Toronto's Harbourfront Line

Light Rail Transit in Reserved Right-of-Way as a Local Transit Alternative

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Recent light rail transit (LRT) developments in North America are demonstrating the success of LRT as a high-capacity transit mode linking the suburbs with the downtown. This paper examines a somewhat different application of LRT technology planned for the City of Toronto: that of an upgraded local transit service operating within the downtown area, but generally unaffected by downtown traffic conditions. An LRT line operating in a dedicated right-of-way was recently approved for construction in the center of a roadway along the waterfront of Toronto's downtown in conjunction with major development proposals. The portion of the line connecting to the subway would be constructed subgrade. This will be the first new streetcar line built in Toronto in more than 60 years. The decision is expected to promote a high modal split to transit by ensuring that the new workers and residents being drawn to this area are provided an attractive alternative to the automobile before they have developed automobile-oriented travel habits. This paper provides a description of the facility and discusses the rationale behind many of the decisions that were made by the transportation professionals involved in its design, including the requirement for a dedicated right-of-way, the choice of fixed rail technology, and the traffic engineering problems associated with proper integration of the LRT and automobile traffic at existing and proposed signalized intersections.

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TORONTO IS A WATERFRONT city and, like many such cities around the world, it grew from the shipping harbors on its shoreline. However, with the advent of commercial railways in the 19th century, reliance upon the waterfront diminished and the city's focus shifted further inland. The waterfront subsequently evolved into what was largely an industrial wasteland, cluttered with abandoned factories and shipping warehouses.

An ambitious plan for waterfront renewal is now under way and is bringing people back to the area. The plan is to create a neighborhood with a diverse mix of residents and workers, and an unusually high proportion of parks and public activities that would become an extension of downtown Toronto.

The Harbourfront light rail transit (LRT) line, which recently began construction, was proposed to assist in providing the public accessibility so crucial to the creation of a world-class waterfront, and to help prevent such a significant development from creating traffic chaos. The line will operate on a dedicated right-of-way and therefore be largely removed from the effects of traffic congestion. (In Toronto "LRT" is synonymous with exclusive right-of-way operation.) It will serve as a feeder route, connecting the waterfront developments to the downtown subway system.

HARBOURFRONT LRT DESCRIPTION

Construction on the 2.13-km Harbourfront LRT line began late in 1987. It will be below ground for 0.67 km from a turnback loop at Union Subway Station, thence south under Bay Street, a major downtown arterial roadway, to Queen's Quay, the collector roadway serving the existing and future developments along the waterfront (see Figure 1). The line will come to grade at a portal on Queen's Quay immediately west of Bay Street on a ramp 65 m long with a 7.5 percent rise. It will continue west along Queen's Quay in a dedicated right-of-way to a turnback loop at Spadina Avenue. The at-grade portion of the right-of-way will be on a center median that is raised approximately 125 mm (5 in.) above adjacent traffic lanes (except at intersecting roadways). The right-of-way will have a minimum width of 6.72 m along the midblock sections and 7.76 m at platform locations.

The facility will include a subgrade station at Union Station and another on Bay Street immediately north of Queen's Quay. Platforms will be provided in each direction along Queen's Quay at York Street, Simcoe Street (a proposed roadway), and Rees Street, and at the turnback loop at Spadina Avenue. All platforms on the at-grade section will be a minimum of 30 m long and 1.50 m wide to accommodate a train of two nonarticulated cars. The side platforms at the below-grade Bay/Queen's Quay Station will be 36 m long and 2.50 m wide with connections to adjacent developments. The station design will allow pedestrian crossings at the subgrade track level via a controlled

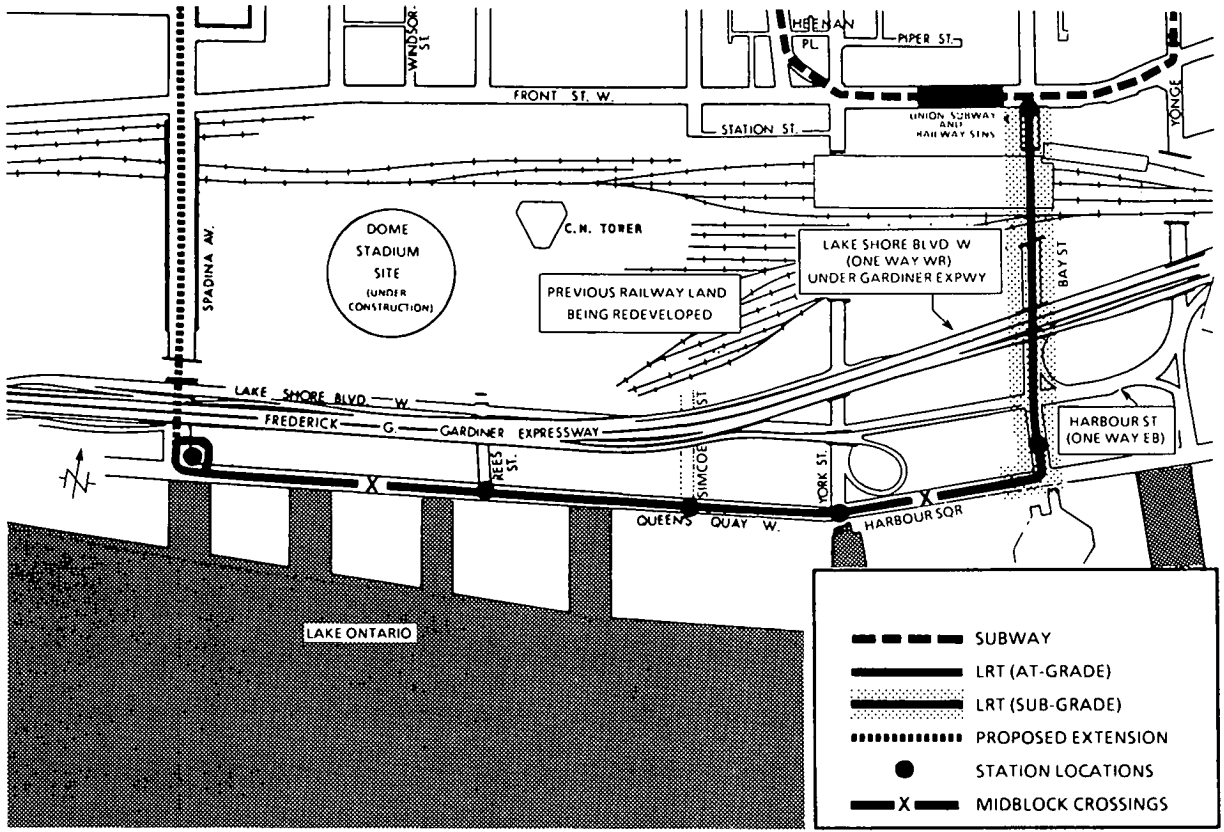

FIGURE 1 Harbourfront LRT alignment.

crosswalk to eliminate the need for patrons to cross at street level. This form of crossing is believed to be a first for North America.

The platform at Union Station loop will be 45 m long in order to accommodate two articulated cars simultaneously. It will be connected to the existing subway mezzanine level at Union Station by an underground passage equipped with a set of stairs and an escalator.

Initially, single vehicle operation has been proposed with President's Conference Committee (PCC) cars or Canadian light rail vehicles (CLRVs) from the existing fleet, with future upgrading to articulated light rail vehicles (ALRVs). Ultimate demand levels may be accommodated by operating ALRVs at 2-min headways with an average operating speed in the order of 12 mph. Traction power of 600 volts dc will be provided through two substations, with side-pole support for overhead wires.

The total project cost is estimated to be $51 million (U.S. $38 million) in escalated dollars (not including rolling stock). The line is scheduled to open late in 1989.

DEDICATED RIGHT-OF-WAY

Planners recognized early in the study process that if major developments close to the downtown area were to be given the go-ahead, a transit service would have to be provided that would afford new workers and residents an attractive alternative to the automobile. When future traffic conditions were considered in light of projected transit demands, it became obvious that an efficient transit service connecting the waterfront to the downtown could only be provided if it operated in its own right-of-way and was therefore generally free from interference from other traffic.

Current and Future Traffic Volumes

The Harbourfront LRT will operate under Bay Street south from Union Station to Queen's Quay and then west on Queen's Quay to a turnback loop at Spadina Avenue. This section of Bay Street is currently a major downtown arterial roadway and its intersections with Lake Shore Boulevard (one way westbound) and Harbour Street (one way eastbound) are major access points to and from the Gardiner Expressway. Current volumes in the p.m. peak hour are shown in Table 1. Even with an efficient transit service in the area, it is anticipated that once the future developments in the waterfront are completed, certain of the movements shown in Table 1 may exceed the available capacity of the intersection.

Weekday traffic congestion on Queen's Quay is also a price that will be paid for new developments in the area, not only because of the sheer

TABLE 1 TRAFFIC VOLUMES IN THE P.M. PEAK HOUR

Intersection	Approach Volumes (vehicles/hr)		
	Through	Lefts	Rights
Bay and Lake Shore			
Northbound	571	154	0
Southbound	319	0	427
Westbound	2,045	176	80
Bay and Harbour			
Northbound	260	0	17
Southbound	348	173	0
Eastbound			
Harbour Street	720	832	0
Adjacent ramp from Gardiner Exp.	258	0	35

increases in traffic volumes, but also because of the variety of movements to and from developments adjacent to the roadway. Queen's Quay west of Bay Street does not have weekday traffic problems now, as it has very limited office and commercial development. It is, however, subject to severe traffic congestion on weekends and holidays from the late spring to the early fall due to the recreational and tourist attractions aleady in place.

During such weekend periods of congestion the existing local bus service often inches along with the rest of the traffic, and there are few incentives to encourage motorists to switch to a transit service with such conditions.

Future Demand

When all of the planned development is completed (much of which is already under construction), there will be an additional 138 500 m^2 (about 1.5 million ft^2) of office floor space in the vicinity of this section of Bay Street and adjacent to Queen's Quay.

The demand for the LRT service is not limited to development on the waterfront. The major railway yard facilities located west of Bay Street and north of the Gardiner Expressway are also a site planned for extensive redevelopment (see Figure 1). The catalyst for this development is the SkyDome, metropolitan Toronto's new domed stadium, under construction and scheduled to open in 1989. Approximately 127 600 m^2 (about 1.37 million ft^2) of floor space is planned within a convenient walking distance of this section of Queen's Quay.

When these developments are completed, the new transit service will be required to carry an estimated 3,800 passengers south from Union Station on an average weekday morning rush hour. There are only two surface routes in

the Toronto Transit Commission (TTC) system that have a peak-point, peak-hour demand near this level, but they are both bus routes operating on major suburban arterial roadways in the northern metropolitan area and have multiple branches, including express services. The practical capacity of a regular bus service in mixed traffic conditions in this area is generally considered to be little more than 3,000 passengers per hour, a scheduled headway of approximately 1 min.

ALTERNATIVES FOR DEDICATED ROW OPERATION

Once the need for a dedicated right-of-way (ROW) had been recognized, three principal alternatives were considered in addition to LRT in a permanently designated median ROW:

- Diesel buses in reserved curb lanes;
- Diesel buses in a dedicated median lane; and
- LRT in a median lane with a legislated ROW in peak periods only.

A brief outline of the reasons for rejecting these alternatives follows.

Buses in Reserved Curb Lanes

Due to the numerous driveways and accesses to adjacent developments along Queen's Quay, right-turning automobiles would need to share the curb lanes even if these lanes were to be reserved for buses. The large number of right-turning automobiles expected at various points along Queen's Quay, combined with interference to right turns from heavy pedestrian volumes on adjacent sidewalks, means that this alternative could be expected to offer little or no improvement over mixed traffic conditions.

Bus Lanes in the Roadway Median

Operation on a reserved ROW in the middle of these roadways would offer a higher level of priority than curb lanes; however, diesel bus operation would require a wider right-of-way than fixed rail (about 7 m as opposed to 6.72 m). Buses are not as comfortable as light rail vehicles, are environmentally inferior because of noise and fumes, and their lower carrying capacity per vehicle results in a higher operating cost. Furthermore, if any portion of a bus line were to be constructed subgrade, special requirements for ventilation would be required.

LRT with Exclusive Peak-Period ROW

Government staff of the City of Toronto, which has jurisdiction over Queen's Quay, initially favored legislating an LRT right-of-way providing

the required exclusivity in peak periods only by lane markings or overhead signs. The TTC strongly opposed this, based largely on a judgment call that legislation that could be weakened, modified, or even eliminated by a future city council vote was not a sufficient guarantee of exclusivity. Such a guarantee was considered essential because the very large capital investment would be of questionable value if any portion of the line eventually operated in mixed traffic conditions.

Given the level of traffic congestion in Toronto's downtown as well as the significantly greater cost of LRVs versus buses, it is the TTC's position that it would not be economical to build another streetcar line in mixed traffic conditions.

SUBGRADE ALIGNMENT ON BAY STREET

The decision to grade-separate a portion of the Harbourfront LRT line arose from the realization that, in addition to full right-of-way protection, the projected high level of demand would require fully integrated, fare-paid transfer facilities at Union Station, which is the principal subway and inter-regional rail terminal in downtown Toronto. After examining a number of design alternatives, it was recognized that the most feasible method of achieving these two requirements would be by grade-separation. The initial design was prepared with a short subgrade alignment from Union Station south to immediately north of Lake Shore Boulevard.

However, the Metropolitan Toronto Department of Roads and Traffic understandably expressed concern that the operation of LRT on a dedicated ROW would reduce the capacity of the heavily used intersections on Bay Street, particularly at Lake Shore Boulevard and at Harbour Street. For example it was estimated that with the anticipated traffic growth in the area, the LRT on the surface would have the effect shown in Table 2 on delay to the average motorist traveling through the intersections in the peak hour.

In addition, from 1980 to 1985 the intersections of Bay Street with Lake Shore Boulevard and Harbour Street consistently appeared in the listing of the top 20 accident locations in metropolitan Toronto. In fact in 1982 they were actually the first and second worst accident locations in the metropolitan area. The reasons for this accident history are high traffic volumes (and consequent congestion), visiting motorists' unfamiliarity with the area, and reduced visibility (at Lake Shore Boulevard) due to the support structure for the Gardiner Expressway overhead. It was therefore concluded that the

TABLE 2 AVERAGE DELAY PER VEHICLE IN THE P.M. PEAK HOUR

Intersection	Existing Traffic	Future Traffic	
		LRT At Grade	LRT Subgrade
Bay-Lake Shore	110	160	125
Percent increase		+45	+14
Bay-Harbour	165	340	170
Percent increase		+105	+3
Bay-Queen's Quay	25	75	70
Percent increase		+200	+180

introduction of an exclusive-median LRT system passing through these intersections at-grade would further aggravate a situation that was already a cause for serious concern.

With these factors in mind, the design was modified to extend the subgrade section from immediately north of Lake Shore Boulevard to just south of Harbour Street and thus avoid interference with the operation of these intersections.

Further extending the grade separation onto Queen's Quay had a number of advantages. With the previous design and the LRT tunnel portal located on Bay Street, the station at the Bay-Queen's Quay intersection was proposed to be located at grade on Queen's Quay, immediately west of Bay Street. Boarding and alighting patrons would use island passenger platforms adjacent to the LRT right-of-way, which they would access using the intersection crosswalk on the appropriate signal phase (as is illustrated later in Figure 3). This stop location was expected to be the line's second busiest (next to Union Station). It would, however, be located south of major developments on either side of the lower end of Bay Street, result in an unacceptable stop spacing to Union Station, and lead to capacity problems in the long term without provision of an intermediate station. Because of this last reason, a station would also have to have been built under Bay Street immediately north of Harbour Street.

If the subgrade portion were extended beyond the Bay-Queen's Quay intersection, these two stations could be consolidated into one subgrade facility under Bay Street, north of Queen's Quay, at a location more central to the adjacent developments. The majority of transit patrons would thus have a quicker travel time with elimination of one stop and the requirement to travel at grade through the busy Bay-Queen's Quay intersection. The absence of the LRT would also permit greater flexibility to deal with future traffic volumes traveling through this intersection. In addition, the large volume of patrons destined for the Bay-Queen's Quay area would be served much more conveniently with a subgrade, weather-protected station as opposed to at-grade island platforms.

Higher cost was the only major disadvantage to the proposal to extend the subgrade portion of the line beyond the Bay-Queen's Quay intersection. To assist in this decision, the contract documents specified that interested construction firms prepare bids for both options. The final decision to further extend the tunnel section of the line was made only after studying these comparative bids.

INTEGRATION OF LRT INTO THE QUEEN'S QUAY TRAFFIC SYSTEM

As indicated previously, the LRT will be operated on a raised center median, 125 mm (5 in.) above the adjacent traffic lanes. This will keep automobiles from infringing on the right-of-way but, with rounded edges provided along the median, will not represent a barrier in the event of an emergency. The initial proposal was for LRT operation in the center of Queen's Quay on the road surface, but with tracks bordered by 6-in. curbs to guarantee an exclusive right-of-way. This design was rejected because the raised median allows easier crossing by emergency vehicles, and because the raised-curb concept would allow garbage and debris to collect and make snow removal and drainage more difficult.

As shown in Figure 2, the total right-of-way of Queen's Quay required at midblock locations is 27 m, which will provide for a 6.72-m LRT right-of-way, two traffic lanes in each direction, and 3-m sidewalks on each side of the street. At intersections this right-of-way varies, but typically widens to approximately 31 m to accommodate a left turn lane and a 1.5-m wide platform.

The LRT median will come to grade at the six intersecting roadway/driveways that are shown in Figure 1. The TTC required that all crossings be signalized to allow consideration of greater priority for the LRT and enhance the safety of the operation.

Passenger platforms at York, Simcoe, and Rees streets will be constructed on the far side of the intersection for two conventional reasons:

- To make the most efficient use of the road right-of-way. Left turn lanes are provided on Queen's Quay in at least one direction at each of the three intersections, and the required roadway right-of-way is minimized if the platform is located on the far side of the intersection in the "shadow" of the left turn lane (see Figure 3).
- To provide the greatest potential for transit signal priority (discussed later).

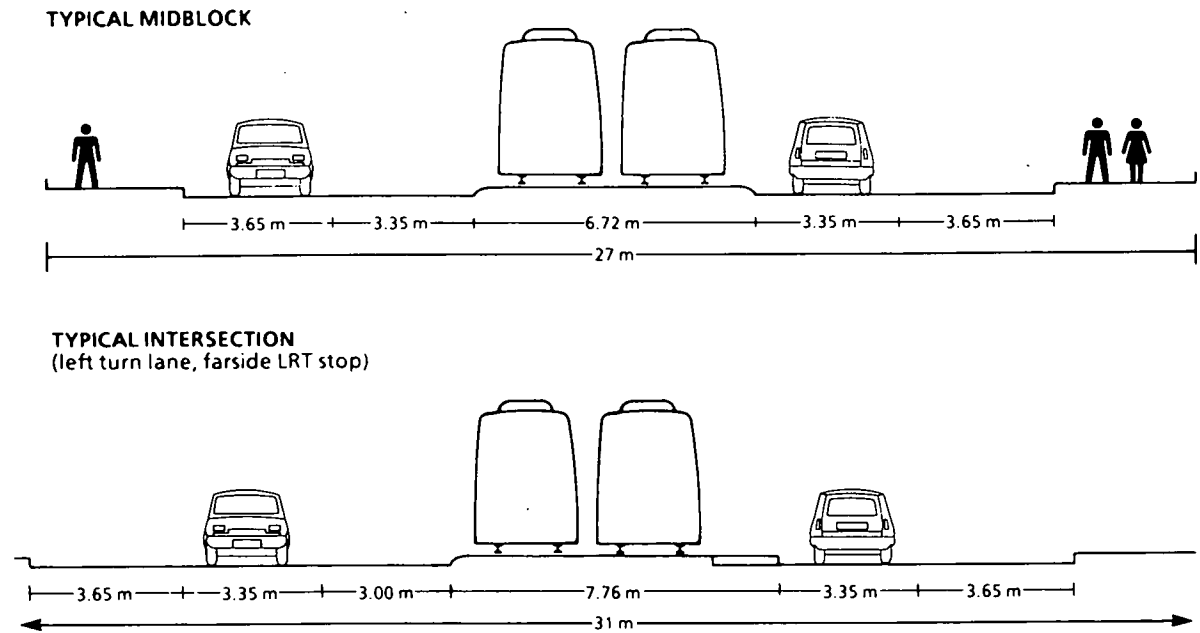

FIGURE 2 Harbourfront LRT at-grade cross-section dimensions.

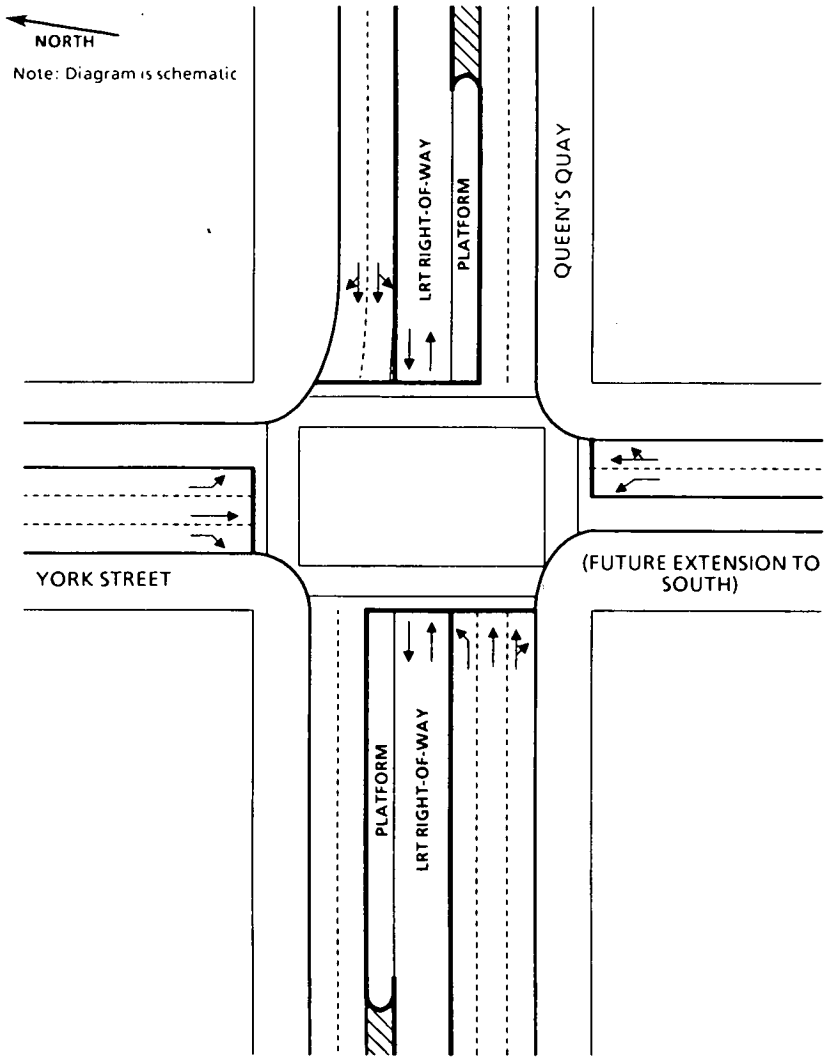

FIGURE 3 Sample intersection treatment.

Traffic Signal System

If separate left turn lanes were to be incorporated on Queen's Quay at all signalized crossings as illustrated in Figure 3, the preferred signal phasing would be as follows:

- Phase 1—east-west left turn phase for traffic in left turn lanes,
- Phase 2—east-west green phase for LRT and through/right-turning traffic, and
- Phase 3—north-south green phase.

At the two midblock crossings it was not possible to widen the right-of-way of Queen's Quay to incorporate left turn lanes in addition to the two traffic lanes in each direction. It was also not feasible in light of anticipated traffic volumes to designate one of the two traffic lanes for left turns only. For this reason the curb lane at such locations will be designated for through and right-turning traffic and the second lane will be designated for through and left-turning traffic. The locations where left turns are to occur from a lane that is shared with through traffic cannot use the phasing outlined above.

The Metropolitan Toronto Department of Roads and Traffic has proposed a signal phasing that would incorporate callable signal phases for the LRT line. This phasing scheme is shown in Figure 4 and would operate as follows:

- Phase 1—green signal for all eastbound automobile traffic and east-west pedestrian flow on the south side of intersection,
- Phase 2—green signal for eastbound and westbound LRT—only if required (callable),
- Phase 3—green signal for all westbound automobile traffic and east-west pedestrian flow on the north side of the street,
- Phase 4—same as Phase 2 (callable),
- Phase 5—green signal for all north-south automobile and pedestrian movements,
- Phase 6—same as Phase 2 (callable).

Note that due to capacity restraints, Phase 6 would not be available if both Phase 2 and Phase 4 had already been required for that signal cycle. That is, a maximum of two LRT phases could be called per cycle, but the phase would be available at three separate times within each cycle.

For consistency, this phasing scheme is being proposed even at those intersections with exclusive left turn lanes.

As stated before, LRT platforms will be located on the far side of the intersection to permit the greatest flexibility for transit priority at intersections. Although the details are still being finalized, the concept of the

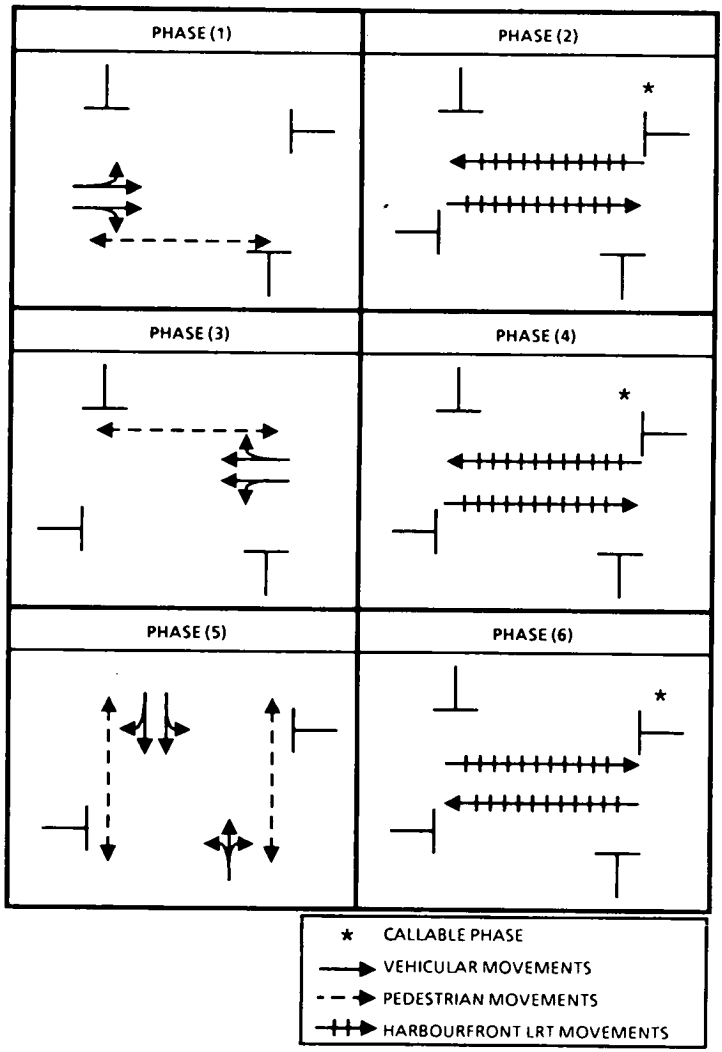

FIGURE 4 Proposed traffic signal phasing for midblock intersections.

intended design is that of traffic signal actuation by the LRV when it has traveled a short distance from a far-side platform, at a point well in advance of the downstream signal. Still under study is the extent to which signal timing and phasing can be adjusted within the framework illustrated in Figure 4 and thereby minimize signal delay to the LRT.

Queen's Quay-Spadina Turnback Loop

The turnback loop at the line's western terminus is illustrated in Figure 5. The loop will operate in a counterclockwise direction, with the entrance onto Spadina Avenue incorporated into the existing Spadina Avenue-Lake Shore Boulevard intersection. The northbound stop bar on Spadina Avenue would be relocated to south of the loop exit so that the LRVs could access the median right-of-way during the green phase (Lake Shore Boulevard is one way eastbound at this point). At the entrance to the loop from Queen's Quay, a "half" signal would be implemented to control westbound (but not eastbound) automobile traffic whenever an LRV is waiting to enter the loop.

The loop was designed to allow additional trackage to be added at a future date to accommodate an extension of the LRT line north on Spadina Avenue, including track for LRV storage in advance of the conclusion of a SkyDome event. Although service will terminate at Queen's Quay, a 0.83-km length of track is required on Spadina Avenue to allow vehicles to run-in to service from King Street. The proposed extension of LRT service along Spadina Avenue is discussed briefly in the following section.

PROPOSED EXTENSION

When the recommendation for a Harbourfront LRT was made to the metropolitan Toronto Council in 1985, it was intended as the first phase of a longer line that would continue north on Spadina Avenue from Queen's Quay to the east-west Bloor-Danforth subway line, as is illustrated schematically in Figure 6. Although the council approved the Harbourfront LRT, the second phase—referred to as the Spadina LRT line—was referred back for further study of the impact it may have upon the traffic on Spadina Avenue and upon the communities through which it would operate. These communities, which include Toronto's Chinatown, the Garment Industry, and the Kensington Market, make Spadina Avenue one of the most diverse neighborhoods in metropolitan Toronto.

The Spadina bus service carries 2,500 passengers south from the Bloor-Danforth subway line every weekday a.m. peak hour. It is the third busiest surface route of the approximately 130 routes in metropolitan Toronto and is nearing the practical capacity for bus service in mixed traffic.

The construction of the SkyDome was only one aspect of a major development package that was approved for the whole of the railway lands north of the Gardiner Expressway and on both sides of Spadina Avenue (see Figure 1). It has been estimated that with these developments this peak-hour demand will grow from 2,500 to 5,600. Crowded buses, bunching of vehicles, and reduced running speeds are already becoming increasingly characteristic of this route.

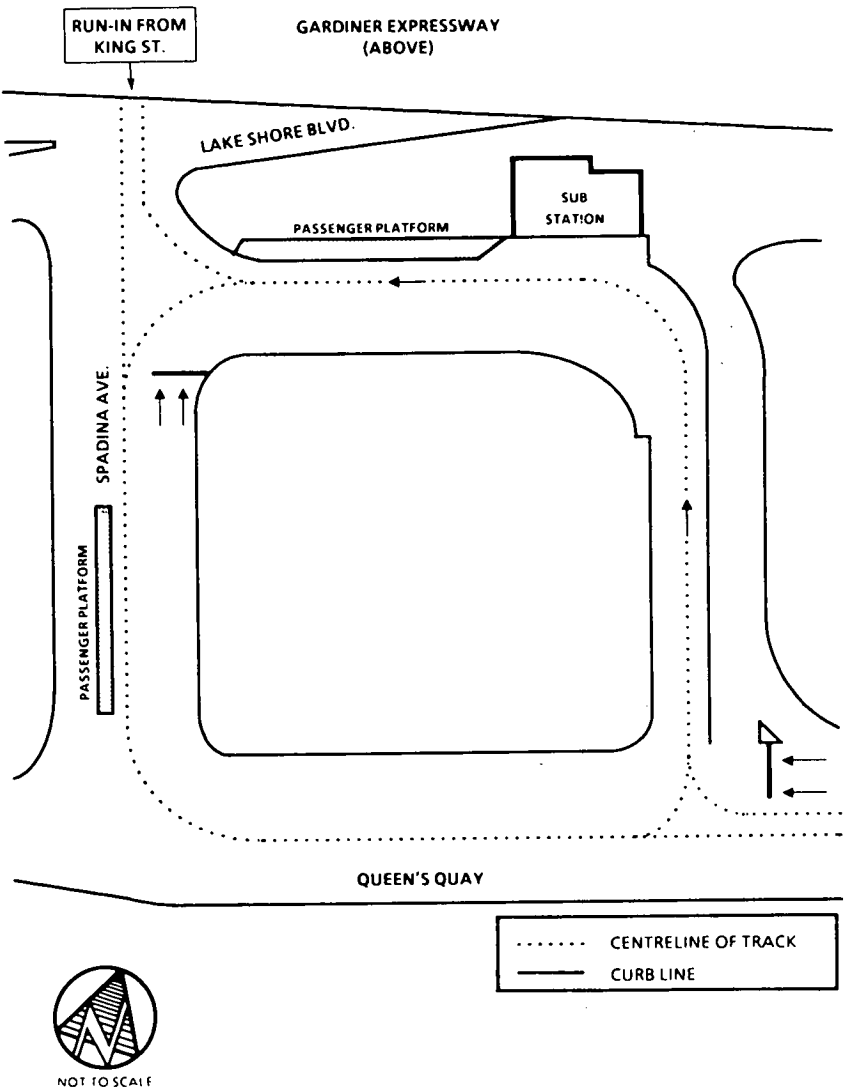

FIGURE 5 The Queen's Quay-Spadina turnback loop.

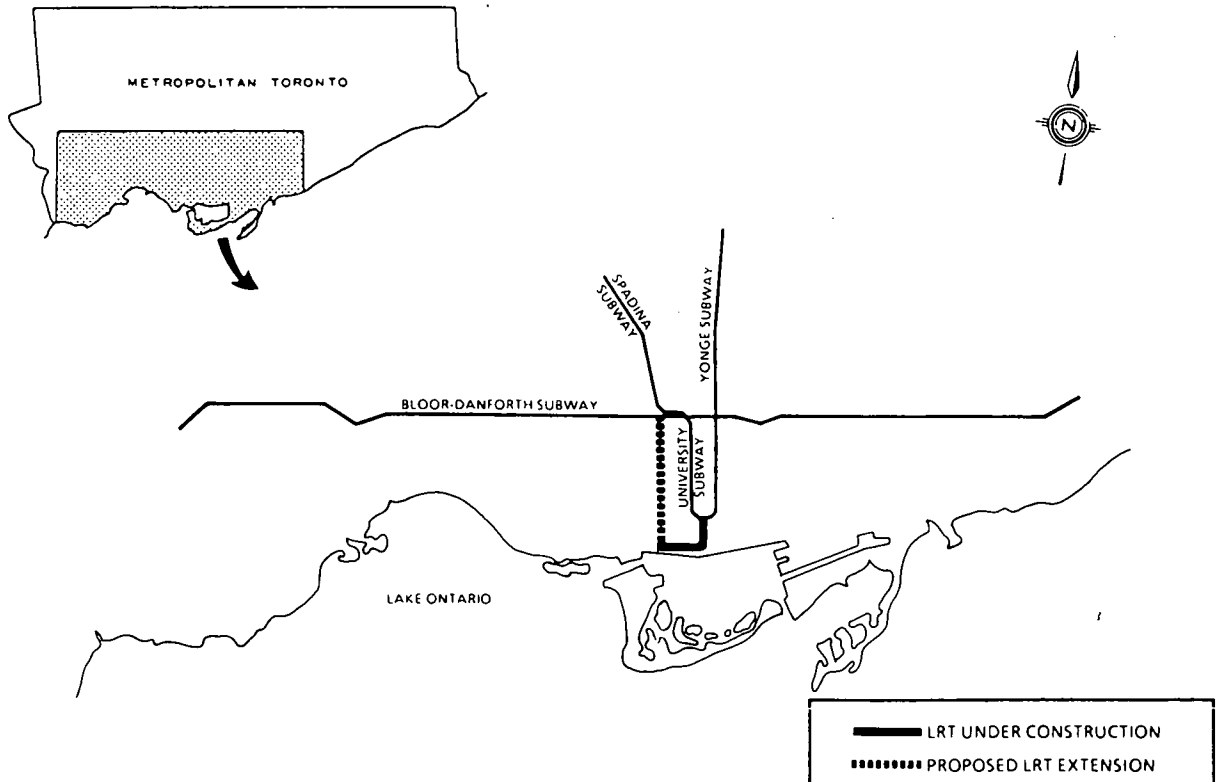

FIGURE 6 The Harbourfront LRT line and proposed Spadina extension.

Due to the wide right-of-way of Spadina Avenue (about 130 ft), this location may lend itself well to a center-median LRT. The proposal is currently under extensive study in response to strong concerns expressed by the public, such as the resulting reduction in on-street parking (a section that has angled parking would have to be converted to parallel parking, resulting in the loss of about 100 on-street spaces), the reduced number of points at which left turns would be permitted across the center of Spadina Avenue, and the possibility of additional traffic infiltration through adjacent neighborhoods as a result.