Application of Simulation and Animation To Analyze Light-Rail Transit Operations

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Application of computer simulation and animation to analyze light-rail transit networks is described using a case study of the city of Calgary to investigate alternative alignment strategies. Features of the microcomputer-based simulation method are also described. The model includes an animation display that allows the planners to visually monitor a transit system in a laboratory setting. Trajectory diagrams and level-of-service estimates are also available from the proposed simulation method.

The development of simulation models for analysis of transit operations has been attempted in a number of cities. In order to analyze relative merits of various improvement strategies, the public transit operator needs to estimate the level of service provided by a particular operation when changes are made. The proposed simulation approach has the attraction that complex relationships among various operational characteristics can be realistically modeled. The simulation model also allows for experimentation and fine-tuning of operational procedures.

However, the simulation approach has not yet achieved widespread acceptance because of deficiencies such as the site-specific nature of the models (*1,2*), validation difficulties, and lack of portability of the simulation models available to transit operators (*3,4*).

Andersson (*3*) showed a new direction for simulation modelers by incorporating the ability to output graphic frames that display the instantaneous location of vehicles along the route. This output enhancement was a major improvement to the simulation approach, because the ability to visually monitor the simulated operation has largely eliminated the black box nature of the model. The model presented in this paper has advanced the graphic frames concept to the animation stage by exploiting microcomputer technology.

Simulation applications of various degrees of complexity have been reported for tram operations in cities such as the Hague, Melbourne, and Toronto (*4–6*). However, their dependency on mainframe computers makes demonstration difficult at locations not linked to the particular computer. A common feature of these models is that they have been developed for specific projects at specific sites.

Simulation Model

The simulation model described in this paper, LRTSIM, is applicable to light-rail transit (LRT) operations. Light-rail trains often interact with street traffic because exclusive right-of-way may not be available throughout the transit system. Therefore, there are similarities between a tram operation and an LRT operation from the point of view of simulation modeling. As a result, the basic structure and concepts included in the TRAMS package (*6*) is found to be useful in the development of the LRT simulation model. However, LRTSIM is developed on a microcomputer (IBM-compatible) using BASIC computer language, whereas the TRAMS package was based on a minicomputer using FORTRAN-77. Furthermore, significant modifications have been incorporated into the two submodels included in the simulation package described here. These submodels relate to processing of passengers and traffic signals and are described in detail in a later section.

Both software portability and application portability are considered in the development of the simulation package. Software portability is ensured by developing the program on a well-accepted microcomputer. Application portability is ensured by the data-base structure, which allows specification of new networks and operational scenarios. Other useful features such as animation facilities and the self-contained data handling system are described in the next section.

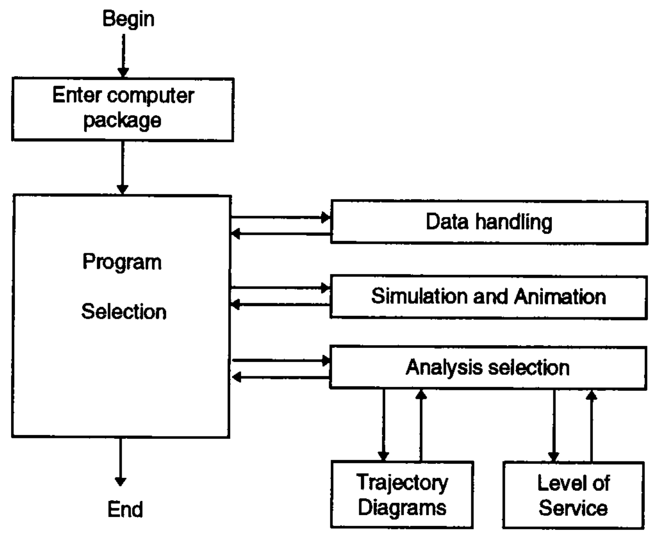

FIGURE 1 Simplified flowchart of LRT simulation package.

Components of LRTSIM

The computer program developed for simulation of LRT operations consists of three main components, responsible for data handling, simulation and animation, and analysis. Generally, the modeling activities take place in the above order. The method of conducting the activities in the context of the simulation package is described in the following sections.

The overall simulation consists of seven modules as illustrated in the flowchart shown in Figure 1. Upon entering LRTSIM, the user sees the initial identification screen and enters the module for the selection of modeling activity. The menu displayed by the above module allows the user to activate the desired modeling activity. Once a particular modeling activity is completed, program control goes back to the modeling activity selection module, and the program user can then select a different activity or exit the program.

Figure 1 also shows that the analysis section consists of three program modules. They are the analysis selection program module, the program module for developing trajectory diagrams, and the program module for computing the level of service provided by the simulated transit operation.

Data Handling Component

The data handling component is developed for efficient management and editing of files. The program user is able to create and modify all data files within the program environment. The color graphics display, extensive use of menu systems, and onscreen instructions are combined to ensure that the data entry process is a pleasant and efficient task. Furthermore, the data handling section allows the program to manage a number of data bases. For each operational scenario, there are nine data files describing the route, transit demand, vehicle, and operational characteristics. The simulation package is readily applicable to LRT operations in any city by modifying the data base using the data handling component.

Simulation and Animation Component

The simulation and animation component is responsible for simulation of the LRT operation described by data files created in the previous section. An important addition to the simulation model is the animation interface, which displays the current status of the simulation on the computer monitor. Animation allows the analyst to visually monitor the simulated operation. Validation of the model is simplified by the use of animation because programming inaccuracies are readily detected on the animation display.

The color graphics animation display contains zooming capabilities as well. Thus the planner can concentrate on a particular section of the network on the animation display while the networkwide simulation is being carried out.

Animation can be used to display the following: (*a*) the transit network (in line diagram form) showing the routes, station locations, and signal locations; (*b*) current location of trains; (*c*) prevailing traffic signal phases, and (*d*) simulation clock.

The program automatically selects the scales for the network display to make use of approximately 95 percent of the computer screen. Therefore, in general, the scale selected for the north-south direction of the display often differs from the scale adopted for the east-west direction. Nevertheless, the program allows the user to modify animation display scales by activating the appropriate menu item. The program also selects the spacing of animation update locations along the routes to ensure relatively smooth animation of train movement.

Simulation and animation can be temporarily suspended at any time in order to select one of the following options: (*a*) switch animation on or off, (*b*) zoom in to a particular area of the transit network, (*c*) select from one of the scaling options for the animation display, (*d*) use equal scales in both north-south and east-west directions of the network display, or (*e*) stop the simulation and exit from that particular section of the program.

The program collects and stores data from the simulated operation according to the specifications stipulated in the data base. For example, if data are required to construct time-distance trajectory diagrams of the operation, the program stores data related to time at which trains are observed at each animation update location. Additional information related to passenger loadings, passenger waiting time, and train arrival and departure times at stations is collected if level-of-service measures are also required.

Analysis Component

As stated earlier, the analysis section of the program provides (*a*) trajectory diagrams and (*b*) the estimation of measures of service related to the simulated transit operation. Measures of service such as the mean and standard deviation of travel time, vehicle occupancy, and waiting time of passengers are reported.

Simulation Method

The event update simulation method used ensures that the events are processed in chronological order of occurrence in the transit operation. The method uses an event selector, an event scheduler, and a number of event processors. The various event processors submit future events to the event scheduler, which sets them up in a queue of events in chronological order so that the event selector can choose the next event to be processed. An efficient method of event scheduling particularly suitable for microcomputer-based simulations is included in the simulation model. The above method uses two data arrays, one for the chronologically ordered events in the near future and the other to store all other events in the order of their submission.

There are seven submodels that simulate the following features of the transit operation: (*a*) route characteristics, (*b*) vehicle characteristics, (*c*) dispatching of vehicles, (*d*) boarding and alighting of passengers from multiple-door trains, (*e*) progression of vehicles, (*f*) traffic signal characteristics, and (*g*) LRT interactions with other traffic.

The two submodels described below are significantly different from the TRAMS model mentioned in an earlier section.

Passenger Boarding and Alighting

The submodel for passenger boarding and alighting accounts for passenger handling at the stations of the transit operation. This submodel satisfies the behavioral characteristics described by Wirasinghe and Szplett (7). Figure 2 provides a schematic description of the method of computing passenger handling time at stations. It is assumed that passenger handling time at a particular station is determined by passenger queue processing time at the train door with the longest passenger queue. The passenger queue consists of boarding passengers as well as alighting passengers. It is shown in Figure 2 that the

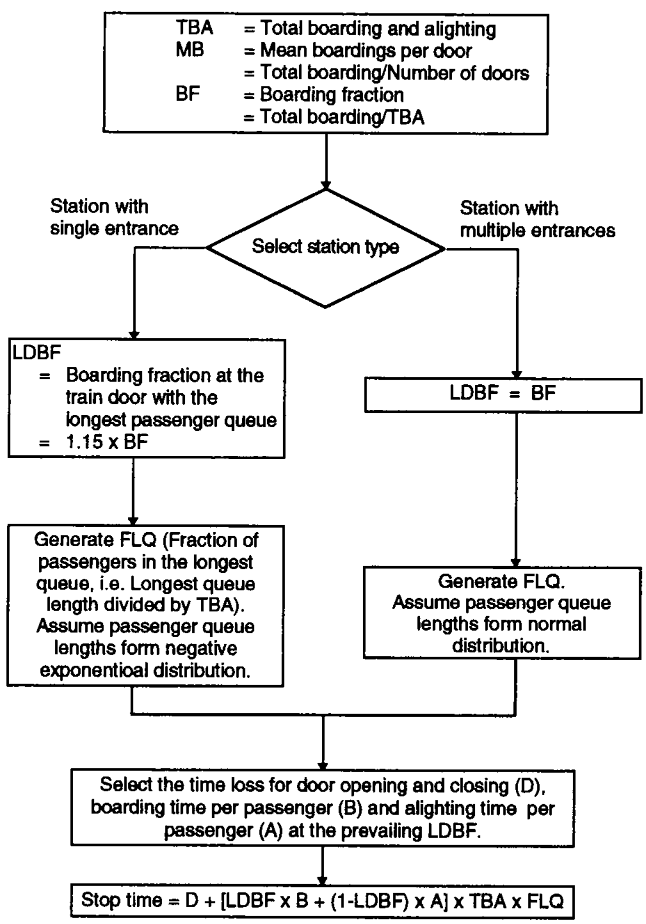

FIGURE 2 Method of computing passenger handling time at stations.

determination of the longest passenger queue during the simulation depends on the type of station. Stations with multiple entrances have passenger queue lengths that follow a normal probability distribution, whereas stations with a single entrance have passenger queue lengths that follow an exponential probability distribution. It is also observed that the fraction of passengers boarding from the longest queue is not significantly different from the fraction of all passengers boarding the particular train when there are multiple entrances leading to the station platform. However, when there is only a single entrance to the station platform from the outside, the fraction of boarding passengers in the longest queue is on average 15 percent greater than the fraction of all passengers boarding the train.

Traffic Signal Characteristics

The simulation model is able to account for three types of traffic signals, as described in the following.

Conventional Street Traffic Signals

Conventional street traffic signals control the progress of light-rail trains when the train operation shares the right-of-way with street traffic. For the purpose of the simulation model, the amber phase is disregarded by including it in the red phase of the traffic signal. The street traffic signal controller in the program allows for fixed cycle phase arrangements and the specification of phase offsets from adjacent traffic signals.

Train Signals

The simulation model also allows for train signal block operations. When a train enters a route segment between two train signals, the signal leading to that particular segment is set to the red phase. At the same time, the signal leading to the route segment just vacated by the train is set to the green phase. The above method protects any other trains entering the route segment occupied by a particular train.

Interlocking Train Signals

Interlocking train signals form a special category of train signals. They are installed in the proximity of train route merge and intersection locations. This particular type of signal prevents more than one train from occupying a merge area of an intersection. Therefore, when a train enters an interlocking segment, all signals on approaches to the particular interlocking segment are set to the red phase to ensure conformity with safety requirements.

Comparison with Field Observations

Comparison of actual field conditions with results from the simulation following existing operating conditions have shown that LRTSIM is able to make reliable estimates of the level of service. Table 1 shows some parameters considered during the validation of the model using data from the Calgary LRT system. The 1987 network was selected because the field data used for comparison were collected in that year. To assist in the comparison of simulation results and field data, critical significance levels for means to be equal were also computed and are shown in Table 1.

For example, the mean travel time in the morning peak traffic conditions on the first route shown in Table 1 is only 1 percent lower than the mean value obtained by the simulation. Comparison of travel time results obtained from the simulation model and the field data for

TABLE 1 Comparison of Simulation Results and Field Data

	Field data		Simulation		
	mean	standard deviation	mean	standard deviation	Critical significance[a]
Travel Time (minutes)					
1. Anderson to University	33.90	2.44	34.23	1.91	0.60
2. Whitehorn to 10 Street S.W.	22.64	1.07	23.43	0.95	0.05
Departure Headways (minutes)					
1. Whitehorn	7.72	3.04	6.01	1.99	0.10
2. Anderson	5.36	1.39	5.01	0.59	0.40
Arrival Headways (minutes)					
1. 10 Street S.W.	7.81	3.29	6.19	3.13	0.16
2. University	5.40	3.72	4.99	1.66	0.60

[a]Critical significance level for means to be equal.

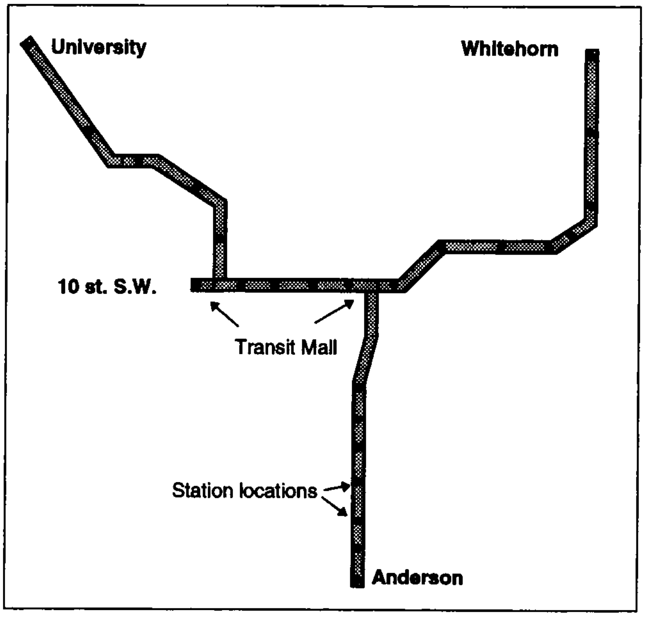

FIGURE 3 LRT routes in Calgary.

the second route shown in Table 1 shows that the mean travel time can be considered equal at a level of significance of 0.05. Table 1 also shows the realistic nature of the mean departure headway available from the simulation model at the first station of each route and the arrival headway at the last station.

ROUTE ALIGNMENT SELECTION APPLICATIONS

The Calgary transit operation in 1987 consisted of light-rail train routes approaching from three directions (northeast, south, and northwest) and converging at a 2-km-long surface transit mall in the city of Calgary (Figure 3). The simulation model is applied to investigate the effect of the transit mall on the level of service provided to transit passengers. According to the current practice in Calgary, trains on the transit mall share the right-of-way with conventional buses. In a typical peak-period operation, trains from the northeast are turned around at the end of the transit mall (forming Route 202). The northwest and southern routes are operated as a single continuous route (Route 201).

The current practice is compared against two alternatives. The first alternative operation consists of two transit malls that would operate on two adjacent parallel east-west streets. The right-of-way on the two streets mentioned above was preserved for future LRT use by the city of Calgary in 1976. It is assumed that equal amounts of bus traffic will use the two malls. Furthermore, it is assumed that one transit mall will be served by trains to and from the northeast corridor (Route 202). The other transit mall is assumed to be used by the continuous route formed by the south and northwest corridors (Route 201).

The second alternative analyzed assumes that trains will operate in underground tunnels below the present transit mall. The city of Calgary owns tunnel space that has been earmarked for future underground operations in the downtown area (*8*).

In addition, three different demand characteristics are considered for each of the above alternatives. The present demand conditions as well as future conditions when passenger demand increases by 50 and 100 percent are used as simulation scenarios. It is assumed that the operator would increase the vehicle dispatch rate to cater to increased passenger demand. Therefore, for future scenarios, train headways are assumed to be approximately inversely proportional to the square root of the total passenger demand (*9*). The train headways selected for the two routes are as follows (present demand level = 1):

	Headway (min)	
Demand Level Factor	*Route 201*	*Route 202*
1.0	5	6
1.5	4	5
2.0	3	4

The vehicle characteristics of the alternative operations are assumed to be the same as those in the present operation.

The simulation results reported below were computed by repeating the simulation of the morning (two hours) operation toward University Station in the northwest. Ten repetitions were performed. Thus the results reflect the mean values that can be anticipated from peak-period operations spanning 2 weeks.

Figures 4 and 5 show the travel time information available from the simulated operations. Figure 4 relates to the morning peak-period travel time on Route 202 (see Figure 3), and Figure 5 relates to the travel time of Route 201.

In the three demand scenarios simulated, introduction of the second mall reduced travel time by approximately 5 percent. This reduction in travel time can be used for a significant saving in fleet size in this particular LRT system. For example, fleet size can be reduced by two trains when travel time is reduced by 5 percent. A further travel time reduction of similar magnitude is available when the transit malls are eliminated and trains avoid interaction with street traffic by using underground tunnels.

There is no significant difference in the mean waiting time experienced by passengers in the above alternative operations for a given demand level for Route 202, as shown in Figure 6. The reduction in the waiting time with increased level of demand is in agreement with the

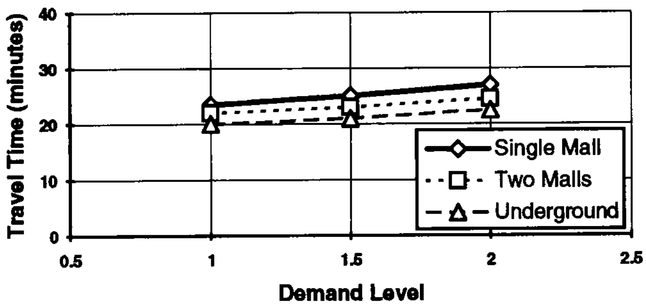

FIGURE 4 Mean travel time of trains on Route 202.

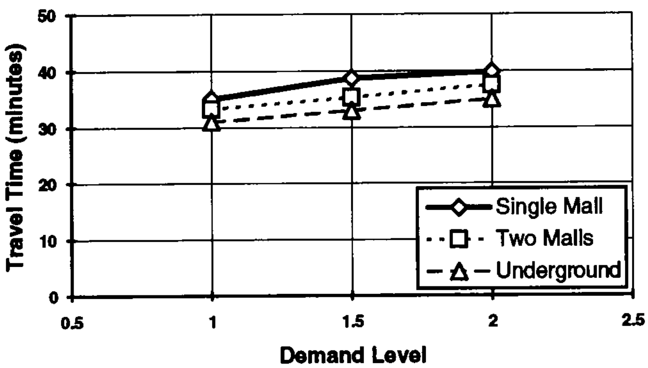

FIGURE 5 Mean travel time of trains on Route 201.

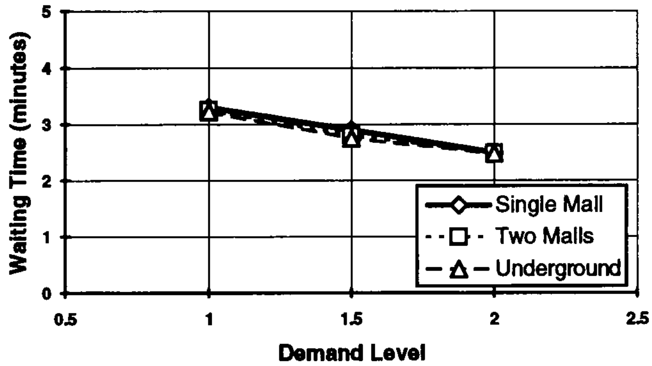

FIGURE 6 Mean waiting time of passengers on Route 202.

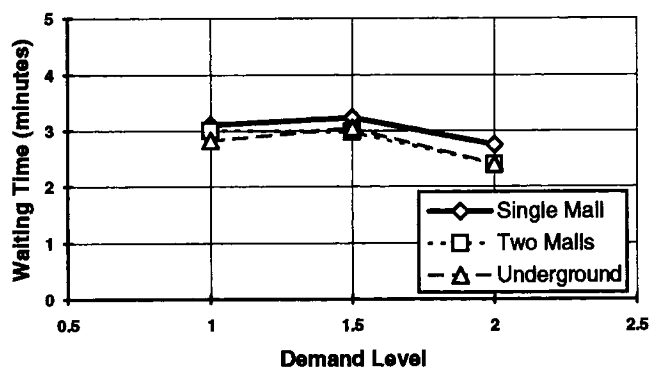

FIGURE 7 Mean waiting time of passengers on Route 201.

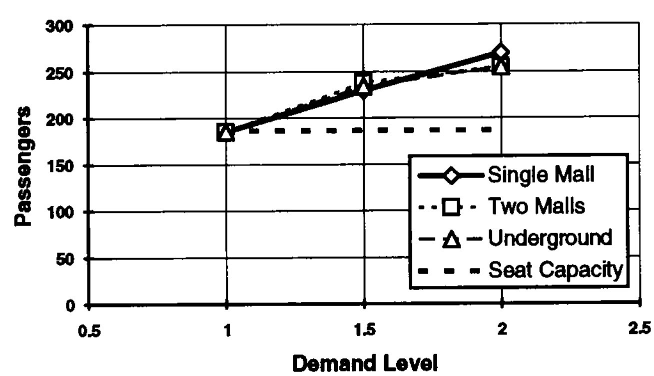

FIGURE 8 Maximum occupancy of Route 202.

increase in the vehicle dispatch rate. For the purpose of this analysis, the waiting time is considered to be the time spent since the passenger arrival time at the train station till the departure time of the train that the passenger is able to board. Insensitivity of waiting time on this particular route is due to the effects of congestion in the mall area, because the route terminates at the end of the mall. However, planned extension of the route to the west should be designed with care because congestion effects will be carried over to stops away from the mall as shown for passenger waiting time on Route 201 (Figure 7).

The mean waiting time of passengers on Route 201 shows that the single-mall option consistently results in increased waiting time for passengers compared with the other two options. As mentioned before, the above increase in mean waiting time is a result of the congestion at the transit mall, which affects the waiting time of passengers at downstream stations. Generally, the single-mall option shows a higher level of bunching on the trajectory diagram of distance versus time (not shown here), which supports the above results.

The simulation model provides other level-of-service measures related to occupancy and train headways. For example, the maximum occupancy for Route 202 is shown in Figure 8, in which a general increase in crowding and number of standing passengers with the increase in passenger demand level can be seen. However, there is no significant difference in the maximum occupancy among the different operating alternatives at a given demand level.

Conclusions

The simulation model application to the LRT system in Calgary has shown that travel time reductions of approximately 5 percent can be achieved with a two-transit-mall operation compared with the present single-mall operation. The model also predicts a further reduction of similar magnitude in travel time if interactions with other street traffic are removed by operating the LRT system in underground tunnels in the city area. Effects of passenger demand increase in the future have also been investigated. The level-of-service measures investigated during the reported analysis cover waiting time, travel time, headways, and occupancy.

LRTSIM, a microcomputer-based simulation model useful in estimating the level of service provided by LRT operations is described. The animation of the simulated operation is a significant advantage from the point of view of validation and the ease of understanding the simulated operation. The in-built data handling section is designed to allow the model to be readily applied to LRT systems in different cities.

The simulation method provides an effective technique in estimating the level of service of an LRT operation. Microcomputer-based simulation allows the inclusion of animation features and graphical features such as trajectory diagrams that allow planners to readily comprehend the features of the transit operation under investigation. Furthermore, detailed analysis of the operation is made feasible because the program can be readily instructed to track passengers as well as vehicles of the simulated operation and retrieve the required data.

Collection of similar data from field experiments is difficult, if not impossible, because of the associated survey costs and possible disruptions to the service during experimentation. On the other hand, repeated application of the simulation model provides an efficient method for collection of data representing successive days of operations. Therefore, the statistical significance of the estimates can be improved with little additional cost.

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REFERENCES

1. Bly, P. H., and R. L. Jackson. *Evaluation of Bus Control Strategies by Simulation.* Laboratory Report 637. Transportation and Road Research Laboratory, Crowthorne, Berkshire, England, 1974.
2. Jackson, R. L. *Simulation Studies of Bus Operations and Control on London Transport Route 11.* Supplementary Report 339. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1977.
3. Andersson, P., A. Hermansson, E. Tengvald, and G. Scalia-Tomba. Analysis and Simulation of Urban Bus Route. *Transportation Research,* Vol. 13A, 1979, pp. 439–466.
4. Miller, E. J., and P. D. Bunt. A Simulation Model of Shared Right-of-Way Street Car Operation. Presented at the 66th Annual Meeting of the Transportation Research Board, Washington, D.C., 1987.
5. Breuers, P.N.J., R. Melsen, F. T. Piso, P. M. Ranke, and H. J. Van Zuylen. Simulatiestudie sneltram Utrecht-Nieuwegein. (A Simulation Study on the Utrecht-Nieuwegein tram route.) *Verkeerskunde,* Vol. 28, No. 12, 1977, pp. 561–564.
6. Vandebona, U., and A. J. Richardson. Simulation of Transit Route Operations. In *Transportation Research Record 1036,* TRB, National Research Council, Washington, D.C., 1985, pp. 36–41.
7. Wirasinghe, S. C., and D. Szplett. An Investigation of Passenger Interchange and Train Standing Time at LRT stations. (ii) Estimation of Standing Time, *Journal of Advanced Transportation,* Vol. 18, No. 1, 1984, pp. 13–24.
8. Bergen, B. Subterranean LRT Cavern Waiting for 21st Century. *Calgary Herald,* January 5, 1986.
9. Newell, G. F. Dispatching Policies for a Transportation Route, *Transportation Science,* Vol. 5, No. 1, 1971, pp. 91–105.