Computer Simulation of a Demand-Scheduled Bus System Offering Door-to-Door Service

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BUSTOP is a simulation model developed for the CDC 3400 using FORTRAN and SPURT languages. The simulation program uses stochastic principles to simulate a demand-scheduled bus system. A passenger's origin and destination are generated from a uniform distribution, and no limit is placed upon the number of locations of origins or destination. Thus, a computer algorithm has been developed that will solve the "many-to-many" problem.

Although this simulation package uses some very simplified assumptions, it is felt that a good beginning has been made toward a useful tool for transportation planning. With some specific modifications in the program, this simulation package could be used to perform detailed sensitivity analysis on the use of a demand-scheduled bus system before any demonstration project is implemented.

Much of the discussion has been oriented toward the implementation of a demand-scheduled bus system to help cope with the transportation problem. New concepts in small bus operations may lead to increased demand for certain types of transit services. However, the cost of demonstration projects is quite high and the use of simulation techniques could provide considerable insight into the economic feasibility of initiating a demand-scheduled bus system.

•AS A result of the steady population growth in urban areas, a multitude of social, economic, and technical problems has arisen of which not the least is the "urban transportation problem." This problem, stemming from increased mileage in urban travel, has placed a severe strain on the transportation system of our cities. Furthermore, the trend of suburban, low-density development coupled with core-oriented cities will continue to exert pressure on the existing transportation system. Concerning the urban transportation situation, there is much debate about the balance among the various transportation modes. Consequently, somewhat dogmatic opinions are frequently reported in various writings. Sometimes overlooked, however, is the role that the urban bus systems play in providing transportation opportunities. In 1960, nearly 75 percent of all urban transit trips were made on urban buses (1). Although statistics of this sort may not reflect the complete urban transit picture (in Chicago, for example, while there are over twice as many trips by bus as by rail transit, fewer person-miles of travel are by bus), it is obvious that buses are an important element in the urban transportation system (2).

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Improvement in the operation of urban bus systems is presently receiving considerable attention as a result of progressive legislation at the national level. Two important measures are the 1962 Federal Aid Highway Act and the Urban Mass Transportation Act. The former stipulates that comprehensive transportation planning include estimates of future demand by persons and goods for all modes of transportation both public and private. This Act has stimulated important research in modal-split models, and, more recently, in submodal split models, i.e., a model to estimate the proportion of transit riders split between rail and surface (bus) facilities. The development of these models has led to investigations of the social and economical characteristics of transit patrons and how they might react to innovations in the transit field.

While the Highway Act is concerned primarily with the planning aspects of urban transit, the Urban Mass Transportation Act is primarily directed towards operational problems. Numerous projects through the country are being partially supported by grants. Many final reports are now becoming available for demonstration projects such as radial express bus routes and crosstown express buses, for example, the final report that evaluates a $5,000,000 experimental research and development project near Pittsburgh where prototypes of an automatically guided and controlled bus system were developed (3).

SMALL BUSES

A Need For Small Buses

Cutbacks in service by transit operators in the suburban area have resulted in an almost complete reliance on the automobile for transportation. Yet a demand for transit service still exists in the suburbs. This consists of (a) captive riders, i.e., persons who neither own nor drive an automobile nor have access to one, and (b) potential riders who would switch from automobile to transit if a suitable level of service were offered. However, low-density suburban development and a resulting low density of demand for transit make regular transit service, at best, a marginal operation.

Small buses offering door-to-door service on a demand-scheduled basis, i.e., scheduled to pick up the customer at his convenience, might prove to be a profitable complement to the automobile. A demand-scheduled bus DSB system could provide flexible, convenient, and comfortable transportation during the day and in the evenings as well. DSB's could facilitate and even encourage social trips that have origins and destinations off the fixed routes of regularly scheduled transit facilities. A side effect could be the reduction of congestion and parking problems.

Small Bus Simulation

Computer simulation of small bus operation in low-density suburban areas has been moderately successful, although somewhat limited in scope (4). The Genie system proposed by students of MIT operates on a demand-scheduled basis—routes and schedules are determined by a computer reviewing locations of buses in the field and the instantaneous state of the demand. The system is designed to serve trips between one point (such as the CBD or a large shopping center) and all surrounding zones. No programs were reported that investigated the feasibility of door-to-door bus service to both dispersed origins and destinations. This is the so-called "many-to-many" problem.

The level of service offered by the Genie system is similar to that of taxi service but with a reduced fare structure made possible by using multi-passenger vehicles. The schedule of each bus is updated at each stop where either a delivery or pickup of passengers is made. The bus then proceeds to its next scheduled destination. Preliminary costing of the system has been made and is reported for rush-hour traffic.

In Menlo Park, Calif., taxi-bus operation was simulated under actual field conditions with radio-dispatched cars, drivers, and dispatchers (5). Time of passenger call, origin, and destination were randomly generated and then transmitted by telephone to the radio dispatcher, who transmitted the information via radio to the taxi-bus driver. The driver through his knowledge of the Menlo Park area scheduled his pickups and deliveries in a manner which he thought was optimum. The driver then delivered or picked up his "passengers" with an allowance for boarding or exiting time.

Two levels of demand were tested in the Menlo Park simulation project: 10 and 20 calls per hour. Eighteen residential addresses and five commercial addresses were selected at random. Trips were then "made" between the residential and commercial addresses.

Computer simulation of small bus, door-to-door operation on a demand-scheduled basis, in conjunction with field tests of prototype vehicles and communication systems, would be a very meaningful research project and would provide answers to many questions concerning this type of bus operation. The continual feedback from field operations could result in almost continuous adjustment of the computer simulation and would permit continuous evaluation of the entire project.

CHARACTERISTICS OF SIMULATION

Transportation problems have become extremely complex and involved with a multitude of variables. Too often the transportation engineer is faced with a seemingly impossible study or evaluation to perform. There are many variables that affect any given stillation, and determining the relationships of all variables becomes a very formidable task. It is in these areas of great complexity that simulation techniques become valuable to the engineer. Often, simulation offers transportation engineers or planners a method of studying complex systems and determining the relative importance of their parts.

The term "to simulate" is very general and all encompassing to some authors and is very restrictive to others. Shubik (6) defines simulation as follows:

> A simulation of a system or an organism is the operation of a model or simulator which is a representative of the system or organism. The model is amenable to manipulations which would be impossible, too expensive, or impractical to perform on the entity it portrays. The operation of the model can be studied and, from it, properties concerning the behavior of the actual system or its subsystem can be inferred.

This is a very general and broad definition of simulation which could incorporate anything from a mathematical to a mechanical model. With Shubik's definition we can apply the term simulation to a soap-box racer, a model bridge, or a mathematical model. To be specific in defining simulation as it applies to this presentation, we use the following definition:

> Simulation is a numerical technique incorporating the use of random numbers, probability functions, and mathematical identities to form a stochastic model that can be used to perform a sensitivity analysis on any given or derived system over extended periods of time. The computational procedure is generally more easily performed with the aid of a computer.

In describing the simulation process, definitions of some of the more commonly used terms are useful.

Entities are the active or physical parts of the world which are simulated. Entities would include vehicles, passengers, roadways, traffic signals, messages, and any other describable object.

An exogenous variable is an input to the model. It is external to the system. As an example, the number and frequency of calls are used as exogenous inputs in this simulation process. However, an output from the model can be used as feedback to change the values of the exogenous variables once the simulation process has begun.

An endogenous variable is an internally generated variable. As an example, the pickup and delivery times for each passenger are endogenous variables.

Control parameters are those variables which can be kept constant or changed during the simulation process. As an example, the maximum number of buses to be assigned to the system can be allowed to remain at a constant number or be allowed to change with an increase in demand. These control parameters can be changed from one simulation run to another to permit sensitivity analyses to be made.

Identities are the mathematical relationships used within the model. As an example:

$$\text{Distance} = \text{ABSF}(\text{Xbus} - \text{Xcall}) + \text{ABSF}(\text{Ybus} - \text{Ycall})$$

where

Distance = distance from the origin of the call (where the passenger is to be picked up) to the bus;
Xbus = X coordinate of the bus;
Xcall = X coordinate of the call;
Ybus = Y coordinate of the bus;
Ycall = Y coordinate of the call; and
ABSF = the absolute value.

Outputs are results obtained from running the simulation model. They may simply be a list of the events and the accompanying times of occurrence or a solution to a question such as the number of buses required to serve a given demand. Statistical measures such as the distribution of waiting times for all passengers may also be outputs from the model.

Utilization of Stochastic Principles

Uncertainty characterizes some of the more important problems. Various probability distributions are used in simulation in order for the random numbers generated to be from a given type of population. As an example, the origin of a call in the simulation of a bus service was assumed to be from a uniform distribution. That is, any location within the designated service area had the same probability for being the origin of a call. The destinations were treated in a similar manner. The number of calls during a given time interval was also assumed to be from a uniform distribution.

One of the more attractive features of simulation is that the probability distribution can be changed to represent more closely the real world data. For instance, it might be known that the origin of a call might follow a distribution other than a uniform distribution. If this should be the case, the distribution more closely representing the true distribution could be substituted. The probability distribution for the number of calls for a given time interval might be more appropriately described by a Poisson distribution. Perhaps a distribution can be obtained from sampling that would more closely represent the population than any of the "standard" distributions. The important point is that any distribution can be used and can be changed or altered at any time to perform a more detailed sensitivity analysis. BUSTOP allows for the use of any desired probability distribution.

There are many ways to generate random numbers from various probability distributions. Naylor, et al, give detailed methodology for generating random numbers (7).

Validation

The validation of a computer simulation model is perhaps the most difficult part of simulation. In many simulations, it may well be impossible, impractical, or uneconomical to perform a complete validation. If historical data exist than the outputs from the model can be tested against the available data. However, too often data are not available.

To validate a bus simulation, current passenger demands (i.e., number of passengers picked up at each bus stop) from existing transit agencies could be used as inputs to the simulation model. The simulation outputs could be compared with any existing data from the transit agency. However, this does not insure a completely acceptable simulation model when it is applied to a different geographical area where the external variables are changed. A bus project could be put into operation to validate the model, but this, of course, is an expensive method. If a large number of variations are permitted in a real demonstration such as can be allowed in a simulation process, then the cost quickly becomes prohibitive.

Computer Languages

Many special purpose simulation languages are available for use. However, many of the languages cannot be used from one computer to another as FORTRAN can be used. Some of the special languages are GPSS, SIMSCRIPT, and DYNAMO. The language used in this simulation was SPURT which is a FORTRAN IV simulation language developed at Northwestern University for the CDC 3400 (8).

THE SIMULATION MODEL

BUSTOP has been specifically developed to simulate an urban-suburban DSB system, which required the general model to solve the so-called many-to-many problem; that is to say, that passengers can require pick-up or delivery at any of a large number of points.

Assumptions

In solving this problem, certain assumptions were made to simplify computation. All of these can be modified to permit the introduction of more generality into the model.

The most obvious assumption is the structuring of the street network. A model city has been drawn which is one mile by one mile. The streets are regularly spaced to provide a grid 9 blocks square. The streets are numbered 0-9 from west to east and from north to south. Thus, a pair of digits locates a particular intersection or node. The bus terminal is located at node (5, 5). All buses originate from this terminal and return there when empty. Bus capacity can be varied, but was normally held to equal 5.

All buses travel either east or west first before traveling north or south. The direction of travel can be determined by comparing the present position of a bus to the coordinates of its next destination. Buses pick up and discharge passengers only at intersections.

Model Input

To make the model as general as possible, a large number of the model's control parameters are left to the judgment of the programmer.

A list of calls for bus service is an exogenous input. Each call generated must include the time the call occurred, the originating node of the call, and the destination node. Each of these variables can be generated as stochastic variables. In the initial programming, the time of each call and the coordinates of the origin and destination were derived from uniform distributions.

Passenger service criteria were developed to insure a reasonable level of service. A minimum and maximum pickup time were specified. This guaranteed the passenger some time after he called the bus to reach the intersection for pickup and that he would be picked up before a maximum time limit had elapsed. These quantities were variables and initially were 1 and 6 minutes, respectively.

An additional criterion determined a maximum travel time. This was a linear function:

$$\begin{aligned}\text{Max Travel Time} &= kn \text{ for } n \le n' \\ &= T + tn \text{ for } n > n'\end{aligned}$$

where

n = number of links between origin and destination (a link is one block long);
n' = a control parameter constant set equal to 10 links;
k = a control parameter constant which equals 1 min/link;

T = a control parameter constant which equals 5 min; and
t = a control parameter constant which equals ½ min/link.

The variable t also represents the travel time assigned to each link. This travel time corresponds to a running speed of 13 mph. This criterion is felt to be one of the more sensitive parts of the model and can be easily revised to perform sensitivity analysis.

In addition, a time penalty was assigned to the bus for each pickup or delivery operation. This control parameter was initially set equal to 15 seconds.

Operation of the Model

The key to the operation of this simulation is the CLOCK subroutine of the SPURT simulation package. CLOCK causes events to happen at the proper time. As events are entered into CLOCK, they are ordered according to time of occurrence. An event number associated with each event time identified the type of action to take place. CLOCK also provides for storage of events which could not take place when scheduled. These events are assigned a queue position and will take place at the earliest possible moment in the program.

Each event is entered into CLOCK as an event type (designated by a number) and a scheduled time of occurrence. This list of events can be manipulated to permit loading various combinations of events into the list or purging then from it.

A general flow chart is shown in Figure 1. As an event is called from the CLOCK, the scheduled time of occurrence and the type of event is determined. All action pertaining to this event is completed before the next event is called. The BUSTOP simulation is comprised of three events: an incoming call demanding bus service, the arrival of a bus at a node, and the production of summary data.

Within the simulation, a number of lists are used to keep track of the model's activities. A passenger list (PLIST) is used to summarize the characteristics of each passenger's trip. PLIST includes the passenger's origin and destination, trip length, service criteria, times of pickup and delivery, and the number of the bus assigned to transport the passenger. A bus log records all activities performed by a given bus. All

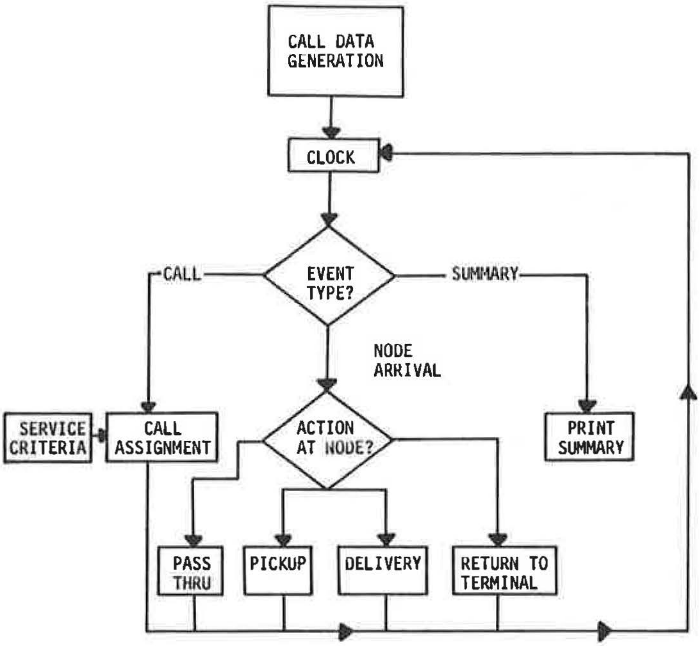

Figure 1. General flow chart.

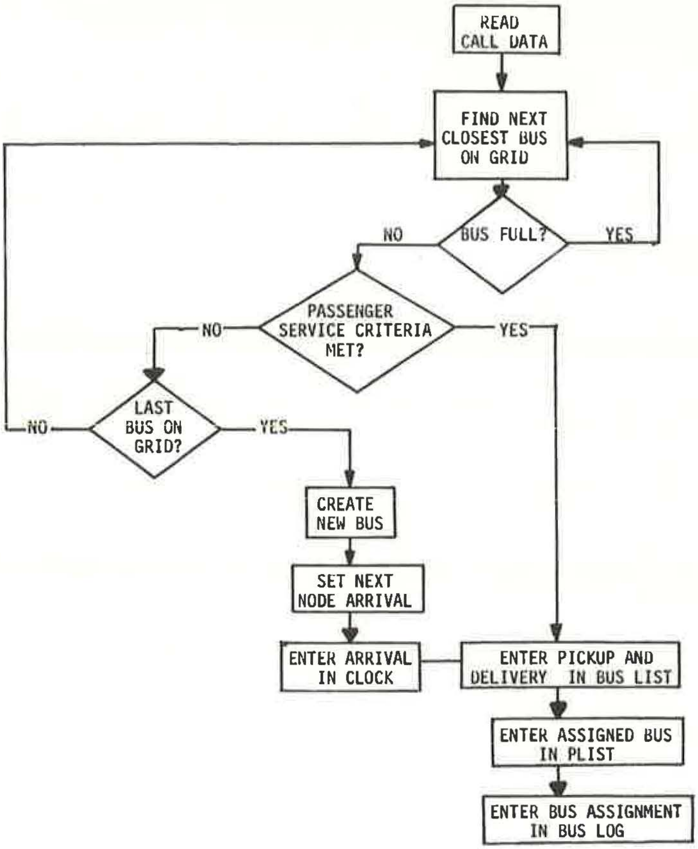

Figure 2. Call assignment.

passenger assignments, pickups, deliveries, and the return of a bus to the terminal are entered by each bus. A separate list for each bus allows testing to determine whether a specific call can be accommodated by that bus.

Call Assignment—If the event called from the CLOCK is a call or demand for service, a bus must be assigned to accommodate the call. The assignment process is outlined in Figure 2. The origin, destination, and occurrence time of the call are determined. The closest bus on the grid is examined to see if adding this passenger to those already assigned will violate capacity restrictions or will result in any passenger's service criteria not being met. If all passengers can be accommodated without violating the service criteria, necessary changes are made in the bookkeeping lists. A new event is then called from the CLOCK.

If the closest bus cannot meet the service or capacity criteria, the next closest bus is considered. If every bus on the grid is incapable of accommodating the new call, a new bus is dispatched from the terminal. The pickup and delivery data are then entered in the bookkeeping lists.

This call assignment is definitely not optimal. No attempt is made to assign a passenger to a bus so that efficiency of the system is maintained at an optimum. Once a passenger is assigned to a bus, that assignment is not changed, regardless of the actions of other buses in the system. The method of assignment is feasible and might reflect at least one algorithm which might be used in a demonstration project. Since the assignment method is a separate subroutine, modifications can be made to gain some insight into the sensitivity of system efficiency to changes in the call assignment method.

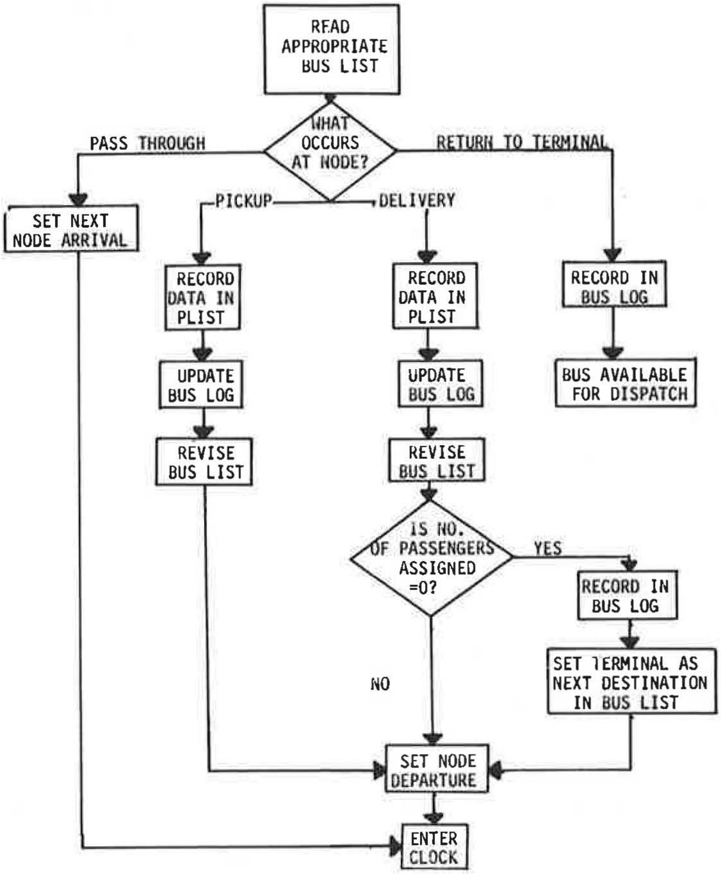

Figure 3. Action at node.

In early tests of BUSTOP, system efficiency was measured by characteristics of each passenger's trip. The mean times for a number of simulation runs that a passenger had to wait for pickup after placing a call ranged from 2.5 to 3 minutes. Excess time was the amount of time that a passenger spent on the bus above that which he would spend if he were the only passenger. Excess time is thus a measure of the delay caused by pickup and delivery of the other passengers. Mean excess time ranged from 3 to 4 minutes. Since no other call assignment algorithms were programmed, it is impossible to tell how these measurements might change. The means, however, do not seem to be unreasonable.

Events Occurring at a Node—If the event called from the CLOCK indicates that a particular bus has arrived at a node, the bus list for that bus is scanned to determine what action is to be taken (Fig. 3). If the bus makes no pickups or deliveries at that node or has not returned to the terminal, the coordinates of the next node are calculated and the time of arrival at the next node is determined and put into the CLOCK. The last entry in each bus list is a special entry indicating that the bus is empty, has no more assignments, and has returned to the terminal.

If the bus list indicates that a passenger is to be picked up at this node, the passenger is recorded as being picked up in the bookkeeping lists. A $\frac{1}{4}$-min pickup penalty is added to the current time and the time of departure from the node is entered into the CLOCK.

When a delivery is to be made at this node, the necessary entries are made in the bookkeeping lists. If the bus has no more passengers assigned to it, the coordinates of the terminal are set as the next destination of the bus. As with a pickup, a $\frac{1}{4}$-min penalty is assessed and the time of departure is placed in the CLOCK.

A bus which arrives at the terminal with no other actions assigned to it is retained there for future assignments.

Throughout the simulation process, variables are updated to allow analysis of the system operation.

Output of the Model—Initial trials with the model found the following descriptive statistics to be helpful in analysis.

1. Passenger Statistics
   a. Waiting time distribution: a measurement from the time the demand call is originated until the bus arrives to pick up each passenger.
   b. Travel time distribution: the time spent on board a bus by each passenger.
   c. Total time distribution: the time spent from origination of the demand call until delivery at the destination for each passenger.
   d. Excess time distribution: the amount of time spent on the bus in excess of the time required for minimum travel time between the origin and destination for each passenger. The sum of the excess time is also calculated.
2. Bus Statistics
   a. Roadtimes for buses: the amount of time which each bus has spent traveling on the roadway grid.
   b. Bus minutes distribution: the distribution of roadtimes.
   c. Passenger minutes distribution: the number of passenger minutes accrued for each bus.
   d. Percent time on road: the relative time each bus has spent on the road compared to total time since the bus was initially dispatched from the terminal.
   e. Passenger minutes per bus minute: a relative measure of the extent to which each bus achieves its capacity.

Additional outputs were utilized to increase insight into the detailed operation of the model. At selected CLOCK time intervals, a subroutine called SUMMARY caused certain of the entries in the bookkeeping lists to be printed. Bus log entries for all buses are printed according to time of occurrence. This yields a complete record of all transactions completed since the last time the summary subroutine was executed. Bus lists for selected buses are printed to allow inspection of uncompleted activities. The position of all buses at the time SUMMARY is executed is also printed.

FUTURE WORK ON THE MODEL

Further work is necessary to extend the initial BUSTOP model. This work has two purposes. The first is to develop a more realistic simulation model which would account for demands from an actual city. More realistic street patterns and travel times should be incorporated into the model. The second is to investigate the feasibility of the bus system. This investigation would consider costs, fares, and subsidies necessary to operate such a system, and how the system operating and service characteristics compare with other modes such as public transit, auto, and taxicabs (Fig. 4).

Demand

As it would be hard to estimate the initial and long-run demands for such a system, a range of reasonable values would be estimated. Analyses carried out for several levels of demand would help to establish the limits for economic feasibility. In addition, possible fare and subsidy relationships would be developed for each demand level tested.

The demand level would be expressed in calls per hour. Different call frequencies for origins and destinations would be assigned to different subareas of the study area. The range of call frequency would be determined from a heuristic analysis of land use, alternative transportation modes, socioeconomic information, number of cars per household, trip purposes, and captive public transit ridership. Service characteristics and fare structure would also be included.

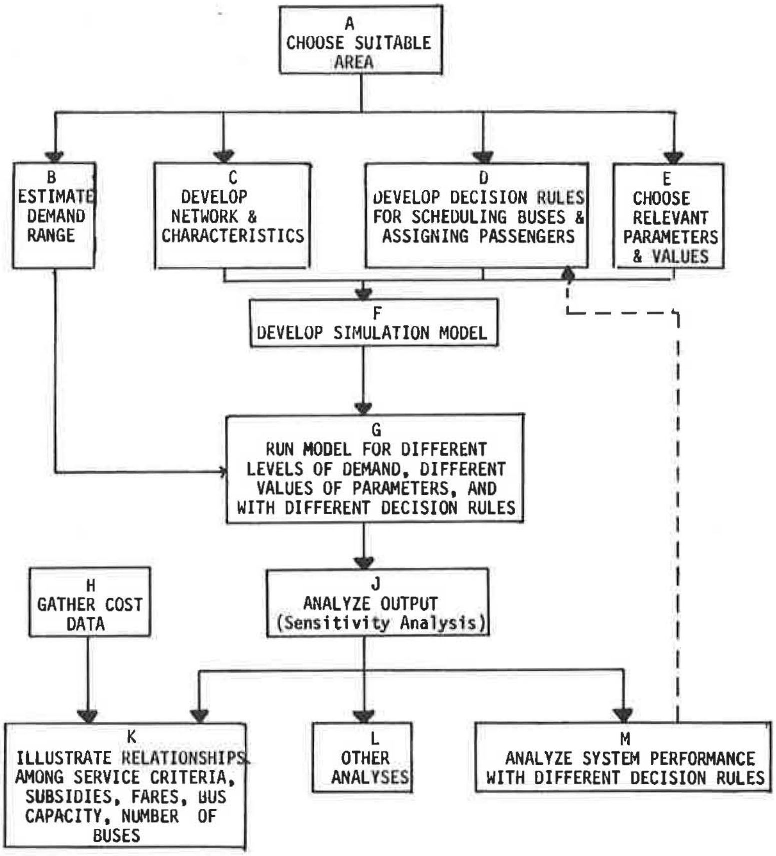

Figure 4. DSB simulation model development flow chart.

Service Criteria

To be realistic, the envisaged system would operate with a limited number of vehicles and chauffeurs. Thus, the absolute guarantees on pickup and total times used in the initial model could be violated in periods of peak demand. Whereas the initial model guaranteed that each passenger would be picked up within 5 minutes, the new model could possibly consider the distribution of pickup times. The system then would have an expected pickup time and would aim towards picking up, say, 95 percent of the passengers within 5 minutes. The expected and the 95 percentile pickup times would again be adjustable parameters in the model and system operation, and costs could be examined over ranges of these two parameters. The total time on the system would be treated in a similar manner. The expected total time would depend on the trip distance. It would be expressed as Kt, where t might be the auto travel time and K the same factor greater than 1. Existing transit travel time might also be used for t in which case K would be less than 1.

Network Structure

Since the study area for the new model would be considerably larger than the simple network in the initial model, a slightly different procedure would be employed. For the larger area it would probably not be feasible to include all streets and all intersections in the study area from a programming point of view. For the operation of the model this would not be necessary either. The links of the network would consist of major arterial and collector streets. In addition, groups of less important streets would be combined into single links.

The service provided would still be door-to-door. Each node would serve as intersections on the grid as well as origins and destinations of the trips. To account for the fact that not all trip ends are located exactly at the nodes, the pickup and delivery penalties would be replaced by an average "access" time, which would include time to travel from the node to the actual trip end, time for the passenger to enter or leave the vehicle, and time to return to the same node. Each node would have a different access time.

After the average travel times on each link are estimated, minimum time path trees could be generated to obtain the shortest travel time with the corresponding route between each pair of nodes.

Decision Rules—Scheduling and Routing

The decision rules assign passengers to the buses and set the order in which the passengers assigned to a given bus are to be served. The objective of these decision rules is to make the assigning and scheduling process as close to optimal as possible. One such set of decision rules has already been discussed. It is proposed that other sets be developed and tested to see which set enables the highest service levels and lowest operating cost. It may be that different sets be desired for peak and off-peak operation.

The assigning and scheduling would be done using average travel times via the quickest routes. A new algorithm has to be developed for routing the buses and keeping track of them. It is proposed that from the tree generations a "next-node" matrix be developed. The row subscripts of this matrix would be the current location of the bus. The column subscripts would represent the next node in the bus list. The entries would contain the identification number of the next node the vehicle must pass through on the shortest path to the next node on the bus list. When the vehicle reaches each point it looks at the matrix again to find the succeeding node. In this way, the location of the bus can be readily determined at all times.

Vehicle Movement

Whereas the bus schedules would be determined using the average link travel times, in reality the buses could not be expected to keep exactly to it. To simulate this, as the bus enters each link, its travel time on it could be stochastically determined from a distribution which uses the average travel time as a distribution parameter.

System Costs

For the feasibility analysis the costs to be considered would be those of vehicles, communication equipment, maintenance, repairs, operating personnel, and computer time.

Input Variables

For the model runs there would be four basic parameters which would be varied: (a) demand level, (b) level of service, (c) bus size, and (d) number of buses. For each combination of demand level and level of service, the combination of bus size and number of buses which yields the minimum total cost would be determined. From these combinations, relationships among total cost, demand, and service can be illustrated. The total cost can further be divided into fares and subsidies and more relationships shown.

In addition to varying the above four parameters, different decision rules can be tried out to see if better service can be provided and if the number or size of buses can be reduced.

Other Analyses

Other analyses would be carried out to provide additional information about system performance. For example, a fixed-route fixed-schedule system could be compared to the door-to-door service. A comparison could also be made of the cost and efficiency of using competent dispatchers in place of a computer.

DEVELOPING AN OPERATIONAL SYSTEM

The Vehicle

The size and type of vehicle would depend on the level of service desired, economic considerations, and handling characteristics. It would most likely be designed to carry from 4 to 20 passengers. It would require good acceleration characteristics because of the frequent stops and the ability to maintain speeds commensurate with the speed limits of the area.

For the type of service studied in the initial simulation runs, a small compact vehicle, carrying 4 to 7 passengers, would be most practical. It would be easy to handle on local streets, and it would not have an adverse effect on the environment or on other vehicles.

Larger vehicles might be more economical if a different type of service (solely on arterial streets, for example) were to be provided or if the trip patterns were strongly oriented around a limited number of heavy generators.

The Chauffeur

The provision of personnel to operate the vehicles could prove one of the most difficult problems to solve. Since it is almost impossible to hire drivers for split shifts, it probably would be necessary to employ them on the basis of two 8-hr shifts, with a few starting earlier and a few quitting later. If the demand is sufficient, it may be desirable to provide 24-hr service and employ 3 complete 8-hr shifts. The result, of course, is a serious underutilization of personnel during the off-peak periods. This problem is a common one, faced by all existing transit operators.

If the demand-scheduled system is set up to provide neighborhood service alone, a partial solution may be possible. Under these conditions, chauffeurs need not be so highly trained as regular bus drivers nor so knowledgeable about a large area as taxi drivers. Perhaps part-time personnel could be used. If such a system were to be operated by an existing taxicab company, then their current operators would have adequate experience and knowledge of the area street system. Each vehicle-operator combination could be used for the DSB or regular taxicab operation as demands warranted.

Vehicle Control

The problem of vehicle control is one of the more difficult problems encountered in the operation of a DSB system. Two basic types of information must be exchanged between the vehicle and the central control station. First, the chauffeur must be made aware of his next destination. Second, the station must know the location of each vehicle, at least at intervals, if not continuously. In addition, the chauffeur must also inform the central control of successfully completed pickups and deliveries. Many different systems are conceivable, varying in sophistication, complexity, and cost.

The simplest system, perhaps, would involve the use of two-way radios. The driver would relay his position orally to the control station, where an operator would then code it into a computer. The computer would calculate future destinations for the vehicle, and this information would then be transmitted orally from the operator to the driver. The choice of route would be left up to the driver. In the case of neighborhood service, the choice would not significantly affect the results. In larger areas, efficient operation would depend on the driver's ability to select the best route from previous experience.

A great many improvements could be made, in steps, up to what might be termed an ultimate system. Here, the vehicle would be automatically monitored continuously by radio and its position fed directly into the computer. The computer could also have stored within it the minimum time path between every pair of nodes in the service area. The desired route could be transmitted directly to the vehicle, perhaps being displayed in a schematic form on a console in front of the driver. Such a system would provide excellent service and flexible operation, but of course only at a very great cost.

Using a DSB

The most desirable method for requesting DSB service would seem to be the telephone. Callers could give operators at the central control station their origin, destination, and a desired pickup time if immediate service is not requested. The operator would then feed the information into the computer.

Fares could be collected on the vehicle, or a billing operation might be instituted whereby passengers would use credit or bank-charge cards. Alternatively, billing could be included in the caller's telephone bill. If calling from home, a passenger, after having reached a central switchboard, might dial a sequence of digits giving his origin and destination. Another billing procedure could be the use of a monthly flash-pass.

Revenue

At least four sources are available to finance such a system. The most obvious is direct fare collection. There is evidence that people would be willing to pay a reasonable amount for such a service. Whether or not this would be sufficient to pay for the system is highly conjectural at this stage.

Assuming direct fare collection is inadequate, the next obvious source of funds is direct government subsidization. A subsidy to this type of system invokes fewer political problems than to a conventional system, since equal service is in fact provided to all.

A third possible source of funds would be from merchants of the area. This could be especially true of proprietors in older business districts who are faced with nearly insurmountable problems of providing adequate parking for private automobiles. A subsidy might be an attractive alternative to acquiring expensive developed property for parking lots. The merchants of the area would further benefit because DSB passengers would be constrained and encouraged to shop only within the DSB service area.

A fourth possible source is to obtain a Mass Transportation Demonstration Grant from the U.S. Department of Housing and Urban Development. It is this source which enabled the start of the minibuses in Washington, D.C. and the Skokie Swift Project in Skokie, Ill.

IMPLEMENTING A DSB SYSTEM

One possibility for implementation has been advocated and stems from the fact that most small buses use standard light-truck engines, axles, and chassis components (9). Therefore, the small buses would be compatible with maintenance facilities of small truck fleet operators. Since nearly every city of any size has one or more truck fleets, a potential exists whereby the trucking company might profitably operate a small bus transit company. It could take advantage of experience in fleet operation and also would not have to risk the entire business in a new venture. The addition of new vehicles and personnel would be only an extension to an existing plant. Some drivers could work in both operations—part-time driving a bus and part-time delivering freight.

The fleet owners may also explore the possibilities of using small buses as delivery vans during the off-peak passenger hours. The seats could be designed for quick removal through a rear door in a manner similar to the air cargo-passenger system used by the airline companies. Since peak periods of freight traffic and passenger traffic are apt to be at different times during the day, this type of operation could smooth out the peak period demand for equipment.

As well as trucking companies, an existing taxicab firm might manage and operate the system. Its experience in management and operations and its communications equipment would be valuable.

One means of expanding small bus operation would be through suburban real estate developers who could include small bus service along with the community swimming pool and par-three golf course as an enticement to buy a house in their subdivision. In addition to reducing the need for two cars, the development may fill up quicker if people did not need to purchase a second car immediately.

PRESENT SMALL BUS OPERATIONS

The feasibility of small bus operations is being investigated by the Department of Housing and Urban Development (HUD) through a research project for developing criteria for non-rail transit vehicles. They are giving special attention to a small bus door-to-door operation which could feed larger trunk line systems.

One of the more successful small bus demonstration projects is the minibus operation in Washington, D. C. This is a downtown shuttle bus system initiated in 1963 which operates over a 1.6-mile route along a major shopping street. A fleet of 14 buses operate on a 3-min headway with a regular fare of five cents. Patronage during the 1964 Christmas season averaged about 9600 daily. Normal daily loads were about 6000.

Mansfield, Ohio, (population about 50,000) is served by a fleet of eighteen Ford Econolines which have been equipped to carry 12 passengers each. Service on twelve routes is provided at half-hour intervals with some 15-min headways during the afternoon rush. Passenger counts averaged 3,000 in 1965 with a peak of 4,000 during the Christmas season. Regular fare is 25 cents. The routes fan out from a central point at the town square which is also the only transfer point between buses.

Atlantic City, N. J., has had a jitney operation since 1916. Most of the vehicles are IHC Metro buses and most are owned by the operators who have a franchise with the city. About 190 jitneys operate along a route which extends for about four miles parallel to the boardwalk. There is no scheduled headway; however, the jitneys are about one minute apart. No one stands in the jitneys and if the vehicle is full, the driver passes people wating at the curb until someone leaves his vehicle. Each jitney seats 10 people and maintenance is the responsibility of the vehicle owner; however, each jitney must pass safety inspection.

The new transit system envisaged in this paper involves three concepts which are relatively new to transit operations. The first is the use of small buses. The three examples show that such a concept is practical and economically feasible. Although the Atlantic City jitneys have been in operation since 1916, they have not received widespread attention or duplication.

The second concept is demand scheduling. In practice, this has only been evident in taxicab operation. In theory, this concept is receiving wider attention, the MIT student report being an example.

The third concept is door-to-door service. A demonstration project was recently conducted in Peoria and Decatur, Ill., which has door-to-door service on a fixed-route, fixed-schedule basis (10). The Menlo Park experiment also utilized this concept, however, the level of service was considerably below that considered in BUSTOP. The Menlo Park experiment was a physical simulation without passengers.

BUSTOP is a computer simulation which employs these three concepts. What is required now is a practical demonstration project which also employs these three new concepts.

CONCLUSIONS

Simulation can be a very effective tool in transportation planning. In many instances simulation provides an inexpensive way of evaluating alternative measures to be used in a transportation system without funding for hardware equipment. Before implementation of any demonstration projects, simulation can provide much insight into operational characteristics, equipment requirements, cost, and effectiveness. With the aid of an appropriate simulation package, cost-effectiveness relationships can be developed without the installation of actual operations.

Since the computer algorithm has been developed to solve the many-to-many problem, much more flexibility is allowed in the use of simulation to study various types of transit services. Through detailed sensitivity analysis, a more appropriate transit system with various operational characteristics can be selected for implementation.

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REFERENCES

1. Automobile Manufacturers Association. Urban Transportation-Issues and Trends. Detroit 1963.
2. Chicago Area Transportation Study. Final Report, Volume 2, 1959.
3. Transit Expressway Report. MPC Corporation, Pittsburgh, 1967.
4. Hansen, Mark E., Ed. Project Metran—On Integrated Evolutionary Transportation System for Urban Areas. MIT Report No. 8, 1966.
5. Jones, Paul S. Miniature Bus Systems. Proc., SRI Urban Transportation Alternatives Symposium, Menlo Park, 1964.
6. Shubik, Martin. Simulation of the Industry and the Firm. American Economic Review, L. No. 5, Dec. 1960.
7. Naylor, T. H., Balintfy, J. L., Burdick, D. S., and Chu, K. Computer Simulation Techniques. John Wiley and Sons, New York, 1966.
8. A Description of SPURT. Department of Industrial Engineering and Management Sciences, Northwestern University, 1967.
9. Lyndall, Jack. Little Buses Do a Big Job. Fleet Owner, July 1965.
10. Blurton, Michael, A.S. Special Bus Service. Traffic Engineering, Feb. 1967.