Calgary Light Rail Transit Surface Operations and Grade-Level Crossings

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This paper presents an overview of Calgary light rail transit (LRT) surface operations and grade-level crossings. At present, the LRT system incorporates approximately 30 km (18.6 mi) of double track and 31 stations. Approximately 87 percent of the LRT system is composed of surface operation in a shared right-of-way. Outside of the downtown area, the LRT operates adjacent to and in the median of arterial roadways and in an existing rail corridor. In this environment, the LRT has priority over street traffic, preempting the traffic signals at intersecting roadways. Downtown, three LRT lines merge and run under line-of-site operation along the 7th Avenue Transit Mall along with transit buses and emergency vehicles. Although trains are not given special priority along 7th Avenue, traffic signal phasing provides progression to minimize delays as the LRT travels between stations. Based on experiences documented in this paper, it is demonstrated that LRT can operate harmoniously with private vehicles, pedestrians, and bicycles in the right-of-way of city streets. Strategies developed maintain an acceptable level of traffic operations at intersecting streets while giving priority to LRT operation through traffic signal preemption. Existing traffic signal and railway crossing equipment and control techniques have also been adapted to manage the interaction between LRT operations and private vehicle, pedestrian, and bicycle traffic at intersecting streets and LRT stations, and to accommodate nonstandard crossing configurations such as skewed intersections.

TRB has identified Task 1 of TCRP Project Integration of Light Rail Transit into City Streets to "gather, review and summarize published and unpublished information relevant to the problem for domestic and foreign LRT systems" (*1*).

The objective of this paper is to present an overview of Calgary light rail transit (LRT) surface operations and grade-level crossings. Included in this paper are the observed volumes for a range of surface-level crossing configurations.

BACKGROUND

Calgary is a city of approximately 738,000 people situated at the base of the Rocky Mountain foothills in southern Alberta, Canada. The city's economy is based on agriculture, energy, and tourism. Approximately one-third of the present employment is located downtown and in the inner city, one-third along the east industrial area, and one-third throughout the rest of the city.

Since the 1960s, Calgary's history has been one of overall steady growth, almost doubling in 20 years from a population of 400,000 in 1971 to 800,000 at present. The fact that the entire urban area is under the jurisdiction of the Calgary City Council makes Calgary truly a uni-city. This allows the city to exercise almost complete control over its urban environment, including its transportation system.

This combination of strong, continuous growth and uni-city jurisdiction has contributed to a successful LRT system in Calgary.

Before the 1940s, the downtown area was served primarily by streetcars. However, streetcar service was gradually phased out in favor of diesel and trolley buses on high-density routes. Streetcar service ended in 1951 and trolley bus service ended in 1974. Studies of rapid transit began in the mid-1960s, with the first plan recommending two legs of a heavy rail system and a downtown subway. After an evaluation of alternate rail transit alternatives and busways, LRT was selected on the basis of economics, system capacity, and the potential for influencing development.

In the early 1970s, Calgary instituted a new express bus service that was marketed as the Blue Arrow Express System. The Blue Arrow system acted as its own feeder in the farthest suburbs and connected with crossing feeder routes as it approached downtown. Limited stops between the outer suburbs and the downtown area gave it some of the characteristics of an express service. A series of park-and-ride lots was developed, with particular emphasis placed on proposed future rail corridors. Thus, the Blue Arrow and its feeder systems combined with park-and-ride lots to form a prototype for the development of the LRT system in terms of service and corridors.

IMPLEMENTATION OF LIGHT RAIL TRANSIT

In 1981, the initial 10.9-km (6.8-mi) LRT leg, extending from Anderson Road in south Calgary to downtown, opened for revenue service. In the downtown area the LRT operates along the 2-km (1.2-mi) transit mall on 7th Avenue. This transit mall is reserved for LRT, bus operations, and emergency vehicles only.

In 1985, a second 9.8-km (6.1-mi) leg was added to the northeast. The third leg of the system to the northwest was completed in 1987, extending from downtown to the University of Calgary. A 1-km (0.6-mi) extension of the northwest line was opened in 1990.

The existing LRT system, illustrated in Figure 1, is operated as two lines—Anderson to Brentwood (south to northwest) and Whitehorn to downtown (northeast). On weekdays, the LRT system carries approximately 100,000 passengers (378 boarding passengers per operating hour). Average weekday bus ridership is approximately 161,800 passengers (45 boarding passengers per operating hour). Information on peak-hour LRT ridership and level of service is presented in Table 1.

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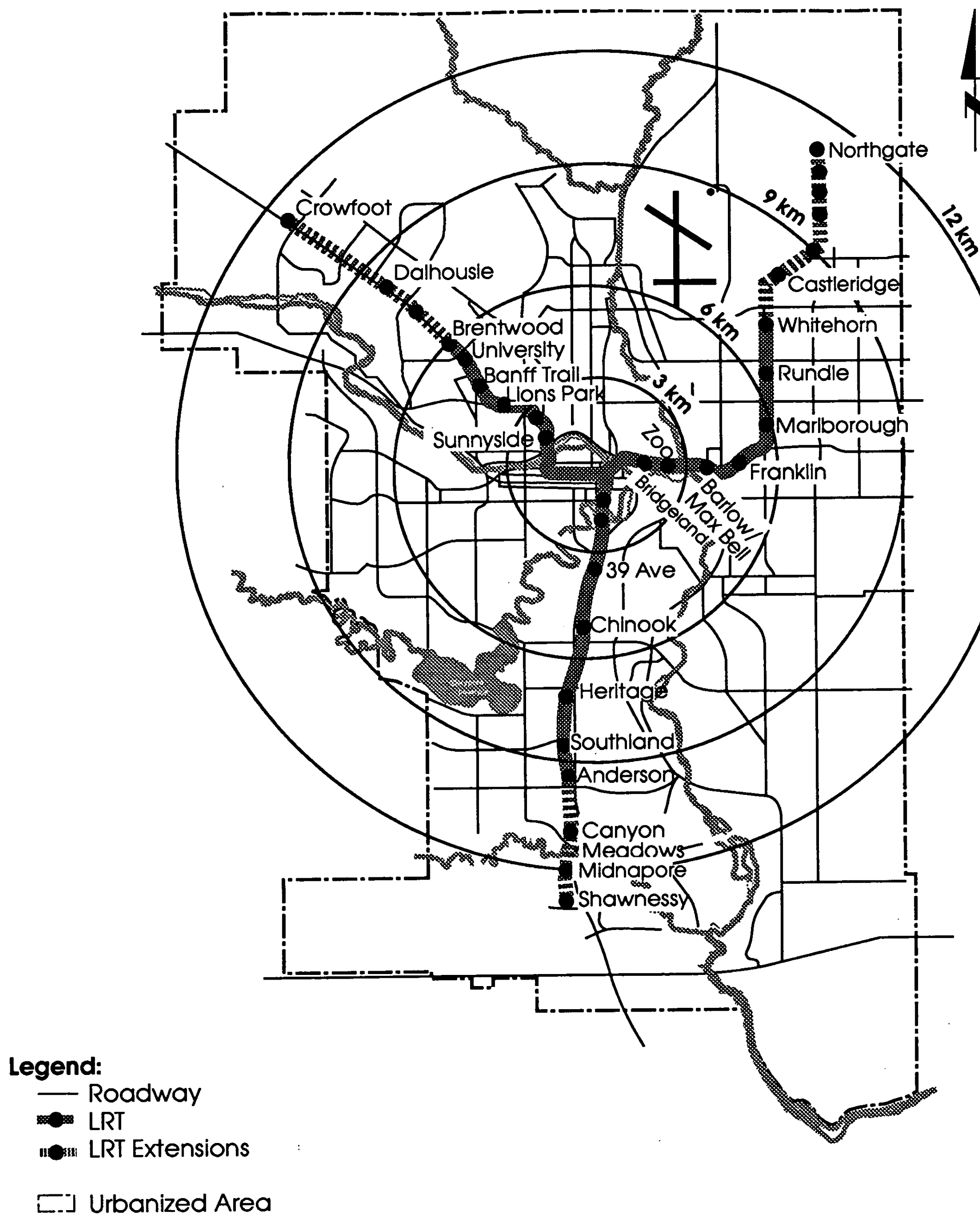

FIGURE 1 Calgary roadway and LRT networks.

OVERVIEW OF CALGARY LRT SURFACE OPERATION

Calgary's LRT system consists of approximately 30 km (18.6 mi) of double track, of which surface operation comprises 87 percent, 5 percent is on grade-separated bridges, and 8 percent is underground. Surface LRT alignments are located in the right-of-way of city streets, an existing railway corridor, and an exclusive right-of-way. There are 43 grade-level LRT/roadway crossings, of which 20 are controlled by railway gates and traffic signals, 10 by railway gates only, and 13 by standard traffic signals only. Pedestrian access to the four side-load platforms outside downtown is controlled by railway signals, pedestrian gates, and staggered bedstead railings. Access across the tracks to the staggered, side-load station platforms along the 7th Avenue Transit Mall is controlled by standard traffic and pedestrian signals at roadway intersections.

Outside downtown, train movements are controlled by an automatic block signal system, which allows only one train to occupy each section or "block" of track. At grade-level roadway crossings outside of the downtown, the trains preempt the normal operation of the traffic signals to allow uninterrupted movement between stations. Downtown, cross-street traffic and train and bus

TABLE 1 Observed Peak-Hour Volumes on Calgary LRT

LRT LINE	TRAINS PER HOUR PEAK DIRECTION (1-way) (T/H)	CARS PER HOUR (1-way) (C/H)	HEADWAY (SEC)	LENGTH OF TRAIN SET (# OF CARS)	PASSENGERS PER HOUR IN PEAK DIRECTION (PPH)	VOLUME/CAPACITY % IN PEAK DIRECTION Capacity = (C/H) X load factor (162 persons/car)
South	12	36	240 -360	3	4,200	72%
NW	11	33	240 -360	3	1,900	36%
NE	11	33	300 -360	3	3,300	62%

movements on 7th Avenue are controlled by conventional traffic signals.

Different methods have been developed to manage the interaction of train operations with automobile, pedestrian, and bicycle traffic within the street system and at LRT stations, as well as to accommodate nonstandard crossing configurations. This paper includes a discussion of experiences and lessons learned from surface rail operations in the following environments:

1. On-street LRT operations with bus and emergency vehicles on an exclusive transit mall (7th Avenue Transit Mall);
2. LRT operation in the median of an arterial roadway with full traffic signal preemption (northeast LRT operation on 36th Street N. E.);
3. LRT operation parallel to a major arterial roadway (9th Street S. W.);
4. Nonstandard LRT crossing configurations (e.g., skew angle crossing at 7th Avenue and 4th Street S. E.); and
5. Control of grade-level pedestrian access to side-load station platforms (Sunnyside, Lion's Park, and Banff Trail Stations) and a retrofit program for handicapped access to center-load station platforms (Erlton, Chinook, Heritage, and Southland Stations).

7th Avenue Transit Mall

Seventh Avenue South is located near the geographic center of downtown Calgary and has functioned for many years as the central spine for transit service. Downtown planning and transportation studies in the 1970s recommended that this street be transformed into a mass transportation corridor with 6th Avenue and 9th Avenue South acting as primary westbound and eastbound bus routes, respectively. A major step in this transformation occurred in 1973 with the implementation of a 1.6-km (1-mi) reverse-flow exclusive lane on 7th Avenue for westbound buses and a peak-period exclusive lane for eastbound buses. During this period, major transportation studies also identified 7th Avenue as an exclusive at-grade downtown transit corridor for LRT and bus operations. The contraflow bus lane ended in 1979 when construction commenced on the south LRT leg. The conversion of 7th Avenue to an exclusive transit mall was completed in May 1981 with the commencement of LRT service.

The 7th Avenue Transit Mall extends over 14 blocks downtown Calgary, from 4th Street East to 10th Street W.—a distance of approximately 2 km (1.2 mi). Within this area, trains from the south and northwest LRT legs (Route 201) and northeast leg (Route 202) merge and operate on the street with buses and emergency vehicles (see Figure 2). An area equivalent to the two center lanes on a four-lane downtown roadway is used for LRT traffic, with the outside curb lanes reserved for buses and LRT stations. Eleven unidirectional raised platforms have been strategically placed every three to four blocks along the corridor, and in these areas buses must use the two center lanes to travel around the stations.

Currently, Routes 201 and 202 operate at peak-hour headways of 5 and 6 min, respectively (22 trains per direction—total both lines), in three-car train sets and carry a combined ridership of 7,500 passengers per hour (peak hour, peak direction) along 7th Avenue. The combined train frequency is every 2 to 3 min. In addition, five bus routes operate along 7th Avenue between 1st Street E. and 8th Street W., producing a peak-hour bus volume of 25 buses per direction. Table 2 presents a summary of the grade-level roadway and pedestrian crossings and the p.m. peak-hour crossing volumes along 7th Avenue.

The traffic signals along the 7th Avenue Transit Mall function as part of the downtown system, which is under centralized computer control. LRT trains are not given special priority at signals downtown; however, a signal progression has been designed along 7th Avenue to minimize delays as the LRT travels between stations. The characteristics of the 7th Avenue signal operation are presented in Table 3.

It is also noted that pedestrians are restricted to sidewalks and may legally cross the transit corridor at crosswalks only. At selected locations where jaywalking has presented a problem (e.g., 3rd Street S.E., 9th Street S.E., and between 1st Street E. and Centre Street), post-and-chain barriers, pedestrian gates, and bedstead railings have been installed adjacent to the sidewalks to channel pedestrian flows and discourage midblock crossings. In addition, the LRT stations on 7th Avenue may be accessed through an extensive network of elevated pedestrian walkways (the PLUS 15 system) that link major office buildings and connect with designated parking corridors on 4th Avenue South and 9th Avenue South (see Figure 3).

Transit operations on the 7th Avenue Transit Mall have been investigated using TRANSITSM (*2,3*), an event-by-event simula-

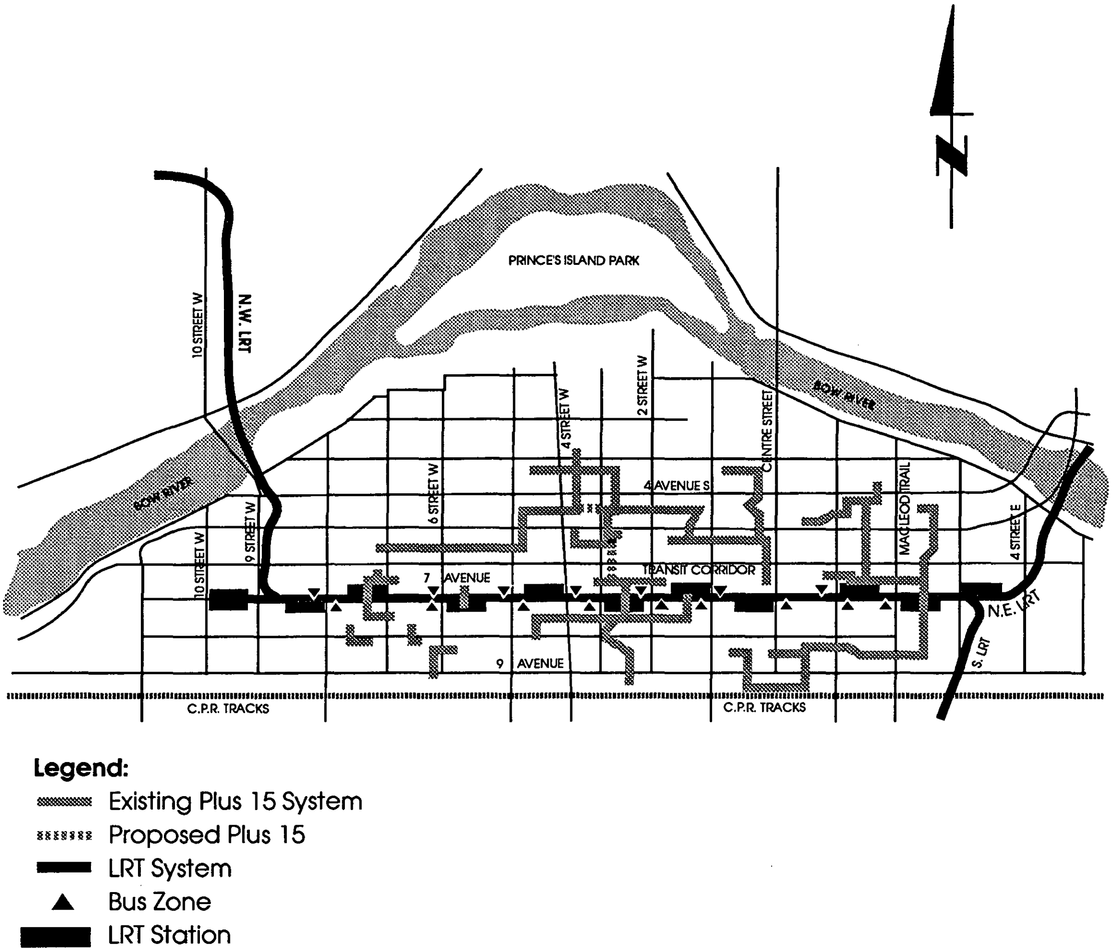

FIGURE 2 7th Avenue South Transit Mall.

tion model written in the General Purpose System Simulation computer language. The simulation model is based on the following assumptions related to the logic of traffic operations:

- Trains cannot be operated so that two or more trains bunch together at any station. Therefore, the maximum station capacity is one train, whereas the capacity of a bus stop depends on the length of curb space provided.
- No train can be overtaken by buses at any station because of the system geometry.
- Buses interact with trains in the inner lanes and at stations but only LRT is permitted to dwell at the stations.
- The queue discipline is "first-in-first-out" to allow vehicles to be processed sequentially.
- Pedestrian flows on the simulated area are not explicitly considered in the model.
- The running, dwell, and terminal layover times are random quantities with empirically determined means and standard deviations.
- No two trains can occupy the same block of street at any time to avoid blockage of upstream intersections.

TRANSITSM was developed with over 3,500 statements consisting of five bundles, specifically, eastbound transit, westbound

TABLE 2 7th Avenue Transit Mall Characteristics

NUMBER OF GRADE LEVEL VEHICULAR CROSSINGS	MAXIMUM VEHICULAR CROSSING VOLUMES (VEHICLES PER HOUR)	NUMBER OF PEDESTRIAN CROSSINGS	MAXIMUM PEDESTRIAN VOLUMES (PERSONS/ HOUR)	PEAK PERIOD TRAIN FREQUENCY (TRAINS/ HOUR)	PEAK HOUR BUSES 2-WAY
14	320 - 2100 (avg: 1020)	26	150 - 950 (avg: 560)	45	50

TABLE 3 7th Avenue Transit Mall Signal Operation

TIME PERIODS	CYCLE LENGTH (SEC)	SIGNAL GREEN SPLIT FOR 7th AVENUE (SEC)
A.M. Peak Period	70	24 - 46
P.M. Peak Period	80	24 - 56
Off-Peak (day)	70	24 - 46
Night	60	24 - 36

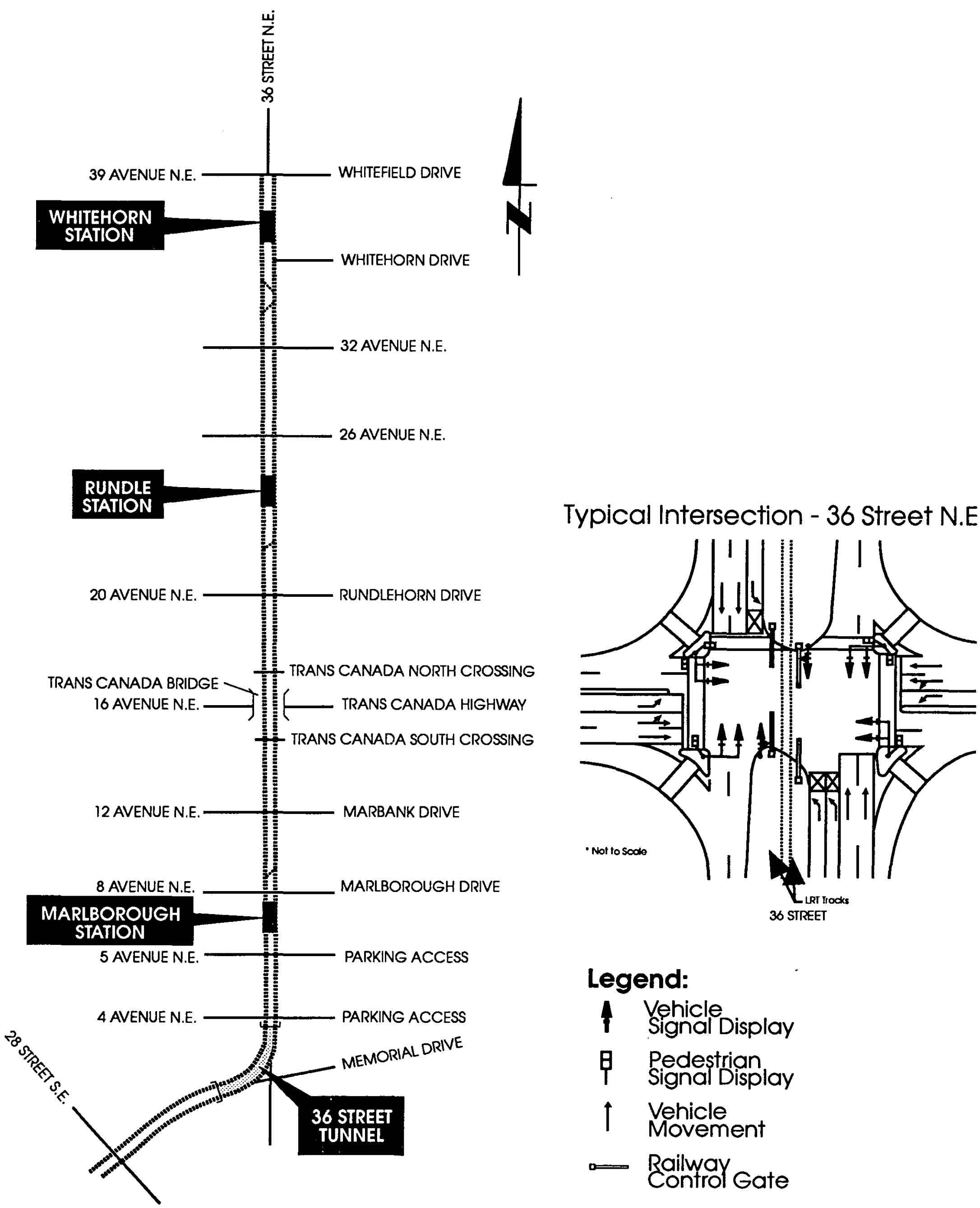

FIGURE 3 Northeast LRT—36th Street N.E. corridor.

transit, traffic signal plans, traffic on the 12 intersecting streets, and a simulation tuner that regulates the duration of each experimental run. The model is capable of simulating 2 hours of a.m. peak, 6 hours of midday, 3 hours of p.m. peak operation, and 11 hours of combined operation per day. The computer to real-time ratio is 1:100.

The findings of the simulation analysis indicated that the surface transit mall has a threshold capacity beyond which an unstable transit operation exists. The key constraints on train capacity are at the switch points on the east and west ends of 7th Avenue where Routes 201 and 202 enter and exit the transit mall. The threshold capacity was reached at a headway of 4 min. per line or a one-way capacity of 30 trains per hour for LRT operation only. With a 5-min. headway per line, the transit mall capacity (one-way) is 24 trains per hour and 30 buses per hour. This threshold slightly exceeds the existing operating conditions on the transit mall, at which LRT headways are 5 and 6 min., respectively, per line (22 trains per hour) and bus volumes are 25 buses per hour.

Simulation also demonstrated that transit operations on the mall became unstable (i.e., bunching of trains and an increase in travel time) for combined train headways less than 2 min.

When the present use of the transit mall by LRT and buses becomes impractical, it will necessary to divert bus operations from 7th Avenue to other downtown streets. Over the long term, expansion of the downtown platforms to accommodate four-car train sets will be required. In addition, construction of a LRT subway beneath 8th Avenue S.W. (at an estimated cost of over $200 million) could also be considered to provide additional transit capacity.

Northeast LRT Operation on 36th Street N.E.

The operation of the Northeast LRT in the 36th Street N.E. corridor provides a case study of how surface LRT operations may be integrated within the median of a major arterial roadway with traffic signal preemption.

Thirty-sixth Street N.E. is a four-lane arterial roadway that extends through an intensely developed area containing extensive commercial development and medium-density residential development. Within this corridor, there are 10 grade-level intersection crossings by LRT over a 3.6-km (2.2-mi) distance, as shown in Figure 2.

The average daily traffic flow on 36th Street N.E. is approximately 35,000 to 40,000 vehicles, with the daily directional split at about 50/50. The presence of major commercial land uses generates a high volume of left-turn and cross-street traffic in the area between 4th Avenue and 12th Avenue N.E. and the intersections at 20th Avenue/Rundlehorn Drive, 26th Avenue, and 32nd Avenue N.E. A summary of p.m. peak-hour train, vehicular, and pedestrian volumes at the 10 at-grade crossings is presented in Table 4.

The track alignment for the northeast LRT line is located in the median of 36th Street N.E. Continuous concrete barriers and chain-link fencing near the stations separate LRT and automobile traffic and discourage jaywalking. All intersections are controlled by railway gates and preemptive traffic signals that give priority to approaching trains. Any "green time" lost to vehicles and pedestrians because of LRT signal preemption is subsequently restored once the train has cleared the crossing. Pedestrian access to the three center-load LRT stations is accommodated by pedestrian bridges that are accessed by stairways and spiral ramps. The maximum LRT operating speed on 36th Street N.E. is 80 km/hr, whereas the posted speed limit for vehicular traffic is 60 km/hr.

The 10 grade-level intersections are signalized with left-turn phasing on 36th Street and approach phasing on the side streets so that the signal shows green for both through and left turn in one direction, then switches to through and left turn for the opposite approach. Signal controllers are connected to the central traffic control computer. The central computer selects timing plans by time of day, but cycle length and splits are determined by the traffic signal controllers. There are stop-line loop detectors on all intersection approaches.

On weekdays, the traffic signals on 36th Street N.E. are only coordinated during off-peak hours. With the combined train headway during peak periods averaging 3 min and the existence of LRT preemption, it is not practical to operate coordination plans during peak periods. However, the signals are coordinated throughout the weekend period, when trains operate at headways of 12 to 15 min.

Although the current LRT operation on 36th Street N.E. is reasonably efficient, there are significant delays to side street and left turning traffic from 36th Street N.E. at certain times because of long gate warning times or consecutive gate activations from closely spaced trains. To address these issues, a recent study (*4*) recommended that the following measures be implemented to fine-tune existing operations:

Reduce Basic Gate Warning Time

Currently, the gate warning time is set for the greater of 20 sec or the time required for the pedestrian to walk the length of the crosswalk that crosses the LRT tracks. Using these criteria, gate warning times along 36th Street N.E. average 25 sec.

The grade-level LRT crossings along 36th Street are located within signalized intersections at which no vehicles normally stop; they are within the line of sight of train operators, who are accustomed to in-street operation. It takes approximately 14 sec to completely lower the gates after activation of the flashing lights and bells, and the traffic signals show a red light to all opposing traffic approximately 6 sec after the start of the warning devices. In short, before the railway gates are lowered, no more vehicles can get onto the tracks and no vehicles should be queued on the tracks.

On the basis of these factors, it was determined that the gate warning times could be reduced a minimum of 15 sec, or the actual time required for a pedestrian to reach the safety of the median island before the LRT arrives at the crossing. Using a pedestrian walking speed of 1.22 m/sec (4 ft/sec) all intersections with an east-west pedestrian crosswalk would require at least 18 sec for pedestrian clearance. Fine-tuning gate warning times in this manner could reduce some gate warning times by as much as 10 sec.

Raise Gates Earlier

At present, the gates begin to rise after the rear of the train leaves the island circuit. When the gates start to rise, the traffic signals time 6 sec of yellow and red light clearance before a green signal is given to opposing traffic.

It was concluded that the gates could safely start to rise 1 sec after the train first enters the crossing. This change would reduce the total preemption time by 4.5 sec for a three-car train crossing at 80 km/hr.

TABLE 4 36th Street N.E. LRT Corridor Traffic Characteristics

GRADE LEVEL ROADWAY CROSSING	COMBINED PEAK HOUR TRAIN FREQUENCY (SEC)	PEAK HOUR TRAFFIC VOLUME CROSSING 36TH STREET VPH (2 - WAY)	PEAK HOUR PEDESTRIAN VOLUME CROSSING 36TH STREET PERSONS/HR (2 - WAY)
4th Street N.E.		288	12
5th Avenue N.E.		607	53
8th Avenue/Marlborough Dr. N.E.	180	519	137
12th Avenue/Marbank Dr. N.E.	-360	981	15
16th Avenue EB ramp 16th Avenue WB ramp		129 223	NA
20th Avenue/Rundlehorn Dr. N.E.		1422	54
26th Avenue N.E.		922	41
32nd Avenue N.E.		1898	49
Whitehorn Drive N.E.		206	28

Install Advance Vehicle Detectors

Currently, only stop-line vehicle detectors are used at traffic signals. More efficient traffic signal operation could be achieved with the installation of advance detectors.

Educate LRT Controllers and Operators

It was concluded that the effect of train operations on the intersection operation could be minimized by careful attention to train departure times and minimizing between-station stops at switch points. This training, in addition to recent initiatives to improve communication between LRT controllers and operators, has improved the efficiency of LRT operations and reduced the delay to vehicular traffic at grade-level roadway crossings.

LRT Operations on 9th Street S.W.

The operation of the Northwest LRT on 9th Street S.W. at the west end of the 7th Avenue Transit Mall is an example of surface LRT operation adjacent to an arterial roadway with major cross-street traffic and standard traffic signal control and railway lights and bells. Figure 4 shows this particular surface operation (note that 9th Street S.W. is one way southbound). In the p.m. peak hour, a total of 320 vehicles per hour cross the LRT in one direction, and 150 pedestrians per hour cross both the transit mall and the northwest LRT line. The corresponding volumes on the transit mall in the p.m. peak hour are 45 trains and 50 buses per hour. The northwest LRT line carries 22 trains per hour during the p.m. peak hour.

LRT Operations on 7th Avenue and 4th Street S.E.

The intersection of 7th Avenue and 4th Street S.E. at the east end of the 7th Avenue Transit Mall is an example of nonstandard LRT crossing configuration in which the northeast LRT operates on a skew angle through the intersection. The direction of traffic flow and the general configuration of the crossings at the east end of the transit mall are shown in Figure 5.

At the 3rd Street east location, there are 45 trains per hour in both directions in the p.m. peak hour. At the 6th Avenue location, there are 22 trains per hour in the p.m. peak period and 14 buses per hour. This is close to the capacity of 48 trains per hour as determined by simulation.

Grade-Level Access to LRT Stations

The experience gained from construction and operation of each of the LRT lines has resulted in changes in the scale and design of Calgary's LRT stations.

The initial south LRT line includes six center-load stations that are accessed by stairways and a single set of escalators that operate in the peak travel direction. No provision was made to include elevators and ramps to accommodate people with disabilities at these stations; however, equivalent funds were committed by the City Council to upgrade the specialized, door-to-door Handi-Bus service. Downtown, short stairways and access ramps were constructed at the 7th Avenue stations.

The design of the second leg of the LRT system to the northeast incorporated the LRT alignment in the median of an expressway and major arterial roadway. The seven center-load stations on this

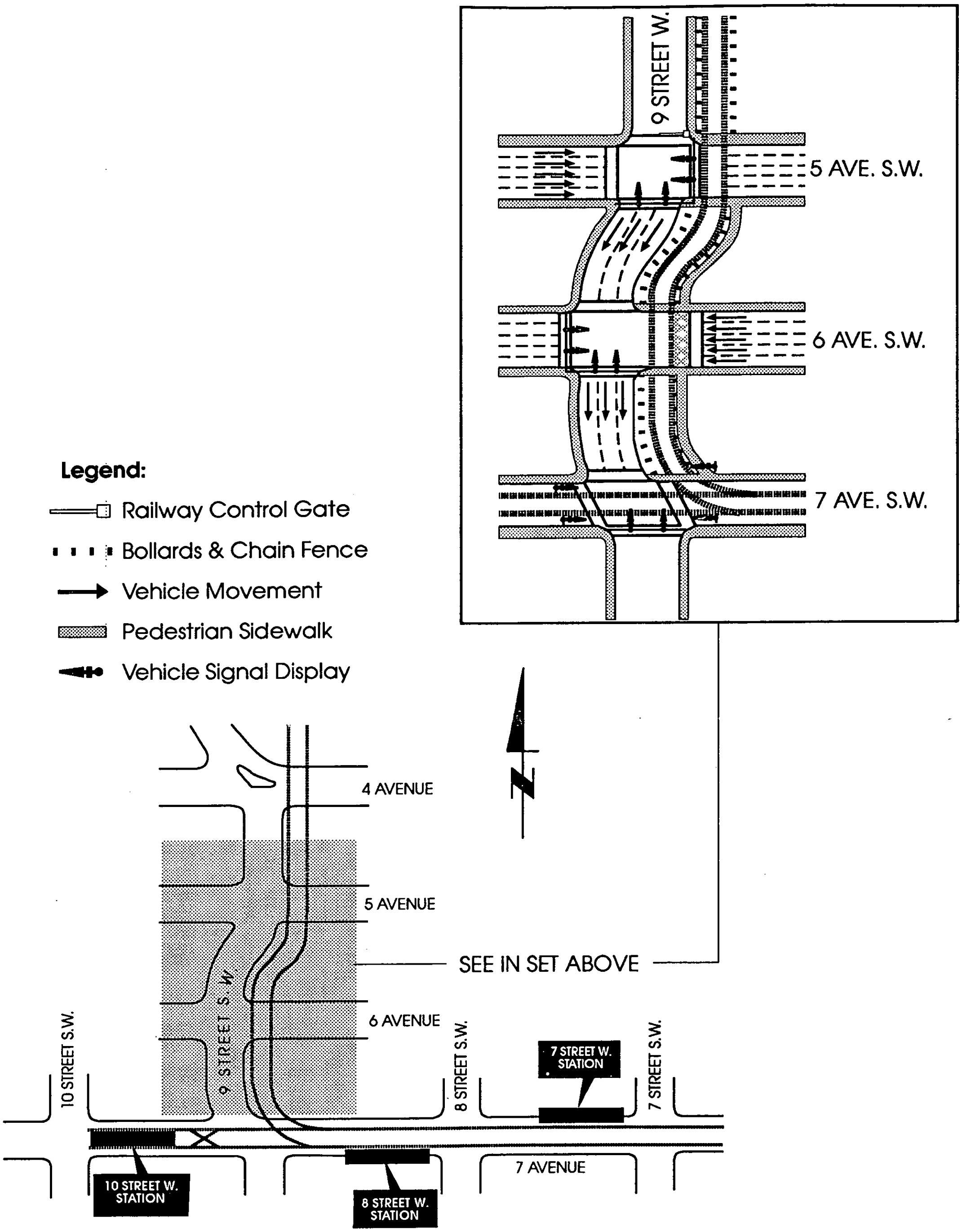

FIGURE 4 **LRT operations on 9th Street S.W.**

line are fed by stairways and ramps spanning the roadways. Within the stations, an elevator and two sets of escalators link the fare process area to the platform.

The design of the newest phase of the LRT system in northwest Calgary reflects lessons learned from the first two LRT lines. Stations in established inner-city communities (e.g., Sunnyside, Lions Park, and Banff Trail) incorporate low-scale, side-loading platforms with grade-level access across the LRT tracks. As illustrated in Figure 6, railway signals, pedestrian gates, and staggered bedstead railings provide pedestrian crossing protection at designated access points. These grade-level crossings enhance transit customer access by providing short, direct travel paths to the LRT platforms and also form part of the community pathway and bicycle network that link northwest communities. Large signs have also been installed to alert customers to check both directions before proceeding across the tracks. Provision of grade-level access to the northwest stations has greatly improved customer access. As well, standard railway crossing signals and pedestrian gates have been effective in providing crossing protection for the volume of pedestrian and bicycle traffic that crosses the LRT corridor.

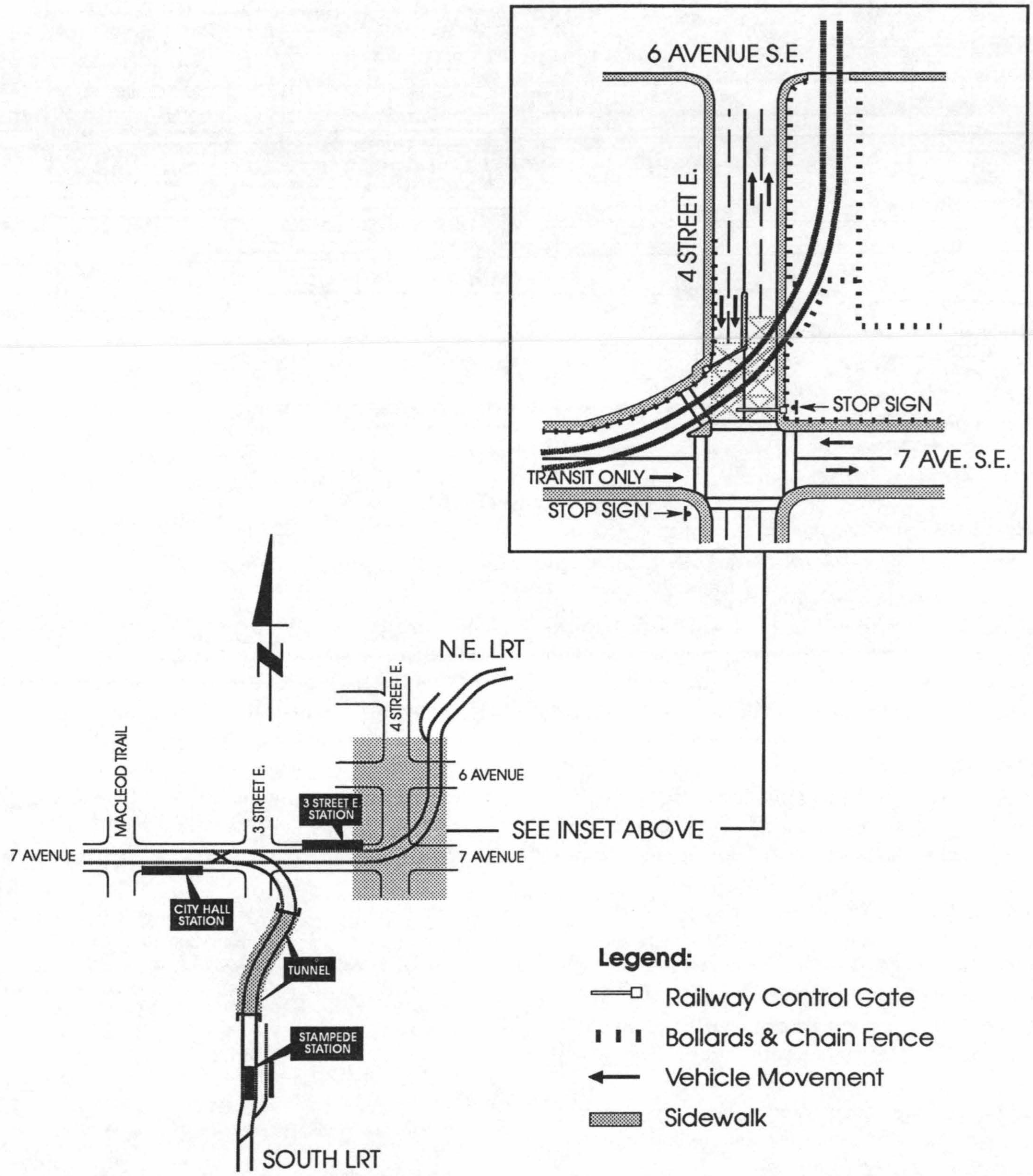

FIGURE 5 7th Avenue and 4th Street S.E.—skewed crossing.

FIGURE 6 LRT station grade-level access.

Based on the favorable experience with grade-level access to the northwest LRT stations, new grade-level pedestrian connections are being constructed to accommodate handicapped access to the south LRT stations. The new access connections incorporate a ramp and a concrete apron linking the south end of the station platform to the park-and-ride lots, as shown in Figure 7. There is a single grade-level crossing of the southbound LRT track, which is controlled by railway signals and staggered bedstead railings. A "help" phone, a stand-alone ticket validator, and new lighting are provided at the foot of the new stairway and ramp.

CONCLUSIONS

Based on more than a decade of operating experience, Calgary Transit has demonstrated that LRT technology can be integrated

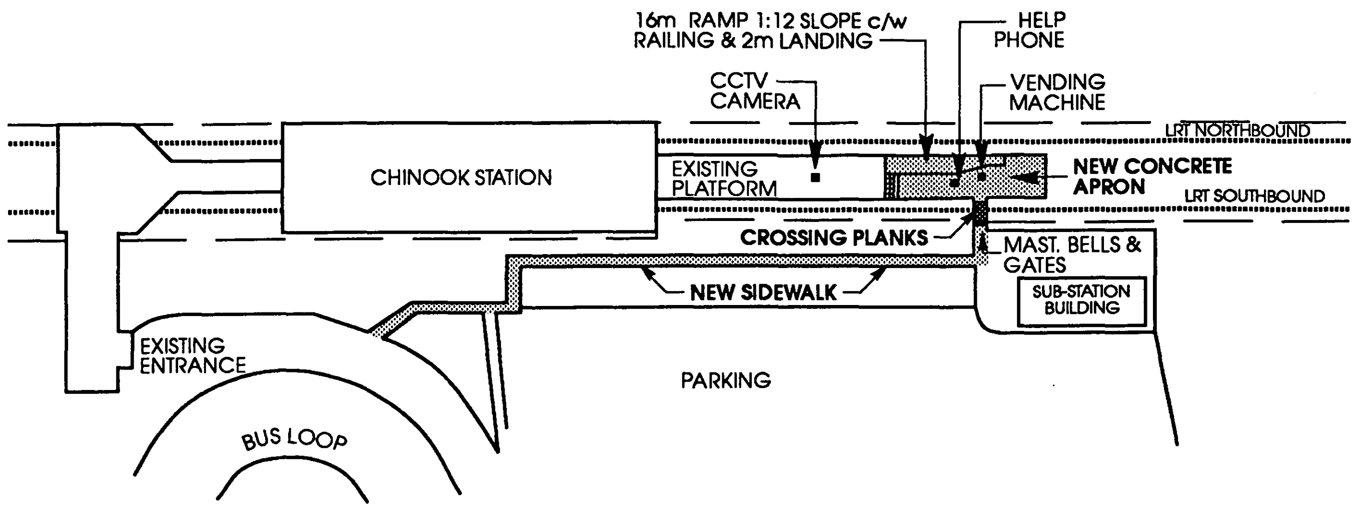

FIGURE 7 Chinook LRT station—handicapped access.

with the rights-of-way of city streets. The ability to adapt surface LRT operations within a variety of environments ranging from the exclusive transit mall downtown and the right-of-way of major arterial roadways has been a key factor in the economical development of the Calgary LRT system. Adoption of signal preemption for LRT operations at grade-level crossings and development of a comprehensive, balanced range of access modes (e.g., feeder bus, park-and-ride, automobile passenger drop-off, and walking and cycling) has also created an integrated system that is competitive with the private automobiles for traveling downtown (*5*).

Strategies have been developed to maintain an acceptable traffic operation within shared LRT and roadway rights-of-way by fine-tuning traffic signal and railway gate controls at grade-level roadway crossings and developing simulation models to establish threshold capacities for LRT operations downtown. Existing traffic signals, railway crossing equipment, and other traffic and pedestrian control techniques have also been adapted to manage the interaction between LRT operations and private vehicle, pedestrian, and bicycle traffic at intersecting streets and LRT stations and to accommodate nonstandard crossing configurations such as skewed intersections. To enhance pedestrian safety along the 7th Avenue Transit Mall, posts and chains, bedstead barriers, and No Jaywalking signs have been installed at several locations. In addition, Calgary Transit has worked with the local police to obtain more support in enforcing the jaywalking laws. These actions have led to a gradual reduction of level crossing accidents.

Other actions that have enhanced safety include the development of an in-house grade-level crossing committee involving Calgary Transit management and front-line operator membership to review all grade-level crossings. Public awareness campaigns have also been developed to reinforce existing LRT safety features.

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