nally set in March 1974. Considerations of time and money in a period of inflation encourage this kind of speedup.

OPERATIONS

The control system consists of a simple wayside block signal system. All red-light conditions will be enforced by magnetic inductive trip stops to provide maximum safety. Restrictive speeds of 30 km/h have been established in the subway curves, at the ends of the line, and at the approaches to all at-grade crossings. The restrictive speed zones are enforced by timed signal changes from red to green and the associated trip stops.

To facilitate traffic and train movements at the at-grade crossings, a special traffic-control system is being implemented that links and coordinates the LRT train-crossing signals with adjacent road intersection traffic signals.

The proposed service will provide 5-min headways in the peak hours for trains of two or three cars and 10-min headways at midday for one-car trains. The bus route system will be reorganized in the northeast sector to provide timed transfers between bus and rail.

The average speed of operation will be 30 km/h; the maximum scheduled speed will be 50 km/h. At midday three trains will be running; in the peak hours there will be six.

CONCLUSIONS

In 1974 Edmonton was faced with a rapid residential development in its northeast sector. After a careful analysis of the opportunities available, the least cost solution to the transportation problem was found to be an LRT line that used the CNR right-of-way. For the particular conditions in Edmonton, the LRT solution was able to be implemented within the budget of $65 million.

Calgary's Light-Rail Transit System

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This paper describes some of the background to the development of the South Corridor light-rail transit (LRT) line in Calgary. Characteristics of the city, the corridor, and the existing transit system are also presented. The results of a recent study undertaken to determine the type and timing of transit improvements are briefly summarized. Alternatives studied in detail included LRT, busways, and exclusive bus lanes; LRT was selected and implementation has begun. Finally, the paper describes the vehicles and route chosen.

This report describes the light-rail transit (LRT) system that has been approved for construction in the city of Calgary. The urban context, the evaluation process, the vehicle type, and the alignment are described.

BACKGROUND

Planning for rapid transit began in 1966 with a series of studies carried out by Simpson and Curtin Ltd. Preliminary plans for an extensive network of rapid transit lines were developed. Two of the high-priority corridors were approved in principle by the City Council. This allowed protection of the right-of-way and acquisition of more than 25 hm^2 of the required land.

Since this study was completed, several significant changes have occurred. The population has grown more slowly than was expected; the population density is lower than was anticipated; the growth patterns have shifted; many proposed roadways have not been, and probably will not be, constructed; and construction costs have increased dramatically. These changes have made inadequate certain aspects of the system originally proposed. In particular, the capital cost of the proposed 32-km grade-separated network would now cost several hundred million dollars, which is clearly unrealistic for a city the size of Calgary.

The prime function of a report published in 1973 (1) was to develop a policy combining and coordinating transportation improvements. A road construction program on a much smaller scale than previous plans was proposed. A number of interim transit improvements were recommended, including an extended express bus system, installation and expansion of the dial-a-bus system, expanded bus-shelter installations, and installation of several traffic-control measures for the priority treatment of buses. Progress is being made in each phase of the program, and an increase in ridership has been observed.

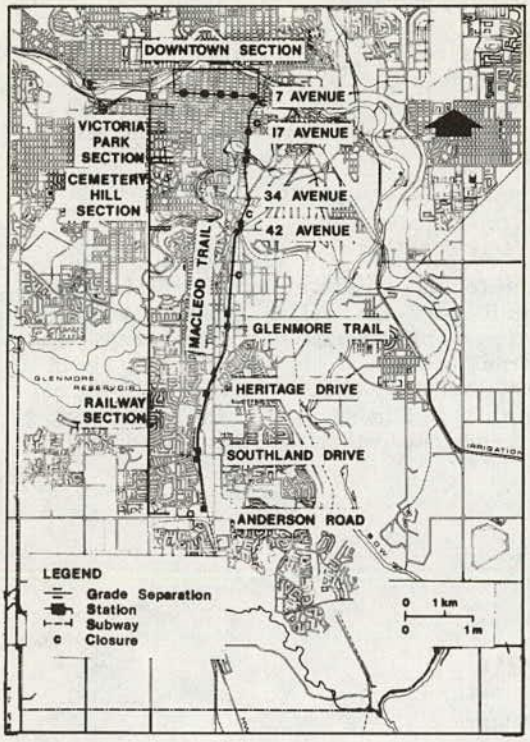
In 1975, the city of Calgary undertook two studies to examine the need for and to plan major transportation facilities. The reports (2, 3) described the need for rapid transit in the South Corridor and the staging of transit and roadway improvements. The City Council approved these reports in principle and directed the administration to proceed with functional planning and preliminary engineering for an LRT line in south Calgary.

Subsequent consideration, including consultation with officials of the government of the province of Alberta, led to the decision to commission a major, independent review of these and prior transportation studies to verify the appropriateness and costs of LRT in the South Corridor. This review was carried out by consultants, and the results were presented to the City Council in May 1977. The report essentially endorsed LRT and the council directed that detailed design and construction should start as soon as financing could be arranged. These arrangements were completed in July 1977, and implementation started on July 25, 1977, with the purchase of 27 light-rail vehicles (LRVs).

The City

In 1976, Calgary's population was 470 000, and the labor force was 207 500. The population is expected to reach 618 000 in 1986 and 778 000 in 1996. About 58 000 people, or 30 percent of the work force, are employed in the downtown area. There has typically been low-density development with a distinct separation between residential and employment areas. Despite the low density, development is contiguous, and there is little urban development beyond the city limits.

Figure 1. LRT alignment selected for Calgary.



The Corridor

The first leg of the LRT system extends 16 km to the south of the downtown area. Gross residential density is about 2000 persons/km^2. Single-family homes make up 70 percent of the dwelling units in the suburbs. Recently, higher density development has increased, and substantial opportunities for further development still exist.

A large industrial area lies to the east of the proposed line, as shown in Figure 1. In addition, two major shopping centers lie within 500 m of an LRT station.

Existing Transit Ridership

Service is provided by line-haul and feeder buses on fixed routes, express buses in the peak hours, all-day express service in major corridors, park-and-ride facilities, and a small dial-a-bus service. The existing bus fleet carries a significant portion of total trips, but it is less than the share carried by transit in some other Canadian cities of similar size. The system, which uses 410 diesel buses, carried 41 000 000 passengers in 1976. Ridership is currently 87 trips/person/year, an increase of 20 percent since 1971. In the prevailing direction at the peak hour, transit had about a 20 percent share of riders at a screenline 8 km south of the downtown area and a 35 percent share in the downtown area. Peak-hour transit demand in the corridor was 2600 persons/h in the peak direction in 1976 and is projected to increase to 4200 persons/h in the peak direction by 1982.

ALTERNATIVES ANALYSIS

The South Corridor could be expected to show a major deficiency in transportation capacity over the next two decades. This deficiency could be resolved by constructing certain road improvements and providing higher capacity transit service. Studies indicate that in the long term it will be impossible to accommodate travel demand by means of the road improvements that are politically and financially feasible. There are, however, several options.

Improvements to transit could either precede or follow road construction. If transit preceded road construction, several projects could be deferred for a substantial length of time. If the road improvements were staged first, however, transit improvements could be delayed only until the early 1990s. Potential savings, both financial and environmental, are therefore achievable only if transit precedes road construction. The effectiveness of this strategy depends on the extent to which transit increases its share of the market. This, of course, depends on the level of service and capacity offered and on the time of implementation.

Transit Alternatives

Three candidate solutions—exclusive bus lanes, LRT, and busways—were examined in detail. Previous work had demonstrated that other systems—heavy-rail transit (HRT) and personal rapid transit (PRT)—were not feasible. HRT systems were excluded because of the high capital cost. An extensive rail system on a completely protected right-of-way would exhaust the city's capacity to support debt repayment. Because of the particular characteristics of Calgary's LRT corridors, there is relatively little interference with other surface traffic; the benefits of complete grade separation are therefore small. Further, it was felt that the geometric requirements for HRT and the need for complete separation would pose unnecessary restrictions on construction staging. PRT was discarded after consideration of recent setbacks in its development. It was apparent that reliability would not be good and that development and construction costs would be too great to be borne by the city.

Comparative analyses of the three candidate modes assumed that all would operate over a 13-km surface route from the south side into the downtown area. The bus-lane system was assumed to occupy the curb lanes of Macleod Trail between Anderson Road and downtown. No stations, other than widened sidewalks with bus shelters, would be constructed. The LRT system would follow the alignment shown in Figure 1. The selected route was almost 13 km. Seven percent of the line would be underground and the rest at grade. Five structures would be built to separate cross traffic, and there would be about nine grade crossings outside of the downtown area. Twelve stations, spaced about 1200 m apart, would be constructed. The average vehicle speed would be about 32 km/h including make-up and layover time. The system is described more fully below. Minor deviations from this alignment were assumed for the busway in order to minimize the length of the busway that would be underground. All three systems would operate at grade through the downtown area on an exclusive transit mall.

Traffic Impact

A system of exclusive bus lanes would have the greatest impact on traffic because it would sharply reduce the capacity of roadways that already experience significant congestion. The interference with right-turning traffic (assuming curb lanes were used), local access, and cross traffic would make it impossible to achieve high speeds or reliable scheduling. The number of buses required would exceed the capacity (estimated at 300 buses/h in both directions) of the main transit corridor through the downtown area. This would necessitate the use of other streets for some routes, thereby increasing walking distances and again conflicting with other surface traffic. The busway would avoid most of the conflicts outside of the downtown area but would also entail the problem of congestion and capacity in the downtown area. LRT would have the least impact on traffic for several reasons. The headways would be longer, the dwell times would be shorter, and the signalling system could be more readily incorporated into conventional railway grade-crossing protection.

Flexibility to Increase Capacity

The capacity of the bus lanes and busway alternatives is limited by the available street space in the downtown area, as well as by the capacity of the stations along the line. Construction of a bus subway in the downtown area is impractical because of space limitations and cost. The LRT system would have greater capacity initially and could be incorporated into a downtown subway at some point in the future.

Level of Service

The assessment of level of service was based on a quantitative measure of travel time and the subjective assessment of comfort and convenience. The LRT alternative saves 500 000 passenger h/year compared with the busway and 1 500 000 passenger h/year compared with the bus lane. LRT and busways were felt to be comparable in terms of comfort since the improved ride quality and ventilation of the LRT offset the higher number of seats on the busway. Bus lanes would be less comfortable but could be more convenient because of the possibility of reducing the number of transfers.

Cost Comparisons

Capital and operating costs were prepared for each alternative; see Table 1. The operating cost estimates (in 1976 dollars) shown were for 4200 persons/h/direction and were based on standard 52-passenger buses or six-axle articulated LRVs. Bus lanes would be the least costly, but only because existing road space would be used. Should these lanes of traffic be replaced, the total cost of the system would be similar to that of the busway proposal. Busway and LRT costs were similar. The cost advantages of the busway are eliminated and reversed with increasing ridership. Indeed, the busway would become less economic after about 5 years of operation. It should also be noted that the annual cost of the LRT alternative is almost entirely debt repayment, while the annual cost of the bus alternative contains a large operating or labor component. LRT therefore provides some protection against wage-related inflation.

Social and Environmental Impacts

The alternative alignments and transit modes were evaluated against the following social and environmental criteria:

1. Visual intrusion—loss of privacy or views of unaesthetic features;
2. Open space—physical loss of existing public space or recreational facilities;
3. Residential—need to acquire existing housing stock;
4. Commercial or industrial—need to acquire existing commercial or industrial buildings;
5. Heritage buildings—need to acquire potential historical sites;
6. Pedestrian connectivity—reduction of pedestrian movements across the proposed LRT line or interference with pedestrian movements along it;
7. Noise impact—consideration of ambient noise readings for adjacent land use, rating increases over ambient as minor (0 to 3 dBA), moderate (3 to 5 dBA), or significant (greater than 5 dBA); and
8. Air pollution—assessment of the effect on air quality.

Table 2 summarizes the results of this evaluation.

RESULTS OF THE EVALUATION

On the basis of the evaluation summarized above, LRT was recommended as the most appropriate transit mode. LRT has less impact on traffic than the bus, and its potential to expand to other corridors and to increase capacity is greater. Annual costs are slightly higher, but the city would be protected to some extent from increasing operating costs due to inflation, growth, and reduced productivity. The environmental impact is low for all alternatives, but LRT is preferable for those alternatives that would use a new right-of-way (i.e., away from existing streets). Most importantly, however, it was felt that the level of service and capacity that could be offered would be essential in achieving long-term transit objectives.

Vehicle Selection

The transit line was designed for use by a six-axle articulated LRV. The Transportation Department has purchased 27 Düwag U2 cars that incorporate the modifications made for the city of Edmonton. This decision was taken after consideration of several factors. It is one of the largest cars available that is suitable for on-street operation. Since it was ordered by Edmonton, savings are anticipated in purchase (on the initial and follow-up orders), parts inventory, maintenance facilities, personnel training, service contracts, and so on. The car has been proven in revenue service and has a simple, rugged design, which makes it very attractive in view of the lack of LRT operating experience in Calgary and the small scale of operations. A number of minor changes (greater braking capability, anticlimbers, and so on) will be required, but none compromise the reliability or the design integrity of the car.

LRT Alignment

The LRT line consists of four distinct sections.

Railway Right-of-Way

The line will be constructed within the existing 32.8-m right-of-way of the Macleod Subdivision of Canadian Pacific Ltd. (CP). Railway service, about six trains/d, will be maintained. In the southern section (that is, south of Glenmore Trail), the line will occupy 9.5 m of the railway property. The CP line will not have to be relocated from its present position in the center of the right-of-way. Additional land will be required at the stations and has been obtained outside of the railway right-of-way. Figures 2 and 3 show typical stations in this section.

In the northern section, provision has been made to serve industrial sidings both east and west of the CP line. This is achieved on the west side by the provision of a parallel industrial lead, again within the existing right-of-way. Figure 4 shows this and other typical cross sections.

The LRT tracks will be grade separated from the industrial lead and from Forty-Second Avenue, the point at which the LRT line leaves the rail right-of-way. In addition, grade separations will be provided at Southland Drive, Macleod Trail, and Glenmore Trail.

Railway and LRT operations will be protected by conventional gates at crossings, by the usual operating rules, and by a Jordan rail (in case of derailment). The adjacent land use is primarily industrial, so little landscaping or buffering has been planned (although this would be included in adjacent parcels as they develop). There is existing residential development for about 2 km along one side of the line. Fortunately, there is also a 20-m strip of land on which some buffering can be provided.

Cemetery Hill Section

After the line leaves the railway right-of-way, it will enter a station and then follow a public street in a protected way for several hundred meters. At Thirty-Fourth Avenue it will enter a tunnel under Macleod Trail as it passes between two cemeteries. A subway was chosen for this section both because the grades would otherwise be excessive and because the available right-of-way is limited. Cut-and-cover methods will probably be used, but no temporary decking will be provided.

Table 1. Comparison of costs for bus-lane, busway, and LRT alternatives for Calgary.

Item	Cost ($000s) Bus Lanes[a]	Busway[b]	LRT
Structures	5 280	52 620	53 310
Equipment and vehicles	7 380	6 800	22 450
Property and demolition	2 520	12 520	13 420
Utility relocation	—	3 770	6 870
Engineering and commissioning	790	6 480	9 270
Contingency	160	8 222	10 530
Total capital cost	17 570	90 410	115 850
Annual capital cost	1 820	7 870	10 360
Annual operating cost	3 710	3 360	1 900
Total annual cost	5 530	11 230	12 260

[a] The capital cost for bus lanes is significantly lower than those for the busway and LRT because the bus-lane costs do not include the replacement of two road lanes taken from Macleod Trail for exclusive bus use. To be financially compatible with the alternatives, the bus-lane costs should include the addition of a two-lane roadway (or widening of an existing roadway) in the South Corridor. While this additional cost was not specifically estimated in this study, its addition to the bus-lane cost would likely bring the total cost for this option to a level approximately equal to that of the busway alternative.

[b] The busway costs shown in this table are for operation of the busway with standard buses.

The subway will be 600 m long and will emerge on the north side of the hill.

Victoria Park Section

Between Cemetery Hill and downtown, the line will operate on one side of an arterial roadway. Property has been purchased to widen the existing road right-of-way by 15 m. Minor cross streets would be closed. Figure 5 shows a typical cross section.

Downtown Section

A short subway will take the line under the four-track CP line that runs through the city. The LRT line would then emerge and run at grade along Seventh Avenue. Five stations of the type shown in Figure 6 would be provided. Important features of the stations are (a) access to the intersections at each end of the stations, (b) access to Calgary's elevated pedestrian walkway system, (c) use of extensive glazing and curved forms to reduce the apparent bulk of the station, (d) offset train-loading locations to distribute passengers over the length of the station, and (e) space for turnstiles and accumulation of passengers, should these be required.

Private vehicles would be excluded from Seventh Avenue. This route would be turned over to the LRT vehicles, buses, and emergency vehicles. The stations are generally spaced three blocks apart; buses would thus have an exclusive lane westbound and need only use the track area for one out of three blocks. They would not, of course, be allowed to stop for passengers while they were on the LRT tracks. In the eastbound direction, an exclusive bus lane would be provided for the entire length of the downtown area. Buses could drive over the rails to pass other buses or to make left turns.

The operational problems and potential delays are recognized, but these are much less costly than subway construction. It should also be noted that this system may have a greater capacity, since the subway signalling system could limit headways to 90 s, while a much greater frequency is available under line-of-sight operation on the surface.

Fare Collection

Two options are being considered for fare collection. The first is the no-barrier system used in Europe. Passengers would purchase a ticket before boarding the vehicle and would be required to validate that ticket either in a station or on the car. Inspectors, empowered to levy stiff penalties, would provide supervision and en-

Table 2. Evaluation of the social and environmental impacts of the three alternatives.

Alternative	Criteria[a] 1	2	3	4	5	6	7	8
Bus lanes								
Downtown	-1	0	0	0	0	-1	-2	-2
Victoria Park	-1	0	0	0	0	0	-1	-2
Industrial area	-1	0	0	0	0	0	0	0
Residential area[b]	0	0	0	0	0	0	0	0
Busway								
Downtown	-1	0	0	8 buildings	1 building	-1	-2	-2
Victoria Park	0	+	30 units	3 buildings	2 buildings	-1	-1	-2
Industrial area	-2	-2	0	0	1 site	-1	-1	0
Residential area[b]	0	0	0	2 buildings	0	+	-2	0
LRT								
Downtown	-3	0	0	8 buildings	1 building	0	-1	0
Victoria Park	0	+	30 units	3 buildings	2 buildings	-1	0	0
Industrial area	-1	0	0	17 buildings	1 site	-1	0	0
Residential area[b]	0	0	0	2 buildings	0	+	-1	0

Note: + = positive impact, 0 = neutral impact, -1 = minor negative impact, -2 = moderate negative impact, -3 = significant negative impact.

[a] Criteria 1 to 8 are defined in the text. [b] South of Heritage Drive.

forcement. Such a system would save hundreds of thousands of dollars annually in labor and would simplify the design and operation of the station enormously. The alternative is to man the stations and provide control through barriers and turnstiles. It is proposed that Calgary have a free zone in the downtown. Passengers would need a validated ticket to enter a suburban station and would get off at a downtown station at which no barriers or turnstiles would exist. People could enter the car free in the downtown area but would need a validated ticket to be allowed to leave an outlying station. A decision on the fare-collection system will be made after experimentation on the bus system in Calgary.

Figure 2. Typical suburban station platform.

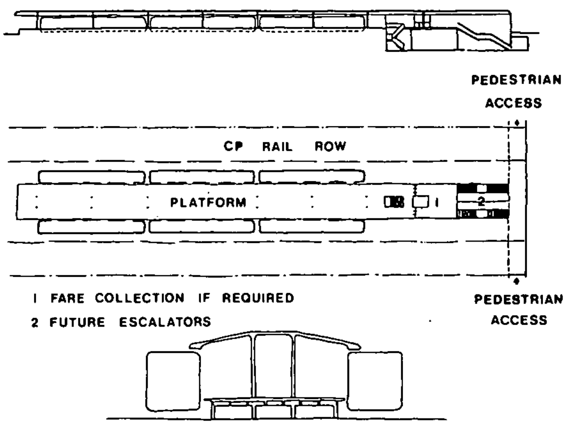
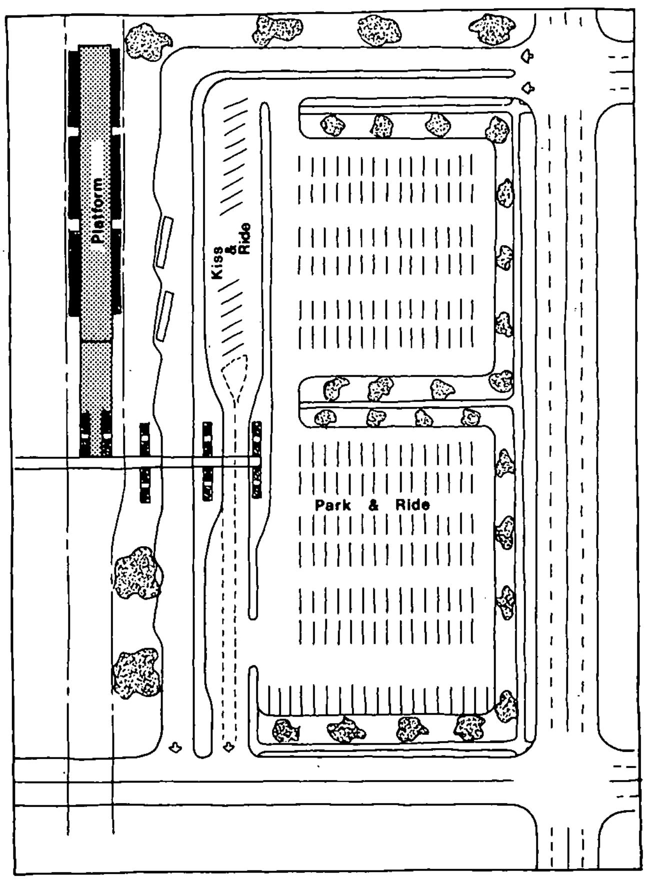


Figure 3. Typical suburban station area.



Shops and Yards

The shops and yards will be located on site at the extreme south end of the line. It is proposed to combine the facility with a bus garage. This site would have sufficient space to accommodate servicing, heavy and light maintenance, and cleaning and storage for a fleet of about 60 LRVs and 200 buses. It is anticipated that economies of scale will be realized by the joint use of this site.

Figure 4. Arrangement of LRT line and stations along railroad right-of-way.

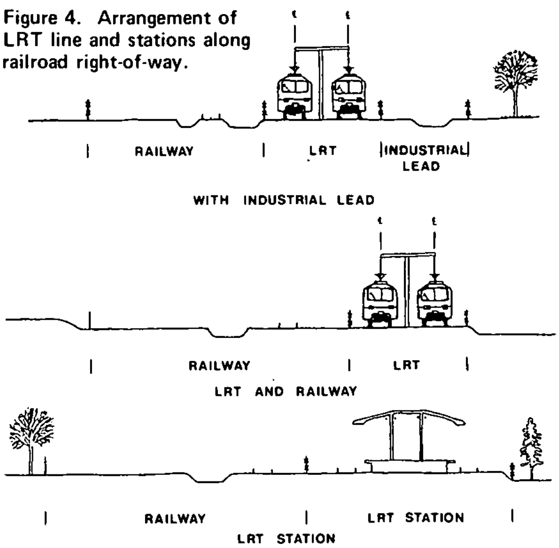


Figure 5. Arrangement of LRT line along arterial road.

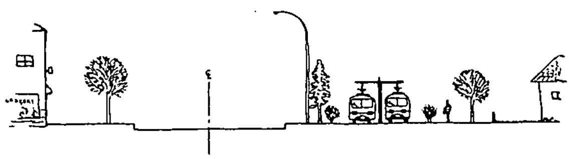
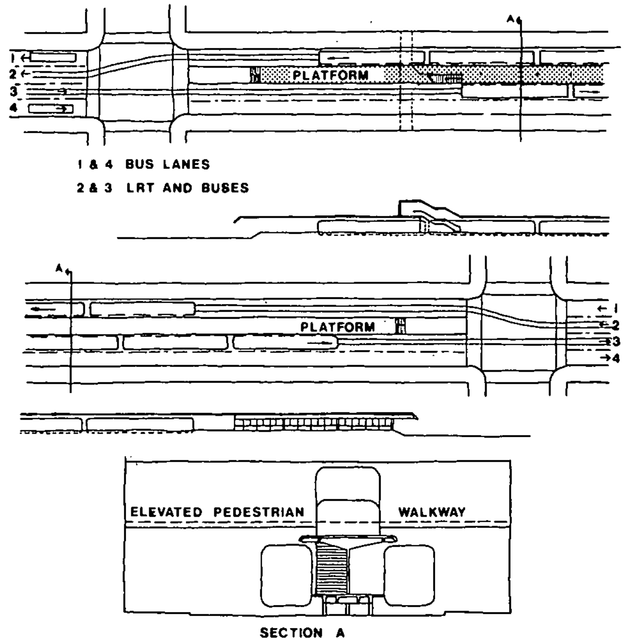


Figure 6. Arrangement of typical downtown station.



SUMMARY

In response to increasing congestion and related transport problems, the city of Calgary has conducted a number of studies of possible solutions. The most recent studies have examined the roles, costs, and impacts of roadways, exclusive bus lanes, busways, and LRT. It became apparent that long-term costs (both economic and environmental) could only be minimized by pursuing alternatives that have a strong transit component. LRT was chosen after an evaluation of alternatives that were felt to be appropriate for a medium-sized city like Calgary. Since it provides a high level of service at reasonable cost and substantial flexibility for improvement and expansion, LRT is the most suitable alternative to meet the city's objectives.

An alignment was selected in an area that has substantial redevelopment potential. The adjacent land use is such that there is little negative environmental impact and rights-of-way costs are low.

A number of at-grade crossings will be permitted in order to reduce the cost of implementation. Because relatively few roads cross the alignment, the operating speed will still be high. The flexibility to construct further grade separations in the future has been maintained. The designers, taking into account the small scale of operation and the unhappy experience of some other recent transit projects, have developed a technically unsophisticated solution. Economy, ease of implementation, and simplicity of operation and maintenance have been the cornerstones of the planning philosophy.

ACKNOWLEDGMENTS

Much of the work summarized in this paper was carried out for the city by Underwood McLellan and Associates Ltd., De Leuw Cather Canada Ltd., IBI Group, and L. T. Klauder and Associates. Their efforts and subsequent implementation have been generously supported by the province of Alberta through Alberta Transportation.

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Buffalo's Light-Rail Rapid Transit System

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The 1976 agreement in principle by the Urban Mass Transportation Administration (UMTA) to participate in the financing of Buffalo's $336 million light-rail rapid transit (LRRT) project was the culmination of almost 10 years of planning by the Niagara Frontier Transportation Authority and the western New York community for an integrated bus and rail rapid transit system. At least 5 more years of design development and construction lie ahead. This agreement also marked the end of a lengthy, and often frustrating, alternatives analysis process that helped to guide UMTA's development of federal policy on major urban mass transit investments. Buffalo will be the first U.S. city to have a completely new rail transit project that features the advantages of light-rail technology. This paper describes the LRRT project and reports on the results of the alternatives analysis process. Comparative cost-effectiveness statistics for various transit alternatives are included in the paper. The current phase of project development (general architecture and engineering) is described, and a schedule is given for the completion of the system.

June 10, 1976, was a very significant day for Buffalo. On that day, former U.S. Secretary of Transportation William T. Coleman, Jr., and former Urban Mass Transportation Administration (UMTA) Administrator Robert E. Patricelli committed UMTA in principle to participate in the financing of construction and implementation of a 10.3-km (6.4-mile) light-rail rapid transit (LRRT) system in Buffalo. This culminated almost 10 years of planning and design effort by the Niagara Frontier Transportation Authority (NFTA), local governmental agencies, and the Buffalo community, bringing the dream of improved public transportation for the area to fruition. Five more years of effort lie ahead but, with the assurance of federal financing for the project, the job can be tackled with much more enthusiasm.

LRRT is the term given by the NFTA staff to the 10.3-km rail component of an improved public transportation system for the NFTA area. It is a compromise solution derived from the analysis of rail alternatives studied for the system. LRRT combines the best features of both the heavy-rail transit (HRT) and light-rail transit (LRT) alternatives. Its annual operating and maintenance costs are minimized by eliminating on-board fare collection and using high-platform loading of vehicles. Maximum alignment flexibility is maintained in order to operate, wherever practical, at grade. Full system service can be provided for the nonambulatory handicapped.

The LRRT system was recommended by NFTA since it is cheaper to construct than HRT and can be operated more economically than LRT, while retaining most of that mode's flexibility. This is particularly true as the extended system alternatives are compared. The 10.3-km line is the initial portion of an approximately 27-km (17-mile) rail system that will eventually serve Buffalo, Amherst, and the Tonawandas with direct rail service. The initial network of integrated bus and rail service is shown in Figure 1. Future extensions to both Amherst (B) and the Tonawandas (C+E) are also shown. Figure 2 depicts the construction methods and stations of the system. Figure 3 provides a profile of this line.