A SIMULATION MODEL FOR EVALUATING BUS ROUTES AND SCHEDULES IN SMALL CITIES

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ABSTRACT

This paper discusses the simulation portion of a computer model which may be used by small city mass transit decision-makers to determine costs and benefits of alternative routing-scheduling systems. Given the results of an origin-destination survey, the model first determines the schedules for the routes, the number of trip demands which will be lost due to poor routing or poor scheduling, and the best travel pattern for the trip demands which can be serviced by the routing-scheduling system. The simulation portion of the model then simulates the operation of the buses on the routes, and the loading, unloading, and transfer of passengers in order to determine trip revenues, vehicle operating costs, and a variety of customer service measures.

I. INTRODUCTION

This paper discusses the simulation portion of a computer model which will prove useful to mass transit decision-makers in their struggle to provide a viable mode of transportation. Routing and scheduling decisions are some of the more important decisions which transit management personnel must make. For a variety of reasons, these decisions are made very conservatively. In order to improve customer service, there appears to be a need for a vehicle to aid in making good routing-scheduling decisions more quickly.

Failure of transit operations is most pronounced in small cities, perhaps because of a lack of experienced personnel. One approach to the problem of the small city mass transit operation is a means which would allow transit officials to test various routing-scheduling alternatives before implementation. It is suggested that the proper approach to this problem is one of systems analysis. Various alternatives (routes and schedules) should be defined, their costs and benefits should be examined, and the choice of the "best" alternative should be based on criteria to be established in the particular case. Alternative and criteria definition may not be too difficult; however, costs and benefits development is a difficult problem.

OVERVIEW OF THE COMPLETE MODEL

This paper examines the simulation section of a transit system model which may be used by transit officials to define costs and benefits of alternative routing-scheduling systems. The complete model encompasses a three-phase procedure: (1) Given route and headway information for a particular alternative, schedules for the routes are determined. (2) The benefit measures are determined in a two-step process. Some of the measures are determined in a pre-simulation analysis. The system is then simulated to determine (the majority of) the benefits in terms of customer service, revenues, and operating costs. The simulation section of the model is the focus of this paper. (3) The manpower costs are determined.

The first phase of the model encompasses schedule determination. Schedules for the routes are based upon headways,[1] distance between bus stops, bus travel time, and a decelerate - unload-load-accelerate factor.

The benefits methodology can be considered as two distinct operations: the pre-simulation analysis and the simulation itself. Although the majority of the benefit measures are developed during simulation, the simulation itself is dependent, to a great extent, upon the pre-simulation section of the model. Given trip demand information, before the actual simulation begins the demands for trips between origin and destination points must be converted to trip demands between bus stops. Thus, minimum time routes must be determined for the trip demands. If there are no direct routes between origin and destination, a transfer route must be determined. Should no transfer route exist, then the trip is lost due to either poor routing or poor scheduling.[2] This analysis must be accomplished for each routing-scheduling alternative prior to the simulation of the alternative.

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[1]Headway times are the times that a bus leaves the origin point on a route.

[2]The trips lost due to poor routing are those lost because no route services the origin or destination area. Those lost due to poor scheduling are the trips lost because the schedules for the routes servicing the origin and destination areas are not compatible with the trip demand time requirements.

Having determined the trip demands which can be serviced by the routing-scheduling alternative, the alternative may then be simulated to determine the majority of the benefit measures (those measures not developed in the pre-simulation analysis). The simulation portion of the model is the focal point of this paper. Operation of the buses on the routes, and the loading, unloading, and transfer of passengers is simulated to develop the majority of the benefit measures in terms of customer service (for example, waiting time, travel time, transfers, overcrowded buses), revenues, and vehicle operating costs.

Since mass transit is labor intensive, the cost of driver wages is the most significant dollar cost of the system. Once the benefit measures have been developed, the labor costs of the system are determined by using a heuristic procedure developed by Samy E. G. Elias (2). The third phase of the model--the cost phase involving the Elias heuristic procedure--is not discussed in this paper.

Obviously, a computer simulation model of a transit system has the potential of "getting out of hand" very quickly. At the current stage of computer technology, the cost of computer time limits the magnitude of a project that can be handled by a transit firm. Realizing the need for help in the area of small city mass transit, this model has been developed for use by small cities (population less than 150,000--approximately 75 buses). However, it seems that the approach developed herein could be expanded when computer capabilities permit in order to serve larger cities. Furthermore, it is hoped that the model may be used by the larger cities by applying it in neighborhoods or sections of the city (inherent in neighborhood or section application, however, is the problem of suboptimality).

USES OF THE MODEL

The model will enable transit officials to judge the cost of alternative routing-scheduling schemes relative to the respective measures of customer service. Customer service measures to be used as criteria in a specific case may be selected from the group of benefit measures generated by the model.

The model may also be used to supply information--costs and revenues of proposed routes--which would prove useful in subsidy negotiations. For example, suppose the current routing scheme generates revenues of $10,000 at a cost of $2,000. Further, suppose that a new traffic generator in terms of a shopping center and apartment complex has resulted from new development, and that the model indicates that a revised routing scheme to service this area will generate $11,000 in revenue at a $4,000 cost. The current scheme suggests $8,000 profit while the revised scheme suggests $7,000 profit. The city or shopping center may deem it worthwhile to grant a $1,000 subsidy to the transit firm in order to supply service to the area.

The model may prove useful in equipment investment decisions when new systems are being planned. A decision to purchase 19-passenger buses could prove costly if buses of this size result in a significant number of standee passengers. The model may be used to determine the optimal bus size judged on the basis of standee statistics.

The model may also be useful in determining the effect on customer service as a result of bus breakdowns at specific times on specific routes. The older, less reliable buses could then be used on the less critical routes, as indicated by the output of the model.

Hopefully, the suggested model will have another use--as a classroom teaching device. If mass transit is to become viable in the future, more professional personnel will be needed. A less complex version of this model is being developed for use as a teaching aid in the training of such individuals.

The following section is devoted to a discussion of the benefits of a routing-scheduling system. In the discussion of relevant benefit measures, the importance of customer service is noted, and the customer service factors examined in this paper--waiting time, travel time, trip time, transfers, reliability, and seating status--and the various measures of these factors are discussed. Section III examines the simulation, including the input and the methodology. Section IV is concerned with the output of the simulation and implications for transit management.

II. THE BENEFIT MEASURES

The basic thrust of this paper is on the service scheduling problem--the benefits part of the cost-benefit approach. One of the pressing needs of mass transit is to make transit more attractive to the public (2:1). This need is only partially met by new, plush, air-conditioned buses. Service is the important factor in meeting this need. It can be expected that improved service will generate improved revenue (demand) via some service response function. Typically, poor routing and service will decrease ridership drastically, but excellent routing and service will only increase ridership slowly (4:212).

No attempt is made to isolate a single "most important" measure of customer service. Rather, the model develops, for each alternative routing-scheduling scheme, a number of different measures for various factors. The decision-maker can then choose the relevant criteria for the specific case under consideration.

The importance of the selected factors (discussed below) is emphasized by studies concerning user-perceived attributes of transportation (1, 3, 6, 7). Important factors cited in the Survey Research Center study (3) are frequency of service (avoid waiting), transfers, flow of traffic (stops-starts versus steady flow), fastness-speed, convenience, expense, comfort, distance, and crowdedness. The

University of Maryland studies (1, 6, 7) cite basically the same factors, but two additional attributes are also suggested: reliability (arrive at intended time) and a desire to avoid walking more than a city block. Quandt and Baumol (5) suggest a lesser number of important variables--speed, frequency of service, cost, convenience--in their research, although a broad definition of their suggested variables might include all of the above mentioned factors.

In attempting to determine relevant service factors, this writer has emphasized those factors which he would consider to be important if he were to make a transport mode decision: waiting time, travel time, trip time, transfers, reliability of service, and seating status. As noted above, the importance of these factors is evidenced by the literature.

Waiting Time is defined as the time between passenger arrival and bus arrival, at both origin and transfer points.

Travel Time is the time spent on the bus, from origin to destination.

Trip Time is the total journey time: the sum of waiting time and travel time.

Transfers is the total number of transfers needed to travel between an origin-destination (OD) pair.

Reliability of Service is a measure of late arrival at destination.

Seating Status is the only "comfort" factor considered in this research. The day of the "standee" bus rider is gone--if a bus rider finds that, too frequently, he is required to stand for part of his journey, he will soon find a different mode of transportation. Consequently, statistics on the per cent of standee-passenger-miles are collected.

III. THE SIMULATION: INPUT REQUIREMENTS AND METHODOLOGY

LANGUAGE

The language used in the entire model, including the simulation, is FORTRAN. Since the model was designed for use in small cities, the FORTRAN language seemed more appropriate than any of the simulation languages. If it were to be necessary to make minor modifications in the model, it is felt that personnel with expertise in FORTRAN may be available within the transit firm, whereas personnel with expertise in a simulation language may not be available internally.

DATA REQUIREMENTS

The user must provide proposed route and schedule information and trip demand information as input to the model. The required route and schedule information is simply the distance between successive bus stops on the routes, the headway times for each of the routes (for both weekday and weekend, if weekday and weekend schedules differ), and the repetitive schedules[3] for each of the routes. Should the user desire to use the scheduling phase of the model rather than provide the schedules, other inputs are required. Since the focus of this paper is on the simulation segment of the model, the scheduling phase is not discussed herein.

The trip demand data required for the model is more complex than the routing and scheduling data. The demand for trips between zones is the demand which the system hopes to service. Trip demand information for each trip includes trip (origin-destination) requirements, days of the week the trip is demanded, required arrival time at the destination, and earliest time the passenger would be willing to board a bus. The origin-destination information must be specified according to zones--the zones being small areas of the city. Thus, a grid marked off in squares may be superimposed on the map of the city in order to establish the zones. Trip demands may then be assigned to the zones (or cells), and it is assumed that the passengers demanding the trips will consent to walk to bus stops located within horizontally or vertically adjacent cells. Having established the zones, the user must then supply, as input to the model, information concerning origin and destination zone for the trip, days of the week the trip is demanded, required arrival time at the destination zone, and the earliest time the passenger would be willing to board a bus. It should be noted that the primary use of the model is in evaluating service characteristics for "constant" type trips, that is, regularly planned trips such as those to work. Trips of this type are the primary concern of the transit system--the system should satisfactorily serve these demands. Various studies have shown that work trips account for a large majority of the transit system trips. A recent study in a New Jersey city indicated that 75 per cent of the trips were of the work-school variety (9).

For each zone in which a bus stop is located, the user must supply, as input, the zone number and the bus stop numbers located within that zone. The model must also be supplied with transfer point information for all points at which routes intersect (that is, at which transfers are possible). The input information includes the zone number and the bus stop numbers at the point of intersection of the intersecting routes in the zone.

During the simulation, in order to determine the time of arrival of a bus at the next bus stop on

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[3]A repetitive schedule is important in instilling customer confidence in bus service. That is, if bus service is provided at half hour headways, it is best that schedule time at a specific stop be a constant number of minutes, say five, after the hour and half hour. Therefore, even though the bus may be able to travel a distance in a shorter time during a light traffic period than during a rush period, it is best to use the same schedule during both periods.

a route, three elements are added to the current time. The first element is the time required to traverse the distance between nodes (information developed during the scheduling phase of the model). The second element is the product of the number of passengers loaded and unloaded at the current stop and the length of time required to load a passenger. Thus, the user must supply the passenger load time information. The third additive element is a stochastic factor drawn from a distribution supplied by the user. Since the time required to traverse a distance is not a constant (as assumed by a repetitive schedule), this stochastic factor allows the bus to operate ahead of or behind schedule. The user must specify the distribution from which the stochastic factor is to be drawn. Several distributions may be specified depending upon the type of travel conditions (for example, suburban traffic may be less dense than downtown traffic, thus the user may wish to specify two distributions).

Several other inputs are required: the capacities of the buses on the routes, bus fare, per-mile operating cost of the buses (excluding labor), and a "go-no go" distribution to be discussed below.

TRIP DEMAND DATA COLLECTION

The difficulty encountered in collecting trip demand data will depend upon the objectives of the particular study. If the model is used to determine the effect on present passengers as a result of proposed schedule changes, then an on-board bus survey of the present passengers would provide the necessary trip demand data. A more complex problem is presented when the model is to be used to evaluate new service. In such cases, gathering of the trip demand data is expected to be a much more difficult problem. It is not the purpose of this paper to delve into the merits and demerits of origin-destination surveys. However, in small cities it is felt that origin-destination surveys will supply the necessary trip demand data, given the cooperation of civic groups, employers, and news media.

METHODOLOGY

The schedules for the routes and the list of trip demands which the routing-scheduling system will service are developed prior to the simulation phase of the model, during the scheduling and pre-simulation segments respectively. Should the user desire, the scheduling phase of the model may be bypassed, in which case the user would input the proposed schedules for the routes. Before the simulation of a routing-scheduling alternative begins, we must determine which trip demands can be serviced by the system. Given a demand for a trip between origin and destination zones, the pre-simulation procedure first determines if the routing system services both the origin and destination zones. If either of the zones is not serviced by the routing scheme, the total number of trips lost during a period of one week as a result of failure to service this trip demand are accumulated as trips lost due to poor routing. If the origin and destination cells are serviced by the routing scheme, the pre-simulation procedure determines if the bus schedule satisfies the arrival, departure, and trip time requirements of the trip demand. If these requirements are not satisfied, the total number of trips lost during a period of one week as a result of failure to service this demand are accumulated as trips lost due to poor scheduling. If several routes can satisfy the trip demand, the optimal[4] route is determined (for both weekday and weekend trips, if the schedules differ). Trips which can be serviced by the system are sorted according to route and scheduled boarding time for use during the simulation segment of the model.

The simulation portion of the model simulates the operation of the buses on the routes, and the loading, unloading, and transfer of passengers. The system can be simulated for any period of time (in weeks) desired by the decision maker. An examination of the general procedure that occurs each time a bus arrives at a bus stop may be useful. When a bus arrives, the number of standee-passenger-miles, passenger-miles and total miles for the route are updated. The passengers to depart at the node are unloaded and the transfer time is stored for any transfer passengers.

The bus is then loaded. The current time is compared with the list of trip demands and all those passengers whose scheduled boarding time is prior to the current time are loaded. If a trip will require a transfer, the number of transfers is incremented when the trip is loaded. On any given day, it is possible that a regularly demanded trip will not be taken due to illness, for example. This "go-no go" decision is based upon the value of a random variable drawn from a distribution input by the user. The number of paid trips is then incremented.

If the bus arrives late at the node, the number of late passengers, late buses, and late passenger-minutes are incremented. Waiting time for the number of passengers loaded at the node is also incremented.

After all of the buses which have arrived at bus stops at the current time have loaded and unloaded according to the above procedure, the transfer passengers are loaded and waiting time is incremented for the transfer passengers. The number of standees is determined, and the time of arrival at the next bus stop is generated for the buses which have unloaded and loaded. If the time of arrival at the next bus stop is less than the scheduled time for that node, then the arrival time is set equal to the scheduled time. Thus, it is assumed that a bus will never run ahead of schedule--a strict practice in the transit industry.

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[4]Criteria for the optimal route are not discussed herein, since this section of the model is not a part of the simulation.

IV. OUTPUT OF THE SIMULATION--IMPLICATIONS FOR TRANSIT MANAGEMENT

OUTPUT OF THE MODEL

The model has not been used, as yet, in an actual transit system. Model development and "de-bugging" was based on a variety of routing and scheduling systems posited to serve computer generated trip demands. Consequently, results of the various systems will not be discussed, since they lack practical relevance. However, a discussion of the output of the model should prove worthwhile.

Output of the model is similar to that in Figures 1 and 2. It should be emphasized that the results are for an average operating day. Thus, the trip loss statistics indicate the average number of trips lost due to poor routing and poor scheduling in a single day of operation.[5] The potential demand is the average number of trips which would be taken if satisfactory service (that is, service which meets departure, arrival, and travel time requirements of the demand) were available. The per cent of lost potential demand statistics present trip losses due to poor routing and poor scheduling as percentages of potential demand, since some users of the model may be more interested in per cent figures than in the absolute figures presented earlier. The average travel time per passenger mile is the mean number of minutes a passenger spends on the bus to travel one mile. Average waiting time per passenger mile is the mean number of minutes that a passenger spends waiting for a bus for each mile he travels. Little information is supplied by the total passenger miles statistic if it is considered without reference to other statistics. For example, 14 people who each travel one mile yield a total passenger miles statistic of 14. Alternatively, one person who travels 14 miles yields the same statistic. Obviously, a transit system would prefer to service many short trips rather than a few long trips. Thus, the total passenger miles statistic should be used in conjunction with other statistics.

The standee passenger miles statistic is similar to the total passenger miles statistic, in that a value of, say, 14 for this statistic can result from 14 passengers being required to stand for one mile or from one passenger being required to stand for 14 miles. The average travel time and waiting time per trip statistics are the mean number of minutes a passenger spends on the bus and waiting for the bus, respectively, in order to take one trip. The average trip time is the sum of the travel time and waiting time statistics. Average number of transfers per trip is equal to the total number of transfers divided by the total number of trips. The average number of transfers per passenger mile has a similar interpretation.

The late buses statistic is the mean number of late buses per day. If a bus arrives late at a node, any passenger departing at that node is assumed to be late. The late passengers statistic indicates the number of late passengers as a result of late buses. The per cent of late passenger trips statistic presents the late trips (passengers) as a per cent of total trips. The average number of late passenger minutes statistic is equal to the number of late passenger minutes divided by the number of late passengers--that is, the mean late arrival time for late passengers. Finally, it should be emphasized that the vehicle operating cost does not include labor. Bus driver labor costs may be determined by the Elias heuristic procedure.

Thus, for a given system of routes and schedules, the model determines a variety of different customer service statistics. The decision-maker may then examine those statistics which he considers to be of importance. If any of the statistics are "out of line," the decision-maker can make changes in the system which he feels will be effective. Results of the modified system can then be determined by running the model again.

Figure 2 is an example of the output information for each route. This information is also in terms of an average operating day. When faced with what appear to be critical late arrival statistics, the obvious response is to make adjustments in the system to reduce the level of these late arrival statistics. The output shown in Figure 2 will prove useful in such efforts. This type of information should provide guidance as to the nodes at which schedule changes may prove helpful. For example, the late arrival statistics in Figure 2 suggest that the buses on route 4 operate relatively reliably until bus stop 14. On the average, 2.57 buses arrive late at node 14 daily, resulting in the late arrival of 2.21 passengers who depart at that node. The late arrival at this node appears to contribute to the buses operating behind schedule from node 14 to the end of the route. However, the buses make up some of the lost time since a daily average of only .75 buses arrive late at the end of the route. It would be advisable to delay the scheduled arrival time at node 14 by one minute and simulate the system with the schedule based on this change.

VALIDATION

The problems involved in validation of the model depend upon the objectives of the study in which the model is used. If the objective is to improve service in an existing system, the model could be verified by simulating the existing system and comparing the results of the operating system to those of the simulated system. Unfortunately, if the model is used for planning a new

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[5]Note that the trip loss statistics in Figure 1 appear excessively high. These results are based upon a skeletal system of four routes which serviced only a few hundred of a possible 3500 zones in a city. Furthermore, for the purposes of this example, trip demand information was generated by the computer. Thus, there were a large number of trip demands in zones which were not serviced by the skeletal system of routes.

FIGURE 1

System Results[1]

TRIP LOSSES DUE TO POOR ROUTING 69007.857
TRIP LOSSES DUE TO POOR SCHEDULING 1856.143

POTENTIAL DEMAND 71168.929 TRIPS
PER CENT OF LOST POTENTIAL DEMAND DUE TO POOR ROUTING 96.963
PER CENT OF LOST POTENTIAL DEMAND DUE TO POOR SCHEDULING 2.608
PER CENT OF LOST CONTROL FACTOR DUE TO POOR ROUTING 690.079
PER CENT OF LOST CONTROL FACTOR DUE TO POOR SCHEDULING 18.561
AVERAGE TRAVEL TIME PER PASSENGER MILE 8.483 MINUTES
AVERAGE WAITING TIME PER PASSENGER MILE .169 MINUTES
TOTAL PASSENGER MILES 219.279
PER CENT OF CONTROL PASSENGER MILES 2.193
STANDEE PASSENGER MILES 0.000
PER CENT OF CONTROL STANDEE PASSENGER MILES 0.000
NUMBER OF PAID TRIPS 304.929
TRIP REVENUES $76.232
AVERAGE TRAVEL TIME PER TRIP 6.100 MINUTES
AVERAGE WAITING TIME PER TRIP .121 MINUTES
AVERAGE TRIP TIME 6.221
AVERAGE NUMBER OF TRANSFERS PER TRIP .024
AVERAGE NUMBER OF TRANSFERS PER PASSENGER MILE .033
AVERAGE NUMBER OF TRANSFERS PER CONTROL TRIP .001
AVERAGE NUMBER OF TRANSFERS PER CONTROL PASSENGER MILE .001
LATE BUSES 5.179 LATE PASSENGERS 2.643
PER CENT OF LATE PASSENGER TRIPS .867
AVERAGE NUMBER OF LATE PASSENGER MINUTES 1.000
VEHICLE OPERATING COST $77.78

[1]The "control" statistics in the output above are not discussed herein. These statistics are developed in order to compare alternatives in which a service response function--changes in demand resulting from various levels of customer service--has been included. However, the change in demand to be expected as a result of various levels of customer service has not been explored in the transit industry; consequently, no "neat" service response functions exist.

FIGURE 2

Route Output

ROUTE 4 INFORMATION

PASSENGER MILES 68.321
TOTAL TRIPS 80.964
TOTAL MILES 105.000
STANDEE PASSENGER MILES 0.000

BUS STOP	LATE BUSES	LATE PASSENGERS
1	0.00	0.00
2	0.00	0.00
3	0.00	0.00
4	.18	.25
5	.11	.04
6	.11	.04
7	.14	0.00
8	.14	0.00
9	.11	0.00
10	.07	0.00
11	.14	.07
12	.14	.07
13	.18	.14
14	2.57	2.21
15	2.61	0.00
16	1.50	0.00
17	1.50	0.00
18	1.50	1.54
19	1.43	2.46
20	1.29	0.00
21	1.29	.75
22	1.29	0.00
23	1.29	0.00
24	1.29	0.00
25	1.29	0.00
26	1.29	.07
27	1.29	0.00
28	.75	0.00
29	.75	0.00

system, there will be no operating system which may be used for verification and "fine-tuning" of the model. In cases such as these, the only alternative is a modified "Turing" test (8:252-253): Show the results of the model to experienced transit system personnel and elicit their opinion on the reasonableness of the results.

IMPLICATIONS FOR TRANSIT MANAGEMENT

A few words directed at errors in criteria selection appear advisable. Obviously, the average number of transfers per trip is a somewhat important customer service factor. Passengers prefer not to transfer. However, this fact does not imply that one system is preferable to another system simply because it results in a lower number of transfers per trip. If two systems have similar results in all other statistics, then the system with the lower transfer statistics will be preferable. However, if other statistics are not similar, the transfer statistics should not be used as criteria at face value. It should be realized that transfer statistics can be driven to zero-level by devising a system with no interconnecting routes, or by ensuring that transfer layovers are exceedingly long. Thus, on one hand, a low number of transfers per trip indicates that few passengers have to transfer to reach their destination--a desirable characteristic. On the other hand, a low number of transfers per trip may indicate that the service is so poor that transfers are almost eliminated.

Previously, it was suggested that the model, although developed for use in small cities, could be used in neighborhoods or sections of larger cities. Caution should be taken if such a use of the model is planned. Decisions related to routing or scheduling changes based on information from the small area should be made in light of the fact that the routes serving these areas typically interconnect with other routes in the larger city. Thus, routing or scheduling changes on the routes serving the small area will affect the other routes. That is, the entire system is affected by such changes, and suboptimization for the small sections may result in a system that is significantly less than optimal for the entire large city.

During the development of this model, a basic system was simulated for periods ranging from 1 week to 21 weeks and the results (for an average operating day) for the various periods exhibited little variance. This evenness of results can be attributed to the fact that start-up time is not a significant factor in this simulation. The need for lengthy simulation in order to reach a steady-state condition is not encountered in the simulation of buses operating on routes. Thus, it is suggested that relatively short time periods, say 4 weeks, be simulated. Simulation for longer periods will be more expensive, and the results will not vary noticeably. Consequently, computer time required for the simulation portion of the model is relatively short when compared to the computer time required for the pre-simulation analysis. During the pre-simulation analysis, significant computer time is required to determine if the system of routes and schedules will service the trip demands, and to determine the optimal travel pattern for the trip demands which are serviced by the system.

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