ACKNOWLEDGMENT

No claim of originality is made for many of the concepts here identified, and some may even be protected by existing corporate patents. The judgments expressed here represent in part the personal opinions of the author, deriving from experience and professional judgment, but nevertheless are not to be taken as final or absolute. In particular, these comments do not necessarily represent the views or policies of the U.S. Department of Transportation, the Federal Railroad Administration, or the Transportation Systems Center.

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Traffic-Control Measures at Highway-Railway Grade Crossings With Provisions for Light Rail Transit

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Railway rights-of-way in cities are attractive alternatives for transit corridors, but, for modes that are not fully grade-separated, such as light rail transit systems, there may be problems with combined railway and transit crossings of arterial streets. This situation has been studied in Edmonton, Alberta, where a light rail transit line is under construction. The surface portion of this line is along the railway right-of-way, and as a result, the operation of its eight grade crossings is regulated by railway authorities. The short headways of light rail transit could cause frequent disturbances to the road traffic that operates at saturation during peak hours. This paper illustrates the method used for the analysis of the problem and discusses the surveys conducted. The basic principles governing the solutions to the grade-crossing problem are (a) the coordination of adjacent signalized intersections in such a way that the impact of the crossing closure is minimized and the system recovers shortly after the closure, (b) the integration of light rail transit scheduling and control with traffic control, i.e., restricting the closures to the periods of minimum impact on road traffic, and (c) the use of special features to increase safety.

The northeast sector of Edmonton contains industrial and recreational complexes and has a residential population of approximately 100 000 persons, which is expected to increase to 150 000 persons by the year 1980. One-third of this growth is expected to occur in new outlying areas, and the balance will be in the presently developing areas and the older developed areas.

At present, the transportation needs of the area are served by an arterial road network and the public-transit system of buses and trolleybuses. To serve the future needs of the area, the construction of a light rail transit (LRT) line augmented by a feeder bus system was approved in 1973. The LRT system is suitable for the population thresholds expected, and the availability of the Canadian National Railway (CNR) right-of-way along which the line can run makes it a cost-effective option.

The line, which will be in operation by 1978, will be 7.2 km (4.5 miles) long, 1.6 km (1 mile) of which will be tunneled beneath the streets of downtown Edmonton. The remainder will operate on the surface along the CNR right-of-way. Two stations will be underground and three will be on the surface (Figure 1). So that the line will be cost-effective, the surface portion will, at implementation, retain eight existing grade crossings.

At present, the arterial roadways in the area operate at a high level of service during peak hours and special events, and extensive queues on the links crossing the railway tracks are common. The introduction of the LRT line will increase the disruptions of these arterial roadways, and this loss of capacity and the decreased safety will be potential disruptions to the LRT operations. Thus, to achieve safe and efficient transportation in the northeast sector of Edmonton will require integrated management of all modes including the LRT.

PROBLEMS

Existing Situation

At present 20 to 24 railway trains traverse the grade crossings in a 24-h period, but since the majority of them do so during off-peak periods, they are not a major traffic disruption.

Nevertheless, the signalized intersections adjacent to the railway crossing [those 35 to 122 m (115 to 400 ft) from them] are a source of serious capacity problems in the morning and afternoon peak hours for the following reasons:

1. Conflict between the major traffic flows from generators north and east of the central business district,
2. Heavy left-turn movements that require 2½ or 3-phase control,
3. Isolated vehicle-actuated operation of traffic signals,
4. Physical restrictions that prevent intersection improvements, and
5. Restrictions to the road network because of the presence of the railway, major industrial and recreation facilities, and topography.

These capacity problems and the directional nature of the traffic cause long queues.

The queueing and capacity problems were surveyed and analyzed by the use of helicopter and surface crews. The major objective of the surveys was to obtain data with which to illustrate the operation of the transportation network in this area. These data were then used as the basis for an analysis of the situation that is expected after the introduction of the LRT. The surveys also showed the interaction of the traffic-actuated signals at two adjacent intersections (Figures 2, 3, and 4).

The schematic example of a real-time-space diagram in Figure 2 shows the degradation of the network performance in area C in the afternoon. The critical traffic conditions develop between 4:15 and 5:30 p.m. as the traffic inflow exceeds the capacity of the downstream intersection. [For clarity, the traffic conditions in the opposite direction are illustrated on a separate diagram (Figure 3).] The inflow traffic is generated at the upstream three-phase intersection during two signal phases with some right turns on red and is discharged at the downstream three-phase intersection during one signal phase. The solid horizontal lines in the diagram show the length of the queue for each traffic lane during three time profiles of the vehicular (green) interval: the beginning, the midpoint, and the end. The actual cycle time for both intersections is identified. The following observations can be made.

1. During the off-peak period, each intersection had a different cycle length. The upstream intersection consistently used a shorter cycle length than did the downstream intersection. The individual offsets varied.
2. As the traffic volumes increased, the cycle length at the upstream intersection increased. Since traffic at the downstream intersection approached saturation, the discharge phase operated at maximum capacity. The offset began to stabilize at this point.
3. During the peak period, two phases of each intersection (west and south approaches) became saturated and operated at maximum capacity. Uniformity of cycle lengths was established and small variations in cycle lengths that were shorter than the maximum were caused by the third unsaturated phase.

Several surveys taken on different days confirmed the consistency of the traffic events illustrated in these diagrams.

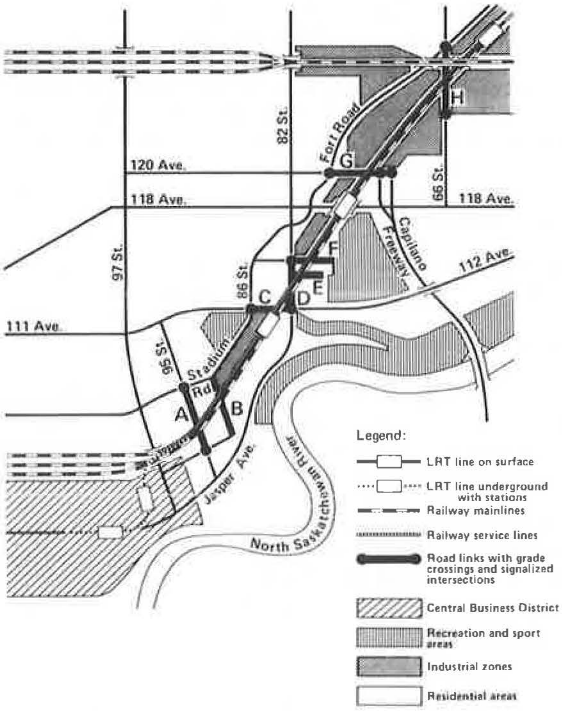
Traffic conditions during the morning peak periods are less severe (Figure 4), but the critical problem of queuing across the track area is still present. The analysis of the diagrams and the helicopter film indicate the following:

1. The operation of two traffic-actuated signals 180 to 360 m (525 to 1200 ft) apart under directionally pronounced saturated traffic flows became similar to a fixed-time-linked system of operation.
2. The traffic flow was the medium that induced the linkage. Because of the deficient capacity of the downstream intersection, this linkage did not produce progression.
3. The approaches to intersections having traffic-flow rates lower than saturation increased the delays and the number of stops in the major directions. These approaches also lowered the overall intersection capacity by excessive extensions of their vehicular (green) intervals, which operated at low levels of service.
4. Because of the width of the railway crossing (two to six tracks) and the queuing phenomena, the number of vehicles that stopped in the crossing area was high (on the average there was one stop longer than 20 s in every second cycle).
5. The average saturation-flow rate at the downstream intersection was 1530 passenger automobile units/h of green time per lane.

Problems Expected as a Result of Light Rail Transit Operation

The existing traffic conditions during peak hours are far from satisfactory, and the introduction of the LRT line will further increase the problems. The LRT trains will operate on a 5-min headway (300 s) in each direction during peak hours and, on the average, will interrupt traffic every 2.5 min. The occurrence of these interruptions will depend on the location of the crossing, the detailed LRT schedule (Figure 5), and the schedule adherence of the trains.

Figure 1. Northeast sector of Edmonton with light rail transit line.



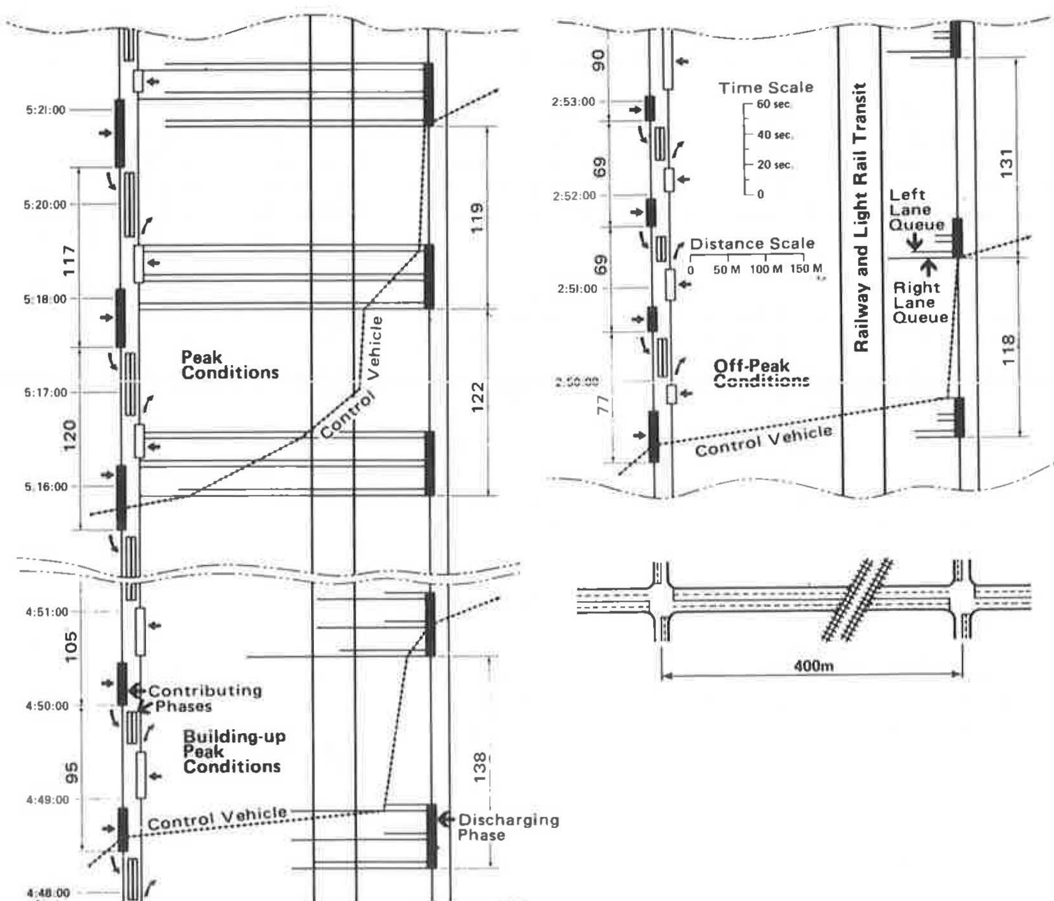
The capacity losses due to these interruptions could be considerable. The cause of these losses is illustrated in Figure 6. This time-space diagram shows the hypothetical trajectories of vehicles and the traffic shadow of a road closure at the railway crossing in a fixed-time system. Such shadows have a specific probability of occurrence. If a normal distribution of offsets between the railway crossings and intersection 2 downstream (both operating in the traffic-actuated mode) is assumed, the capacity losses are estimated to be 10 percent for simple configurations and lighter traffic conditions (e.g., area A) and up to 25 percent for more complex configurations and heavier traffic (e.g., area C).

The increased delays and the increased number of stops are also illustrated in Figure 6. The stopping occurs in front of the railway crossing because of the closure and because of the oversaturation of the downstream intersection. During the peak periods the delays and the number of stops are a function of the capacity losses. In off-peak periods, there will still be significant delays and stops because the tangential routes crossing the LRT line still carry traffic volumes at close to saturation.

The safety hazard will increase as both queuing and train frequency increase.

There will be irregularities in the LRT schedule if the safety problem is resolved by applying restrictions to the LRT operations, such as reducing speeds or inducing stops to allow queues to clear the tracks.

Figure 2. Schematized sections of real-time-space diagram for afternoon westbound traffic at railway crossing C.



Design Objectives

The design objectives to solve the problems were specified as follows:

1. The basic objective is the safe operation of both the LRT and the automobile traffic.
2. The related objectives are the minimization of the following: (a) disturbances to the LRT schedule, i.e., delays caused by disruptions at the crossing; (b) capacity losses to the road network; (c) delays to the road traffic; (d) the number of forced stops to the LRT trains; and (e) the number of stops to the road traffic.

TIMING REQUIREMENTS FOR THE CONTROL OF RAILWAY GRADE CROSSINGS

One of the elements that affects the objectives outlined above is the length of the closures of the railway crossings. In Canada there are no regulations that are specific to the operation of LRT vehicles. However, because the Edmonton LRT line used the CNR right-of-way, railway jurisdiction applies, and unfortunately, these regulations do not recognize the performance features of LRT technology.

In Canada the operation of the railways is under the jurisdiction of the Rail Transport Committee of the Canadian Transport Commission. The regulations for grade crossings are in General Order Number E-6 of the Board of Transport Commissioners for Canada.

Section I, paragraph 8 (1) of this order requires that crossing signals operate for not less than 20 s before the crossing is entered by a train at a speed in excess of 16 km/h (10 mph) and that, if the roadway distance between the governing signal and the clearance on the opposite side of the farthest protected track is more than 10.7 m (35 ft), the operating time of 20 s be increased 1 s for each additional 3 m (10 ft). Signals must continue to operate until the train has cleared the crossing. Paragraph 12 identifies gates as adjuncts to signals. The requirement for gates is a function of train and vehicular traffic.

To illustrate the differences between the timings required by the treatment of the crossing according to railway regulations and according to the rules for a signalized traffic intersection, three timings (railway crossings without gates, railway crossings with gates, and LRT crossing as a signalized traffic intersection) are shown in Figure 7.

The most efficient operation would clearly be case 3, the signalized intersection. The governing regulations, however, require the use of gates and flashing lights. The use of separate controls, one for the LRT and the other for the CNR trains, was rejected because of the hazards of dual indications for vehicular traffic. Thus, it was decided to design a control system that uses railway gates and flashing lights with some timing allowances granted by the Canadian Transport Commission for the LRT operation. In addition, the control logic was designed so that it could use the operational features of the LRT.

Figure 8 shows the locations of the LRT crossing-control and detection equipment. The following table gives examples of the sequences of events and the associated timings for one LRT train and for the extreme case of two trains traveling in different directions.

Action	Cumulative Elapsed Time (s) 1 Train	2 Trains
Train detection	0	0
Signals start flashing	1	1
Stop signal for LRT changes to proceed	2	2
Trip stop deactivates	2	2
Gates start closing	6	6
Gates fully closed	19	19
Train enters crossing	21	21
Train in opposite direction enters extended detection	–	30
Train clears crossing	31	31
Gates start lifting	31	–
Gates fully upright	38	–
Detection of train in opposite direction	–	47
Stop signal changes to proceed	–	49
Trip stop deactivates	–	49
Second train enters crossing	–	68
Second train clears crossing	–	78
Gates start lifting	–	78
Gates fully upright	–	85

The detection of the LRT vehicles is achieved through track circuits. If the controls fail to respond, the LRT-system signals maintain a stop indication, and if the train violates this signal, emergency braking is applied to stop the train before it reaches the crossing.

Under normal railway practice, if, shortly after a train has left a crossing, another train is detected coming from the opposite direction, the gates lift and lower again in a short sequence. Because of the frequency of LRT movements this is not desirable. The extended detection circuit prevents this and maintains a minimum time of 10 s between sequential gate closures to allow for road traffic.

CNR crossing control can be incorporated into the system to achieve consistent protection of the crossing. Because the rolling stock used by the railway is unable to operate in the same manner as that of the LRT, only the detection and extension features can be incorporated, but, by using these features, a railway train can extend an approach circuit for LRT and vice versa. This will result in a safer and more consistent operation than if the railway control were not integrated.

DESIGN PRINCIPLES

The basic traffic-control philosophy for the areas and intersections being discussed is the development of a system that could recover after the disruption caused by the LRT crossing closure. To implement this philosophy, three major principles for the design of controls were adopted.

The first principle is the coordination of the traffic signals so that extensive queuing across the railway crossing can be eliminated. This can be done by controlling the capacity of the upstream signals that feed this link so that the queuing in front of the downstream intersection is reduced to an acceptable length, and vehicles that arrive subsequently will then move through the downstream intersection without stopping (Figure 9).

At the same time, this measure will reduce the number of stops and delays in the system. In most cases, vehicles will be stopped only on the approaches to the upstream intersections and will move through the system on a green wave.

The second principle is the integration of the operation of the traffic signals with the LRT controls. The objective of this is to use the periods of time provided by the shadow of the red signals at adjacent intersections for the LRT crossings of the road link (the window principle). Ideally, the time provided by the window will exceed the closure timing required for the crossing, but

Figure 3. Schematized section of real-time-space diagram for afternoon eastbound traffic at railway crossing C.

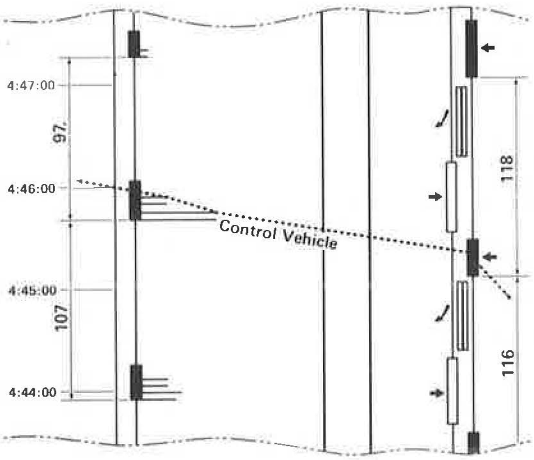


Figure 4. Schematized section of real-time-space diagram for morning eastbound traffic at railway crossing C.

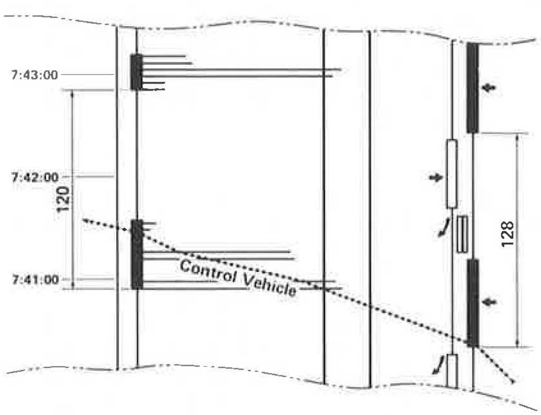


Figure 5. Light rail transit schedule and induced road closures (example).

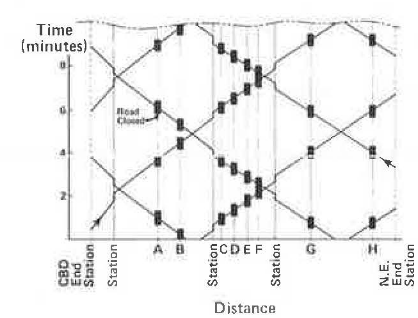
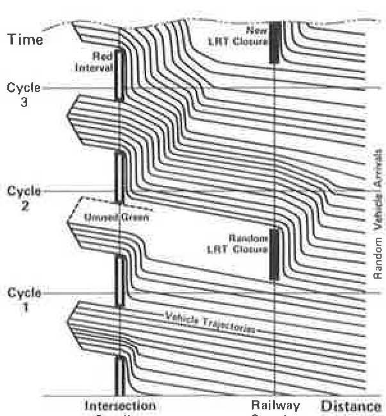


Figure 6. Schematic illustration of capacity losses, increased delays, increased number of stops, and extensive queuing caused by light rail transit crossing closure.



this is a difficult task because of the number of other constraints, such as the LRT scheduling and operation.

The following measures will be used to integrate the intersection control and the LRT operation:

1. The fixed-signal cycle lengths will be defined as an integral fraction of the LRT headways.
2. The LRT will be scheduled to arrive at the crossings during periods protected by red signals at adjacent intersections.
3. In the critical crossing area (area C), the traffic-control system will send a stop signal to the adjacent LRT station. This signal will be programmed so that, when it is released, trains will leave the station to reach the crossing at a time when a window is available. The signal will be transmitted once in shorter cycle lengths and more frequently during longer cycle lengths.
4. The operating speed of the LRT will be influenced by the traffic-control requirements. The goal will be to pass the trains through the crossings without stopping.

Figure 7. Comparison of crossing-control alternatives.

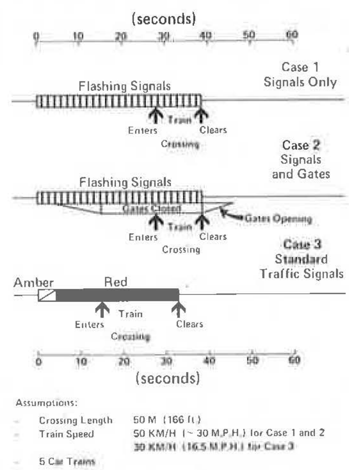


Figure 8. Locations of light rail transit crossing-control and detection equipment.

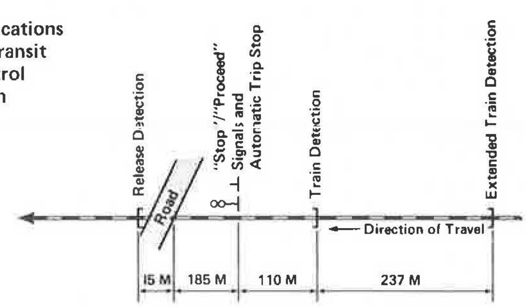
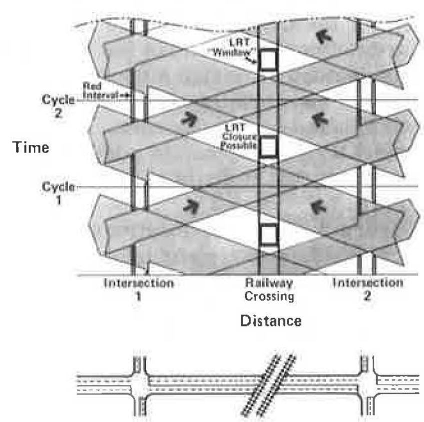


Figure 9. Schematic illustration of the window principle.



5. Although the railway train controls cannot be integrated with the traffic-control measures to the same degree as can the LRT controls, the crossing signals and gates will operate in concert for both modes.

The third principle is the incorporation of special features that are required to guarantee safety within the constraints imposed by the principles of coordination and integration. The major goal is the prevention of queues caused by railway trains, accidents, construction works at adjacent sections of the road network, failures of the control equipment, disruptions in the LRT operation, or the frequent special events in the adjacent recreational facilities. The control algorithm for these special circumstances is based on the detection of unusual queues. The subsequent actions that occur are

1. Warning drivers of the queue or the blockage ahead and advising them to keep the track area clear,
2. Restraining the traffic inflow at upstream intersections,
3. Preferentially treating phases that can relieve the congestion on critical roadway links, and
4. Introducing special phase sequencing that will maintain traffic flow in the directions unaffected by the crossing closure.

These special features will be used individually or in combinations and may be especially useful in areas where the LRT schedule adherence is questionable and where the self-recovery and window principles will be difficult to implement.

EQUIPMENT REQUIREMENTS

The hardware requirements are based on functional principles and design. They must, however, be somewhat flexible to accommodate changes in control tactics and traffic patterns. The basic equipment functions are as follows:

1. Each group of intersections adjacent to the LRT crossings will operate as a traffic-control zone that is characterized by coordinated fixed-time operation and the availability of five independent signal programs. An independent signal program is defined as one having unconstrained choice of the following: cycle length, offsets, interval sequence (program structure), and interval timing.
2. Traffic-control zones containing LRT crossings will also be coordinated in real time. The reference timing (time datum) will be reestablished at regular intervals, despite the fact that individual zones will operate with different cycle lengths. At the beginning, the program changes will be initiated by a time switch.
3. Special features will be implemented at the traffic-control zone level. They will use standard signal-control measures, similar to force off, hold, and skip phase (interval).
4. Special features will not disturb the background control program, i.e., the system will have the capability to restore fully coordinated operation immediately after traffic conditions return to normal.
5. Within the limitations described above, the system will respond to special demands (such as queue detection).

FUTURE CONSIDERATION

Some of the most critical LRT crossings will be replaced by new grade separations in the future. However, in addition to the crossings that will be retained, new grade crossings may be introduced as the LRT network is extended.

The system designed for the first line will be automatically monitored by using the available LRT control hardware. This operating experience will be an important input in the design of special features of the Edmonton computerized transportation-management system.

The use of railway rights-of-way for LRT corridors may be attractive in other cities also, and similar problems with grade crossings may be encountered. These problems should be considered early in the planning process.

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