U.S. Department
of Transportation
**Research and
Special Programs
Administration**

Control of Bus Service Reliability in Bus Transit Networks: Simulation Model

Prepared for:
Office of University Research

User's Manual (Version 2.0)

DOT/RSPA/DPB-50/82/2

Phase II Report
Under Contract DOT-OS-80018
February 1982

Technical Report Documentation Page

1. Report No.
DOT/RSPA/DPB-50/82/2

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Control of Service Reliability in Bus Transit Networks:
Simulation Model User's Manual, Version 2.0

5. Report Date
February 1982

6. Performing Organization Code

8. Performing Organization Report No.

7. Author(s)
William C. Jordan, Mark A. Turnquist

9. Performing Organization Name and Address
Northwestern University*
Evanston, Illinois 60201
*part of research was subcontracted to Cornell Univ.

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DOT-OS-80018

13. Type of Report and Period Covered
Final Report
March 1979 - June 1980

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Research and Special Progams Administration
Office of University Research
Washington, D.C. 20590

14. Sponsoring Agency Code
DPB-50

15. Supplementary Notes
Technical Monitor: Mark D. Abkowitz, DTS-243
Transp. Systems Center

16. Abstract

This manual provides the information required to use the bus network simulation model developed as part of a project on analysis of control strategies for improving service reliability. It supersedes the earlier User's Manual, report DOT/RSPA/DPB-50/79/6, dated March, 1979: The manual includes: 1) an overview of model structure and capabilities, 2) detailed descriptions of all major elements of the model, 3) a flowchart of each subprogram, 4) format and instructions for preparing model input, and 5) an example run of the model.

17. Key Words
Computer simulation, service reliability, urban bus network, control strategy

18. Distribution Statement
Document is available to the U.S. Public through the National Technical Information Service,
Springfield, Virginia 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

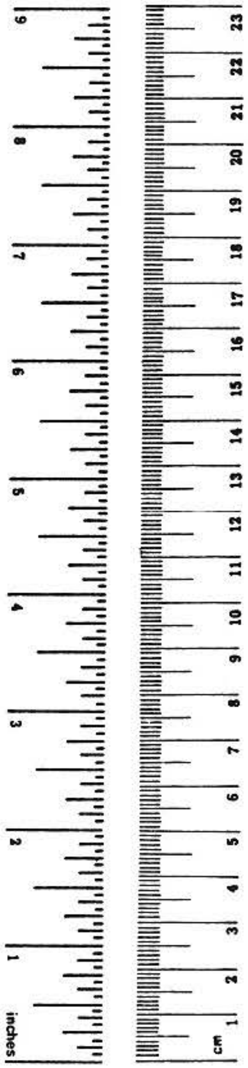
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

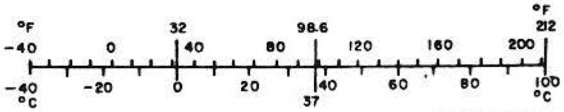
---

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid	
l	liters	2.1	pint	
l	liters	1.06	quar	
l	liters	0.26	gall	
m^3	cubic meters	35	cubic	
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Preface

The development of the computer simulation model described in this manual was begun at Northwestern University and completed at Cornell University, under contract DOT-OS-80018 from the U.S. Department of Transportation. This manual describes version 2.0 of the simulation model, and supersedes the earlier manual by L. A. Bowman and M. A. Turnquist, report DOT/RSPA/DPB-50/79/6, dated March, 1979.

The authors wish to express their appreciation to the contract monitor, Mark Abkowitz, for his helpful advice and assistance throughout this project. The contributions of several graduate students should also be acknowledged. Special thanks are due to Larry Bowman, Chester Hashizume, Steven Blume and James Thompson at Northwestern, and to Siu-Ming Siu at Cornell.

CONTENTS

I. Model Overview

This manual describes a discrete-event computer simulation model of a bus transit system. This model uses the simulation language SIMSCRIPT II.5 (CACI, 1976), and allows bus and passenger movements through the system to be monitored. The major purpose of the model is to test strategies that have potential for improving the efficiency and effectiveness of transit service. These strategies include (but are not limited to) those which attempt to improve service reliability.

The model is very flexible, so as to allow representation of a wide variety of systems. It can be used to analyze single routes (including those which branch) or entire networks of routes. In the current configuration, the model can handle up to 256 nodes, and a like number of routes and links. Generally, the node constraint will be the most binding, because of the creation of internal nodes by the model. This is discussed in more detail in Section IV.A.

The bus system is modeled by defining classes of "entities" which correspond to the major physical elements of the system. For example, bus stops are defined as an entity class. Each entity has "attributes" (words of computer memory) associated with it which describe the state of the system at any time - e.g. a bus stop entity has attributes that store the time the last bus left the bus stop, the number of passengers that have arrived at the stop, the number of bus routes serving the stop, etc.

Two basic types of entities exist. There are elements of the system which exist for as long as the system is modeled, such as bus stops, that are defined as "permanent entities." Secondly, some system elements move into and out of the system, such as passengers, and are "temporary entities."

Entities not only possess attributes but may belong to "sets." A set is a group of entities which is owned by another entity. For instance, a bus stop entity may have (own) a set of passenger entities associated with it, i.e. passengers that are waiting at the bus stop. Entities can move into and out of a set, and may belong to several sets at once.

The physical elements of the bus system are modeled by this entity-attribute-set structure. The dimension of time is incorporated in the model through "events." Events are incidents which occur at points in time that are of importance to the operation of the system being modeled - a bus arrives at a stop, a bus departs from a stop, etc. In a discrete event simulation the state of the system is updated only when an event occurs: some attributes of entities change, entities move into or out of sets, entities are created or destroyed, etc. It is in this manner that certain entities, such as passengers, move through the bus system. Events often give rise to other events. For example the bus departure from a stop event results in the scheduling of an arrival event for that bus at another stop.

Using the concepts discussed above, the basic logic of the bus system model will now be presented. The bus network is actually modeled at two different levels. A macroscopic model examines the movement of buses and passengers over the entire network. This level can be used alone or in conjunction with a more detailed microscopic model. This microscopic view allows selected segments of bus routes to be examined in more detail. Bus activities at intersections and general traffic are explicitly modeled here.

A. Macroscopic Model

In the macroscopic model a bus system is defined by 3 permanent entity classes, 2 temporary entity classes, and 6 events. The permanent entity classes are:

1. bus stops (entity BUS.STOP). Each bus stop is an entity. In describing an entire bus network there may be too many bus stops to define an entity for each one. As a result, each bus stop entity in the macroscopic model generally corresponds to an aggregation of neighboring bus stops.

2. Links (entity LINK). Each link entity connects a pair of bus stop entities. A link physically corresponds to the roadway connecting bus stops.

3. Bus routes (entity ROUTE). A bus route entity is the path (in terms of links) which buses follow in serving bus stops.

The temporary entity classes are:

1. Passengers (entity PASSENGER). Each passenger entity is created when a passenger arrives at a stop, and is destroyed when the passenger gets off the bus at his destination.

2. Buses (entity BUS). A bus entity exists as long as the bus is serving a route. When the bus reaches the end of its route it is destroyed.

The attributes of each of these entity classes, and the set ownership-membership structure is defined and documented in the PREAMBLE of the simulation program. Model input defines the relationships of both permanent entities (which stops each link connects, which links compose a route, the length of links, etc.) and temporary entities (the dispatch schedule for buses on each route, average arrival rates of passengers at each stop, etc.). The model input is discussed in detail in section III.

The third major element in the model is the set of events. The six events in the macroscopic model are:

1. Event PASS.ARRIVE - a passenger arrives at a stop.
2. Event BUS.ARRIVE - a bus arrives at a stop.
3. Event BUS.DEPART - a bus departs a stop.
4. Event DISPATCH - a bus is dispatched to a route.
5. Event END.ROUTE - a bus arrives at the end of its route.
6. Event END.OF.SIMULATION - cancels all future scheduled events.

The interrelationships between events can be described as follows. When a DISPATCH event occurs a bus entity is created and assigned to the appropriate route. The bus entity joins a set (IN.SERVICE.BUSES) of buses serving the route (the ROUTE entity owns the set). A BUS.ARRIVAL event is scheduled for the bus at the route's first stop, the dispatch stop, immediately. the DISPATCH event also schedules the next DISPATCH event to occur according to the input timetable.

When a BUS.ARRIVAL event occurs passengers board and alight the bus - i.e. passenger entities are placed into and taken out of a set of passenger entities owned by the bus entity, the set RIDERS. The bus dwell time at the stop is calculated based on the number of passengers served. One of two events is then scheduled to occur after the dwell time has elapsed. If the bus is not at the last stop in the route a BUS.DEPART event is scheduled. However, if the bus is at its last stop, an END.ROUTE event is scheduled.

A bus departure from a stop occurs only if no new passengers arrive to board the bus before it leaves. If new passengers have arrived the BUS.DEPART event computes the time for these passengers to board and reschedules the BUS.DEPART event to occur after this time. If all passengers have boarded, the time for the bus to travel to the next stop on the route is calculated. In the macroscopic model travel times over links are described by shifted gamma distributions. Travel times are determined by sampling randomly from such distributions. The nature of these distributions is described more completely in section II.C.1. A BUS.ARRIVAL event for the bus is scheduled to occur after the travel time has elapsed.

The END.ROUTE event simply serves the purpose of removing the bus from the IN.SERVICE.BUSES set and making the bus available to serve another route after a specified layover period has expired.

A PASS.ARRIVE event at a stop creates a passenger entity and places this entity in the set QUEUE owned by the appropriate bus stop entity (i.e., the passenger waits at the stop). When a bus arrives at the stop (event BUS.ARRIVE) the passenger entity leaves the set QUEUE and joins the RIDERS as discussed above. When the bus arrives at the passenger's destination or a transfer stop, the passenger leaves the set RIDERS. The model provides an option of two different passenger arrival processes: 1) passengers arrive randomly according to a Poisson process, and 2) passenger arrivals are coordinated with the expected arrival times of buses at the stop. Passengers arrival processes are described more completely in Section II.D. Using one of these two processes each PASS.ARRIVE event schedules the next such event at the stop. The detailed logic associated with each event is presented in Section IV.

B. Microscopic Model

The microscopic model allows a segment of a route to be examined in more detail. The main difference between this and the macroscopic model is the way in which buses move from stop to stop. As discussed above, in the macroscopic model bus travel times are represented as random variables having a shifted gamma distribution for each link. The microscopic model allows bus interactions with traffic and traffic lights to be explicitly represented.

The same entities and events used in the macroscopic model are used in the micro-model. However, three additional permanent classes and four additional events are used in this model. The three new entity classes are:

1. Intersections (entity INTERSECTION). Intersections are located along links (recall links connect bus stops). Hence a link could, theoretically, have any number of intersections associated with it. Each link entity owns a set JUNCTIONS to which intersection entities located on the link belong.

2. Signals (entity SIGNAL). Each intersection entity has a signal entity associated with it. This entity represents a traffic signal, so only signalized intersections can be modeled.

3. Route segments (entity SEGMENT). A segment is defined as a continuous portion of a route which is being simulated microscopically. Each segment entity owns a set MICRO.LINK.SET which contains the link entities composing the route portion being so modeled.

The additional events are:

1. Event BUS.PASSING.STOP - in the micro-model a bus need not stop at a bus stop if there are no passengers to be served there. When a bus passes a stop where it does not stop a BUS.PASSING.STOP event occurs.

2. Event INT.ARRIVAL - a bus arrives at an intersection.

3. Event LIGHT.CHANGE - a traffic signal changes phase.

4. Event STOP.CHECK - a bus must decide whether or not to stop at a bus stop or intersection.

The arrival of passengers at a stop, bus dispatches, and the arrival of a bus at the end of its route occur in the same way in the micro-model as in the macro-model described above. It is the movement of buses between stops which is greatly altered.

The BUS.ARRIVAL event results in the scheduling of a BUS.DEPART event for a bus in the same manner as in the macro-model. However, in the micro-model a bus may encounter difficulty with traffic in leaving the stop, if the bus stop is protected (protected or unprotected bus stops may be considered in the micro-model). A bus must find a gap in traffic when leaving a protected stop. Traffic volumes between consecutive intersections on the route segment are stored as an attribute of the upstream intersection entity (how volumes are claculated is discussed in Section II.B. If a bus stop is protected the BUS.DEPART event is scheduled to occur after a suitable gap has been found in traffic. Otherwise the event is scheduled to occur immediately after all passengers have been served.

When a BUS.DEPART event occurs, the distance to the bus's next potential stop point, either the next bus stop or the next intersection, is known. An acceleration and deceleration rate are randomly determined for the bus. The bus cruising speed on the next link is computed based on the link's traffic density. Assuming a constant rate of acceleration by the bus to the cruising speed and a constant deceleration rate from it, the time for the bus to travel to and stop at the next potential stop is easily determined. However, the bus may not stop at the next stop point (i.e., the traffic signal at the intersection may be green or no passengers may desire service at the next stop). Hence, from the known deceleration rate the time at which the bus must decide whether or not to stop at the next potential stop point can be found. The event STOP.CHECK, which determines whether or not the bus actually stops, is scheduled for this time.

When the STOP.CHECK event occurs it must be determined whether the potential stop point involved is an intersection or bus stop. If it is a bus stop a check is made to see: 1) if there are any passengers who want to alight at the stop, or 2) if anybody is waiting at the stop. If there are any passengers to be served, a BUS.ARRIVAL event is scheduled to occur when the bus reaches the stop (a function of its speed, deceleration rate, etc.). If no passengers are to be served the bus will not stop and a BUS.PASSING.STOP event is scheduled for the time when the bus reaches the stop.

If the potential stop point is an intersection, the phase of the traffic signal is checked. If it is red, the bus will stop and an INT.ARRIVAL event is scheduled for the time when the bus decelerates to a stop at the intersection. If the light is green, an INT.ARRIVAL event is scheduled for the time the bus will reach the intersection given that it will be travelling at, or accelerating to, cruising speed.

An INT.ARRIVAL event denotes the arrival of the bus at an intersection. If the light is red when the bus arrives, the bus entity is placed in the set BUS.QUEUE owned by the intersection to await a light change. A green light allows the bus to pass through the intersection. A STOP.CHECK event is then scheduled for the succeeding stop point, given: (1) the distance to the next potential stop point; (2) the present velocity of the bus; and (3) the acceleration and deceleration rates and cruising speed.

In a similar way the BUS.PASSING.STOP event also schedules the next STOP.CHECK event for a bus.

The LIGHT.CHANGE event for each signal has two main functions. First, if the light changes from red to green, buses waiting at the light (in BUS.QUEUE) pass through the light and the next STOP.CHECK event for each bus is scheduled. Secondly, the LIGHT.CHANGE event adjusts the traffic volumes upstream and downstream of the intersection.

Details on the way traffic volumes are computed, on how bus cruising speed and acceleration and deceleration rates are determined, and on how an acceptable gap for a bus entering traffic is modeled is presented in Section II. Section IV presents much more detail on the logic of each event.

C. Special Model Capabilities

The model allows strategies for improving bus system performance (especially reliability) to be tested. Most potential strategies are reflected by simply changing regular model inputs. However, bus holding strategies and traffic signal preemption by approaching buses require special model capabilities.

Holding strategies basically delay the departure of a bus from a stop until a certain criterion is met. Two types of holding controls are allowed in the model:

1. Hold-to-schedule: A bus is not allowed to leave a stop before its scheduled departure time.

2. Hold-to-headway: A minimum headway between successive buses is established such that a bus is not allowed to leave a stop until at least a time equal to the minimum headway has elapsed since the previous bus left the stop.

These controls are incorporated into the model simply by delaying the BUS.DEPART event until the appropriate time. This type of strategy can be used with either the macro- or microscopic model.

Signal preemption by an approaching bus can only be tested using the microscopic model. This strategy is included in the model by defining another event - event PREEMPTION. The event occurs when a bus arrives at a fixed distance from a preemptable signal, where the signal can detect the presence of the bus. The light changes to green, if it is not already green, and remains in this phase until the bus passes the intersection. The light then returns to its normal operation, with subsequent cycles unaffected by the preemption. The PREEMPTION event schedules the bus arrival at the intersection - event INT.ARRIVAL - based on the distance to the signal, the bus speed, acceleration and deceleration rates, etc.

The PREEMPTION event for a bus is scheduled by a BUS.DEPART, INT.ARRIVAL, or BUS.PASSING.STOP event when the bus's next potential stopping point is the preemptable intersection. The events schedule the PREEMPTION for the time that the bus will arrive at the fixed distance from the intersection at which it is detected. No STOP.CHECK event is scheduled for a preemptable intersection because the bus will never stop at the intersection.

D. Outline of Documentation

Section II of this manual describes in detail the major structural elements of the simulation. This is intended to give the user a thorough understanding of how the model is put together, and of the major assumptions implicit in the model. Section III describes the input data required by the model. Section IV provides details on the individual event routines within the model. Section V describes the output produced by the model, and discusses various output options available to the user. Section VI presents an example of use of the model, including a complete input file and the resulting output.

II. Structural Elements of the Model

The simulation model as a whole represents the interactions of buses, passengers and general vehicular traffic. The nature of these interactions is determined by a series of sub-models, each based on specified assumptions, and constructed in a particular way. The purpose of this section is to describe each of the major sub-models individually, and in detail, so that the user of the simulation gains an understanding of the structural elements upon which it is based.

A. Bus Dwell Times

Dwell time is the time a bus spends at a bus stop serving passengers. Clearly there is a relationship between the number of passengers the bus serves and this dwell time. The form of this relationship is based upon experimental work by Boardman and Kraft (1970). It may be represented as follows.

$$D_i = \alpha + \beta_1 X_i + \beta_2 Y_i + \beta_3 X_i Y_i + \varepsilon \tag{1}$$

where D_i = dwell time of the bus at stop i

X_i = number of boarding passengers at stop i

Y_i = number of alighting passengers at stop i

$\alpha, \beta_1, \beta_2, \beta_3$ = constants

ε = an error term which is assumed to be normally distributed with mean 0 and constant variance σ^2.

The values of α, β_1, β_2, β_3, and σ are inputs to the simulation model. The values of these coefficients have been found empirically to differ in the three cases $X_i = 0$, $Y_i = 0$, and $X_i Y_i \neq 0$ (see Boardman and Kraft (1970)), so inputs of coefficients for these three cases are allowed for. If X_i and Y_i are both zero, the bus is assumed not to stop at the bus stop.

B. Traffic Volumes

For links that are being simulated in detail, the traffic density a bus encounters is critical in determining its speed (see Section II.C). Because intersections are the main points at which traffic volume on a link changes, traffic volume is monitored on each portion of a route segment that is bounded by intersections. Specifically, each intersection has an attribute that stores the volume of traffic between it and the intersection immediately downstream of it. The portion of a route segment between two intersections will be termed a block.

As part of the model input each intersection has three attributes dealing with changes in traffic volume: 1. MAIN.RATE - the average rate at which traffic enters the intersection in the main direction of travel, 2. TURN.PRCT - the average % of this traffic which turns onto the cross street, and 3. CROSS.RATE - the average rate at which vehicles turn into the main direction of travel from the cross street.

Volume changes on a block under the important assumption that vehicle arrivals at an intersection follow a Poisson process. As each intersection in the model has a traffic signal, the flow of vehicles on and off blocks are tied to the changing of traffic signals. Consider the intersections and blocks in Figure 1.

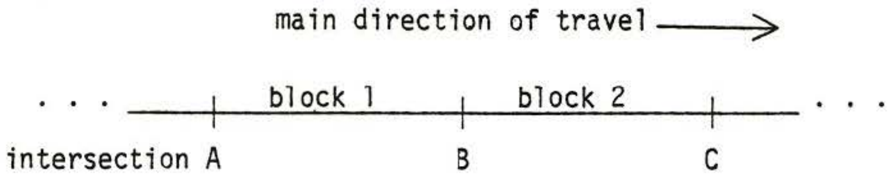


Figure 1. Intersection and Blocks

The traffic volume on blocks 1 and 2 are stored as the attribute DOWNSTREAM.VOL for intersection A and B, respectively. Volume changes caused by a signal change at intersection B occur in the following manner.

When the light changes color from red to green the number of vehicles which turned onto block 2 from the cross street is computed. This is done by sampling from a Poisson distribution with a parameter equal to the product of the CROSS.RATE attribute for intersection B and the cycle length of the signal. This number of vehicles is tested to insure that it does not exceed the capacity of the signal. The signal capacity is*

$$N = \left[\frac{G-D}{\hat{H}} + 2\right] * NL \qquad (2)$$

where N = number of vehicles clearing intersection during the green phase

D = starting delay, seconds

G = length of green phase, seconds

$\hat{H}$ = effective minumum headway spacing, seconds

NL = number of lanes of traffic passing through the light

---

* From Capelle and Pinnell, "Capacity Study of Signalized Diamond Interchanges," HRB Bulletin 291, 1961, p. 1-25. From this source D ≃ 5.8 sec, mean headway ≃ 2.1 sec. Based on log-normal distribution of headway and coefficient of variance of headways ≃ .4 $\hat{H}$ estimated as 1.5 sec.

The minimum of N and the number of vehicles sampled from the Poisson distribution is added to the DOWNSTREAM.VOL attribute of intersection B.

When the light changes from green to red the number of vehicles which left block 1 and entered block 2 or turned onto the cross street is determined. If this intersection has a near- or far-side unprotected bus stop the actual amount of time vehicles have to pass through the intersection will be decreased by the amount of time a bus was standing at the stop during the past green phase (turning traffic is unaffected by a far-side bus stop). The time during the last green phase when a bus was blocking the light is stored as BLK.TIME. As a bus will block only one lane, BLK.TIME is adjusted if the block has several lanes. The number of vehicles going straight through the intersection and the number turning are sampled from a Poisson distribution using MAIN.RATE, TURN.PRCT, the length of the green phase, and the time the traffic lane was blocked to determine the correct parameter. These numbers are checked to insure that the signal capacity is not exceeded, and that they don't exceed the number of vehicles on the block above intersection B. The number going straight is added to DOWNSTREAM.VOL for B. The total number turning and going straight is subtracted from DOWNSTREAM.VOL for intersection A. It is assumed that each block can physically accommodate all vehicles entering it during each phase of the upstream signal.

C. Bus In-Motion Times

In-motion time denotes all aspects of the time a bus is traveling along a route excluding dwell time. The method for determining in-motion time depends upon whether a particular segment of a route is being simulated macroscopically or microscopically.

1. Macroscopic Model

In the basic, or macroscopic, model bus in-motion times on links are assumed to be random variables following a shifted gamma distribution. The amount of the shift corresponds to the minimum, or free-flow, time in which a bus could traverse a link. This value is assumed to be equal to the link length divided by the speed limit. The gamma distribution corresponds to the delay experienced by the bus. The distribution has two parameters. The scale parameter, z, reflects the duration of an average delay. The shape parameter, k, indicates the average number of interferences the bus will encounter per mile.

While z is relatively constant over different street types, obviously the k parameter can vary significantly for a bus traveling on, say, an urban street versus a bus traveling on an expressway. Hence the model allows for the input of the k and z parameters and the speed limit for several different types of links. Additional detail on this issue can be found in Turnquist and Bowman (1979).

In the macroscopic model then, the expected value and variance of in-motion time over a link are as follows:

$$E[T_j] = L_j(kz + 1/S) \tag{3}$$

$$Var[T_j] = L_j \, kz^2 \tag{4}$$

where T_j = in-motion time of bus on link j

L_j = length of link j

S = speed limit on link j

k,z = gamma distribution parameters for link j.

2. Microscopic Model

For a bus traveling on a route segment which is being simulated microscopically, two important sources of bus delay are reflected explicitly in the model: signalized intersections and traffic congestion.

Traffic influences bus travel time through a relationship between traffic density and bus speed. This relationship is based on a study by Radelat (1971):

$$\begin{aligned} BCS &= 20.5 && \text{for } 0 < D \leq 30 \\ BCS &= 23.5 - .1D && \text{for } 30 < D \leq 235 \\ BCS &= 0 && \text{for } D > 235 \end{aligned} \tag{5}$$

where BCS = the expected bus cruising speed, the maximum speed the bus will attain, in mph

D = traffic density in vehicles/lane-mile.

The actual bus cruising speed is assumed to be a random variable normally distributed around the expected value with a standard deviation of 4 miles per hour (Radelat, 1971, pg. 79).

The traffic density, D, is determined by dividing the traffic volume for any given block by the length and number of lanes of the block. Bus velocity is stored as an attribute of the bus entity. In determining the in-motion time of a bus between a bus stop or intersection and the next bus stop or intersection it is not sufficient to take the distance to be traveled and divide by the bus cruising speed. There may be some acceleration or deceleration involved in leaving the present location and/or some deceleration at the next location. Bus acceleration and deceleration rates are assumed to be normally distributed random variables (truncated on each side at 3 standard deviations) with the following parameters (Radelat, pg. 80):

acceleration rate: mean = 2.2 mph/second
std. dev. = .5 mph/second

deceleration rate: mean = 3.0 mph/second
std. dev. = .8 mph/second

However, once an acceleration (deceleration) rate has been generated randomly for a bus, the bus is assumed to accelerate (decelerate) constantly at this rate until the desired speed is reached.

Thus, bus cruising speed over a block, as well as its constant acceleration and deceleration rates can be determined. Given this information, and the distance to be traveled, the bus's initial velocity, and knowledge of whether or not the bus stops at the downstream point, computation of bus travel time between two points is a straight forward application of the linear relationship between velocity, time, and distance. The program routine TRAVEL.TIME handles these computations.

D. Passenger Arrival Process

Passenger arrivals at a bus stop are determined by one of two different processes in the simulation model. The simplest assumes arrivals follow a Poisson process and are uncoordinated with the bus schedule for the stop. This random arrival pattern is an accurate representation of reality only when bus headways are short or service is very unreliable (Jolliffe and Hutchinson, 1975). It is assumed that the average arrival rate, the parameter of the Poisson process, does not vary over the simulation period.

Alternatively, passenger arrivals may be coordinated with the bus schedule. The non-random passenger arrival model used in this simulation model is that developed by Turnquist and Bowman (1979). Considering a schedule headway interval of length H, a passenger arriving in this interval is assumed to have a probability density function of arriving at time t, $0 \leq t \leq H$, given by:

$$f(t) = \frac{e^{u(t)}}{\int_0^H e^{u(t)}} \qquad (6)$$

where $u(t)$ = the passenger's utility for arriving at time t.

This utility function is assumed to be related to the passenger's expected wait time when arriving at time t. Based on empirical tests described by Turnquist and Bowman (1979), the functional form adopted is:

$$u(t) = [E(W_t)]^c \qquad (7)$$

where $E(W_t)$ = expected wait time for a passenger arriving at time t

c = constant coefficient (input by the user).

When aggregated over a population of users, the probability density function in (6) may be interpreted as a time-varying arrival rate of passengers at a bus stop. This rate function is used as the basis for simulating passenger arrivals as a non-stationary Poisson process.

The general form of this rate function is shown in Figure 2. The times $t = t_w$ and $t = t_o$ are those for which $E(W_t)$ is maximized and minimized, respectively, in the interval $0 \leq t \leq H$. To simplify the use of these time-varying rates in the simulation model, the piecewise linear approximation shown in Figure 3 is used.

The average arrival rate function illustrated in Figure 2 is derived under the assumption that the arrival time distributions of successive buses do not overlap. In some cases, bus service is very unreliable relative to the length of the headway, and the bus arrival time distributions will overlap.

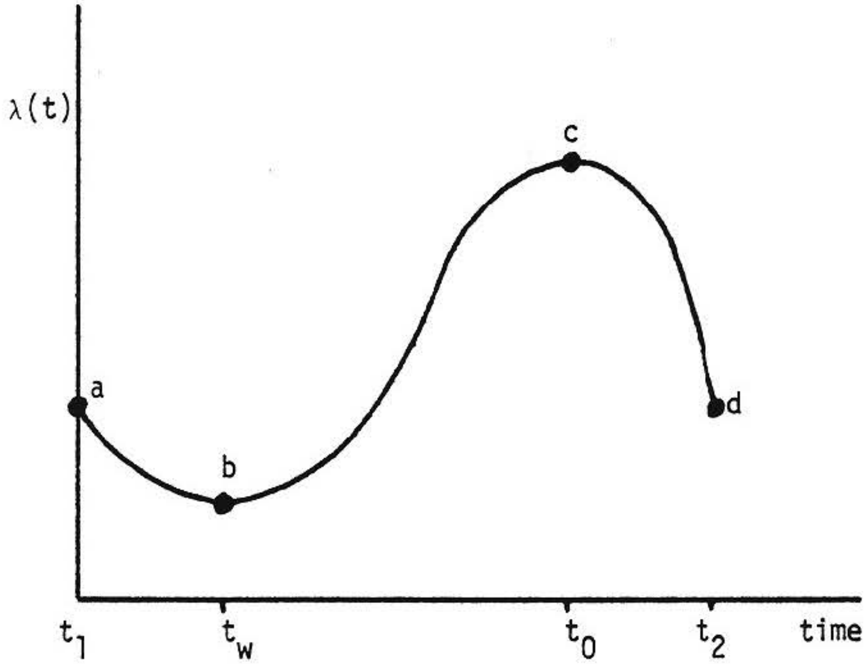


Figure 2. Arrival rate function.

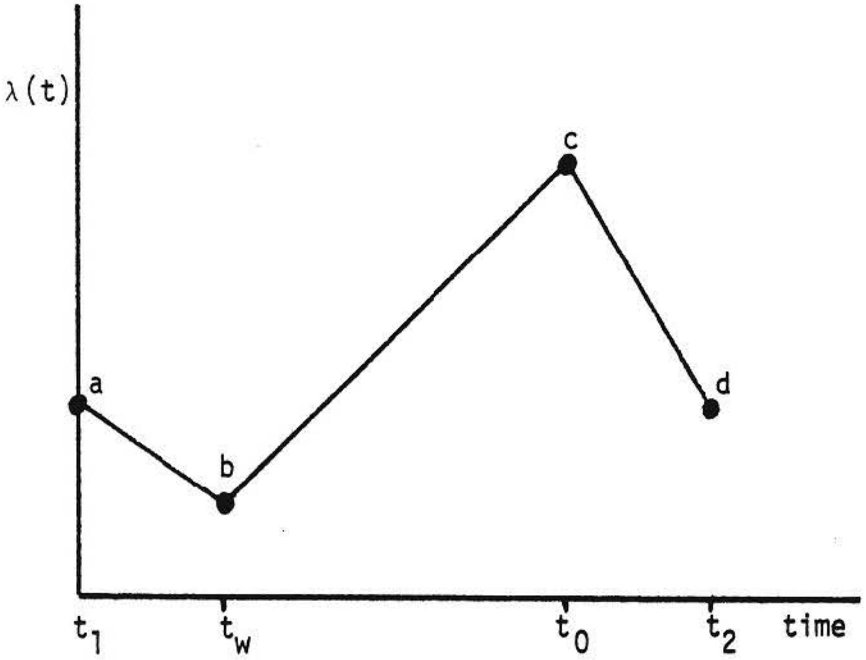


Figure 3. Approximated arrival rate function.

When this situation occurs passenger arrivals in the interval from 0 to H are assumed to be random, i.e. the $\lambda(t)$ function corresponding to Figure 2 (or 3) is a single horizintal line at $\lambda(t) = 1/H$ for $0 \leq t \leq H$.

Note that the model schedules passenger arrivals at a stop without regard to the passenger's destination (the model randomly determines the passenger's destination after arrival at the stop). Hence it is assumed that if a stop is served by several routes, all these routes have basically the same direction. If this is not so, a passenger could have his/her arrival at the stop coordinated with a scheduled bus which s/he doesn't want to board. When a location is served by buses travelling in different directions this should be handled by defining several distinct bus stops at the location.

E. Gap Acceptance

A protected bus stop is one where the bus pulls out of traffic before serving passengers. A bus stopping at such a stop must pull back into the traffic lane before it can depart the stop. A delay arises while the bus waits for a suitable gap to develop in traffic before it can pull out. This delay is only important in this model for buses stopping at protected bus stops that are on links being micro-simulated.

Two factors are important in determining the length of the delay a bus will encounter while awaiting an acceptable gap: 1) the gap size a bus requires to enter traffic, and 2) the size of the gaps between the vehicles composing traffic (here gap is defined to mean the time between the front ends of successive vehicles passing a fixed point). Both the gap size a bus requires and the size of the gaps in traffic are assumed to be random variables. The manner in which the model determines the time a bus waits to enter traffic is now discussed.

Based on information from Solberg and Oppenlander (1966) and Wagner (1966), acceptable gap sizes for buses are assumed to be log-normally distributed. To generate an acceptable gap size for a bus the following steps are taken:

1. Generate a random number, X, from a $N(5,1)$ distribution.
2. Let $Y = (X + 2.81)/9$.
3. The minimum acceptable gap, $G = 10^Y$ seconds.

This procedure is based on the finding by Solberg and Oppenlander (1966) that the following equation describes the behavior of car drivers in chosing gaps to make a right turn from a stop:

$$X = -2.81 + 9.00\ Y \qquad (8)$$

where $Y = \log_{10}$ of acceptance time for right turn

X = probit of acceptance, i.e. "The abscissa which corresponds to a probability of P [probability of gap acceptance] in a normal distribution having mean of 5.0 and variance of 1.0" (Solberg and Oppenlander, 1966, pg. 53).

The median gap accepted was 7.36 sec. This equation is applied to buses with no modification based on Wagner's (1966) findings that truck gap acceptance sizes are not significantly different from those accepted by cars. It is assumed that the gap required for pulling into traffic is similar to that needed to make a right turn.

Daon (1966) and Greenberg (1966) present evidence that the distribution of gaps in traffic is also best described by a log-normal distribution. Their data indicates that the coefficient of variation for gap sizes (std. dev./mean) is practically constant at .4 over the range of speeds encountered on urban streets. Therefore, the following method is used to compute the time until a gap of size G occurs in traffic.

1) Compute the traffic density, D, for the block on which the bus stop is located, as discussed in Section II.C.2.

2) Compute average speed of traffic, S, as shown in equation (9).

$$S = 24.6\ e^{-D/75} \tag{9}$$

where D = traffic density (veh/lane/mile)
S = average speed (mph) .

This relationship is taken from Underwood (1961).

3) Compute the mean gap size (in seconds), μ , as shown in equation (10).

$$\mu = \frac{3600}{D \cdot S} \tag{10}$$

4) Compute the standard deviation of gap sizes, as shown in equation (11).

$$\sigma = 0.4\ \mu \tag{11}$$

5) Draw a sample, t, from a lognormal distribution with mean μ and standard deviation σ, using the SIMSCRIPT function LOG.NORMAL.F. If $t < G$, the gap is too small, and is not accepted. Add t to a cumulative delay counter, and draw another sample. If $t \geq G$, the gap is accepted, and the delay is equal to the cumulative delay incurred prior to this gap.

The routine GAP.ACCEPTANCE performs these computations to compute delays to buses reentering the traffic stream.

F. Passenger Route Selection

In the initialization phase of the model, routine MINIMUM.PATHS (see Section IV.A.3) finds and stores the shortest path, in terms of the expected wait plus travel time, between each pair of stops in the modeled network. A path refers to the stops a passenger will pass through (either remaining on a bus or transferring to another bus) in going from origin to destination. The number of transfers required in traveling over these shortest paths is also stored for each O-D pair. This information is used to direct passenger movements, the underlying assumption being that people will travel the route between their origin and destination that has the shortest expected time.

Different weights can be given to wait and transfer time relative to travel time. That is, if the initial wait time and/or transfer time is considered to be more onerous than on-bus travel time by the average passenger, these values can be input to the model (see Section III.D). In this case a path would be found for each O-D pair minimizing the weighted expected times.

The main product of routine MINIMUM.PATHS is a matrix that stores the next stop in the path of a passenger waiting at a stop or a passenger on a bus arriving at a stop. A passenger waiting at a stop will board any bus that is going to the next stop in his/her shortest path as long as it will not require him/her to transfer more times than is necessary. This check on the number of transfers prevents a passenger at stop i from boarding a bus only to get off at the next stop and wait for a bus that could have been boarded at stop i.

When a bus arrives at a stop, the next stop in the path of each rider on the bus is examined. If the current stop is the passenger's destination, he/she will get off the bus. If the next stop in a passenger's shortest path is the same as the one the bus will travel to next, the passenger remains on the bus. However, if the bus goes next to a different stop or ends its route at this stop, the passenger transfers (i.e., gets off the bus and waits for one going to the next stop in his/her path).

III. Model Input

The input to the model must describe the bus network to be simulated. To make this input as understandable as possible, each data record begins with a mandatory keyword related to the type of data.

Information is required unless noted. Keywords must be typed as shown. Data to be input is in either integer, real or alphanumeric format. Data should be assumed to be integer unless denoted as real or alphanumeric.

The order of the data shown below for each card must be preserved. However, information can be placed on the card in free-format (i.e., there are no specific columns for any piece of data, including the keyword). Alphanumeric input, such as bus stop names, must be composed of 4 or fewer characters, with no blanks separating characters of a single name. Successive pieces of data on a card are separated by one or more spaces, not by commas. A sample input file is shown for the example simulation in Section VI.

The input file contains ten separate blocks of information. The structure of these blocks is described in the following subsections.

A. Street cards - These cards give information on the different kinds of links used in the model.

Keyword	Data	Definitions and Notes
STRT	NST	NST = # of street types defined in the model.
TYPE	NAME K Z SL	NAME = the name of the street type - alphanumeric. K = the shape parameter of the shifted gamma distribution of in-motion times for this street type. Units are miles^{-1}. Z = the scale parameter of the shifted gamma distribution. Units are seconds. SL = speed limit for this street type. Units are miles per hour.

The STRT card must precede the TYPE card(s). There is a TYPE card for each street type in the model - i.e. NST TYPE cards.

B. Bus route cards - These cards give information on the bus routes that are modeled. Information on all bus stops and links is also input in this section.

Keyword	Data	Definitions and Notes
RLS	NR NL NS	NR = the number of routes in the model. NL = the number of links in the model. NS = the number of stops in the model.

Following this RLS card a set of cards is input for each bus route. The first card of the set must be a BSRT card:

Keyword	Data	Definitions and Notes
BSRT	NAME	NAME = the name of the bus route, alphanumeric.

Each BSRT card is followed by this set of cards:

Keyword	Data	Definitions and Notes
NSTP	NSR	NSR = the number of bus stops on this route.
STOP	STOP$_1$ STOP$_2$ ... STOP$_{NSR}$	STOP$_i$ = the name of the i^{th} stop on the bus route, alphanumeric. NSR names must appear on this card. If all names cannot appear on one card, the list can be continued onto as many STOP cards as are needed. The stops must be listed in the order a bus would encounter them on the route. The STOP card(s) must follow the NSTP card.
LINK	TAIL HEAD LEN TYPE	TAIL = name of the stop at the tail of the link, alphanumeric. HEAD = name of the stop at the head of the link, alphanumeric. Buses travel from tail to head on a link. TAIL and HEAD must correspond to the name of a stop listed on the STOPS card. Therefore, the LINK cards must follow the STOPS card. LEN = length of the link in units of .01 miles. TYPE = street type of link, alphanumeric TYPE must correspond to the name of a street type input on the TYPE card discussed above. There is one LINK card for each link on the route.
BUS	NUM CAP	NUM = the number of buses assigned to this route for their first dispatch. CAP = capacity of buses assigned to this route (assumed to be the same for all buses).

Keyword	Data	Definitions and Notes
REST	L	L = the layover period for the bus at the end of the route. Units are minutes.
NDSP	ND	ND = the number of dispatches to be made to this route during the simulation period.
TTBL	$T_1\ T_2\ \dots\ T_{ND}$	T_i = the time in hours and minutes of the ith dispatch to the route, real. Ex. - if the ith dispatch is to be made at 6:45 AM, T_i = 6.45; if at 3:15 PM, T_i = 15.15. There must be ND times input. If they cannot all fit on one card the list of times can continue onto other TTBL cards. These cards must follow the NDSP card in the input.
NXTR	$R_1,R_2,\dots,R_{ND}$	The NXTR card(s) must follow the TTBL card(s). R_i is the name of the route that the bus dispatched at time T_i will serve when it completes service to this route. The R_i are alphanumeric variables. The name of the route must correspond to a name on one of the BSRT cards.
TRTM	$TT_1\ TT_2\ \dots\ TT_{NS-1}$	TT_i = the scheduled or expected travel time from the dispatch stop to the i + 1th stop on the route, a real value. Units are minutes. There is one value on the card for all stops except the dispatch stop. Times must be input in the order that stops are arranged on the route. This card is optional. If it is not used the program computes an expected travel time for each stop. If used it may not appear before the NSTP card.

C. The next group of cards identifies different bus stops which actually have the same location. These stops must be grouped to allow passengers to transfer between buses serving the different stops. An example of this type of situation is two bus routes going in opposite directions on a street having stops at the same location, but on opposite sides of the street. Reasons for defining two bus stops in this case instead of one are discussed in Section II.D.

Keyword	Data	Definitions and Notes
TRNS	NLOC	NLOC is the number of different locations having two or more bus stops defined at the same point; integer variable.
STPS	NS, $S_1, S_2, \ldots, S_{NS}$	One STPS card must be input for each location - there are NLOC STPS cards. For each location a STPS card indicates NS = the number of bus stops defined for this location, an integer variable. $S_1, \ldots, S_{NS}$ = the names of the NS stops at this location. These are alphanumeric variables. The names must be among those defined earlier on the STOP cards.

D. Passenger cards - These cards give information on passenger origin and destination probabilities, arrival rates, and the type of arrival process employed in the simulation.

Keyword	Data	Definitions and Notes
PASS	OD.TYPE TYPE.ARR COEF	OD.TYPE is an alphanumeric input indicating the manner in which O-D probabilities are input. If OD.TYPE = MATR there is a probability input for each origin destination combination. If OD.TYPE = VEC there is one probability associated with each destination regardless of the origin. That is, the probability that any passenger chooses a certain destination is independent of the origin. TYPE.ARR is an alphanumeric input indicating whether the random or non-random passenger arrival process is chosen. TYPE.ARR = RAN for random or = NRAN for non-random arrivals. COEF = the coefficient attached to wait time in the passenger arrival utility equation, a real number. A value of .55 is suggested by Turnquist and Bowman (1979). This value is only input if TYPE.ARR = NRAN.

Keyword	Data	Definitions and Notes
WGHT	WAIT TRANS	WAIT and TRANS are real variables giving the value or weight attached to wait and transfer time relative to on-vehicle time. The WGHT card must immediately follow the PASS card.
OD	ORIGIN DEST PROB	ORIGIN = the name of a bus stop, alphanumeric. DEST = the name of a bus stop, alphanumeric. If OD.TYPE input on the PASS card = VECT, the input for ORIGIN is omitted. If OD.TYPE = VECT, PROB = probability of any passenger having DEST as a destination. If OD.TYPE = MATR, PROB = probability of a passenger arriving at ORIGIN having DEST as a destination. The names ORIGIN and DEST must correspond to a name on the STOP card for some bus route. If OD.TYPE = VECT there is one OD card for each bus stop in the model. If OD.TYPE = MATR there is one OD card for each possible OD pair except for those where ORIGIN = DEST, or where the probability PROB = 0. The OD cards must follow the PASS card. The values of PROB input on all OD cards should sum to 1; i.e., passengers have a probability of 1 of choosing some destination.
RATE	STOP RT	STOP = the name of a bus stop, alphanumeric. RT = the average arrival rate of passengers at the bus stop STOP. Units are passengers per hour. The name STOP must correspond to the name of a bus stop input on the STOP card for some bus route. One RATE card is input for each bus stop in the model.

E. Dwell time cards - The following card indicates dwell time data to be read in.

Keyword	Data	Definition and Notes
DWLT		This card must precede the following dwell time data cards.

As previously discussed dwell time for a bus is computed as a function of the number of passengers served at the stop.

Let D = dwell time; X = the number of boarding passengers; Y = the number of alighting passengers.

Data is input for 3 cases.

Case 1. $Y \neq 0$, $X \neq 0$

Keyword	Data	Definition and Notes
BDAT	α_1 β_{11} β_{12} β_{13} σ_1	α_1 , β_{11} , β_{12} & β_{13} are coefficients in the equation $D = \alpha_1 + \beta_{11}X + \beta_{12}Y + \beta_{13}XY + \varepsilon_1$. Units of α_1 are seconds. Units of β_{11} and β_{12} are seconds/pass. Units of β_{13} are seconds/pass^2. ε_1 is a $N(0,\sigma_1^2)$ random variable. α_1, β_{11}, β_{12}, β_{13}, and σ_1 are real values.

Case 2. $X \neq 0$, $Y = 0$

Keyword	Data	Definition and Notes
BD	α_2 β_{21} σ_2	α_2 and β_{21} are coeffients in equation $D = \alpha_2 + \beta_{21}X + \varepsilon_2$ Units of α_2 are seconds, of β_{21} are seconds/passenger. ε_2 is a $N(0,\sigma_2^2)$ random variable. α_2, β_{21}, and σ_2 are real values.

Case 3. $X = 0, Y \neq 0$

Keyword	Data	Definition and Notes
AT	α_3 β_{32} σ_3	α_3 and β_{32} are coefficients in equation $D = \alpha_3 + \beta_{32}Y + \varepsilon_3$. Units of α_3 are seconds; of β_{32} are seconds/passenger. ε_3 is a $N(0,\sigma_3^2)$ random variable. α_{31}, β_{32}, and σ_3 are real values.

F. Random number generator seeds card - In SIMSCRIPT there are 10 random number generators. The SEED card provides the seeds or initial values used by these generators.

Keyword	Data	Definitions and Notes
SEED	$SD_1, SD_2, \ldots, SD_{10}$	$SD_1, \ldots, SD_{10}$ are the 10 seeds. They must be integer values. Although 10 values must be input on the seed card not all 10 random number generators are used by the model. The following random number generators (RNG) are used: a) RNG 2 is used to generate passenger arrivals according to either a stationary or nonstationary Poisson process as described earlier (Section II.D). b) RNG 3 is used to sample bus dwell time values from a normal distribution (Section II.A). c) RNG 4 is used to sample bus cruising speeds and acceleration and deceleration rates from the appropriate distributions (Section II.C). d) RNG 5 and RNG 6 are used to generate changes in traffic volumes on portions of microscopically simulated links (Section II.B). e) RNG 7 is used to randomly determine the size of gaps in traffic a bus pulling out from a protected stop will encounter, and the minimum gap size the bus will accept (Section II.E).

G. Micro-simulation input cards - All data pertaining to the micro-simulation exclusively is input together. All these cards are optional in the sense that the model can be implemented at the macroscopic level only.

The first card of the micro-simulation input set signals that the data is to be read in. It must be first in this set of cards. Its format is:

Keyword	Data	Definitions and Notes
MICR		

G.1 Route segment input cards -

Keyword	Data	Definitions and Notes
RTSG	NRS	NRS = the number of route segments to be simulated microscopically.

After the RTSG card is read, a set of cards must be input for each of the NRS segments to define the links contained in each. Each set of cards has the following format:

Keyword	Data	Definitions and Notes
SEG		This card indicates that a set of cards for a new segment is being input.
SGLK	TAIL HEAD NLANE	One of these cards is needed for each link in the route segment. These cards for a single route segment must follow a card. TAIL = the name of the stop at the tail of the link, alphanumeric. HEAD = the name of the stop at the head of the link, alphanumeric. NLANE = the number of lanes on this link. The names TAIL and HEAD must correspond to the similar names on a LINK card input for some bus route. The links must be input in the order they appear in the route segment. That is, TAIL on one SGLK card must equal HEAD on the card immediately preceding it.

G.2 Intersection data cards -

Keyword	Data	Definitions and Notes
INTR	NI	NI - the number of intersections to be represented microscopically.

Keyword	Data	Definitions and Notes
INT	TAIL HEAD LOC MN.RT TRN.PRCT CRSS.RT GREEN RED OFFSET PREEMPT	TAIL = name of stop at tail of link on which intersection is located, alphanumeric. HEAD = name of stop at head of link on which intersection is located, alphanumeric. LOC = distance of the intersection from the tail of the link. Units are .01 miles. MN.RT = average rate of vehicle arrivals at intersection in main direction of travel, a real value. Units are vehicles/hr. TRN.PRCT = average % of vehicles arriving at intersection in the main direction that turn out of the main direction, a real value. CRSS.RT = average rate of arrival of vehicles at intersection that turn into main direction from cross street. Units are vehicles/hr, a real value. GREEN = length of green phase at intersection in seconds, integer RED = length of red phase at intersection in seconds, integer. OFFSET = the offset in seconds of the light at the intersection relative to some base common to all lights, an integer value. PREEMPT is an alphanumeric variable. PREEMPT = "PRMT" if the signal can be preempted by approaching buses. If signal is not preemptable, PREEMPT = "NOPT".

One INT card must be input for each intersection in the model. These cards must directly follow the INTR card.

G.3 Protected stop input -

Keyword	Data	Definitions and Notes
PROT	list of the names of stops that are protected, alphanumeric.	If the list cannot fit onto one card it can be continued onto other PROT cards. All stops not listed are assumed to be unprotected.

G.4 When all the above data has been input the following card denotes that the micro-simulation input is complete.

Keyword	Data	Definitions and Notes
ENDM		

H. Options cards - These cards are input only if a holding strategy or signal preemption scheme is to be implemented. The first card to be input denotes that some type of strategy is to be used.

Keyword	Data	Definitions and Notes
OPTS		

H.1 Holding strategy cards - Buses can be held at stops to improve service reliability in two ways: 1) hold the bus until its scheduled departure time (i.e., allow no early departures), or 2) do not allow the interval between consecutive bus departures to be less than some minimum value (i.e., a bus is held if the headway between it and the preceding bus is smaller than the minimum value).

Keyword	Data	Definitions and Notes
HOLD	TYPE	TYPE is an alphanumeric input: = "SCHD" if the hold-to-schedule policy is used = "HDWY" if the hold-to-headway policy is used.

Under either type of holding strategy the stops at which the policy is to be enforced must be input.

Keyword	Data	Definitions and Notes
HSTP	$S_1,\ldots,S_i,\ldots$	$S_1,\ldots,S_i,\ldots$ is a list of the stop names of the stops which are holding points. These names must match the names input on the STOP cards discussed above. If all stops are holding points it is only required that S_1 = "ALL" .

If the hold-to-headway policy is used the minimum allowable headway must be input. Otherwise, this record is omitted. It is assumed that this minimum headway is the same for all the holding points.

Keyword	Data	Definitions and Notes
MINH	H	H = minimum allowable headway in seconds.

H.2 SIGNAL preemption - If buses can preempt certain traffic signals two types of information are required. First, the signals which can be preempted must be noted. This is done for each signal through a parameter on the intersection data card as discussed in section G.2 above. Secondly, the distance above the intersection at which an approaching bus will trigger preemption must be input. It is assumed that this distance is the same for all signals.

Keyword	Data	Definitions and Notes
PREE	D	D = distance from signal at which preemption triggered, in feet.

H.3 End of options card

Keyword	Data	Definitions and Notes
ENDO		This card denotes the end of the option input segment and must be placed immediately after the cards described in this option input section.

I. Echo Input card - Model input may be printed along with the output if the user desires.

Keyword	Data	Definitions and Notes
ECHO	LEVEL	LEVEL = 0 if no printout of inputs data is desired. = 1 if a summary of input data is desired. = 2 if a detailed printout of input is desired.

J. End of input card - When all the data has been input the last card in the data deck is as follows.

Keyword	Data	Definitions and Notes
END	TIME	TIME = the time at which the simulation period ends. This is a real variable with the units of days starting from midnight (i.e. if simulation ends at 9 AM TIME = .375). Note: the time at which the simulated period begins is determined by the timetable of bus dispatches. The model automatically generates passengers beginning approximately one scheduled headway before the first bus arrival at each stop. This allows for a built-in "warmup" period, and relieves the user from having to specify "dummy" bus runs.

IV. Model Routines

The main program, MAIN, of the simulation model performs three functions.

1) It calls the subroutines which read the input data and perform the initialization for the simulation.

2) After the initialization phase the main program schedules the initial events and then passes control to the timing routine which, in turn, calls the events to take place at their scheduled times. Events are initialized by MAIN in the following manner:
    a. A DISPATCH event is scheduled for each route at the first time on the dispatch schedule.
    b. A PASS.ARRIVE event is scheduled for each stop for time 0 in the model. This initial PASS.ARRIVE event does not actually result in a passenger arriving at a stop but causes the first passenger to arrive at the stop sometime within an average headway of the first expected bus arrival at the stop.
    c. If a micro-simulation of a bus route is being performed, each signal is initially set to green in the main direction. The first LIGHT.CHANGE event for each signal is scheduled for the time of the very first bus dispatch plus the offset time for that signal.

3) When no further events are scheduled control returns to the main program which then prints the model output.

Excluding the main program, there are three classes of routines that comprise the model: 1) initialization routines, 2) event routines, and 3) routines called by the events to perform computations used to schedule new events. A detailed discussion of routines, organized by classes, follows.

A. Initialization Routines

1. Routine INITIALIZATION

This routine reads the input necessary for the basic, or macroscopic, model of the bus system. When passenger information is input routine INPUT.OF.PASS.DATA is called. If the input for the microscopic route representation is encountered the routine passes control to routine INI.OF.MICROSIM which then reads this data. If the options to implement preemption or holding strategies are applied routine OPTION.INPUT is called to read in the appropriate data.

INITIALIZATION also creates two arrays which define the interaction of the route, link, and bus stop entities in modeling the bus network:

1) The ragged array INDX has one row corresponding to each bus stop input to the model. Across the columns are shown the numbers of each link (the program assigns numbers to each entity) obtained from the bus stop of that row.

2) The ragged array RTE.LINK has a row associated with each bus route. For any row the columns show the links that compose that route, in the order they occur.

2. Routine INI.OF.MICROSIM

This routine primarily reads the input for the micro-simulated sections of the bus network. Specifics on this input are discussed in Section III.G. In addition the routine finds the distance from each intersection to the next downstream intersection and stores this value as an attribute of the intersection.

3. Routine INPUT.OF.PASS.DATA

Passenger arrival rates, destination probabilities, and coefficients for the bus dwell time equations are read from the input file by this routine.

4. Routine OPTION.INPUT

This routine reads in the data associated with holding strategy and preemption control.

5. Routine MINIMUM.PATHS

Passengers traveling between a specific origin and destination are restricted to movement along one path between the stops. A path is a sequence of stops in which successive stops are connected by a link. The path to which passengers are restricted is the one that minimizes their expected wait plus travel time.

The routine MINIMUM.PATHS finds the minimum time path for each origin-destination (OD) pair in the model. To do this, an expanded graph is built with separate directed arcs in the graph representing:

a. expected bus in-motion time on each link of each route,

b. expected passenger wait time at each origin stop for a bus from each route serving the stop, and

c. expected transfer time at each stop between buses of each pair of routes serving that stop.

There are two types of nodes representing each bus stop:

a. there is one node representing the stop itself,

b. there is a node for each bus route serving the stop.

Arcs and nodes are interrelated in the following manner:

a. Expected wait time arcs are directed from the type "a" node for each bus stop to the type "b" nodes for that bus stop.

b. Expected transfer time arcs are directed from each type "b" node for a bus stop to every other type "b" node for that stop.

c. For every link in each bus route there is an expected in-motion time arc connecting the type "b" nodes for the appropriate route and stops.

Additionally, in some cases it is desirable to define two bus stops located at the same point. For example, bus routes oriented in opposite directions may have stops located across the street from one another. These stops can be defined as two distinct type "a" nodes. However, because of their relative proximity, passenger transfers from one route to the other are possible. Hence an arc is defined connecting type "a" nodes that have the same location. The travel time over this arc (i.e., the time it takes a passenger to walk from one stop to the other) is considered to be zero.

Expected wait, in-vehicle and transfer times are computed for each arc, based on the input data. After the expanded graph has been built and expected travel times have been associated with each arc, Dijkstra's algorithm (Dijkstra, 1959) is used to compute the shortest (expected travel time) path between each pair of nodes.

The user should be aware of a capacity constraint in the model with respect to total number of nodes. In the current configuration, the total number of nodes in the expanded internal network must be less than or equal to 256. This limitation is imposed by the packing factor used in allocating storage, and is specific to IBM computers. The limit for other computer systems would likely be different.

To determine the total number of nodes in a network, one sums the number of bus stops and numbers of routes serving each stop. Thus, the constraint may be written as follows:

$$N + \sum_{i=1}^{N} n_i \leq 256$$

where N = number of bus stops in network

n_i = number of routes serving stop i.

The products of the path-finding process are several arrays which define the paths of passengers through the bus network. A matrix MIN.PTH has one column for each type "a" node and one row for each type "a" and for each type "b" node in the expanded graph. Element (i,j) in this matrix is the stop following i in a passenger's shortest path from stop i to stop j. Array TEMP.RTE gives the route associated with each type "b" node and array TEMP.STOPS gives the type "a" node to which each type "b" node is related.

STOP.NODE is a matrix giving for each type "a" node, the type "b" nodes associated with it. These arrays are used in the model each time a passenger arrives at a bus stop to determine the next stop enroute to his/her destination.

6. Routine LENGTH.OF.PATHS

This routine simply calculates the length of the minimum expected wait plus travel time path for each O-D pair. This information is stored in the matrix PATH.LENGTH which has a row and column associated with each bus stop. The primary use of this matrix is to compute the effective speed of each passenger in traveling through the system (i.e., the passenger's O-D path length divided by his/her time in the system).

7. Routine ARR.TIME.DIST

This routine creates three tables that relate to the arrival time of buses at stops in the modeled system:

1) The average time between buses, regardless of the route, at each bus stop is computed. It is stored in the vector HEADWAY.AVE which has one member for each bus stop.

2) If the information on the scheduled travel time from the dispatch stop to all other stops on a route has not been input (this would appear on the TRVL.TIMES card as discussed in Section III.B) then this routine computes these times for the route. In making these computations the scheduled travel time is assumed to be the expected travel time. The expected travel time from the dispatch to any other stop on the route is computed as the sum of two values:

a) the expected in-motion time over the links between the stops - in-motion times are assumed to follow a shifted gamma distribution as discussed in Section II.C.

b) the expected dwell time at intervening stops - as discussed in Section II.A, this is assumed to be a function of the expected number of passengers served. However, to simplify the computations it is assumed that only boarding passengers are important.

The computed values are stored in the matrix EXPECT.WT.TRV.

3) As discussed in Section II.D, if the passenger arrival process is coordinated with bus schedules, the distribution of bus arrival times becomes critical. These distributions are assumed to be triangular and symmetric around the scheduled time with a parameter b. The b parameter is assumed to be the same for buses of a given route at a given stop. This routine computes the b parameter for every route-bus stop combination. These values are stored in the matrix DEVIATION.PAR.

8. Routine ECHO.INPUT

If directed to do so by the input on the ECHO card (see Section III.I), input data will be printed. The routine ECHO.INPUT controls this action. Either a summary or a detailed description of input data may be requested:

a) The summary of input data displays the following information:

1. It tells whether a bus network is being macroscopically modeled or whether some route segment is being microscopically examined.
2. The number of routes, links, and bus stops is displayed.
3. For each bus route the following information is printed:

  - the number of buses and capacity of the buses initially awaiting dispatch on the route;
  - the number of dispatches to be made during the simulated period;
  - whether or not a schedule of travel times between stops on the route was input;
  - the layover period for buses at the end of the route;
  - the stops that compose the route.

4. The type of passenger arrival process in effect is printed.
5. For each bus stop, the average arrival rate of passengers and the number of routes serving the stop are listed.
6. If route segments are being simulated microscopically, the number of such segments is listed.
7. The number of bus stops at which holding strategies are employed is listed.
8. The length of the simulated period in hours and minutes is printed.

b) The detailed description of input data prints out the information given by the summary as well as the following:

1. For each link in the network the bus stops at the tail and head of the link, the link's street type, the length, and the number of lanes (only relevant for links in microscopically modeled route segments) are printed.
2. For each street type the speed limit and the parameters of the gamma distribution of bus travel times over links of this type are displayed.
3. For each bus route the following additional information is printed:
    - the expected (scheduled) travel time from the dispatch point to each stop in the route is printed, whether this value is input or computed from the shifted gamma distributions characterizing travel times (see Section II.C);
    - the dispatch schedule as well as the route each bus dispatched serves at the end of its run.

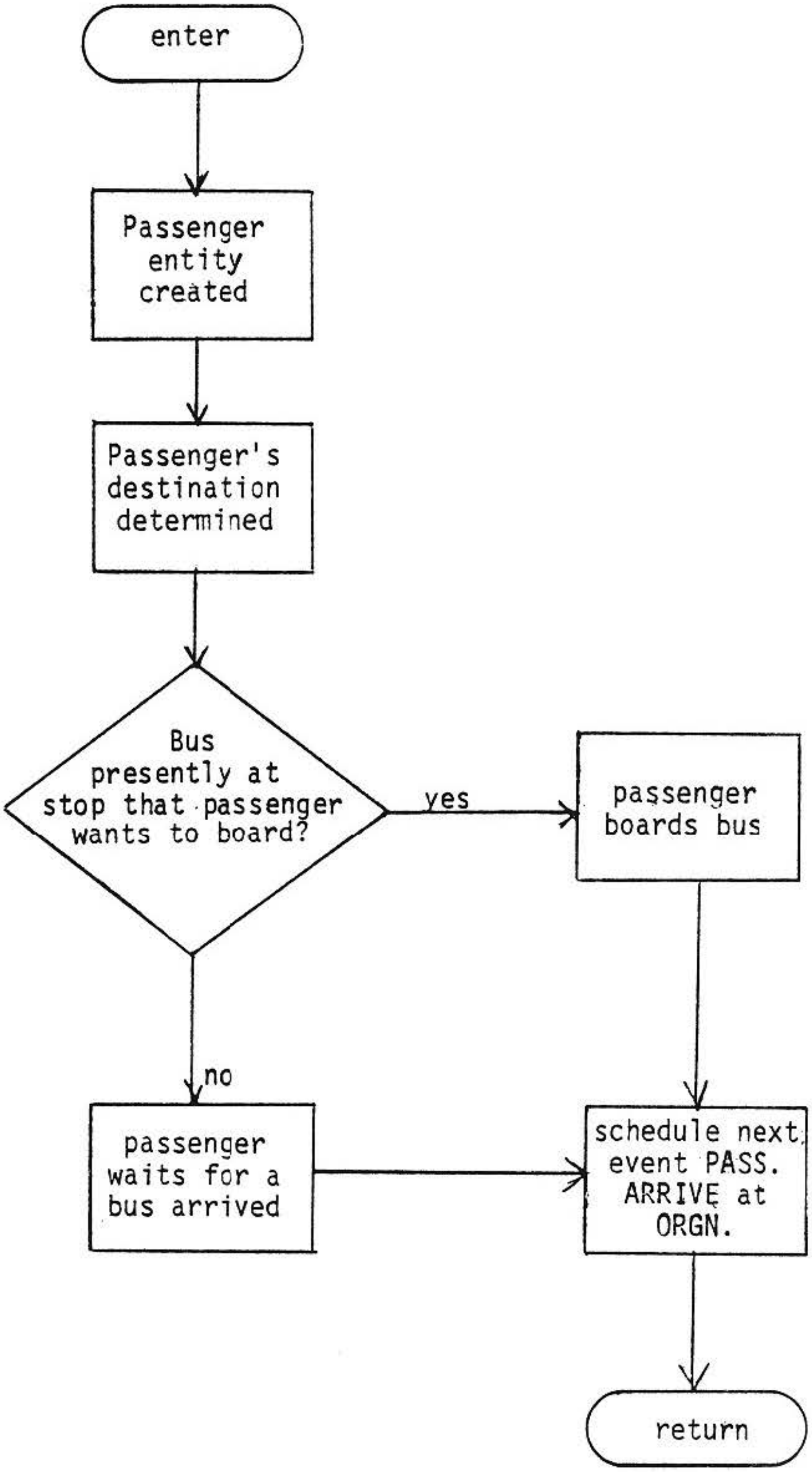
4. Coefficients for the expected dwell time equations are printed.
5. The random number generator seeds are printed.
6. If there are any route segments being simulated microscopically, the stops composing each segment are listed. Additionally for all intersections located on these segments the following information is displayed:
   - the link on which the intersection is located and the distance from the link tail to the intersection;
   - the average arrival rate of traffic in the main direction at the intersection, as well as the percentage of this traffic that turns off at the intersection;
   - the average rate at which cars turn into the main direction of travel from the cross street at the intersection;
   - the length of the green and red traffic signal phases at the intersection, as well as the signal offset;
   - whether or not the intersection possesses a signal which buses can preempt.
7. Protected bus stops on the segments are listed.

B. Event Routines

1. Event PASS.ARRIVE given ORGN

This is the event for a passenger arrival at the origin stop ORGN. The flowchart for this event is shown in Figure 4. When the passenger arrives at the stop, s/he joins the set of waiting passengers, QUEUE, for this stop unless the bus to be boarded is already at the stop.

Figure 4. Event PASS. ARRIVE given ORGN.



Should there be a bus at the stop that the passenger can board, then s/he boards the bus, waiting for previously arrived passengers to board, if any. The time at which this passenger will complete boarding is stored in PASS.ON.TIME, an attribute of the bus. This attribute is used to prevent the bus from departing while the passenger is in the process of boarding.

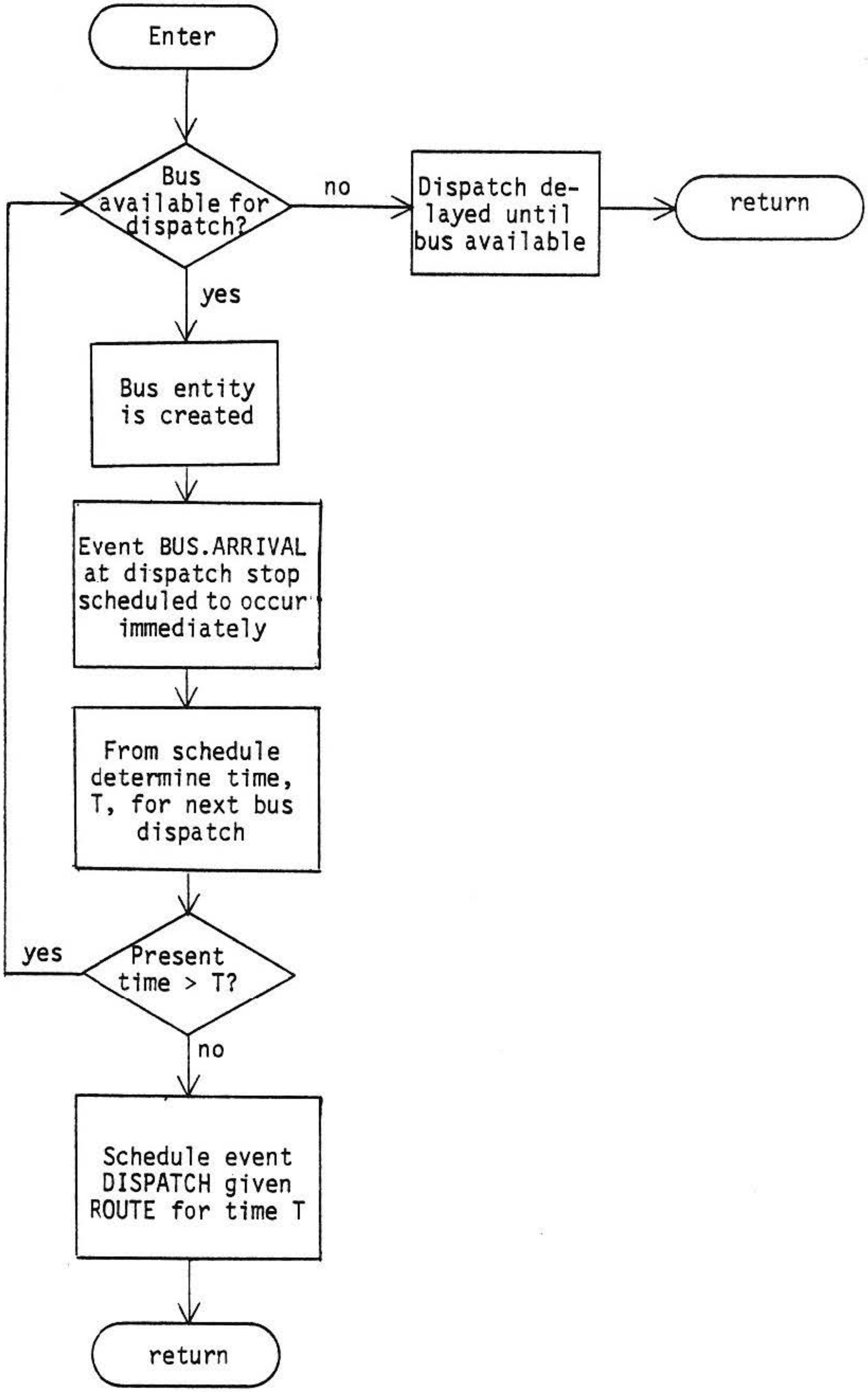
If passenger arrivals are random, the next passenger arrival at the stop ORGN is scheduled by sampling from an exponential distribution. If passenger arrivals are coordinated with the bus schedule, the event calls a subroutine GENERATE.NONRANDOM.PASS.ARRIVAL. This routine then schedules the next passenger arrival at ORGN as though arrivals are a non-stationary Poisson process as discussed in Section II.D.

2. Event DISPATCH given ROUTE

This is the event for a bus dispatched to serve the route ROUTE. The flow chart for this event is shown in Figure 5. Bus entities are created by this event and scheduled for immediate arrival at the dispatch stop for ROUTE. If there is no bus available for dispatch, a flag is set indicating that when the next bus becomes available it should be dispatched immediately.

If a dispatch has been made, then the next dispatch is scheduled according to the timetable stored in the matrix SCHEDULE. If, however, the time for the next dispatch has been delayed due to a shortage of buses, a check is made to see if there are additional available buses. If yes, another dispatch is made. If not, the flag is set indicating a delayed dispatch.

Figure 5. Event DISPATCH given ROUTE.



3. Event BUS.ARRIVAL given BUS

This is the event for the arrival of bus BUS at a bus stop. The flowchart is shown in Figure 6. The event has several basic processes.

a) Passengers of BUS are examined to determine which ones want to alight. For the alighting passengers, if the stop is their destination, statistics on the passenger are written to a file and the passenger entity is destroyed. Transferring passengers get off the bus and into the queue of waiting passengers at the stop, or walk to another stop at the same location where they make their transfer.

b) Passengers waiting at the stop are allowed to board the bus if the next stop in the OD path matches the next stop of the bus, and if the bus has sufficient capacity.

c) When all boarding and alighting has been completed, the dwell time of the bus at the stop is computed. If this stop is not the last stop in the route BUS is serving, then a departure of the bus from the stop is scheduled at the end of the dwell time. Otherwise, the arrival of the bus at the end of its route is scheduled for after the dwell period and the layover period allowed for the bus.

4. Event BUS.DEPART given BUS

This is the event for the departure of bus BUS from a bus stop. The flowchart is shown in Figure 7. The event first checks to see if all passengers have boarded the bus. If there is a new passenger who has not completed boarding at this time, then the event is rescheduled at the time the passenger will have finished boarding. If all boarding has been completed,

Figure 6. Event BUS.ARRIVAL given BUS

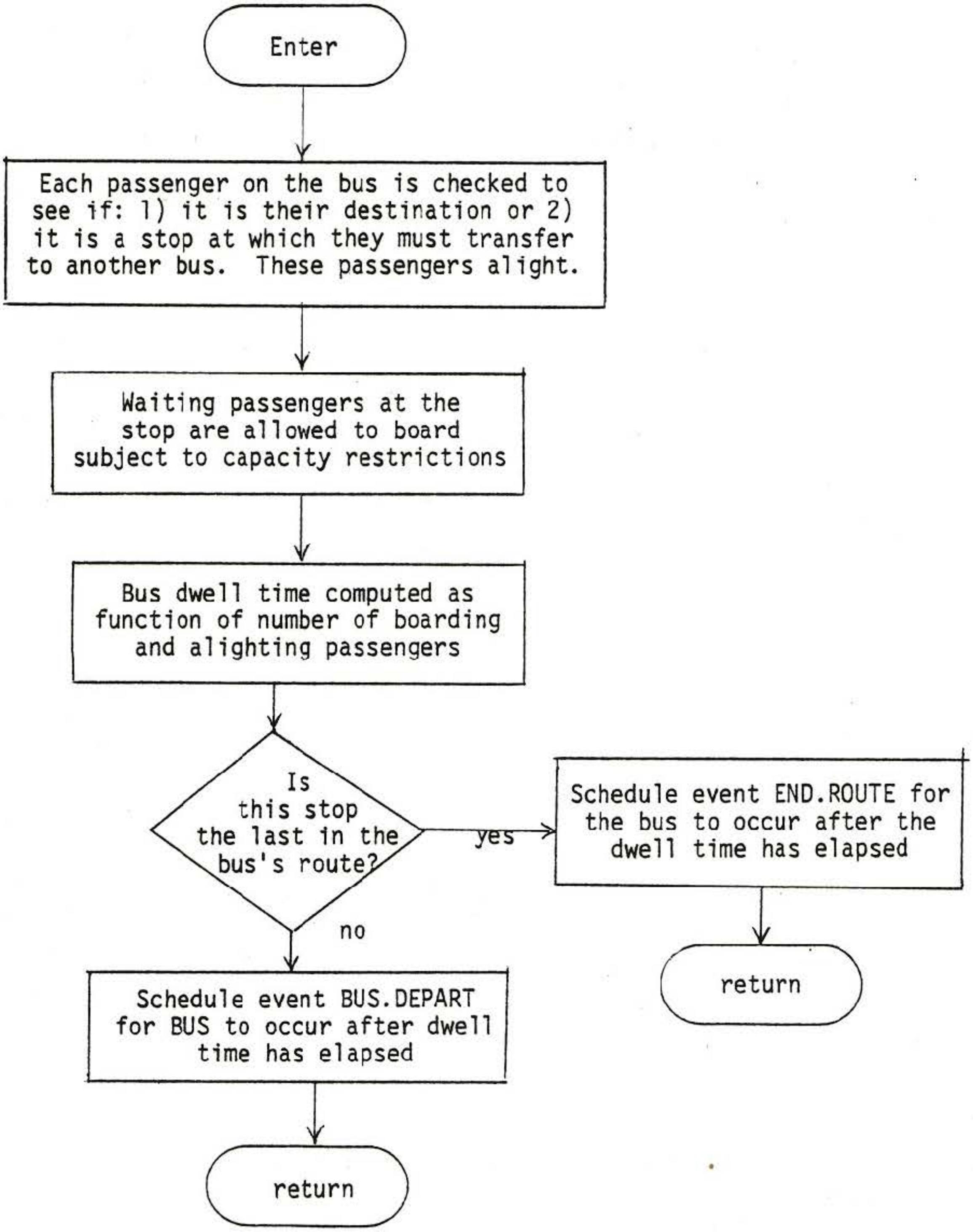
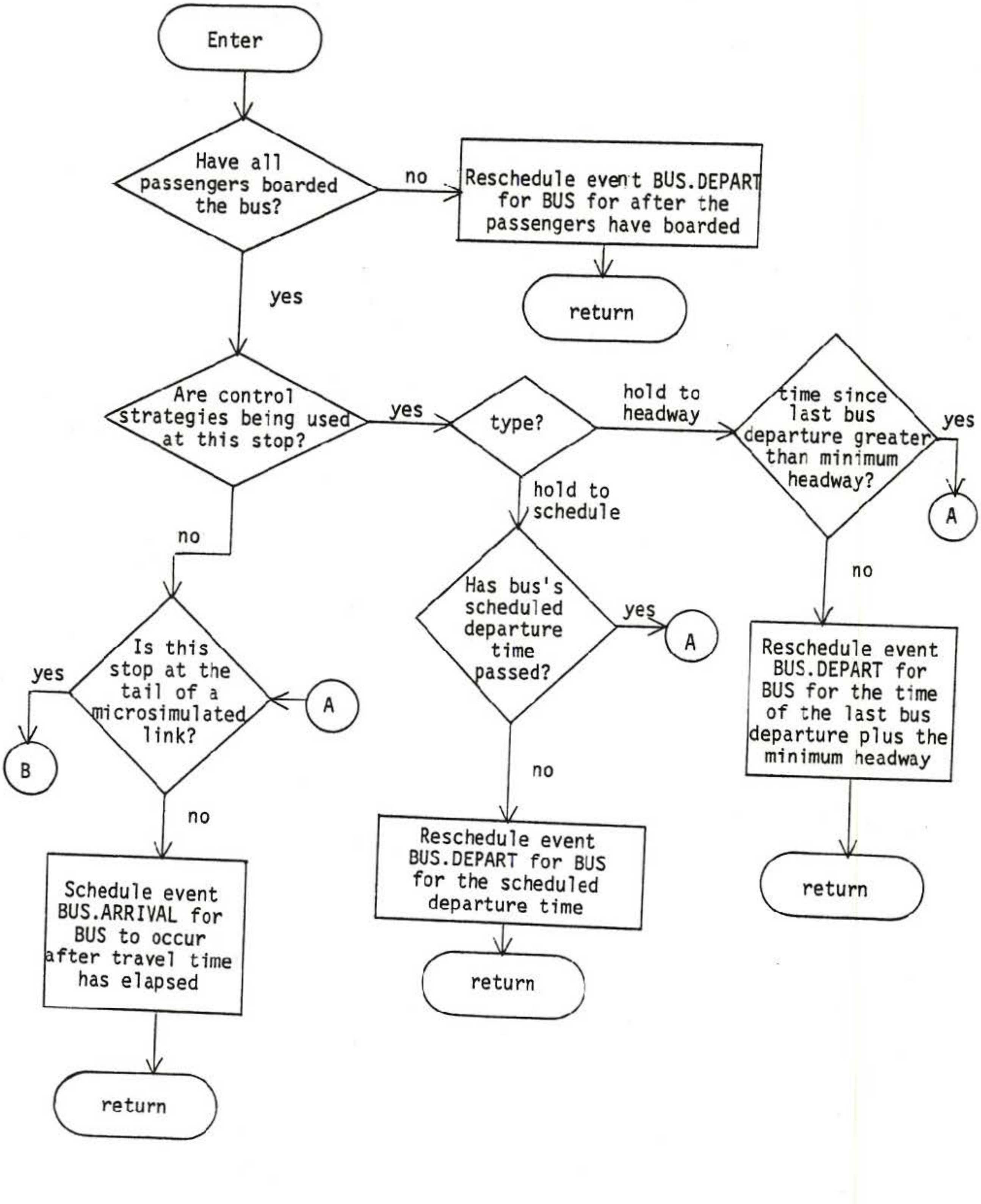
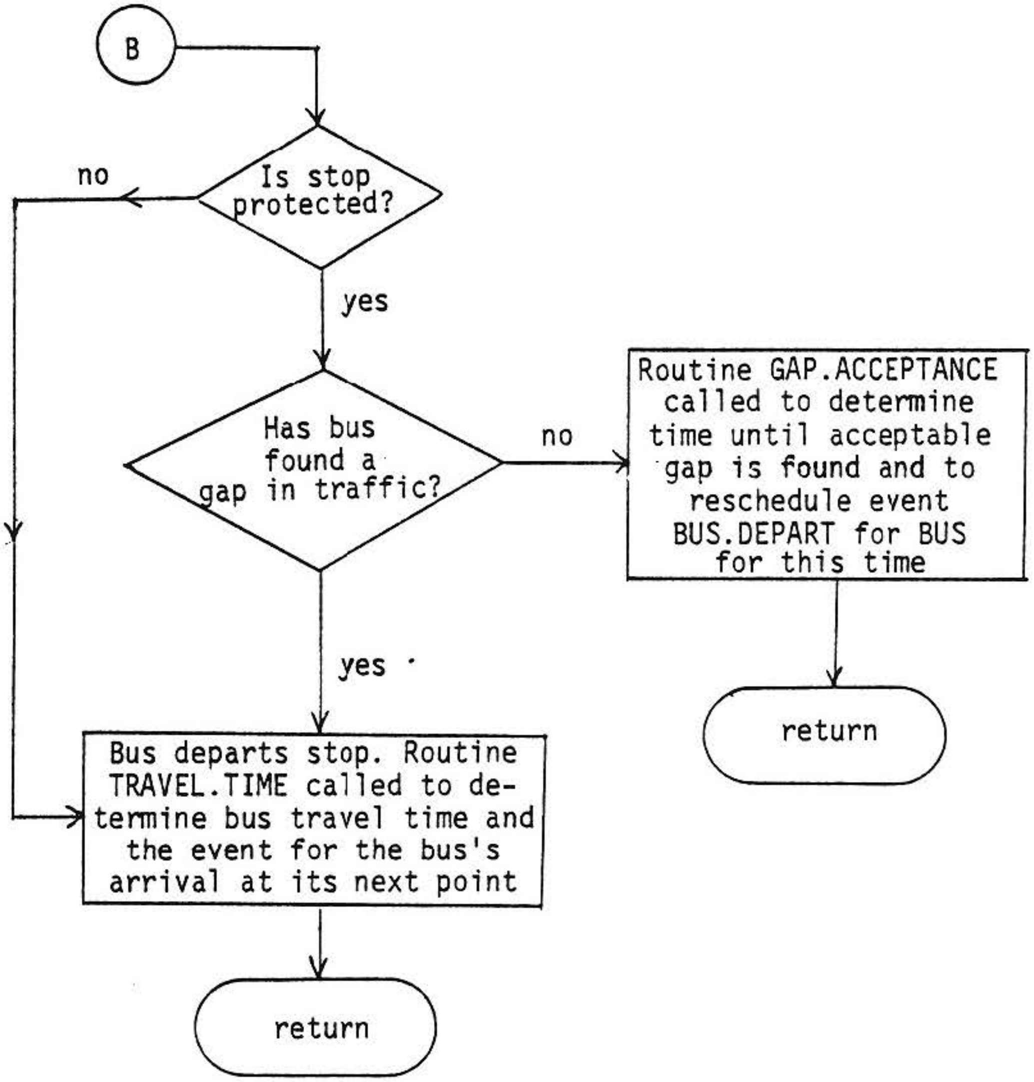


Figure 7. Event BUS.DEPART given BUS



Event BUS.DEPART (con't)



the event determines whether or not the next link in the bus's route is being micro-simulated. If it is not, the travel time to the next stop is computed from a shifted gamma distribution and a bus arrival scheduled at that stop.

If the next link is being micro-simulated, several things must be checked before the bus can depart. If this stop is a protected stop the bus must find a gap in traffic. The event does this by calling the subroutine GAP.ACCEPTANCE. This routine determines the time until a gap in traffic will appear into which the bus can pull out, sets a flag indicating a gap has been found, and reschedules the BUS.DEPART event for BUS at that time.

When the gap has been found or if the bus stop is unprotected, the travel time of BUS to the next bus stop or intersection, whichever it will encounter first, must be determined. This is done by a call to the subroutine TRAVEL.TIME. After determining the travel time, this routine will schedule the appropriate bus arrival.

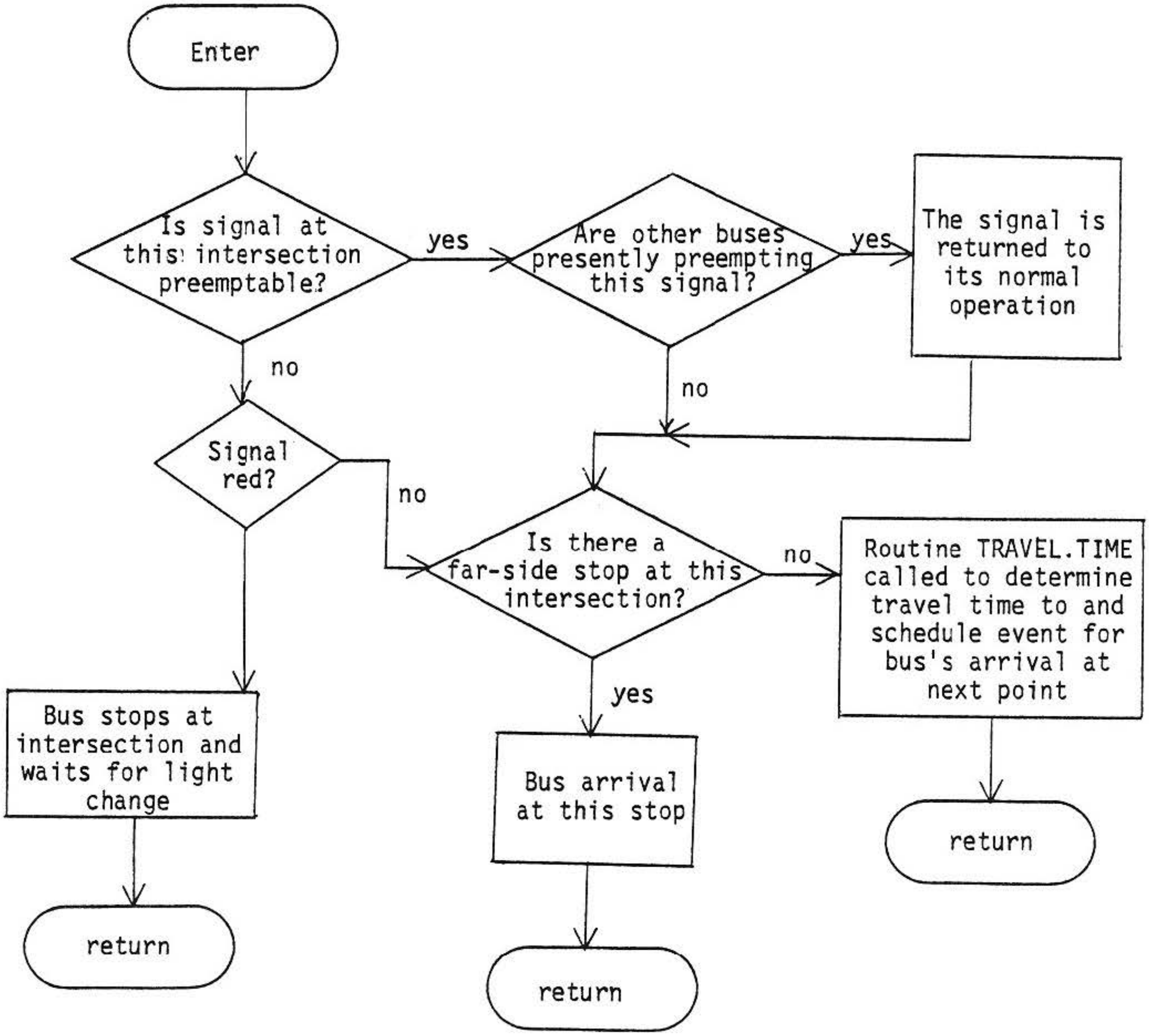
If holding strategies are being used in the model, a check is made to see if the bus must be held, and if so, BUS.DEPART is rescheduled.

5. Event INT.ARRIVAL given BUS

This event denotes the arrival of the bus BUS at an intersection. A flowchart for the event is shown in Figure 8. Clearly, the action taken by BUS depends on the color of the light. If the light is red the bus joins a queue of buses at the light.

If the light is green the bus passes through the light. The travel time of the bus to the next intersection or bus stop, whichever comes first, must be determined. This is done by calling the routine TRAVEL.TIME which also schedules the appropriate bus arrival.

Figure 8. Event INT.ARRIVAL given BUS



If the light can be preempted the bus has control of the signal when it reaches the intersection. After passing through the intersection, if there are no other buses preempting the signal, the bus returns the signal to normal operation. The signal is returned to normal control by immediately making it the color it would have been if no preemption had occurred. Phase changes are then scheduled to occur at the times they would have occurred had the light not been preempted.

6. Event LIGHT.CHANGE given LIGHT

This event denotes the change of phase of the traffic signal LIGHT. The flowchart is shown in Figure 9. Whenever a light changes phase, the appropriate changes in traffic volumes are made for the blocks separated by the intersection. The details of the volume change process are discussed in Section II.B.

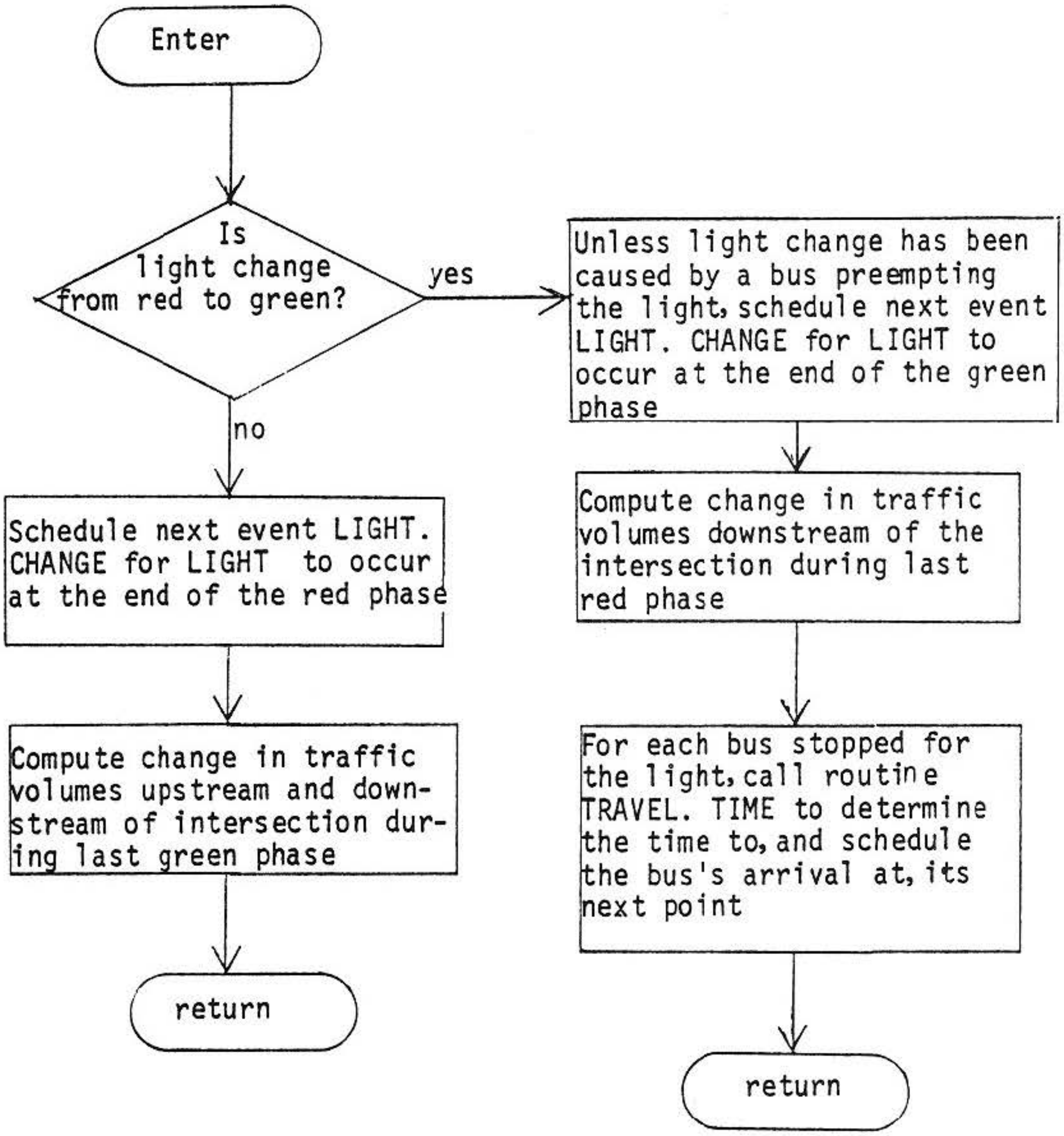
The event has several other functions. When the light changes from red* to green, buses that have stopped for the red light must be processed. It is assumed that every such bus will be able to travel through the new green cycle. For each of these buses the routine TRAVEL.TIME is called to determine the travel time and schedule an arrival of the bus at the next stop or intersection, whichever it will encounter first. Of course, the next LIGHT.CHANGE event for LIGHT will be scheduled for the end of the green cycle.

Likewise, when the light changes from green to red, a LIGHT.CHANGE event is scheduled for LIGHT at the end of the red cycle.

---

*Light color is that in the main direction of travel.

Figure 9. Event LIGHT.CHANGE given LIGHT.



7. Event STOP.CHECK given BUS, DWN.LOCATION, LOC.DIST, CR.SPD

This event occurs when the driver of the bus BUS must decide whether or not to decelerate for the next traffic signal or bus stop. A flowchart giving a simplified view of the event logic is shown in Figure 10. The given parameters are: DWN.LOCATION - an alphanumeric variable telling whether the bus next encounters an intersection (DWN.LOCATION = "INTR") or a bus stop (DWN.LOCATION = "BSTP"); LOC.DIST gives the distance in miles from the bus's present location to the next light or stop; CR.SPD is the cruising speed of traffic on the block on which the bus is travelling.

If the bus next encounters a traffic signal which can be preempted, the STOP.CHECK event is scheduled only if there is a far-side stop at that intersection. That is, if a signal can be preempted the bus will always receive a green light so a decision on whether or not to stop at the intersection need only be made if a far-side stop exists.

8. Event PREEMPTION given BUS and SPEED

As an option, the model allows buses to preempt the right-of-way through designated intersections. See the flowchart for this event, shown in Figure 11. When the bus BUS is a certain fixed distance from the intersection, the signal at the intersection will first detect the presence of the bus. If the present phase of the light is green, the light will remain green until the bus passes through the intersection, extending the green phase, if necessary. If the light is red when the bus is first detected, the light immediately changes to green and remains so until the bus passes the intersection. After the bus passes the intersection the signal resumes operation on the normal schedule.

Figure 10. Event STOP. CHECK given BUS, DWN. LOCATION, LOC. DIST., CR. SPD.

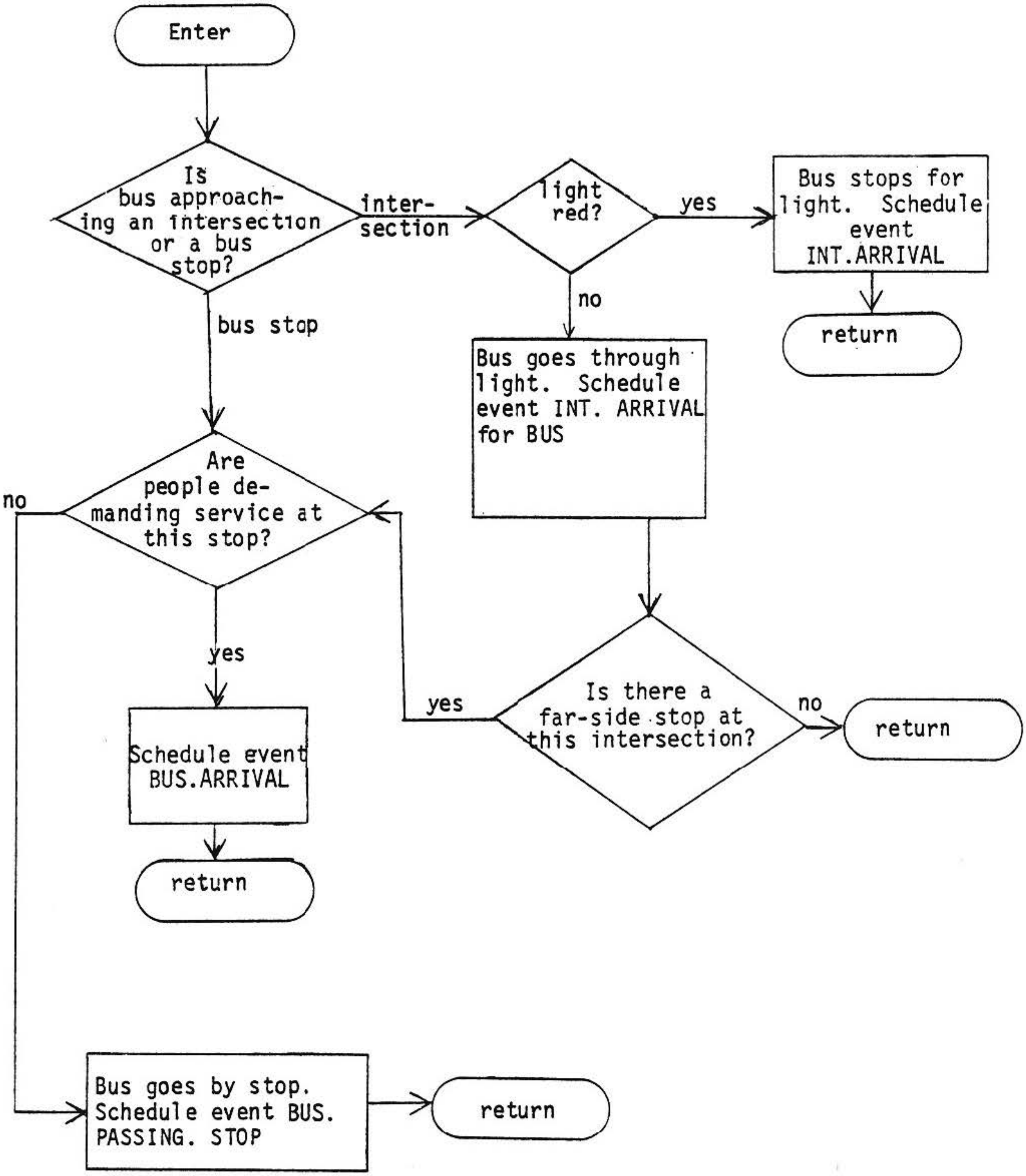
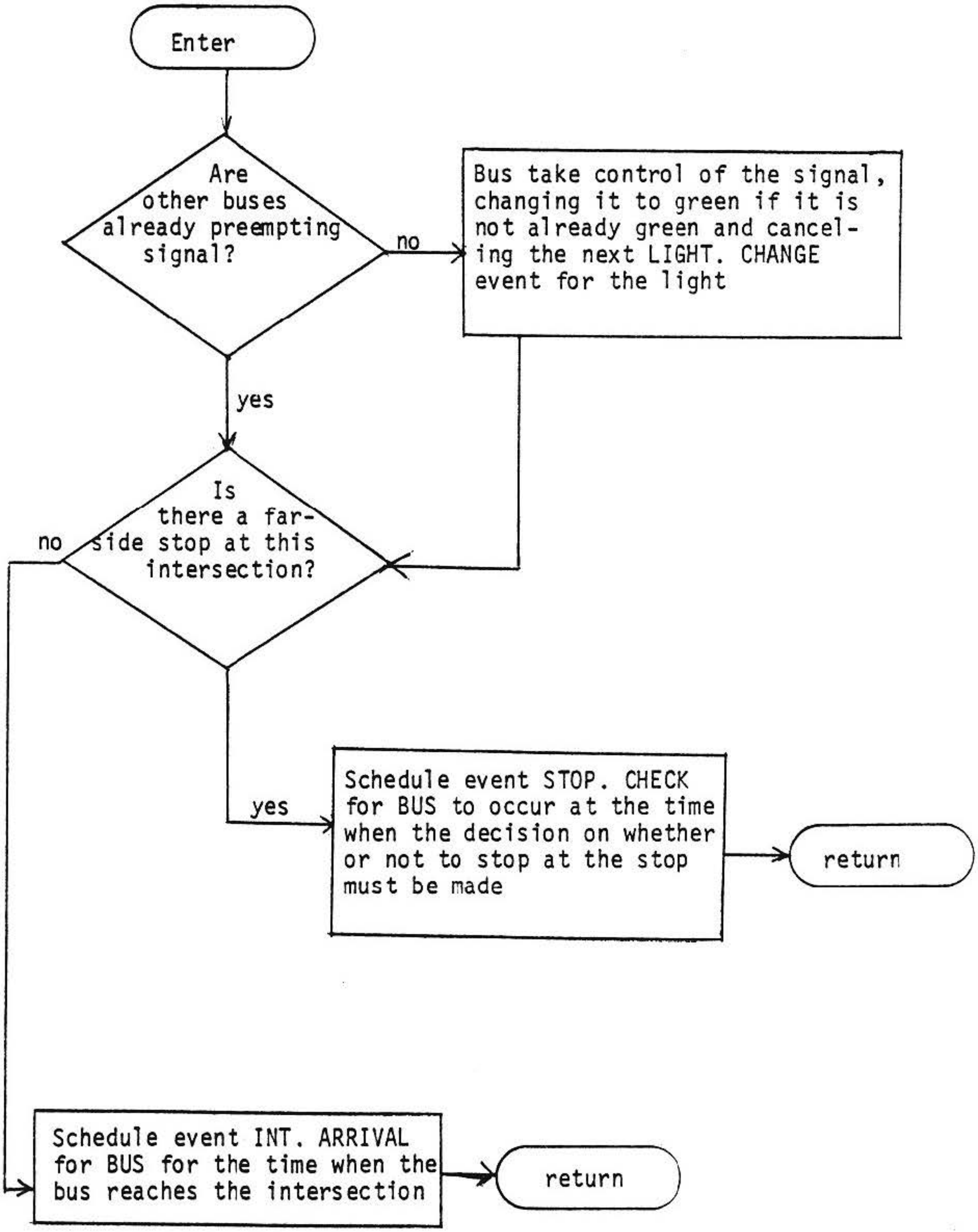


Figure 11. Event PREEMPTION given BUS and SPEED



Since the light remains green until the bus passes the intersection, it is assumed that there is no near-side bus stop at the intersection.

Note that the event argument SPEED is the cruising speed the bus can attain on the block upstream of the intersection. This is not necessarily the bus's present speed.

9. Event BUS.PASSING.STOP given BUS

This event occurs when bus BUS passes a bus stop without stopping because there are no people to serve. This happens only at bus stops on micro-simulated links. The flowchart for this event is shown in Figure 12.

10. Event END.ROUTE given BUS

This event denotes the completion of service on its current route by the bus BUS. The flowchart is shown in Figure 13. The event has two purposes. The first is to destroy the entity representing this bus.

Secondly, this bus is assigned a new route to serve, following the minimum required layover time. If the flag has been set for this route indicating that a dispatch has been delayed then the bus is dispatched as soon as it becomes available. If there has been no delayed dispatch, a counter of the buses available for dispatch on the route is incremented by one.

11. Event END.OF.SIMULATION

When the simulation period ends, this event takes control. It destroys all the events that have been scheduled for after this time. Bus and passenger entities still in existence remain in their locations in the model. No statistics are collected on these entities still in existence at simulation s end. From here, control is returned to the main program to process the model output.

Figure 12. Event BUS. PASSING. STOP given BUS

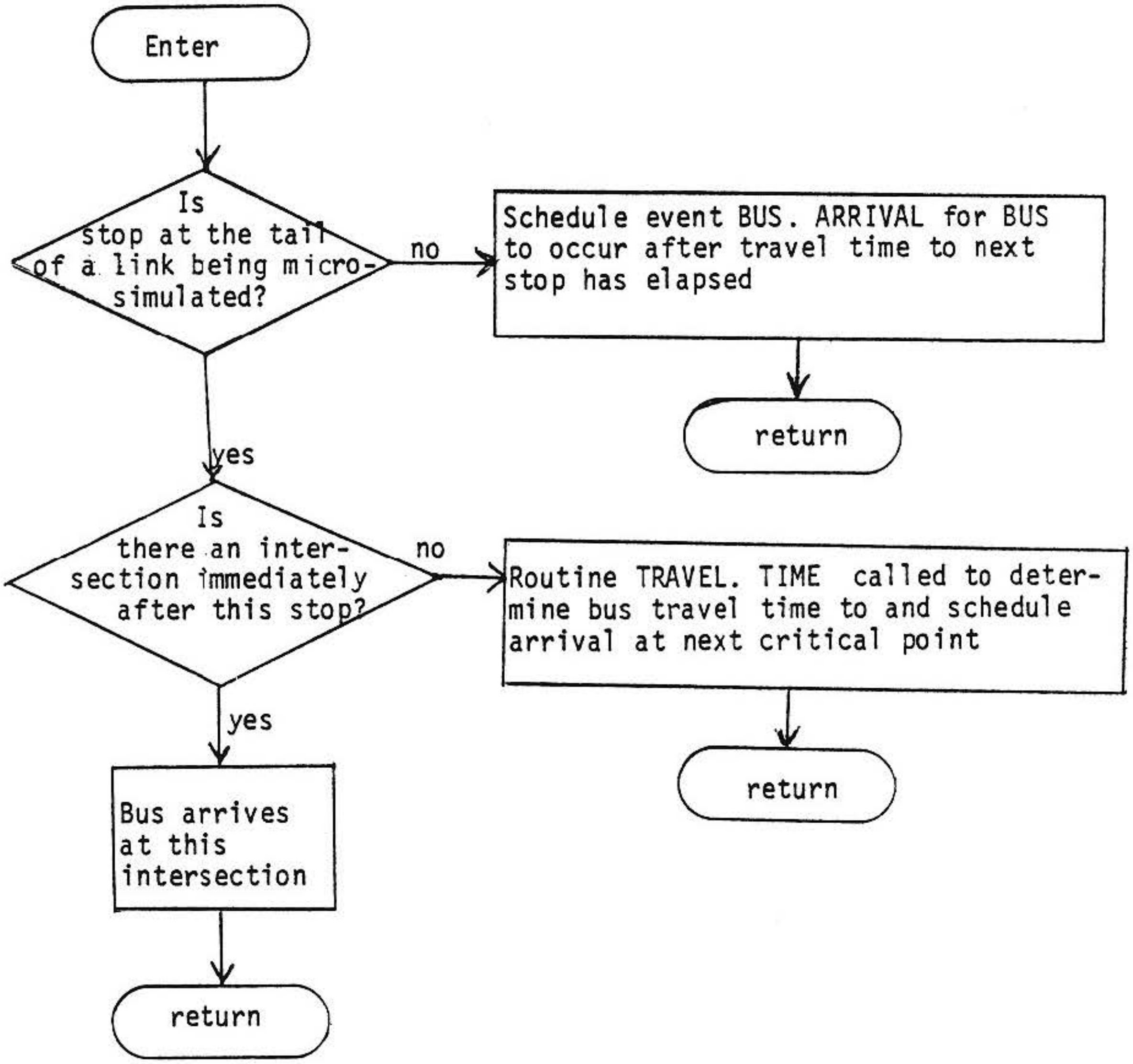
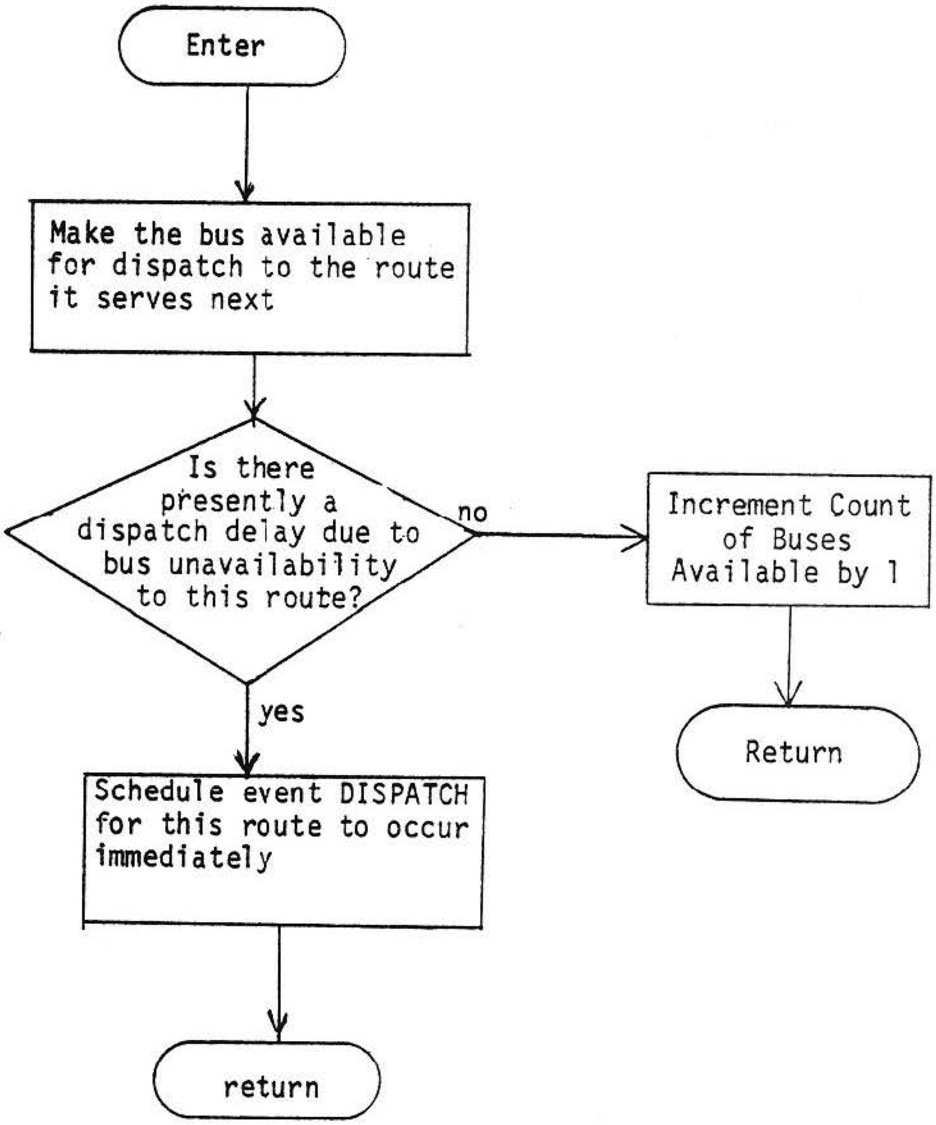


Figure 13. Event END.ROUTE given BUS



C. Routines Called by Events

1. Routine GENERATE.NONRANDOM.PASS.ARRIVAL given STOP

This routine is called by the PASS.ARRIVE event to schedule the next passenger arrival at stop STOP when the passenger arrival process is coordinated with the bus schedule. As described in Section II.D, this routine determines the average passenger arrival rate function over the scheduled headway interval. The eight points needed to define this function are computed and stored by the routine as follows: points t_1 and t_2 are stored in the SERV.INT matrix, the remaining 6 points are stored in the DENS.FUNC matrix.

The passenger arrival process is assumed to be described by a non-stationary Poisson process with a parameter defined by the computed rate function. The sampling of the next arrival time from a non-stationary process utilizes a technique discussed by Kaminsky and Rumpf (1977).

2. Routine GAP.ACCEPTANCE given BUS

This routine is called by the BUS.DEPART event when the bus BUS intends to depart from a protected bus stop on a link which is being micro-simulated but has not yet found a gap in traffic. This routine generates the time before appearance of a gap suitable for the bus to pull into traffic. The methodology used is discussed in Section II.E. The routine schedules a BUS.DEPART event for BUS for the time when the acceptable gap will appear.

3. Routine TRAVEL.TIME given BUS

This routine determines the travel time for the bus BUS over micro-simulated links. Travel time is computed from the moment BUS leaves a bus stop or intersection until the moment it must decide whether or not to stop at the next intersection or bus stop.

V. Model Output

At the end of a simulation run, the model produces the following statistics characterizing the operation of the bus network.

A. Bus stop statistics

For each bus stop the following information is printed:

1. the number of passengers beginning and ending their trips at the stop, as well as the number of passengers transferring from one bus to another at the stop;
2. the number of buses that stop at the stop;
3. the mean, standard deviation, minimum and maximum of the deviation from scheduled arrival times for buses stopping at the stop.*
4. the mean, standard deviation, and maximum of the number of passengers on board buses as they leave the stop;
5. if holding strategies are imposed at the stop, the number of buses held, the average length of the hold, and the average number of passengers on the held buses.

B. Passenger Statistics

The model produces two different types of output on passenger movements. At a very disaggregate level, each time a passenger reaches his/her destination, the following information is written to an output file (which is not printed along with the other output):

- the stop at which the passenger originated (written to the file in columns 1-5);
- the stop at which the passenger completes his/her trip (in columns 6-10);
- the number of transfers the passenger has made (in columns 11-15);
- the time the passenger arrived at the origin, in days (in columns 16-25);

---

[1] These statistics are aggregated for all routes serving a particular stop. If the user wishes to disaggregate the statistics by route, separate stops (at the same physical location) can be defined, with each stop served by a single route.

- the time a passenger first boards a bus, in days (in columns 26-35);
- the time the passenger reaches his/her destination, in days (in columns 36-45);
- the length of time the passenger spent in transferring, in days (in columns 46-55);
- the sum of squares of the passenger's transfer time (in columns 56-70).

Additionally, the effective speed of travel is computed (the distance each passenger travels divided by the time from when s/he arrives at the origin stop to when s/he alights the bus at his/her destination). The mean, standard deviation, and maximum, as well as a histogram of effective speed for all passengers is part of the printed output.

C. Bus Route Statistics

For each bus route the mean, standard deviation, and the maximum of the bus travel times from the dispatch point of the route end are printed.

D. Preemptable Signal Statistics

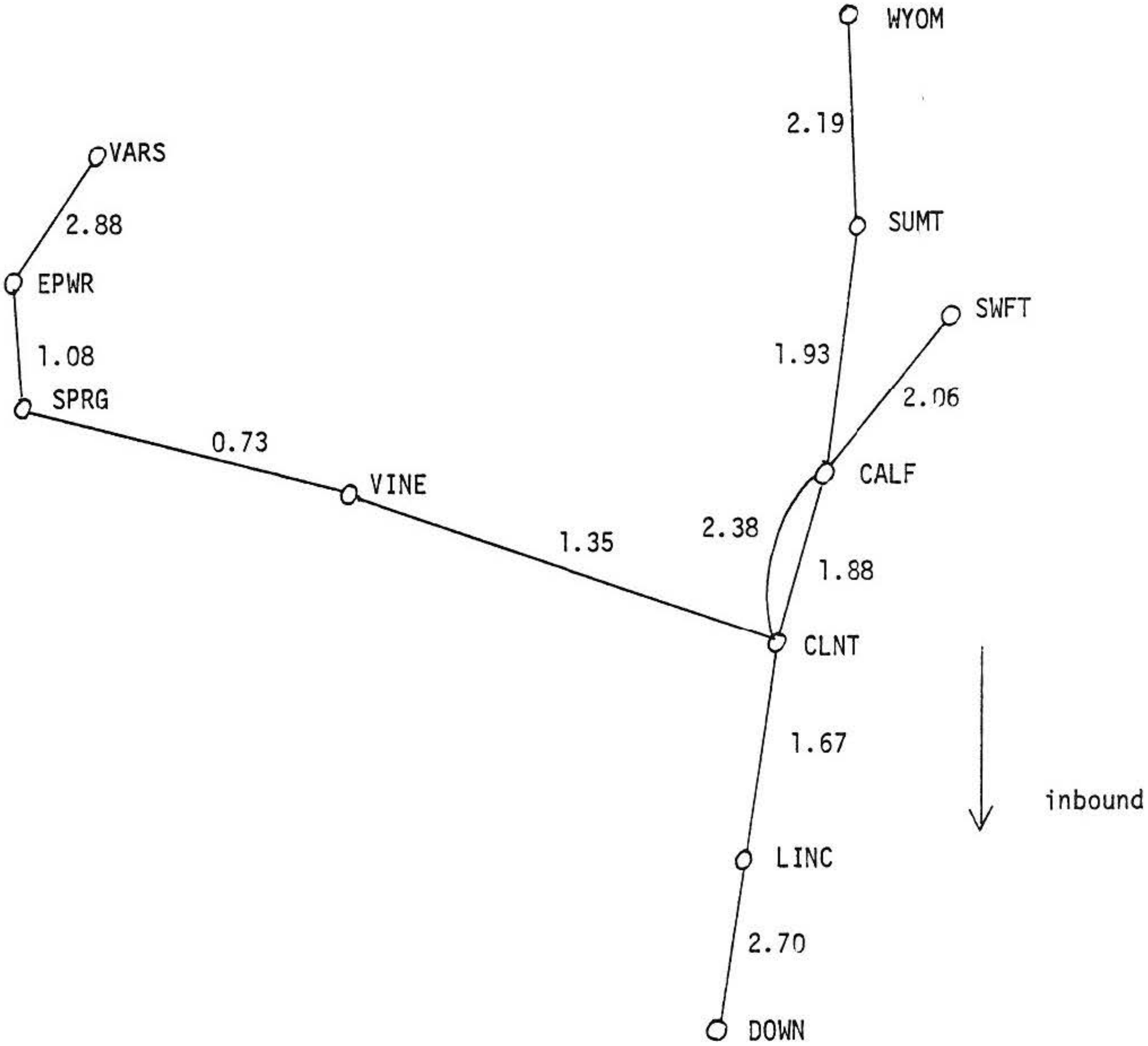
For each traffic signal which can be preempted by a bus the following information is printed:

1. the number and percentage of buses passing through the intersection that actually preempt the signal;
2. the average length of the preemptions and the number of distinct preemptions (note that several buses traveling close together could conceivably pass through the light during a single preemption);
3. the average number of passengers on buses preempting the signal.

VI. Example of Simulation

Figure 14 shows an example of a bus network modeled at the macroscopic level. The bus stops shown in the figure are aggregations of "real-world" bus stops. The numbers associated with the links connecting the stops are distances in miles. Three bus routes serve this network: 1) VARS to DOWN and back, 2) WYOM to DOWN and back, and 3) SWFT to DOWN and back.

Figure 14. Route network for example



Several modifications are made to this simple network structure for use with the simulation model:

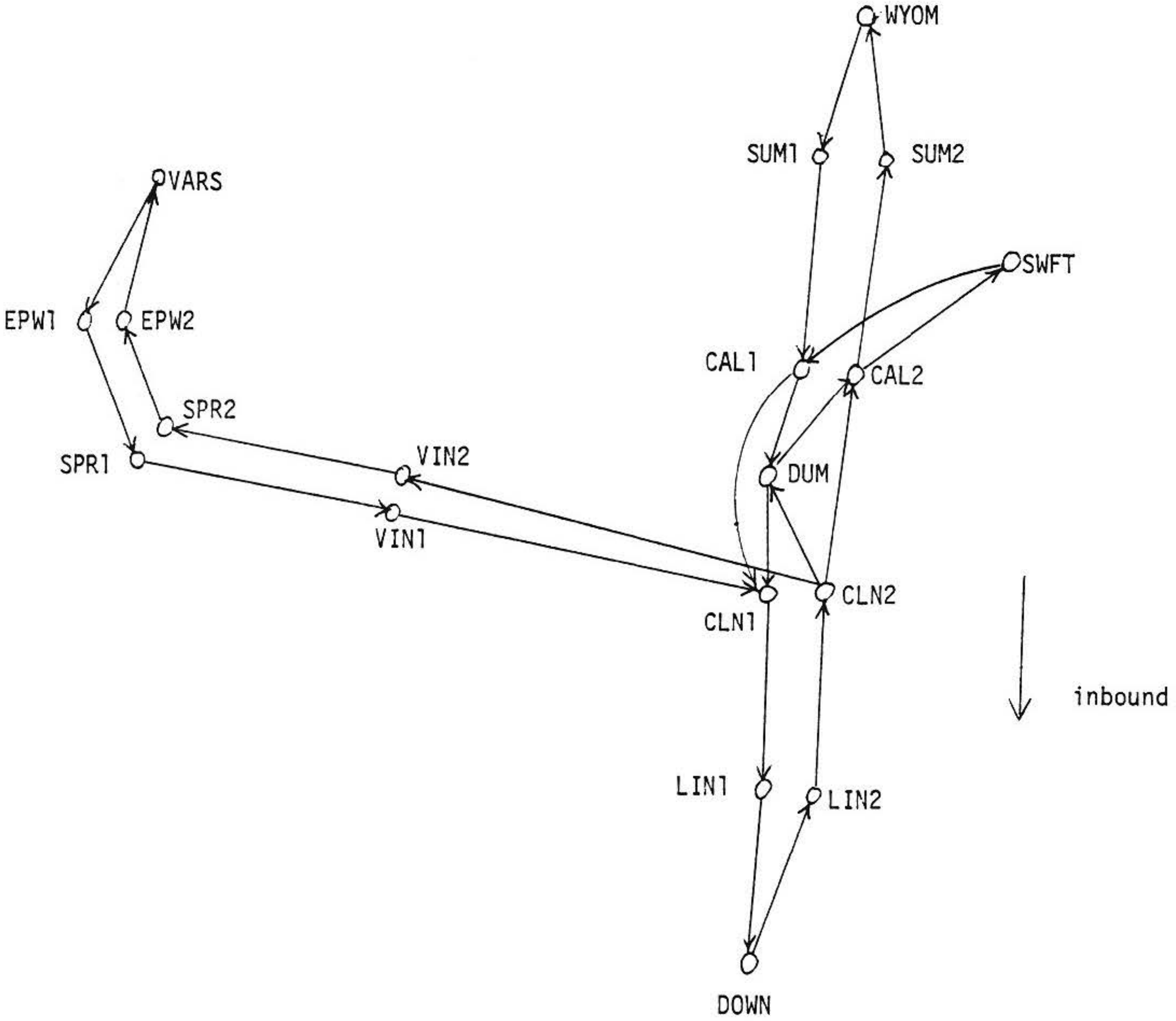
a) Note that there are two links connecting stop CALF and CLNT (the two routes traveling between these stops take different paths). A link is defined in the model by the stops at its endpoints. Two stops cannot be directly connected by more than 1 link. To model the situation shown in Figure 14, a dummy stop (DUM) is defined between stop CALF and CLNT on one of the links. This dummy stop will have a passenger arrival rate of zero defined for it (see the RATE input card). Figure 15 shows this dummy stop.

b) The inbound (toward DOWN) and outbound (from DOWN) sections of each route are broken into two distinct routes. There are two reasons for this: 1) buses have layover periods at the downtown part of their route (stop DOWN) as well as at their outer terminus; and 2) the simulation model operates under the assumption that each route will serve any stop at most once. Therefore, the network is modeled as though it is served by 6 routes.

c) Stops which are served by buses traveling in different directions are divided into several stops. For example, stop LINC in Figure 14 is served by buses traveling both inbound and outbound. In the model this stop is broken into 2 stops, LNC1 and LNC2, handling traffic in opposite directions. Passengers are allowed to transfer between buses serving these two stops.

Figure 15 shows that macroscopic modeled bus networks as it would be input to the simulation model. The dummy stop DUM is not divided into two stops to serve oppositely directed traffic as buses never stop at this "stop."

Figure 15. Macroscopically modeled bus network as input to model.



Suppose it is desired to model microscopically bus movements inbound to stop DOWN over the route segment shown in Figure 16. Then additional stops 9th, 8th, and 7th are defined between stops LINC and DOWN. Intersection locations, as noted in Figure 16, are also input.

Figure 17 shows the model input for the bus network described in Figures 15 and 16. Some points of note on this input are:

a) For the macroscopic model two types of links are defined;
   INBD - those links inbound to stop DOWN, and
   OTBD - those links outbound for stop DOWN. A morning peak period is being modeled, so travel time characteristics in these directions should be different due to unequal congestion levels.

b) The traffic signals at the five intersections in the microscopically modeled route segment are preemptable by approaching buses.

Figure 18 shows the output from the simulation run.

Figure 16. Microscopically modeled route segment

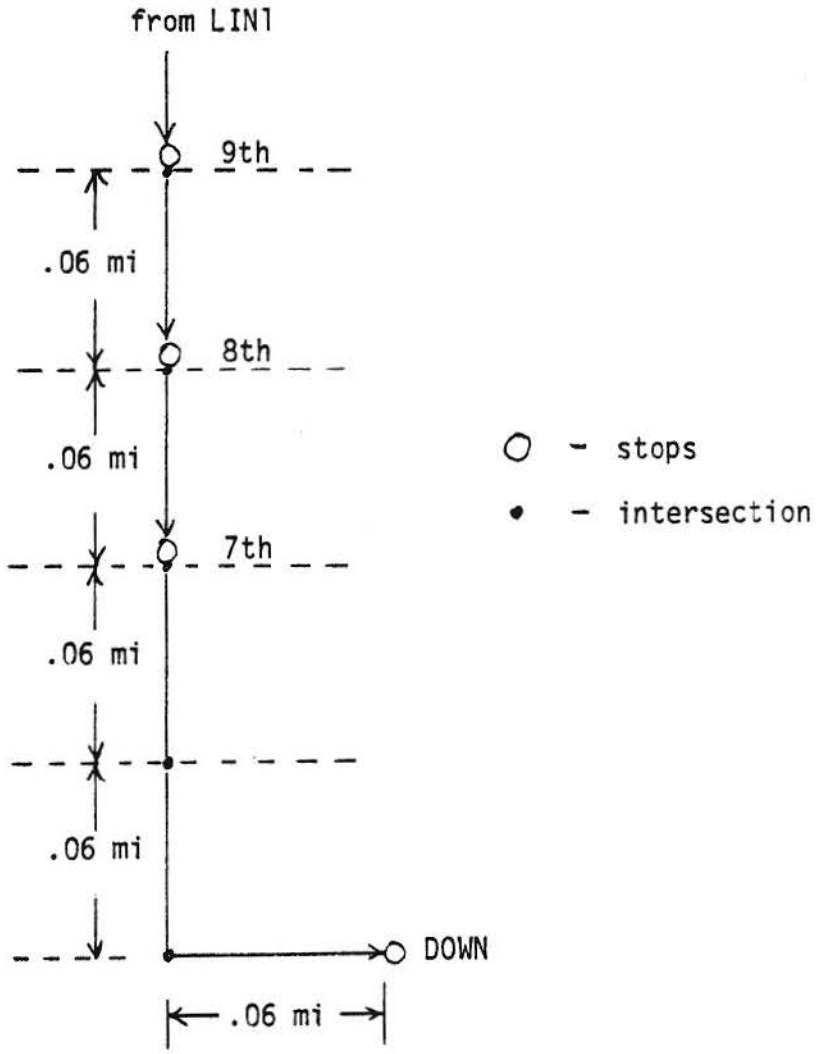


Figure 17. Input for example run.

```
STRT 2
    TYPE INBD 17 17 25
    TYPE OTBD 7 36 25
RLS 6 27 22
BSRT BND1
     NSTP 9
     STOP SWFT CAL1 DUM CLN1 LIN1 9TH 8TH 7TH DOWN
     LINK SWFT CAL1 206 INBD
     LINK CAL1 DUM 119 INBD
     LINK DUM CLN1 119 INBD
     LINK CLN1 LIN1 167 INBD
     LINK LIN1 9TH 240 INBD
     LINK 9TH 8TH 6 INBD
     LINK 8TH 7TH 6 INBD
     LINK 7TH DOWN 18 INBD
     BUS 6 70
     REST 0
     NDSP 14
     TTBL 5.46 6.06 6.19 6.34 6.47 6.59 7.11 7.23 7.35 7.47
     TTBL 8.00 8.15 8.33 8.51
     NXTR BND2 BND2 BND2 BND2 BND2 BND2 BND2 BND2 BND2 BND2
     NXTR BND2 BND2 BND2 BND2
     TRTM 10. 5.5 5.5 7. .2 .2 .6 16.
BSRT BND2
     NSTP 6
     STOP DOWN LIN2 CLN2 DUM CAL2 SWFT
     LINK DOWN LIN2 268 OTBD
     LINK LIN2 CLN2 167 OTBD
     LINK CLN2 DUM 119 OTBD
     LINK DUM CAL2 119 OTBD
     LINK CAL2 SWFT 227 OTBD
     BUS 1 70
     REST 3
     NDSP 12
     TTBL 5.50 6.20 6.45 7.02 7.17 7.32 7.44 7.56 8.08
     TTBL 8.20 8.32 8.45
     NXTR BND1 BND1 BND1 BND1 BND1 BND1 BND1 BND1 BND1
     NXTR BND1 BND1 BND1
     TRTM 15. 8. 5. 5. 9.
BSRT RED1
     NSTP 9
     STOP WYOM SUM1 CAL1 CLN1 LIN1 9TH 8TH 7TH DOWN
     LINK WYOM SUM1 219 INBD
     LINK SUM1 CAL1 193 INBD
     LINK CAL1 CLN1 188 INBD
     LINK CLN1 LIN1 167 INBD
     LINK LIN1 9TH 240 INBD
     LINK 9TH 8TH 6 INBD
     LINK 8TH 7TH 6 INBD
     LINK 7TH DOWN 18 INBD
     BUS 5 70
     REST 0
     NDSP 12
     TTBL 5.53 6.14 6.29 6.44 6.56 7.09 7.19 7.29 7.55
     TTBL 8.18 8.35 8.54
```

Figure 17. Input for example run, cont.

```
     NXTR RED2 RED2 RED2 RED2 RED2 RED2 RED2 RED2 RED2
     NXTR RED2 RED2 RED2
BSRT RED2
     NSTP 6
     STOP DOWN LIN2 CLN2 CAL2 SUM2 WYOM
     LINK DOWN LIN2 268 OTBD
     LINK LIN2 CLN2 167 OTBD
     LINK CLN2 CAL2 188 OTBD
     LINK CAL2 SUM2 193 OTBD
     LINK SUM2 WYOM 208 OTBD
     BUS 2 70
     REST 3
     NDSP 11
     TTBL 5.35 6.15 6.40 7.05 7.20 7.35 7.47 8.00
     TTBL 8.10 8.20 8.42
     NXTR RED1 RED1 RED1 RED1 RED1 RED1 RED1 RED1
     NXTR RED1 RED1 RED1
BSRT WIN1
     NSTP 10
     STOP VARS EPW1 SPR1 VIN1 CLN1 LIN1 9TH 8TH 7TH DOWN
     LINK VARS EPW1 288 INBD
     LINK EPW1 SPR1 108 INBD
     LINK SPR1 VIN1 73 INBD
     LINK VIN1 CLN1 135 INBD
     LINK CLN1 LIN1 167 INBD
     LINK LIN1 9TH 240 INBD
     LINK 9TH 8TH 6 INBD
     LINK 8TH 7TH 6 INBD
     LINK 7TH DOWN 18 INBD
     BUS 8 70
     REST 0
     NDSP 15
     TTBL 5.31 5.49 6.07 6.19 6.31 6.43 6.55 7.07 7.19 7.31 7.46
     TTBL 8.03 8.18 8.33 8.48
     NXTR WIN2 WIN2 WIN2 WIN2 WIN2 WIN2 WIN2 WIN2 WIN2 WIN2 WIN2
     NXTR WIN2 WIN2 WIN2 WIN2
BSRT WIN2
     NSTP 7
     STOP DOWN LIN2 CLN2 VIN2 SPR2 EPW2 VARS
     LINK DOWN LIN2 268 OTBD
     LINK LIN2 CLN2 167 OTBD
     LINK CLN2 VIN2 135 OTBD
     LINK VIN2 SPR2 73 OTBD
     LINK SPR2 EPW2 108 OTBD
     LINK EPW2 VARS 276 OTBD
     BUS 1 70
     REST 3
     NDSP 13
     TTBL 5.45 6.10 6.30 6.50 7.08 7.20 7.32 7.44 7.56 8.08
     TTBL 8.20 8.33 8.53
     NXTR WIN1 WIN1 WIN1 WIN1 WIN1 WIN1 WIN1 WIN1 WIN1 WIN1
     NXTR WIN1 WIN1 WIN1
TRNS 7
     STPS 2 CAL1 CAL2
     STPS 2 CLN1 CLN2
```

Figure 17. Input for example run, cont.

```
     STPS 2 LIN1 LIN2
     STPS 2 SUM1 SUM2
     STPS 2 EPW1 EPW2
     STPS 2 SPR1 SPR2
     STPS 2 VIN1 VIN2
PASS MATR NRAN  .55
     WGHT  2.0  2.0
     OD DOWN LIN2 20
     OD DOWN 7TH 8
     OD DOWN 8TH 10
     OD DOWN 9TH 10
     OD DOWN CLN2 12
     OD DOWN CAL2 8
     OD DOWN SUM2 15
     OD DOWN WYOM 4
     OD DOWN SWFT 6
     OD DOWN VIN2 3
     OD DOWN SPR2 1
     OD DOWN EPW2 1
     OD DOWN VARS 2
     OD LIN1 DOWN 50
     OD LIN1 9TH 20
     OD LIN1 8TH 15
     OD LIN1 7TH 15
     OD LIN2 CLN2 12
     OD LIN2 CAL2 17
     OD LIN2 SUM2 29
     OD LIN2 WYOM 7
     OD LIN2 SWFT 13
     OD LIN2 VIN2 11
     OD LIN2 SPR2 2
     OD LIN2 EPW2 2
     OD LIN2 VARS 7
     OD CLN1 DOWN 33
     OD CLN1 9TH 15
     OD CLN1 8TH 15
     OD CLN1 7TH 15
     OD CLN1 LIN1 22
     OD CLN2 CAL2 45
     OD CLN2 SUM2 11
     OD CLN2 WYOM 3
     OD CLN2 SWFT 19
     OD CLN2 VIN2 6
     OD CLN2 SPR2 3
     OD CLN2 EPW2 3
     OD CLN2 VARS 10
     OD DUM DOWN 100
     OD CAL1 DOWN 30
     OD CAL1 9TH 10
     OD CAL1 8TH 10
     OD CAL1 7TH 10
     OD CAL1 LIN1 22
     OD CAL1 CLN1 18
     OD CAL2 SUM2 36
     OD CAL2 WYOM 19
```

Figure 17. Input for example run, cont.

```
OD CAL2 SWFT 45
OD SUM1 DOWN 20
OD SUM1 9TH 10
OD SUM1 8TH 10
OD SUM1 7TH 10
OD SUM1 LIN1 15
OD SUM1 CLN1 8
OD SUM1 CAL1 27
OD SUM2 WYOM 100
OD WYOM DOWN 9
OD WYOM 9TH 4
OD WYOM 8TH 4
OD WYOM 7TH 4
OD WYOM LIN1 13
OD WYOM CLN1 13
OD WYOM CAL1 25
OD WYOM SUM1 28
OD SWFT DOWN 27
OD SWFT 9TH 10
OD SWFT 8TH 10
OD SWFT 7TH 10
OD SWFT LIN1 17
OD SWFT CLN1 8
OD SWFT CAL1 18
OD VIN1 DOWN 31
OD VIN1 9TH 15
OD VIN1 8TH 15
OD VIN1 7TH 15
OD VIN1 LIN1 24
OD VIN2 VARS 100
OD SPR1 DOWN 37
OD SPR1 9TH 10
OD SPR1 8TH 10
OD SPR1 7TH 10
OD SPR1 LIN1 33
OD SPR2 EPW2 33
OD SPR2 VARS 67
OD EPW1 DOWN 30
OD EPW1 9TH 15
OD EPW1 8TH 15
OD EPW1 7TH 15
OD EPW1 LIN1 25
OD EPW2 VARS 100
OD VARS DOWN 24
OD VARS 9TH 10
OD VARS 8TH 10
OD VARS 7TH 10
OD VARS LIN1 7
OD VARS CLN1 3
OD VARS CAL1 4
OD VARS SWFT 3
OD VARS VIN1 8
OD VARS SPR1 7
OD VARS EPW1 14
OD 9TH DOWN 50
```

Figure 17. Input for example run, cont.

```
     OD 9TH CAL1 10
     OD 9TH VARS 10
     OD 9TH SWFT 10
     OD 9TH WYOM 10
     OD 9TH SUM1 10
     OD 8TH DOWN 50
     OD 8TH CLN1 20
     OD 8TH SPR1 10
     OD 8TH VIN1 10
     OD 8TH VARS 10
     OD 7TH DOWN 60
     OD 7TH LIN1 20
     OD 7TH CLN2 10
     OD 7TH VIN2 10
     RATE DUM 0
     RATE DOWN 202
     RATE 9TH 20
     RATE 8TH 20
     RATE 7TH 20
     RATE LIN1 279
     RATE LIN2 10
     RATE CLN1 110
     RATE CLN2 133
     RATE CAL1 133
     RATE CAL2 53
     RATE SUM1 74
     RATE SUM2 6
     RATE WYOM 39
     RATE SWFT 60
     RATE VIN1 17
     RATE VIN2 1
     RATE SPR1 6
     RATE SPR2 3
     RATE EPW1 20
     RATE EPW2 4
     RATE VARS 169
DWLT
     BDAT 1. 3. 1.5 .02 3.
     BD 2. 3. 3.
     AT 1.8 1.5 1.5
SEED 1 2 3 4 5 6 7 8 9 10
MICR
RTSG 1
     SEG
     SGLK 9TH 8TH 3
     SGLK 8TH 7TH 3
     SGLK 7TH DOWN 3
INTR 5
     INT 9TH 8TH 0 400. 0. 0. 37 33 15 NOPT
     INT 8TH 7TH 0 400. 0. 0. 34 36 15 NOPT
     INT 7TH DOWN 0 400. 0. 0. 27 43 15 NOPT
     INT 7TH DOWN 6 400. 0. 0. 41 29 15 PRMT
     INT 7TH DOWN 12 400. 0. 0. 34 36 15 PRMT
     PROT DOWN
ENDM
```

Figure 17. Input for example run, cont.

```
OPTS
HOLD SCHD
     HSTP CLN1
HOLD HDWY
     HSTP LIN1
     MINH 120
     PREE 300
ENDO
ECHO 2
END .375
```

```
----MICRO RUN IS SPECIFIED----

----FOR THIS SIMULATION RUN:
     NO. OF ROUTES      =    6
     NO. OF LINKS       =   27
     NO. OF BUS STOPS   =   22

----LINK DETAIL----
     TAIL      HEAD    STREET-TYPE    LENGTH(MILE)  NO. OF LANES
     SWFT      CAL1       INBD           2.06           0
     CAL1      DUM        INBD           1.19           0
     DUM       CLN1       INBD           1.19           0
     CLN1      LIN1       INBD           1.67           0
     LIN1      9TH        INBD           2.40           0
     9TH       8TH        INBD            .06           3
     8TH       7TH        INBD            .06           3
     7TH       DOWN       INBD            .18           3
     DOWN      LIN2       OTBD           2.68           0
     LIN2      CLN2       OTBD           1.67           0
     CLN2      DUM        OTBD           1.19           0
     DUM       CAL2       OTBD           1.19           0
     CAL2      SWFT       OTBD           2.27           0
     WYOM      SUM1       INBD           2.19           0
     SUM1      CAL1       INBD           1.93           0
     CAL1      CLN1       INBD           1.88           0
     CLN2      CAL2       OTBD           1.88           0
     CAL2      SUM2       OTBD           1.93           0
     SUM2      WYOM       OTBD           2.08           0
     VARS      EPW1       INBD           2.88           0
     EPW1      SPR1       INBD           1.08           0
     SPR1      VIN1       INBD            .73           0
     VIN1      CLN1       INBD           1.35           0
     CLN2      VIN2       OTBD           1.35           0
     VIN2      SPR2       OTBD            .73           0
     SPR2      EPW2       OTBD           1.08           0
     EPW2      VARS       OTBD           2.76           0

----STREET TYPE PARAMETERS----
     STREET-TYPE   GAMMA DISTR. PARAMETERS   SPEED-LIMIT(MPH)
         INBD              17      17               25
         OTBD               7      36               25

----ROUTE PARAMETERS----
                                                          WHETHER SCHEDULED     LAYOVER
ROUTE    NO. OF BUS    CAP. OF BUS    NO. OF DISPATCH    TRAVEL TIMES USED     TIME(MIN)
BND1          6            70                14                 YES               0
BND2          1            70                12                 YES               3
RED1          5            70                12                 NO                0
RED2          2            70                11                 NO                3
WIN1          8            70                15                 NO                0
WIN2          1            70                13                 NO                3

----ROUTE DETAIL----
```

Figure 18. Output from example run.

```
 FOR ROUTE BND1
          STOPS ARE:SWFT CAL1 DUM  CLN1 LIN1 9TH  8TH  7TH  DOWN
SCHEDULED TRAVEL TIME: 0.  10.0 15.5 21.0 28.0 28.2 28.4 29.0 45.0

TIMETABLE IS:
 BUS  1 DISPATCHED AT  5:46, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  2 DISPATCHED AT  6: 6, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  3 DISPATCHED AT  6:19, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  4 DISPATCHED AT  6:34, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  5 DISPATCHED AT  6:47, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  6 DISPATCHED AT  6:59, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  7 DISPATCHED AT  7:11, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  8 DISPATCHED AT  7:23, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS  9 DISPATCHED AT  7:35, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS 10 DISPATCHED AT  7:47, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS 11 DISPATCHED AT  8: 0, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS 12 DISPATCHED AT  8:15, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS 13 DISPATCHED AT  8:33, SERVES ROUTE BND2 UPON COMPLETION OF RUN
 BUS 14 DISPATCHED AT  8:51, SERVES ROUTE BND2 UPON COMPLETION OF RUN



 FOR ROUTE BND2
          STOPS ARE:DOWN LIN2 CLN2 DUM  CAL2 SWFT
SCHEDULED TRAVEL TIME: 0.  15.0 23.0 28.0 33.0 42.0

TIMETABLE IS:
 BUS  1 DISPATCHED AT  5:50, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  2 DISPATCHED AT  6:20, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  3 DISPATCHED AT  6:45, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  4 DISPATCHED AT  7: 2, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  5 DISPATCHED AT  7:17, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  6 DISPATCHED AT  7:32, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  7 DISPATCHED AT  7:44, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  8 DISPATCHED AT  7:56, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS  9 DISPATCHED AT  8: 8, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS 10 DISPATCHED AT  8:20, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS 11 DISPATCHED AT  8:32, SERVES ROUTE BND1 UPON COMPLETION OF RUN
 BUS 12 DISPATCHED AT  8:45, SERVES ROUTE BND1 UPON COMPLETION OF RUN



 FOR ROUTE RED1
          STOPS ARE:WYOM SUM1 CAL1 CLN1 LIN1 9TH  8TH  7TH  DOWN
SCHEDULED TRAVEL TIME: 0.  16.4 31.3 45.8 58.3 76.9 77.4 78.0 79.4

TIMETABLE IS:
 BUS  1 DISPATCHED AT  5:53, SERVES ROUTE RED2 UPON COMPLETION OF RUN
 BUS  2 DISPATCHED AT  6:14, SERVES ROUTE RED2 UPON COMPLETION OF RUN
 BUS  3 DISPATCHED AT  6:29, SERVES ROUTE RED2 UPON COMPLETION OF RUN
 BUS  4 DISPATCHED AT  6:44, SERVES ROUTE RED2 UPON COMPLETION OF RUN
 BUS  5 DISPATCHED AT  6:56, SERVES ROUTE RED2 UPON COMPLETION OF RUN
 BUS  6 DISPATCHED AT  7: 9, SERVES ROUTE RED2 UPON COMPLETION OF RUN
 BUS  7 DISPATCHED AT  7:19, SERVES ROUTE RED2 UPON COMPLETION OF RUN
```

Figure 18. Output from example run, cont.

```
  BUS  8 DISPATCHED AT  7:29, SERVES ROUTE RED2 UPON COMPLETION OF RUN
  BUS  9 DISPATCHED AT  7:55, SERVES ROUTE RED2 UPON COMPLETION OF RUN
  BUS 10 DISPATCHED AT  8:18, SERVES ROUTE RED2 UPON COMPLETION OF RUN
  BUS 11 DISPATCHED AT  8:35, SERVES ROUTE RED2 UPON COMPLETION OF RUN
  BUS 12 DISPATCHED AT  8:54, SERVES ROUTE RED2 UPON COMPLETION OF RUN


 FOR ROUTE RED2
          STOPS ARE:DOWN LIN2 CLN2 CAL2 SUM2 WYOM
SCHEDULED TRAVEL TIME: 0.  18.7 29.8 42.8 56.0 69.9

TIMETABLE IS:
  BUS  1 DISPATCHED AT  5:35, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  2 DISPATCHED AT  6:15, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  3 DISPATCHED AT  6:40, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  4 DISPATCHED AT  7: 5, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  5 DISPATCHED AT  7:20, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  6 DISPATCHED AT  7:35, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  7 DISPATCHED AT  7:47, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  8 DISPATCHED AT  8: 0, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS  9 DISPATCHED AT  8:10, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS 10 DISPATCHED AT  8:20, SERVES ROUTE RED1 UPON COMPLETION OF RUN
  BUS 11 DISPATCHED AT  8:42, SERVES ROUTE RED1 UPON COMPLETION OF RUN


 FOR ROUTE WIN1
          STOPS ARE:VARS EPW1 SPR1 VIN1 CLN1 LIN1 9TH  8TH  7TH  DOWN
SCHEDULED TRAVEL TIME: 0.  22.8 30.9 36.2 46.2 58.8 77.3 77.8 78.4 79.8

TIMETABLE IS:
  BUS  1 DISPATCHED AT  5:31, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  2 DISPATCHED AT  5:49, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  3 DISPATCHED AT  6: 7, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  4 DISPATCHED AT  6:19, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  5 DISPATCHED AT  6:31, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  6 DISPATCHED AT  6:43, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  7 DISPATCHED AT  6:55, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  8 DISPATCHED AT  7: 7, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS  9 DISPATCHED AT  7:19, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS 10 DISPATCHED AT  7:31, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS 11 DISPATCHED AT  7:46, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS 12 DISPATCHED AT  8: 3, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS 13 DISPATCHED AT  8:18, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS 14 DISPATCHED AT  8:33, SERVES ROUTE WIN2 UPON COMPLETION OF RUN
  BUS 15 DISPATCHED AT  8:48, SERVES ROUTE WIN2 UPON COMPLETION OF RUN


 FOR ROUTE WIN2
          STOPS ARE:DOWN LIN2 CLN2 VIN2 SPR2 EPW2 VARS
SCHEDULED TRAVEL TIME: 0.  18.7 29.8 39.3 44.2 51.4 69.7

TIMETABLE IS:
```

Figure 18. Output from example run, cont.

```
BUS  1 DISPATCHED AT  5:45, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  2 DISPATCHED AT  6:10, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  3 DISPATCHED AT  6:30, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  4 DISPATCHED AT  6:50, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  5 DISPATCHED AT  7: 8, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  6 DISPATCHED AT  7:20, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  7 DISPATCHED AT  7:32, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  8 DISPATCHED AT  7:44, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS  9 DISPATCHED AT  7:56, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS 10 DISPATCHED AT  8: 8, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS 11 DISPATCHED AT  8:20, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS 12 DISPATCHED AT  8:33, SERVES ROUTE WIN1 UPON COMPLETION OF RUN
BUS 13 DISPATCHED AT  8:53, SERVES ROUTE WIN1 UPON COMPLETION OF RUN


PASSENGER ARRIVAL PROCESS: NON-RANDOM


    WEIGHT ON WAIT TIME:  2.00
    WEIGHT ON TRANSFER TIME:  2.00

----BUS-STOP DETAIL----
                      AV. PASS. ARRIVAL       NO. OF ROUTES
      BUS-STOP        RATE (PEOPLE/HOUR)      SERVING THIS STOP
        SWFT                 60                     2
        CAL1                133                     2
        DUM                   0                     2
        CLN1                110                     3
        LIN1                279                     3
        9TH                  20                     3
        8TH                  20                     3
        7TH                  20                     3
        DOWN                202                     6
        LIN2                 10                     3
        CLN2                133                     3
        CAL2                 53                     2
        WYOM                 39                     2
        SUM1                 74                     1
        SUM2                  6                     1
        VARS                169                     2
        EPW1                 20                     1
        SPR1                  6                     1
        VIN1                 17                     1
        VIN2                  1                     1
        SPR2                  3                     1
        EPW2                  4                     1

----DWELL TIME COEFFICIENTS----
D =  1.00 +  3.00X +  1.50Y +   .02XY + E  WHERE E IS N(0, 9.00)
D =  2.00 +  3.00X + E  WHERE E IS N(0, 9.00)
D =  1.80 +  1.50Y + E  WHERE E IS N(0, 2.25)
     NOTES: D = DWELL TIME IN SECONDS
            X = NO. OF BOARDING PASSENGERS
            Y = NO. OF ALIGHTING PASSENGERS
```

Figure 18. Output from example run, cont.

```
 ----RANDOM NUMBER SEEDS ARE:
              1           2           3           4           5
              6           7           8           9          10

 ----NO. OF ROUTE SEGMENTS SIMULATED FOP MICRO MODEL:    1

 ----ROUTE SEGMENT DETAIL----

SEGMENT  1
     STOPS ARE:        9TH  8TH  7TH  DOWN
 INTEPSECTION  DIST. FROM    MAIN DIPN.    % TURN OFF   RATE OF TURN        SIGNAL GPEEN   SIGNAL RED     SIGNAL   SIGNAL
 ON LINK        TAIL OF LINK  CAP ARFIVAL   FROM MAIN    VOLUME INTO MAIN   PHASE LENGTH   PHASE LENGTH   OFFSET   PPEEMPTABLE
 (TAIL-HEAD)      (MILE)      RATE(CAR/HR)  DIRECTION    DIPN.(CAR/HF)         (SEC)          (SEC)        (SEC)       ?
  9TH -8TH        0.              757          0.              0                37             33           15        NO
  8TH -7TH        0.              824          0.              0                34             36           15        NO
  7TH -DOWN       0.             1037          0.              0                27             43           15        NO
  7TH -DOWN        .06            683          0.              0                41             29           15        YES
  7TH -DOWN        .12            824          0.              0                34             36           15        YES

 ----LIST OF PROTECTED BUS STOPS:
     DOWN
 ----CONTROL STRATEGY SUMMARY----
   NO. OF BUS STOPS WITH HOLD TO SCHEDULE STRATEGY APPLIED =     1
   NO. OF BUS STOPS WITH HOLD TO HEADWAY STRATEGY APPLIED  =     1
   MINIMUM HEADWAY IMPOSED IS 120 SECONDS.

 ----LENGTH OF SIMULATION RUN:  3:29
THIS IS THE END OF THE SIMULATION
....BUS STOP STATISTICS....


 BUS STOP: SWFT
               PASSENGER INFORMATION: AT THIS STOP
                                       129 PASSENGERS ORIGINATED
                                         0 PASSENGERS TRANSFERRED
                                       198 PASSENGERS COMPLETED THEIP TRIPS

                16 BUSES STOPPED AT THIS STOP

               SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                          MEAN =     367.938 SECONDS
                          STANDARD DEVIATION =   552.616 SECONDS
                          MAXIMUM =   1356.626 SECONDS
                          MINIMUM =       0.     SECONDS

               PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                          MEAN =  17.36
                          STANDARD DEVIATION =  13.21
                          MAXIMUM =  54

               NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP
```

Figure 18. Output from example run, cont.

```
BUS STOP: CAL1
              PASSENGER  INFORMATION: AT THIS STOP
                                           220 PASSENGERS ORIGINATED
                                             0 PASSENGERS TRANSFERRED
                                           118 PASSENGERS COMPLETED THEIR TRIPS

               17 BUSES STOPPED AT THIS STOP

              SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                         MEAN =    230.662 SECONDS
                         STANDARD DEVIATION =     232.831 SECONDS
                         MAXIMUM =    545.190 SECONDS
                         MINIMUM =   -407.889 SECONDS

              PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                         MEAN =  39.76
                         STANDARD DEVIATION =  20.03
                         MAXIMUM =  70

              NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP




BUS STOP: DUM
              PASSENGER  INFORMATION: AT THIS STOP
                                             0 PASSENGERS ORIGINATED
                                             0 PASSENGERS TRANSFERRED
                                             0 PASSENGERS COMPLETED THEIR TRIPS

               17 BUSES STOPPED AT THIS STOP

              SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                         MEAN =    580.180 SECONDS
                         STANDARD DEVIATION =     137.003 SECONDS
                         MAXIMUM =    820.942 SECONDS
                         MINIMUM =    325.277 SECONDS

              PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                         MEAN =  36.82
                         STANDARD DEVIATION =  21.37
                         MAXIMUM =  70

              NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP




BUS STOP: CLN1
              PASSENGER  INFORMATION: AT THIS STOP
                                           227 PASSENGERS ORIGINATED
                                             0 PASSENGERS TRANSFERRED
                                           106 PASSENGERS COMPLETED THEIR TRIPS

               24 BUSES STOPPED AT THIS STOP
```

Figure 18. Output from example run, cont.

```
                  SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                            MEAN =     302.827 SECONDS
                            STANDARD DEVIATION =     415.329 SECONDS
                            MAXIMUM =     988.023 SECONDS
                            MINIMUM =   -356.161 SECONDS

                  PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                            MEAN =  42.37
                            STANDARD DEVIATION =  15.52
                            MAXIMUM =  70

                  THERE ARE HOLDING STRATEGIES IMPOSED AT THIS STOP
                              6BUSES, OR  25.00PERCENT OF ALL ARRIVALS, WERE HELD.
                              2.810 MINUTES WAS THE AVERAGE DELAY TO A HELD VEHICLE.
                            THE AVERAGE NUMBER OF PASSENGERS ON A DELAYED BUS WAS  41.83.


      BUS STOP: LIN1
                  PASSENGER INFORMATION: AT THIS STOP
                                            603 PASSENGERS ORIGINATED
                                            134 PASSENGERS TRANSFERRED
                                            236 PASSENGERS COMPLETED THEIR TRIPS

                   24 BUSES STOPPED AT THIS STOP

                  SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                            MEAN =     443.271 SECONDS
                            STANDARD DEVIATION =     521.600 SECONDS
                            MAXIMUM =   1367.618 SECONDS
                            MINIMUM =   -183.347 SECONDS

                  PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                            MEAN =  65.08
                            STANDARD DEVIATION =  11.56
                            MAXIMUM =  70

                  THERE ARE HOLDING STRATEGIES IMPOSED AT THIS STOP
                              7BUSES, OR  29.17PERCENT OF ALL ARRIVALS, WERE HELD.
                               .922 MINUTES WAS THE AVERAGE DELAY TO A HELD VEHICLE.
                            THE AVERAGE NUMBER OF PASSENGERS ON A DELAYED BUS WAS  67.00.


      BUS STOP: 9TH
                  PASSENGER INFORMATION: AT THIS STOP
                                             42 PASSENGERS ORIGINATED
                                              0 PASSENGERS TRANSFERRED
                                            307 PASSENGERS COMPLETED THEIR TRIPS

                   22 BUSES STOPPED AT THIS STOP
```

Figure 18. Output from example run, cont.

```
          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =    858.801 SECONDS
                    STANDARD DEVIATION =   1040.241 SECONDS
                    MAXIMUM =   2722.118 SECONDS
                    MINIMUM =   -165.368 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  52.86
                    STANDARD DEVIATION =    9.77
                    MAXIMUM =  68

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: 8TH
          PASSENGER INFORMATION: AT THIS STOP
                                        44 PASSENGERS ORIGINATED
                                         0 PASSENGERS TRANSFERRED
                                       288 PASSENGERS COMPLETED THEIR TRIPS

           22 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =    898.670 SECONDS
                    STANDARD DEVIATION =   1047.227 SECONDS
                    MAXIMUM =   2761.874 SECONDS
                    MINIMUM =   -145.553 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  41.86
                    STANDARD DEVIATION =    9.79
                    MAXIMUM =  62

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: 7TH
          PASSENGER INFORMATION: AT THIS STOP
                                        44 PASSENGERS ORIGINATED
                                         0 PASSENGERS TRANSFERRED
                                       245 PASSENGERS COMPLETED THEIR TRIPS

           22 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =    982.035 SECONDS
                    STANDARD DEVIATION =   1059.030 SECONDS
                    MAXIMUM =   2942.757 SECONDS
                    MINIMUM =    -69.215 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
```

Figure 18. Output from example run, cont.

```
                    MEAN =  32.73
                    STANDARD DEVIATION =  10.12
                    MAXIMUM =  57

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: DOWN
          PASSENGER INFORMATION: AT THIS STOP
                                        515 PASSENGERS ORIGINATED
                                         64 PASSENGERS TRANSFERRED
                                        654 PASSENGERS COMPLETED THEIR TRIPS

           48 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =     321.754 SECONDS
                    STANDARD DEVIATION =     570.326 SECONDS
                    MAXIMUM =    2073.995 SECONDS
                    MINIMUM =     -48.556 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  26.31
                    STANDARD DEVIATION =  23.44
                    MAXIMUM =  70

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: LIN2
          PASSENGER INFORMATION: AT THIS STOP
                                         35 PASSENGERS ORIGINATED
                                          0 PASSENGERS TRANSFERRED
                                        130 PASSENGERS COMPLETED THEIR TRIPS

           26 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =      46.717 SECONDS
                    STANDARD DEVIATION =     182.071 SECONDS
                    MAXIMUM =     618.868 SECONDS
                    MINIMUM =    -189.594 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  15.54
                    STANDARD DEVIATION =  14.64
                    MAXIMUM =  50

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP
```

Figure 18. Output from example run, cont.

```
BUS STOP: CLN2
              PASSENGER INFORMATION: AT THIS STOP
                                       313 PASSENGERS ORIGINATED
                                        30 PASSENGERS TRANSFERRED
                                        70 PASSENGERS COMPLETED THEIR TRIPS

               24 BUSES STOPPED AT THIS STOP

              SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                        MEAN =    107.028 SECONDS
                        STANDARD DEVIATION =    225.449 SECONDS
                        MAXIMUM =    608.492 SECONDS
                        MINIMUM =   -363.944 SECONDS

              PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                        MEAN =  29.33
                        STANDARD DEVIATION =  23.82
                        MAXIMUM =   70

              NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: CAL2
              PASSENGER INFORMATION: AT THIS STOP
                                       126 PASSENGERS ORIGINATED
                                         0 PASSENGERS TRANSFERRED
                                       206 PASSENGERS COMPLETED THEIR TRIPS

               13 BUSES STOPPED AT THIS STOP

              SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                        MEAN =    466.720 SECONDS
                        STANDARD DEVIATION =    359.110 SECONDS
                        MAXIMUM =    910.500 SECONDS
                        MINIMUM =   -224.954 SECONDS

              PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                        MEAN =  34.85
                        STANDARD DEVIATION =  22.78
                        MAXIMUM =   70

              NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: WYCM
              PASSENGER INFORMATION: AT THIS STOP
                                        92 PASSENGERS ORIGINATED
                                         0 PASSENGERS TRANSFERRED
                                        45 PASSENGERS COMPLETED THEIR TRIPS
```

Figure 18. Output from example run, cont.

```
     11 BUSES STOPPED AT THIS STOP

    SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
               MEAN =       64.917 SECONDS
               STANDARD DEVIATION =      251.252 SECONDS
               MAXIMUM =      782.903 SECONDS
               MINIMUM =     -284.864 SECONDS

    PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
               MEAN =  14.12
               STANDARD DEVIATION =   6.43
               MAXIMUM =  28

    NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: SUM1
    PASSENGER INFORMATION: AT THIS STOP
                                   134 PASSENGERS ORIGINATED
                                     0 PASSENGERS TRANSFERRED
                                    30 PASSENGERS COMPLETED THEIR TRIPS

      8 BUSES STOPPED AT THIS STOP

    SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
               MEAN =       47.708 SECONDS
               STANDARD DEVIATION =      155.652 SECONDS
               MAXIMUM =      316.724 SECONDS
               MINIMUM =     -185.106 SECONDS

    PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
               MEAN =  38.25
               STANDARD DEVIATION =  20.10
               MAXIMUM =  70

    NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: SUM2
    PASSENGER INFORMATION: AT THIS STOP
                                    12 PASSENGERS ORIGINATED
                                     0 PASSENGERS TRANSFERRED
                                   144 PASSENGERS COMPLETED THEIR TRIPS

      5 BUSES STOPPED AT THIS STOP

    SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
               MEAN =      275.052 SECONDS
               STANDARD DEVIATION =      322.121 SECONDS
               MAXIMUM =      697.505 SECONDS
```

Figure 18. Output from example run, cont.

```
                    MINIMUM =    -200.044 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  14.60
                    STANDARD DEVIATION =    7.00
                    MAXIMUM =  23

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: VAPS
          PASSENGER INFORMATION: AT THIS STOP
                                       412 PASSENGERS ORIGINATED
                                         0 PASSENGERS TRANSFERRED
                                        52 PASSENGERS COMPLETED THEIR TRIPS

           16 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =       91.594 SECONDS
                    STANDARD DEVIATION =      227.647 SECONDS
                    MAXIMUM =     811.507 SECONDS
                    MINIMUM =    -106.592 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  49.83
                    STANDARD DEVIATION =  16.00
                    MAXIMUM =  70

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: EPW1
          PASSENGER INFORMATION: AT THIS STOP
                                        33 PASSENGERS ORIGINATED
                                         0 PASSENGERS TRANSFERRED
                                        65 PASSENGERS COMPLETED THEIR TRIPS

           11 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =      10.709 SECONDS
                    STANDARD DEVIATION =      103.974 SECONDS
                    MAXIMUM =     149.777 SECONDS
                    MINIMUM =    -183.773 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  47.18
                    STANDARD DEVIATION =  14.91
                    MAXIMUM =  70
```

Figure 18. Output from example run, cont.

```
          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: SPR1
          PASSENGER INFORMATION: AT THIS STOP
                                  12 PASSENGERS ORIGINATED
                                   0 PASSENGERS TRANSFERRED
                                  35 PASSENGERS COMPLETED THEIR TRIPS

           10 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =       6.895 SECONDS
                    STANDARD DEVIATION =     145.332 SECONDS
                    MAXIMUM =     226.590 SECONDS
                    MINIMUM =    -220.536 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  43.10
                    STANDARD DEVIATION =  13.38
                    MAXIMUM =  70

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: VIN1
          PASSENGER INFORMATION: AT THIS STOP
                                  37 PASSENGERS ORIGINATED
                                   0 PASSENGERS TRANSFERRED
                                  44 PASSENGERS COMPLETED THEIR TRIPS

            9 BUSES STOPPED AT THIS STOP

          SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                    MEAN =      -19.635 SECONDS
                    STANDARD DEVIATION =     170.565 SECONDS
                    MAXIMUM =     284.509 SECONDS
                    MINIMUM =    -253.253 SECONDS

          PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                    MEAN =  39.56
                    STANDARD DEVIATION =  10.11
                    MAXIMUM =  55

          NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: VIN2
          PASSENGER INFORMATION: AT THIS STOP
```

Figure 18. Output from example run, cont.

```
                                          4 PASSENGERS ORIGINATED
                                          0 PASSENGERS TRANSFERRED
                                         45 PASSENGERS COMPLETED THEIR TRIPS

                8 BUSES STOPPED AT THIS STOP

              SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                        MEAN =     -1.460 SECONDS
                        STANDARD DEVIATION =     194.074 SECONDS
                        MAXIMUM =     442.011 SECONDS
                        MINIMUM =    -257.723 SECONDS

              PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                        MEAN =   11.12
                        STANDARD DEVIATION =    9.35
                        MAXIMUM =  34

              NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: SPR2
              PASSENGER INFORMATION: AT THIS STOP
                                          5 PASSENGERS ORIGINATED
                                          0 PASSENGERS TRANSFERRED
                                         16 PASSENGERS COMPLETED THEIR TRIPS

                8 BUSES STOPPED AT THIS STOP

              SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
                        MEAN =     61.796 SECONDS
                        STANDARD DEVIATION =     210.536 SECONDS
                        MAXIMUM =     538.093 SECONDS
                        MINIMUM =    -181.893 SECONDS

              PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                        MEAN =   10.00
                        STANDARD DEVIATION =    8.93
                        MAXIMUM =  31

              NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP



BUS STOP: EPW2
              PASSENGER INFORMATION: AT THIS STOP
                                          7 PASSENGERS ORIGINATED
                                          0 PASSENGERS TRANSFERRED
                                         12 PASSENGERS COMPLETED THEIR TRIPS

                6 BUSES STOPPED AT THIS STOP

              SCHEDULE DEVIATION STATISTICS FOR THESE BUSES ARE:
```

Figure 18. Output from example run, cont.

```
                 MEAN =     110.067 SECONDS
                 STANDARD DEVIATION =     282.457 SECONDS
                 MAXIMUM =     622.038 SECONDS
                 MINIMUM =   -255.449 SECONDS

        PASSENGERS ON BOARD BUSES WHEN THEY LEAVE THIS STOP:
                 MEAN =   9.83
                 STANDARD DEVIATION =   8.93
                 MAXIMUM =  29

        NO HOLDING STRATEGIES ARE IMPOSED AT THIS STOP
```

Figure 18. Output from example run, cont.

```
.....STATISTICS ON THE EFFECTIVE SPEED OF PASSENGERS FROM
     ORIGIN BUS STOP TO DESTINATION BUS STOP.....

          MEAN =  5.585 MPH
          STD. DEV. =  1.885 MPH
          MINIMUM =    .328 MPH

          HISTOGRAM OF EFFECTIVE SPEED
     .....INTERVAL....  .... OCCURENCES.....

           0 TO  1 MPH          12   *
           1 TO  2 MPH         117   *************
           2 TO  3 MPH         174   *******************
           3 TO  4 MPH         413   **********************************************
           4 TO  5 MPH         372   *****************************************
           5 TO  6 MPH         447   **************************************************
           6 TO  7 MPH         754   ************************************************************************************
           7 TO  8 MPH         558   **************************************************************
           8 TO  9 MPH         146   ****************
           9 TO 10 MPH          46   *****
          10 TO 11 MPH           6   *
          11 TO 12 MPH           0
          12 TO 13 MPH           0
          13 TO 14 MPH           0
          14 TO 15 MPH           1
          15 TO 16 MPH           0
          16 TO 17 MPH           0
          17 TO 18 MPH           0
          18 TO 19 MPH           0
          19 TO 20 MPH           0
          20 TO 21 MPH           0
          21 TO 22 MPH           0
          22 TO 23 MPH           0
          23 TO 24 MPH           0
          24 TO 25 MPH           0
          25 TO 26 MPH           0
          26 TO 27 MPH           0
          27 TO 28 MPH           0
          28 TO 29 MPH           0
          29 TO 30 MPH           0
          30 TO 31 MPH           0
          31 TO 32 MPH           0
          32 TO 33 MPH           0
          33 TO 34 MPH           0
          34 TO 35 MPH           0
          35 TO 36 MPH           0
          36 TO 37 MPH           0
          37 TO 38 MPH           0
          38 TO 39 MPH           0
          39 TO 40 MPH           0
```

Figure 18. Output from example run, cont.

```
.....STATISTICS ON BUS TRAVEL TIMES FOR EACH ROUTE.....

        FOR THE BND1 ROUTE, BUS TRAVEL TIME STATISTICS ARE:
             MEAN =  73.20 MINUTES
             STD. DEV. =   3.41 MINUTES
             MAXIMUM =  80.64 MINUTES



        FOR THE BND2 ROUTE, BUS TRAVEL TIME STATISTICS ARE:
             MEAN =  62.67 MINUTES
             STD. DEV. =   2.99 MINUTES
             MAXIMUM =  66.43 MINUTES



        FOR THE RED1 ROUTE, BUS TRAVEL TIME STATISTICS ARE:
             MEAN =  85.01 MINUTES
             STD. DEV. =   2.76 MINUTES
             MAXIMUM =  88.94 MINUTES



        FOR THE RED2 ROUTE, BUS TRAVEL TIME STATISTICS ARE:
             MEAN =  74.20 MINUTES
             STD. DEV. =   7.37 MINUTES
             MAXIMUM =  83.32 MINUTES



        FOR THE WIN1 ROUTE, BUS TRAVEL TIME STATISTICS ARE:
             MEAN =  84.81 MINUTES
             STD. DEV. =   2.88 MINUTES
             MAXIMUM =  88.97 MINUTES



        FOR THE WIN2 ROUTE, BUS TRAVEL TIME STATISTICS ARE:
             MEAN =  76.17 MINUTES
             STD. DEV. =   5.61 MINUTES
             MAXIMUM =  83.98 MINUTES
```

Figure 18. Output from example run, cont.

```
....PREEMPTABLE SIGNAL STATISTICS....

    THE SIGNAL AT INTERSECTION   4 LOCATED ON THE LINK BETWEEN STOPS 7TH  AND DOWN CAN BE PREEMPTED BY APPROACHING BUSES.
                      12 BUSES OR  54.55 PERCENT OF THE TOTAL PASSING THE INTERSECTION PREEMPT THE SIGNAL.
                     THE AVERAGE LENGTH OF A PREEMPTION WAS      12.40 SECONDS FOR  10 PREEMPTIONS (NOTE: SEVERAL
                     BUSES MAY CAUSE 1 PREEMPTION).
                     THE AVERAGE NUMBER OF PASSENGERS ON A BUS PREEMPTING THE SIGNAL IS  35.42 .

    THE SIGNAL AT INTERSECTION   5 LOCATED ON THE LINK BETWEEN STOPS 7TH  AND DOWN CAN BE PREEMPTED BY APPROACHING BUSES.
                      14 BUSES OR  63.64 PERCENT OF THE TOTAL PASSING THE INTERSECTION PREEMPT THE SIGNAL.
                     THE AVERAGE LENGTH OF A PREEMPTION WAS      10.93 SECONDS FOR  14 PREEMPTIONS (NOTE: SEVERAL
                     BUSES MAY CAUSE 1 PREEMPTION).
                     THE AVERAGE NUMBER OF PASSENGERS ON A BUS PREEMPTING THE SIGNAL IS  33.71 .
```

Figure 18. Output from example run, cont.

References

1. Boardman, T.J. and W.H. Kraft, "Predicting Bus Passenger Service Time - Part II," Traffic Engineering, 40 (Feb., 1970), pp. 36-40.

2. C.A.C.I., SIMSCRIPT II.5 Reference Handbook, Los Angeles, 1976.

3. Capelle, D.G. and C. Pinnell, "Capacity Study of Signalized Diamond Interchanges," Highway Research Board Bulletin 291, 1961, pp. 1-25.

4. Daon, A., "On Flow Within Platoons," Australian Road Research, March, 1966, p. 4-13.

5. Dijkstra, E.W., "A Note on Two Problems in Connexion with Graphs," Numerische Mathematik, 1 (1959), pp. 269-271.

6. Greenberg, I., "The Log-Normal Distribution of Headways," Australian Road Research, March, 1966, pp. 14-18.

7. Kaminsky, F.C. and D.L. Rumpf, "Simulating Nonstationary Poisson Processes: A Comparison of Alternatives Including the Correct Approach," Simulation, 29:1 (July, 1977), pp. 17-20.

8. Radelat, G., Simulation of the Operation of a Mass Transportation System: Urban Buses on an Arterial Street, D.Eng. Dissertation, Catholic University, 1973.

9. Solberg, P. and J.C. Oppenlander, "Lag and Gap Acceptances at Stop-Controlled Intersections," Highway Research Record 118, 1966, pp. 48-67.

10. Turnquist, M.A. and L.A. Bowman, Control of Service Reliability in Bus Transit Networks, report DOT/RSPA/DPB-50/79/5, U.S. Department of Transportation, Office of University Research, March, 1979.

11. Underwood, R.T., "Speed, Volume, and Density Relationships" in Quality and Theory of Traffic Flow, Bureau of Highway Traffic, Yale University, 1961, pp. 143-188.

12. Wagner, F.A., "An Evaluation of Fundamental Driver Decisions and Reactions at an Intersection," Highway Research Record 118, 1966, pp. 68-84.

☆U.S. GOVERNMENT PRINTING OFFICE: 1982 522-046/8462 1-3

REQUEST FOR FEEDBACK TO
The DOT Program Of University Research

This booklet is intended to serve as a reference source for transportation analysts, planners and operators. Your comments will be reviewed by the persons responsible for writing and publishing this material. Feedback is extremely important in improving the quality of research results, the transfer of research information, and the communication link between the researcher and the user.

YES	NO	
☐	☐	Did you find the report useful for your particular needs? If so, how?
☐	☐	Did you find the research to be of high quality?
☐	☐	Were the results of the research communicated effectively by this report?
☐	☐	Do you think this report will be valuable to workers in the field of transportation represented by the subject area of the research?
☐	☐	Are there one or more areas of the report which need strengthening? Which areas?
☐	☐	Would you be interested in receiving further reports in this area of research? If so, fill out form on other side.

Please furnish in the space below any comments you may have concerning the report. We are particularly interested in further elaboration of the above questions.

Cut Out Along This Line

DOT/RSPA/DPB-50/82/2
"Control of Bus Service Reliability in Bus
Transit Networks" -- Simulation Model User's
Manual Versoin 2.0

COMMENTS

Thank you for your cooperation. No postage necessary if mailed in the U.S.A.

RESEARCH INTEREST

PLEASE CHECK YOUR AREAS OF INTEREST. YOU WILL BE NOTIFIED AS NEW REPORTS ARE PUBLISHED.

TRANSPORTATION

- ☐ Air
- ☐ Highway
- ☐ Maritime & Ports
- ☐ Mass Transit
- ☐ Pipeline
- ☐ Rail

ECONOMIC REGULATION

- ☐ Air Carrier
- ☐ Motor Carrier
- ☐ Railroads

TRANSPORTATION STUDIES IN SPECIAL AREAS

- ☐ Advanced Technology
- ☐ Energy
- ☐ Environment
- ☐ Facilities & Terminals
- ☐ Hazardous Materials
- ☐ Safety
- ☐ Tunnelling
- ☐ Construction, Rehabilitation & Maintenance
- ☐ Efficiency, Productivity & Innovation
- ☐ Elderly, Handicapped & Disadvantaged
- ☐ Freight, Goods Movement & Commodity Flow
- ☐ Modeling - Demand, Supply & Traffic
- ☐ Rural Development, Planning & Policy
- ☐ Urban Development, Planning & Policy

☐ OTHER (PLEASE LIST) ____________________

____

____

U.S. DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration
Washington, D.C. 20590

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. G-126

POSTAGE WILL BE PAID BY ADDRESSEE

OFFICE OF UNIVERSITY RESEARCH
Attn: HELEN L. ENGRUM (DPB-50)
U.S. DEPARTMENT OF TRANSPORTATION
400 Seventh Street, S.W.
Washington, D.C. 20590

PLEASE LIST YOUR NAME AND ADDRESS.

NAME ____________________

TITLE ____________________

ORGANIZATION ____________________

STREET ____________________

CITY, STATE, ZIP CODE ____________________