solicited for the following items, which were then stored in city facilities and provided to contractors as city-furnished materials or equipment:

1. Girder and tee rails and accessories—3.6 Gg (8000 tons),
2. Timber ties—57 000,
3. Feeder cables—427 km (1 400 000 ft), and
4. Rectifier units for 25 substations.

The first LRVs for Muni are currently scheduled to be delivered to San Francisco beginning in June 1978 at a delivery rate of approximately 10 units/month. Muni Metro service will be inaugurated in late 1978 and complete service is anticipated by summer 1979.

Edmonton's Northeast Light-Rail Rapid Transit Line

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Edmonton's light-rail transit (LRT) line has a total length of 7.2 km, 1.6 km of which is in subway. The line goes from the central business district (CBD) to the northeast sector of the city and uses the Canadian National Railways right-of-way. The project was approved at $65 million and is currently below estimates as well as ahead of schedule. The LRT line is the result of a balanced transportation plan that was finally adopted in 1974 to serve a city of nearly 500 000. The subway portion has two underground stations with full mezzanine floors. The mezzanine floors are part of an overall pedestrian system and connect with the basements of adjacent buildings. The subway was built to accommodate the largest standard subway car. The equipment specifications for the 14 articulated cars were based on performance and proven reliability. The construction methods used caused a minimum of interference in the CBD. Since relatively small portions were let successively, local contractors were able to use proven techniques to handle the work on a fixed-price basis. Despite the severe inflation of 1975 and 1976, costs were kept within reasonable limits. The proposed service will provide 5-min headways in the peak hour, giving a capacity of 5000 passengers/h. At midday the headway will be 10 min. The LRT line will be fully integrated with the bus transit system, and timed transfers will be provided between bus and rail. The LRT line in Edmonton makes use of available opportunities and provides the least expensive solution to the transportation problems of the northeast sector and its rapid residential development.

In September 1974 the city of Edmonton turned the first sod on a 7.2-km light-rail transit (LRT) line to serve the northeast sector of the city; inauguration of the service was scheduled for spring 1978. Extensions to this line and the construction of other lines are in the planning stages.

The LRT line under construction consists of a 1.6-km length of subway in the central business district (CBD) that has two underground stations and a 5.6-km surface section, which is contained within a Canadian National Railways (CNR) right-of-way, that has three surface stations. The line will use 14 articulated cars and will provide a peak single-direction capacity of 5000 passengers/h. The LRT line will be fully integrated with the Edmonton Transit surface bus system, which currently operates 590 buses that carry 57.1 million passengers annually, using the timed-transfer concept. The capital cost of this project is estimated at $65 million; at the present time approximately 99 percent of this project has been contracted, committed, or completed.

PLANNING

Edmonton has grown rapidly since World War II from a population of 160 000 in 1951 to 451 000 in 1976. The CBD has seen intensive high-rise development, while at the same time extensive residential development has occurred on the periphery. Older developed communities throughout the city are normally well maintained or redeveloped by private enterprise. City planning has a very active role in Edmonton and is constantly involved in forecasting studies, preparation and assessment of plans (at district and subdivision levels), and administration of zoning and development controls. The city's departmental organization provides that all municipal functions, such as engineering, utilities (the city owns its own electricity, telephone, and water utilities), traffic, and parks, work closely with the City Planning Department.

These developments in Edmonton have had a major impact on the transportation facilities and systems. Several major transportation studies have been conducted since 1960 and have recommended solutions ranging from a freeway network to a full rail rapid transit system, but these plans could not be implemented because of a lack of funds and difficulties in establishing rights-of-way. These studies and the general situation were reviewed in 1968, and a revised, more balanced approach was recommended that put greater emphasis on developing the arterial roadway system and improving the transit system to handle more of the peak loadings. Certain LRT routes were recommended for detailed investigation in corridors where there appeared to be available separate rights-of-way.

As a consequence of this review and subsequent public hearings in November 1972, a general transportation plan was finally adopted by the City Council on July 15, 1974. In the analysis of solutions for the transportation problems of the northeast sector, several alternatives were considered. Because it is limited by the river and the railway line, the existing road network was operating at capacity in the morning and evening peak hours. While the situation existing in 1974 was just tolerable, the new areas being developed in the northeast would overload the roadway system. The options considered were therefore the following.

1. A northeast freeway option: The transit compo-

nent would require 70 buses in the peak hours, including express services for the corridor. The impact of the freeway option would be severe on several neighborhoods. Land acquisition costs would be substantial. Because of the attractiveness of the roadway system, the transit patronage was expected to be half that of any of the public-transportation-oriented alternatives.

2. An all-bus option that would use 150 buses in the peak hours, including express services through the central area of Edmonton: The large number of buses would be expected to handle the majority of the growth in passenger peak traffic from the new northeast development area, but the buses would compete for limited roadway space and produce additional congestion. Allowances for bus priority methods would make it possible to maintain at least 1974 bus speeds.

3. An integrated bus and LRT option: This would use 75 buses in the peak hours, mainly as feeders and cross-city services, and 14 LRT cars on the Northeast Line. The LRT line would operate as an integral part of the transit network (only the hardware would be different). The same flat fare, with free transfer between routes and monthly passes, would be applicable.

In comparing the three alternatives, the capital and operating costs could be estimated and assigned, but the revenue allocations were somewhat arbitrary. The cost estimates were related strictly to the city's budget and did not include savings in time or other such factors sometimes included in economic analyses.

The justification for the project was based on the effect that the various alternates, which would provide approximately similar service, would have on the city budget. Edmonton did not have rail transit operating costs available, so Toronto's operating costs were used in the original estimates.

The initial calculations in 1973 allowed for a 6 percent annual inflation in labor costs and a 4 percent inflation in construction costs. The annual cost impact was then calculated for 1978 (the earliest year any of these alternatives might be implemented). In estimating revenues for the all-bus system it was assumed that fares and passengers would continue to increase, maintaining a constant deficit. In 1973 the budget impact (in terms of net annual cost to the city) was calculated and yielded the following results for 1978, allowing for inflation:

Option	Net Cost to City ($000 000)
Freeway	6.2
All-bus system	2.0
Integrated bus-rail system	1.5

By March 1974, it was clear that the calculations should be reviewed. Inflation was far more severe than expected, ridership had increased more than originally anticipated (but not enough to offset inflation), and fares had remained constant. The 1974 recalculation showed the following results:

Option	Net Cost to City ($000 000)
Freeway	9.7
All-bus system	5.4
Integrated bus-rail system	3.7

After 1974 the freeway option was not recalculated, but the provincial government made available capital and operating grants for transit; this made a substantial difference in the annual budget costs to the city. The capital grants could be applied either to buying buses or to constructing rail transit:

Option	Net Cost to City ($000 000)
Freeway	9.7
All-bus system	1.1
Integrated bus-rail system	0.2 gain

Every year at budget time, these estimates have been updated. Estimated costs have been replaced with actual costs where possible. The relative attractiveness of the integrated bus-rail option has remained the same despite inflation.

The City Council approved the construction of an LRT line to serve the northeast section of the city in August 1973, and a local engineering firm was commissioned to do preliminary design and estimating work for the project. Emphasis was placed on keeping the system and its functions simple and as inexpensive as practical from the outset. By the end of March 1974, this preliminary work was completed, and the City Council confirmed the plans for the line; approved the budget for the construction of the project, which was then estimated at $54.7 million; and called for the construction to be completed by July 1978, subject to obtaining funding assistance. The province of Alberta announced in June 1974 an urban public transit capital assistance program to provide $45 million over a 6-year period; the City Council allocated these funds to the LRT project. Due to severe inflation in 1975 and 1976, the budget had to be reviewed in 1976, and the estimated costs were raised to $65 million.

PRINCIPAL FEATURES

Subway Portion

The LRT line has a 1.6-km subway portion in the CBD that has two underground stations; see Figure 1. In order to allow for any future eventualities, the geometric standards chosen were for the largest standard car then on the market, the Toronto car. The curve radius used in the tunnel was 160 m.

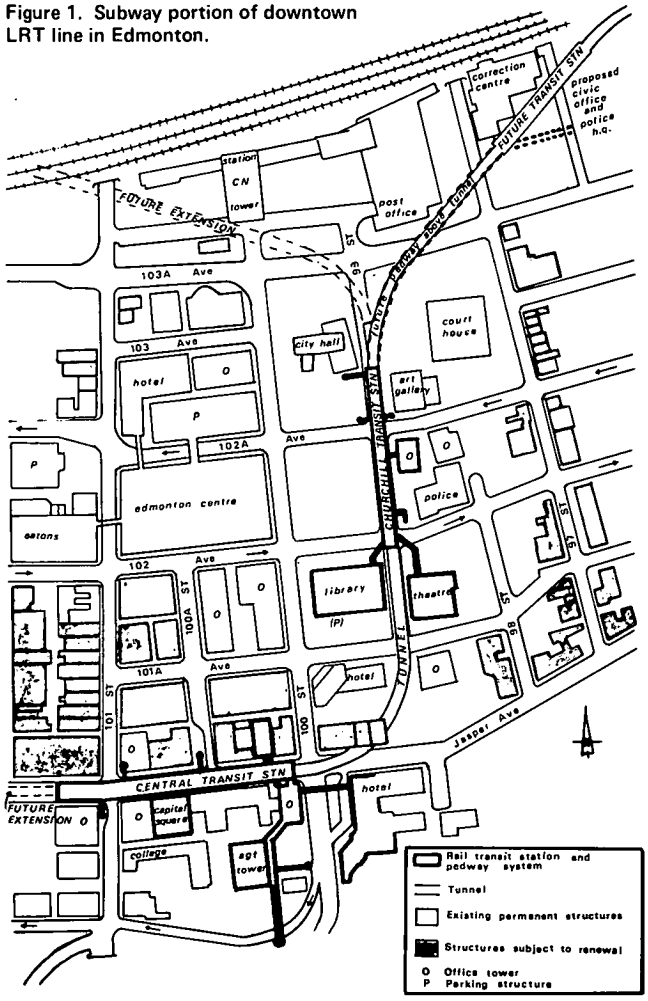
The stations are of the conventional subway type; they have a mezzanine floor that runs the full length of the station above the track and platform level. The mezzanine floor is connected with the pedway system that is being developed in downtown Edmonton. The mezzanine floor allows for interconnection with the basements of adjacent buildings. This floor has a clear span of 18.6 km, and space is provided for future commercial development.

Just before the point at which the subway surfaces, a third station shell has been built. The area east of 97 Street is subject to redevelopment, and this station can be activated when this redevelopment occurs. Immediately north of the Churchill Station, a wye-shaped stub has been built into the cut-and-cover portion of the subway to allow for a possible future extension to the north or northwest.

Surface Portion

Edmonton has been provided with a wide railway right-of-way to the northeast that cuts diagonally across the north-south and east-west grid pattern of roads. The original rights-of-way of the Canadian Northern Railway System and Grand Trunk Pacific Railway were side by side, leaving at present a space for two tracks and a platform between them. This space is rented from the

Figure 1. Subway portion of downtown LRT line in Edmonton.



CNR (a crown corporation formed from the amalgamation of these two railways) for $65 000/year.

The area that is served by the Northeast Line includes several special major destinations—Clarke Stadium, the Coliseum, and the Exhibition Grounds. In addition there is rapidly increasing residential development in the area. Stations have been located at the crossings of major arterial streets, thus allowing easy integration with the surface bus system. All except two of the crossings will be at grade. The system will be protected by signals that will be integrated and interlocked with the traffic control system and the railway operation. The signal system is described in more detail in the paper by O'Brien, Schnablegger, and Teply elsewhere in this Report. The two intersections that are grade separated are at 118 Avenue and Santa Rosa Road. It will be possible to have grade separations at other intersections in the future if it becomes necessary and funding is available.

The basis of operation is that there shall be no interference with the main line of the CNR. The subway portal lies between the CNR tracks, which provides in effect a grade separation; a second grade separation has been constructed at the main east-west CNR line just south of Belvedere Station.

The one crossing at grade with the CNR is at the rail transit car shops. The old Cromdale streetcar barns were located adjacent to the rail transit line. These barns were recently used only for storage, and the newer sections are now being refurbished. All equipment can be stored indoors; the cars will be assembled and outfitted by Siemens Canada Ltd. in these car shops. The entry into the yard is only suitable for LRT equipment and uses a track radius of 26 m.

The trackage has been designed with a well-graded, compacted, and drained subgrade, 0.6 m of crushed rock ballast, number 1 treated ties, and 45-kg rails—a high standard designed to reduce maintenance costs. The wheels of the cars have been contoured to the standards of the Association of American Railroads.

In the tunnel there are a few test sections that have a rubber mat placed below the ballast. In addition, the ties in the tunnels have been treated with phenol chloride to avoid the odors of the normal creosote-treated ties. The use of ballast in tunnels will reduce vibration and noise.

EQUIPMENT

The specifications for the equipment stressed the performance required rather than details of the car features. The primary aim was to use the production and designs developed for other customers in order to hold costs to a minimum, since the specific requirements for Edmonton were few. The second aim was to select a simple, proven vehicle. The Frankfurt U2 car was selected from the proposals received, since it provided the capacity required at the least cost and had 7½ years of experience and operation behind it; see Figure 2. Some relatively minor modifications were required to suit Edmonton's conditions, including extra heating, double windows, and a continuous-level floor for high-platform loading. It is possible to convert the cars to high- and low-level loading if that is required in the future.

The cars will be finally assembled locally; the local input will consist primarily of the wiring and assembly of the control panels. The installation of carpeting and the fabrication and installation of seating will also be done locally. The Edmonton model is now designated RTE 1. Fourteen articulated cars were ordered from the manufacturers, Siemens Canada and Düwag; the cars will provide a peak-hour capacity of 5000 passengers in one direction.

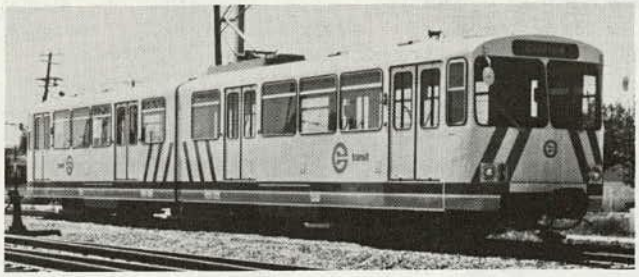
CONSTRUCTION

The Central Station, which will be the downtown terminal, is located on the busiest east-west avenue (Jasper Avenue) at the intersection of the busiest north-south street (101 Street). The year before subway construction was begun, the sewer and water utilities were placed under the sidewalk into two separate oval-shaped tunnels (1.8 m by 1.2 m).

The construction method had to cause a minimum amount of interference and disruption. The station is 18.6 m wide, 213 m long, and 15.2 m deep. The construction method allowed traffic to be restored 4 months after work began. A more detailed description of the time-saving method used is worth describing.

Holes for tangent piles 1.1 m in diameter were bored down through the soil. Reinforcement cages were then inserted, and concrete was poured. Every fifth pile came to the surface, while the four intermediate piles were stopped at the mezzanine level. A longitudinal excavation was then made along the lines of piles, and formwork was placed for a reinforced concrete grade beam. This beam was poured in place. This beam was 1.55 m wide and 2.10 m deep. Interlocking steel sheet piling was then driven on the property side of the grade beam down to the mezzanine level. Future access can therefore easily be provided to the basements of adjacent buildings by cutting through this sheet piling. The

Figure 2. Edmonton's light-rail vehicle.



owners of adjacent properties were responsible for any costs of connecting to the mezzanine floor.

The street surface was excavated after the sheet piling was in place. The excavations were dug as deep as time permitted but, in any event, not deeper than the mezzanine level.

Precast, prestressed standard highway bridge girders, which weighed 36 Mg and were 1.5 m wide and 1.8 m deep, were then placed, spanning the 18.6 m between the two grade beams. The beams were then grouted together. A waterproofing membrane was then applied. This was overlaid with 5-cm styrofoam insulation to minimize frost penetration. A lightweight aggregate concrete surface and a final 13-cm reinforced concrete pavement were then poured to the prescribed contour of the street surface.

After the pavement had been restored, the remainder of the soil was taken out by means of a ramp that was constructed into a side street. Excavation was first completed to the mezzanine level, and strut beams were poured on the excavated ground surface using sand as a trim. The mezzanine floor was then poured over these beams.

The excavation was then completed below the mezzanine level down to the track level. During this process the integrity of the foundations of adjacent buildings was protected by means of a temporary system of movable steel struts to prevent the bottom of the tangent piles from kicking in. When construction was completed, the track slab provided this bracing function.

The same method of construction was used at the Churchill Station and for the cut-and-cover construction northeast of City Hall. The remainder of the construction used open-cut and poured-in-place methods.

During the construction process, steel link fencing was used to protect the public while maintaining high visibility for the work in progress. This interesting feature of downtown life was used by the merchants along the streets to their advantage in promoting business during the 4-month closure of Jasper Avenue. In fact, many merchants enjoyed better-than-normal business during this period.

Central Station on Jasper Avenue and Churchill Station are connected by twin tubes. These tunnels were mined by means of a mechanical mole manufactured by Lovatt of Toronto. The contractor for this portion was the city's own sewer department, which has extensive experience in the tunneling of trunk sewers in Edmonton. The twin tunnels, which are 230 m and 220 m long, curve between the two stations and go underneath several existing structures. One building, the Plaza Hotel, was approved for construction when the LRT project was still in its early planning stage. Its foundation piles were therefore so placed that the two tunnels could be mined without any interference. Two other, older buildings required underpinning. A fourth, a two-story concrete-block building required no underpinning; the soil removal was so well controlled that no wall cracking or other damage to the building occurred.

It should be noted that the city of Edmonton is blessed with excellent soil conditions. The geology is perfect for tunneling or for cut-and-cover operations. There are no groundwater problems, since the groundwater is well below the subway grade. As a result of previous work done at the University of Alberta, the behavior of the till could be predicted with accuracy. The settlement above the tunnel was very small indeed (less than 1 cm).

CONSTRUCTION STRATEGY

The strategy selected for contracting was one in which the work was tendered in relatively small portions (approximately $1.5 million to $4 million each). The designs prepared used proven techniques and methods known to local contractors. Designs of subsequent portions of the project have taken advantage of the experience with previous contracts. Alternate designs have been prepared for many of the sections, and contractors have been encouraged to bid on their own alternatives as well. This approach has enabled a larger number of local contractors to undertake these jobs.

At the same time, these smaller portions could be let at a fixed price, since a contractor could see substantial completion of his work within a year's time. Prompt payment on progress payments has enabled contractors to keep interest costs low. By removing many of the uncertainties with respect to inflation of costs and making quick payment on construction expenditures, prices could be kept relatively low. In fact, the fixed prices then played a major role in maintaining a fast pace of construction, since inflation created the bonus or penalty to the contractor.

The project management team was kept small; the maximum staff was 11 persons including secretaries. When contracts got under way, the staff's prime function was to ensure efficient coordination with other contracts and agencies and to minimize delays or obstructions to the contractors in the performance of their jobs. In the management of the project there has been an efficient and close liaison between the owners, contractors, and consultants.

COSTS

The overall costs were approved at $65 028 943, $45 million of which is being provided by the province of Alberta at the rate of $7.5 million/year (1974 to 1979 inclusive). The balance is obtained from debenture borrowing by the city of Edmonton. The debenture will be repaid from the revenues of Edmonton Transit.

The original cost estimate in March 1974 was $54.7 million. This estimate included expected inflation of 12 percent/year during the construction period. Unfortunately the inflation in construction prices in 1975-1976 was greater than anticipated. In addition, the original estimate for equipment was based on Toronto's latest bid, which was $3 220 000. Allowing for inflation at 12 percent for 2½ years, the financing estimate was $4 402 700, but the actual bid was $7 745 000. Another unexpected cost was a $4 million increase in CNR's estimate for relocating their signal cables and tracks where required.

At the present time, all but $380 000 of the work has been contracted or completed, and it is estimated that the cost to complete the project will be about $100 000 below the approved budget of $65 million.

Delivery of the cars started in April 1977. Testing of the equipment and various systems is now being carried out. Revenue service is scheduled to begin in February 1978, about 6 months ahead of the date origi-

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.