percent of these passengers expressed dissatisfaction with the Queen service.
- Of passengers experiencing short-turning, 28 percent estimated their wait time for the next car at less than 2 min, and 30 percent estimated their wait at more than 5 min.

Development and Evaluation of Alternatives

A number of alternative improvements were developed that would increase the effectiveness with which short-turns can be accomplished while reducing the degree of inconvenience to passengers required to alight and wait or wait initially for a following vehicle. These improvements were in the areas of route structure, scheduling of short-turns, use of articulated light rail vehicles (ALRVs), benefits derived from the Communications and Information System (CIS), and alternate forms of transit priorities.

A word about CIS is in order here. Since 1972 TTC has been developing and testing its Communications and Information System, a centralized communications, monitoring, and control system for surface transit vehicles. CIS can automatically and continuously advise of all schedule deviations over an entire route. Also, it enables the controller supervising the route to observe conditions over the whole route and make service adjustments accordingly. Hence, CIS permits a rapid and coordinated reaction to small disruptions in service. These reactions can keep small disruptions from growing into large gaps that require major corrective actions such as short-turning. In addition, CIS can be used to assist in optimizing the time at which a short-turned vehicle reenters the traffic stream.

A detailed discussion of the relative merits of each alternative is beyond the scope of this paper, but they involved a trade-off among three key factors:

1. The number of persons off-loaded due to unscheduled short-turns,
2. The level of service provided to other passengers, and
3. Operating costs.

There were additional considerations that influenced the evaluation of alternatives. For example, those schemes that fall entirely within TTC's jurisdiction are more easily implemented than are alternatives that require assessment and approval from external agencies.

Major Findings and Conclusions

The study's major findings and conclusions include

1. The short-turning procedure practiced by TTC is an integral component in controlling present streetcar service on Queen Street. When service irregularities have reached a certain point, short-turning is the only reasonable means of restoring service promptly. These procedures are generally well executed by supervisory staff.
2. The sources of irregularities in service that necessitate short-turns vary widely and usually arise from random occurrences that are beyond TTC's control. The largest and most variable source of delays is time required to load and unload passengers at stops.
3. Overall, passenger service levels on the Queen line are good and most passengers are satisfied with the service. A significant proportion (25 percent) has expressed dissatisfaction, and the principal cause for concern is the waiting time in the evening peak period.
4. Improvements that are intended to reduce the frequency of short-turns, improve the effectiveness of procedures, and improve the information that passengers receive can be made in the short term.
5. Benefits could be derived by the longer term strategies of deployment of articulated light rail vehicles, implementation of CIS on the Queen route, and continuation of the pursuit of transit priorities on Queen Street, which is currently the subject of a second major study.

Major Recommendations

The consultant's principal findings led to seven key recommendations:

1. During the evening peak period, the scheduled round-trip time over the entire route should be increased from 120 to 125 min.
2. The minimum gap size required to initiate a short-turn decision should be increased from the present value of twice the scheduled headway to three times the scheduled headway.
3. Short-turn signs should be modified to provide consistency throughout the vehicles and among different types of vehicles in service. Signs should indicate where passengers will be requested to leave the car as opposed to where the car will be turned.
4. Modifications should be made to the existing route structure so that approximately one-third of the vehicles operate only between the Sunnyside and the Woodbine loops during the evening peak period.
5. ALRVs should, when available, be used on the Queen route.
6. CIS should be expanded to encompass all operations on Queen Street.
7. Opportunities for achieving higher priority for streetcars, particularly in the downtown area, through turn prohibitions and preemptive signals, should be pursued aggressively by TTC.

The first recommendation was implemented in late March of this year. The change will be assessed for impact before any more scheduling or route structuring changes are made such as the scheduled short-turn service proposed under Recommendation 4.

The second recommendation, which concerns short-turn criteria, is being adopted in a more general manner. However, route inspectors will still be expected to make individual judgments on the basis of the conditions in specific instances.

The commission's staff has been studying vehicle signing for some time. These studies will continue to be actively pursued in accordance with the consultant's third recommendation.

Recommendations 5 and 6 are long-range matters. The Toronto Transit Commission has already placed an order for 52 ALRVs for delivery in 1986 and 1987. These vehicles are planned for use on the Queen route. One vehicle is on the property for the purpose of checking physical limitations such as loop turning radii, lengths of existing safety islands, and subway station surface platforms.

The deployment of CLRVs and the possible future use of ALRVs will certainly be fully considered in the future as will possible expansion of CIS to cover the Queen route.

Recommendation 7, that the TTC pursue preemption for transit vehicles at traffic signals, has already been made the subject of extensive investigation as explained in an earlier section and as detailed in the next section.

STUDY OF TRANSIT-ACTUATED SIGNAL PRIORITY MEASURES

One key recommendation of the consultant's study was to aggressively pursue transit preemption at traffic signals. A study of preemption had already been initiated by TTC and, although still ongoing, is described.

In response to mounting public complaints about the Queen Street streetcar service, a study was launched early in 1984, before the Queen Streetcar Operations Study, involving staff from the Toronto Transit Commission, the Metropolitan Toronto Department of Roads and Traffic, and the Ontario Ministry of Transportation and Communications. A two-level steering and working committee structure was adopted with appropriate management and technical staff sitting on the respective committees.

This project was first conceived in May 1983, and the terms of reference were approved by the participating agencies in January 1984. The stated objectives of the project were to improve the efficiency and the quality of transit service afforded transit patrons and to improve the total person-movement function of the arterial street as a whole. It was agreed that the improvements in transit performance would be assessed relative to the overall passenger flow in the study corridor for all modes of transport. A pair of test routes was selected in order to study the introduction of traffic signal priority measures, namely an arterial bus route and a central area streetcar route. In view of the practical needs that TTC was facing on Queen Street, that route was the obvious choice for the latter category.

The project has been divided into three distinct phases:

Phase 1. Route selection, base data collection, preliminary analysis, and preemption technology review;

Phase 2. Optimized signal timings and follow-up analysis (if warranted); and

Phase 3. Transit preemption technology and follow-up analysis.

These three separate study phases have been selected in order to show the incremental improvements gained over the base-case situation by applying the two levels of transit priority indicated in Phases 2 and 3. Phase 2 represents the classical transportation systems management (TSM) approach whereby straightforward and low-cost fine tuning is applied to maximize the efficiency of the existing system. Phase 3 involves a more sophisticated transit-based signal preemption system that requires capital expenditure.

The specific steps in the study design are

Phase 1

Step A--Conduct a comprehensive state-of-the-art technology review of transit-based signal preemption systems throughout the world.

Step B--Select two test routes, one arterial bus route and one central streetcar route.

Step C--Collect pertinent data to determine the signal stopped time for both transit and private vehicles.

Step D--Evaluate preliminary benefit-cost relative to Phase 3, based on anticipated potential travel time savings versus probable costs for different available preemption systems

Phase 2

Step E--Optimize signal timings, on the basis of the data collected in Step C.

Step F--Collect follow-up data measuring the effects of the new signal coordination and timing patterns.

Step G--Evaluate Phase 2 and decide whether to pursue a transit-based signal preemption system in Phase 3.

Phase 3 (if warranted)

Step H--Implement a transit-based preemption system on a significant stretch of the study routes to reduce traffic signal delay to transit vehicles to the fullest extent possible (beyond improvements achieved in Step E).

Step I--Collect follow-up data to measure the incremental improvements achieved over signal optimization.

The before-and-after data collection exercise, for comparison of Phase 1 and Phase 2 and of Phase 2 and Phase 3, is a substantial component of this project. The effects of the modified signal operations are being measured by automobile and transit speed and delay surveys on a corridor basis for each phase of the project. Queue length and vehicular delay studies are also required on the cross streets that are affected by any signal timing changes or priority or preemption measures.

To date, the study on Queen Street has progressed to Step E under Phase 2. Step F, follow-up studies, is planned for the spring of 1985 in order to determine the extent of improvements to streetcar operations that are directly attributable to improved signal timings. The majority of traffic signal changes that were implemented under Phase 2 took the form of flashing advanced green phases as well as revised signal off-sets to improve progression on Queen Street for the overall movement of traffic.

SUMMARY

An extensive study of Queen streetcar operations was recently conducted to address the operational problems being experienced on the line and, specifically, to determine whether the inconvenience caused to passengers by the resulting short-turning procedures could be reduced.

The key short-term recommendations resulting from this study are to increase the scheduled round-trip time from 120 to 125 min, implement scheduled short-turns on the route, and increase the minimum gap size required to initiate a short-turn decision from twice the scheduled headway to three times the scheduled headway.

Although it will take time to implement and test these modifications, it is doubtful whether any improvements that may result will be "revolutionary" enough to significantly alter the public's perception of the operational problems inherent in mixed-traffic operation.

If this does prove to be the case, it will merely confirm the suspicion that, where sound planning principles are already being adhered to, significant service improvements can only be achieved by expediting the implementation of state-of-the-art technology, such as CIS and transit preemption at traffic signals. The extension of CIS control throughout TTC is an ongoing development project. TTC has already initiated, and is currently conducting, an extensive study of the application of transit-actuated signal priority measures.

DIRECTION FOR THE FUTURE

There are definite frustrations that arise when the public becomes increasingly aware of significant operational problems such as those on Queen Street, but investigation confirms that the cause of the problem and its solution are generally beyond the control of the transit agency involved. One positive result of such a problem is that the municipalities and politicians are also becoming increasingly aware that operating streetcars in mixed traffic in the downtown area of a large city is in a sense "asking for trouble."

Harborfront LRT

Recently, an LRT line operating in an exclusive right-of-way was proposed as the most efficient way of serving extensive development planned for Toronto's waterfront. This proposal is for LRT operation in the center median of the roadway with a high priority at traffic signals. Left-turning automobiles would not be permitted to share the right-of-way but would make their turn from the right side of the LRT line on a special signal phase. Even though such a facility would further reduce the capacity of a road system, which would experience significant congestion even if the LRT could be removed from the roadway entirely, the proposal has received strong support.

The LRT line, shown in Figure 3, would have a subgrade connection to Union Station, the primary subway and interregional rail terminal facility in downtown metropolitan Toronto. Although the line

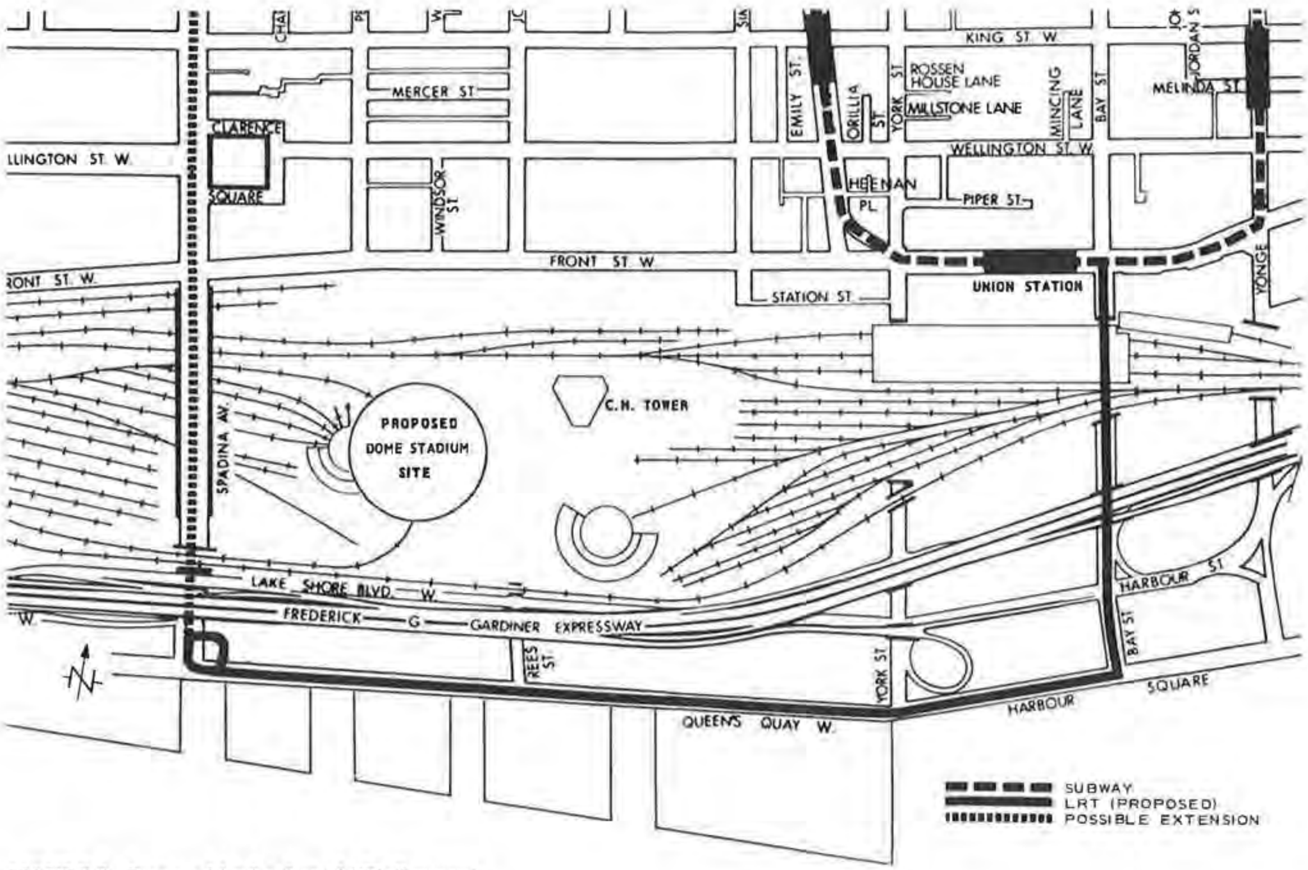

FIGURE 3 Proposed harborfront LRT alignment.

would initially operate only as far as Spadina Avenue, the long-term plan includes a future extension north along Spadina to connect with the Bloor-Danforth subway line.

Scarborough Rapid Transit Line

As mentioned previously, in March of this year the Toronto Transit Commission opened a 4-mi elevated rapid transit line from the eastern terminus of the subway system to the Scarborough City Centre (one of the six municipalities within metropolitan Toronto).

It is interesting to note that, when construction of the first station began in 1980, it was intended as an at-grade LRT line with overhead power collection and low-level loading. In mid-1981 the decision was made to implement the new intermediate capacity transit system technology that required complete grade separation.

The system uses 40-ft cars that are computer controlled with an optional manual feature and, of course, is completely free from the operational problems inherent in mixed-traffic operation.

REFERENCES

1. An Evaluation of Queen Street Transit Operations--Terms of Reference. Operational Planning Department, Toronto Transit Commission, Toronto, Ontario, Canada, 1984.
2. University of Toronto/York University Joint Program in Transportation. Queen Streetcar Operations Study. Final Report. Toronto Transit Commission, Toronto, Ontario, Canada, March 1985.