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# SYSTEMS OPERATION STUDIES FOR AUTOMATED GUIDEWAY TRANSIT SYSTEMS

## DETAILED STATION MODEL FUNCTIONAL SPECIFICATION

GM Transportation Systems Division
General Motors Technical Center
Warren, MI 48090



JULY 1981
FINAL REPORT

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J. Bender, GM TSD, supported by IBM FSD

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**16. Abstract**
Functional requirements are specified for the Detailed Station Model (DSM). The DSM will provide operational and performance measures of alternative station configurations and management policies with respect to vehicle and passenger capabilities. It will provide an analytic tool to support trade studies, and its architecture will facilitate interchange of alternative operational strategy algorithms and station traffic flow patterns to assist in the initial station design selection by planners.



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16. Abstract

In order to examine specific Automated Guideway Transit (AGT) development and concepts, and to build a better knowledge base for future decision-making, the Urban Mass Transportation Administration (UMTA), has undertaken a new program of studies and technology investigations known as the UMTA Automated Guideway Transit Technology (AGTT) program. The objectives of one segment of the AGTT program, the Systems Operations Studies (SOS), are to: 1) develop models for the analysis of system operations; 2) evaluate performance and cost; and 3) establish guidelines for the design and operation of AGT systems.

The Detailed Station Model (DSM) is a discrete event model representing the interrelated queueing processes associated with vehicle and passenger activities in an AGT station. The DSM will provide operational and performance measures of alternative station configurations and management policies with respect to vehicle and passenger handling capabilities and will provide an analytic tool to support trade studies. Its architecture will facilitate interchange of alternative operational strategy algorithms and station traffic flow patterns to assist in the intitial design selection by planners.

The current SOS for AGT Systems reports in this group are: Feeder Systems Model (FSM) Functional Specification (UMTA-MA-06-0048-81-1); System Availability Model User's Manual (UMTA-MA-06-0048-81-2); Availability Model Functional Specification (UMTA-MA-06-0048-81-3); and System Availability Model Programmer's Manual (UMTA-MA-06-0048-81-4

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PREFACE

In order to examine specific Automated Guideway Transit (AGT) developments and concepts--and to build a better knowledge base for future decision-making--the Urban Mass Transportation Administration (UMTA) has undertaken a program of studies and technology investigations called the UMTA Automated Guideway Transit Technology (AGTT) program. The objectives of one segment of the AGTT program, the Systems Operation Studies (SOS), were to develop models for the analysis of system operations, to evaluate performance and cost, and to establish guidelines for the design and operation of AGT systems. A team headed by GM Transportation Systems Division (GMTSD) was awarded a contract by the Transportation Systems Center to pursue these objectives. The Technical Monitor for the project at TSC was Arthur Priver, who was assisted by Li Shin Yuan and Thomas Dooley.

The Detailed Station Model (DSM) is a discrete event model representing the inter-related queueing processes associated with vehicle and passenger activities in an AGT station. The DSM can be used to analyze alternative station configurations and management policies. This Functional Specification identifies the functions performed, the hardware required, and the modeling technique employed by the DSM.

This document was prepared under the direction of the SOS Program Manager at GMTSD, James F. Thompson. The first draft of this report was prepared by the IBM Federal Systems Division (FSD) under the direction of Roger Blanchard, and its final preparation was the responsibility of James G. Bender of GMTSD.

# 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)** | | |
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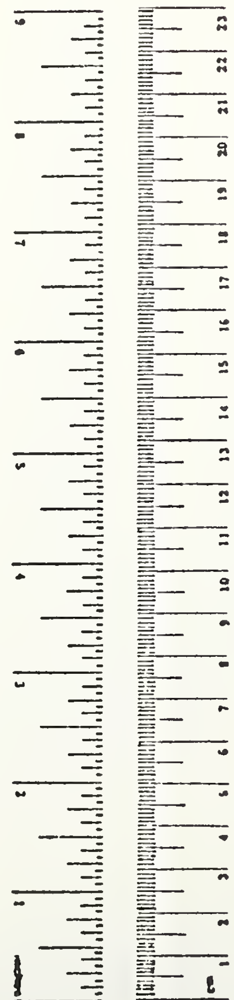
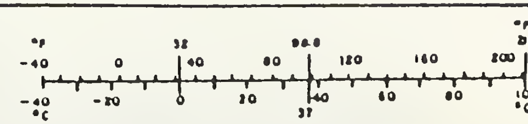


## Approximate Conversions from Metric Measures

| 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 ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# 1.0 INTRODUCTION

## 1.1 Objectives

The Detailed Station Model (DSM) will provide operational and performance measures of alternative station configurations and management policies with respect to vehicle and passenger handling capabilities. A discrete event modeling approach will be used to represent the interrelated queueing processes associated with vehicle and passenger activities in a transit station.

The DSM will provide an analytic tool to support trade studies and evaluations of alternative station designs. Flexibility and modularity will be emphasized in the model to allow detailed analysis of station configurations, operations, and station management policies. The model architecture will facilitate interchange of alternative operational strategy algorithms and station traffic flow patterns to assist in the initial station design selection by planners.

The station operational characteristics produced by the DSM will be analyzed to define accurate station representations for use in the Discrete Event Simulation Model.

The capabilities of the DSM will permit the evaluation of station performance under varying configurations, vehicle load, passenger load, and operation methods. Through the selection of appropriate run options and input variables, the model response will range from simple to complex, e.g., the physical station configuration being simulated could be a single dock on-line station or a station with several docks, vehicle storage, and modal interchange, representing an off-line Dual Mode station. Operating decisions tend to increase in proportion to the level of detail being represented. The DSM accommodates a range of decision points for vehicle motion, passenger flow, trip management, vehicle disposition, merging, and berthing.

## 1.2 Scope

This section lists the design constraints and limitations of the baseline Detailed Station Model. These factors are mainly in the area of representing a network operational environment and of specifying maximum values for quantities and capacities of station elements.

Those DSM features which pertain only to the baseline capability will be implemented in a manner which will permit substitution of feasible alternative procedures or algorithms derived as a result of AGT-SOS analysis tasks. The feasibility of substituting for these baseline features will be established by considering their impact on the basic model architecture and the data interface requirements.

In multiparty service, a group of passengers traveling together will not be broken up to fill empty seats on several vehicles. The group will wait for a vehicle that has sufficient room. In single party service, if the group size is larger than the capacity of an empty vehicle, the group will be broken up and assigned to multiple vehicles.

Waiting trips are not passed over when assigning trips to vehicles to maximize the use of vehicles. Assignment is on a first-in-first-out basis, except for multiparty service in which the destination of boarding trips must be compatible with the trips already on board. Compatibility for demand-responsive multiparty service is established through the use of a probability of compatibility. Compatibility for scheduled service is established through the use of a table which gives the destinations associated with each route (here the destination of the trip must be on the route of the vehicle to be boarded) or through the use of a probability of compatibility.

Transfers will be required to join the end of the trip queue (i.e., no priority). Required transfers will be identified by the use of a user specified probability of transfer of those trips on the vehicle that are not to destinate at the station being simulated.

No provision will be made for multiple sized vehicles in a single run. No distinction between seating and standing capacity/occupancy will be made.

Approximate vehicle launch time will be obtained from a specified distribution of delays, when the vehicle is at the head of an output queue lane. No network merge reservation or metering schemes will be included in the model.

In the case of scheduled service, any delay necessary to keep the vehicle on a schedule will be added to the delay discussed above.

For asynchronous, quasi-synchronous, and synchronous vehicle control, a delay will be calculated to represent the delay a vehicle would have to undergo to ensure that it did not conflict with a vehicle from the bypass link at the station exit merge.

The user will have the option of including (additively) or excluding the above three components of launch delay.

No network level handling of empty vehicles will be included. If an empty is requested, it will arrive at a randomly selected delay time later. If a vehicle becomes empty at the dock and is not needed, it will either be sent to storage or dispatched from the station (simulating an empty vehicle request from another station). The decision will be either deterministic from a function derived by the user or by random selection from a user specified distribution. If storage is full, the vehicle will be dispatched from the station.

Vehicle movement within a station element will be modeled by a travel time based on a vehicle velocity profile. Element capacity and vehicle headway leaving the element will be considered.

Station configuration limitations will include the following:

| | |
|---|---|
| • Maximum number of parallel queue areas for vehicles | 10 |
| • Maximum number of docking lanes | 10 |
| • Maximum number of berths per lane | 6 |
| • Maximum number of vehicles | 200 |
| • Maximum number of concurrent trips | 1,000 |
| • Number of entry ramps from guideway | 1 |
| • Number of exit ramps to guideway | 1 |
| • Number of model entry ramps into input queue area | 1 |
| • Number of modal entry ramps into output queue area | 1 |
| • Number of modal exit ramps from input ramp | 1 |
| • Number of modal exit ramps from boarding area | 1 |

If an offline station becomes congested, arriving vehicles destined for the station will not queue on the guideway. They will be recorded as station rejections and enter the bypass link.

It will not be possible to change any operational policies during a simulation exercise. This effect will be simulated by the use of checkpoint files and simulation restart capability.

Passengers can be affected by failures, but will not cause failures.

With respect to modeling entrained vehicles in a scheduled (i.e., fixed route) environment, there will be a capability to generate trains of vehicles during the demand generation process. The number of vehicles per train will be specified for each route by the user (e.g., all trains on route 1 have three vehicles; all trains on route 2 have five vehicles, etc.). In the event processor, these trains will arrive on the link prior to the station, may enter the station, undergo station processing, and go out as trains. The "switchover" operation of, for example, changing all trains on a route from three vehicles to two vehicles, will not be modeled for the scheduled environment.

The modeling of entrainment in the demand responsive environment will be accomplished in the output area by entraining an entering vehicle to the vehicle serially ahead of it if they have compatible next destinations. The launch time of a vehicle will be calculated when a vehicle is at an output queue lane and available for launch. At launch time, if the head vehicle in a lane is entrained, then it and its followers will be launched at once. Vehicles are considered to be detrained automatically at the boarding berth and will be reentrained in an output queue lane if the criteria discussed above are met.

# 2.0 REQUIREMENTS

## 2.1 Functions

The DSM functions described below provide the definition of a baseline simulation capability.

Those DSM features which pertain only to the baseline capability will be implemented in a manner which will permit substitution of feasible alternative procedures or algorithms derived as a result of AGT-SOS analysis tasks. The feasibility of substituting for these baseline features will be established by considering their impact on the basic model architecture and the data interface requirements.

### 2.1.1 Demand Generation

There will be four sources of demand input to the Detailed Station Model:

- Vehicles (with trips onboard) arriving from the guideway
- Vehicles (with trips onboard) arriving from modal entry into input queueing area
- Vehicles (with trips onboard) arriving from modal entry into output queueing area
- Trips arriving at the ticketing facility

Four sinks of demand will be provided in the Detailed Station Model:

- Vehicles (with trips onboard) departing on guideway
- Vehicles (with trips onboard) departing on modal exit from input ramp
- Vehicles (with trips onboard) departing on modal exit from boarding area
- Trips departing from the deboard area

The DSM will provide the capability to generate data for the four sources from the following generators (in addition, the DSM will accept as input any properly formatted and time ordered demand coded to reflect a specific demand situation as desired by the simulation user):

- Vehicles from guideway:
    - DESM copied to a file as vehicles pass a specified station
    - Vehicle Demand Generator (VDG) - part of input processor

- Vehicles from modal entry into input queueing area:
    - VDG
    - Feeder model (converted into a sequence of vehicles in the same format as from VDG)

- Vehicles from modal exit into output queueing area:
    - VDG
    - Feeder model (converted into a sequence of vehicles in the same format as from VDG)

- Trips
  - Trip Demand Generator (TDG)
  - Asynchronous trip arrivals:
    - + Input as a command (e.g., a failure command)
    - + Used to force a set of trips arriving simultaneously
    - + Will be interleaved with TDG source

The four sources of demand will be read into the Event Processor from four separate files (i.e., not interleaved in time on 1 file). This will allow the files, which are generated before they are used in the Event Processor, to be used in any combination. These sources will be time interleaved at Event Processor execution time.

The remainder of this section will discuss the TDG and VDG functions of the Input Processor.

### Trip Demand Generation (TDG)

For trips arriving at the ticketing facility, each trip will have the following attributes:

- Arrival time at the station being simulated - Arrivals will occur with a mean arrival rate as specified by the user, with individual trips specified by Poisson distributed pseudo-random numbers or user specified distribution table of interarrival time

- Origin station - Set equal to the station being simulated

- Destination station - Selected by using pseudo-random numbers and a table giving the probability of each destination station

- Number of passengers - Selected by using pseudo-random numbers and a table giving the probability of 1 passenger, 2 passengers, etc.

The user will be able to control the mean arrival rate and distribution tables used in this generation process. These tables will be generated by a portion of the Input Processor and will be available in the data base for use in several experiments.

### Vehicle Demand Generation (VDG)

Vehicles that are to enter the simulation will be represented by a set of records, the first of which will be a vehicle header record and a set of trip follower records (one per trip). In VDG, provision will be made to generate vehicles corresponding to a scheduled or demand responsive environment.

In the case of a scheduled environment, where vehicles stop at stations on a pre-assigned route, the header record will be generated as follows:

- Arrival time of the vehicle at the station being simulated (on the guideway link immediately upstream of the station) - Arrivals will occur at a mean arrival rate as specified by the user for each route, with individual arrival times selected using Poisson distributed pseudo-random numbers or user specified distribution table of interarrival times. In the case of asynchronous and quasi-synchronous control, the generation process will ensure serialization by making the interarrival time between any two consecutive vehicles greater than or equal to a user specified headway parameter. In the case of synchronous control, the generation process will ensure the vehicles are in slots by considering each particular interarrival time selected to be a multiple of time slot lengths.

- The next stop of the vehicle - Set equal to the station being simulated if the station is on the route of the vehicle and set equal to some other value otherwise (The user may specify either a list of station numbers for each route or a binary indicator for eadh route to show if the station is on route of the vehicle or not)

- The route of the vehicle - Included for subsequent use in determining the compatibility of trips

- Sink of the vehicle - Determined with a probability for each of the three vehicle sinks discussed above

Trip follower records will be generated using a stochastic process as follows:

- The arrival time of the trip - Set equal to the arrival time of the vehicle

- The destination of the trip - Selected using pseudo-random numbers and a table giving the probability that the trip will destinate at the station being simulated

- Number of passengers in the trip - Selected using a pseudo-random number and a user specified distribution giving the probability of 1 patron, 2 patrons, etc.

The number of trips associated with a vehicle will be selected using pseudo-random numbers and a user specified distribution that gives the probability of 1 trip, 2 trips, etc.

When generating trains, the user will specify the number of vehicles per train for each route. Each vehicle in such a train will have the same arrival time.

In the case of demand responsive environment, where the vehicles follow paths on the basis of trips assigned to them, the vehicle header record will be generated as follows:

- Arrival time of the vehicle at the station being simulated (on the guideway link immediately upstream of the station or at the modal entry) - Arrivals will occur at a single mean arrival rate as specified by the user, with individual arrival times determined by using an exponential interarrival time distribution or a user-specified distribution table of interarrival times

In the case of asynchronous and quasi-synchronous control, the generation process will provide for serialization by ensuring that the interarrival time between any two consecutive vehicles is greater than or equal to a user specified headway parameter. In the case of synchronous control, the generation process will ensure the vehicles are in slots by considering each particular interarrival time selected to be a multiple of the slot lengths.

- Next stop of the vehicle - Will be set equal to the station being simulated with a probability specified by the user

- Route of the vehicle - Will not be set in this case

- Sink of the vehicle - Determined with a probability for each of the three vehicle sinks discussed above

Trip follower records will be generated using pseudo-random numbers as follows:

- Arrival time of the trip - Set equal to the arrival time of the vehicle

- The destination of the trip - Selected using pseudo-random numbers and the probability a trip will destinate at the station being simulated

- Number of passengers in the trip - Selected using a pseudo-random number and a table that gives the probability of 1 patron, 2 patrons, etc.

The number of trips associated with the vehicle will be selected using pseudo-random numbers and a user specified distribution giving the probability of 1 trip, 2 trips, etc. The number of trips will be limited by vehicle capacity. When generating trains, the user will specify a distribution for choosing 1-vehicle trains, 2-vehicle trains, etc. Each vehicle in such a train will have the same arrival time.

Vehicle demand files will be generated by a portion of the Input Processor and stored in the data base. They will be available for use in several experiments in which the vehicle size is the same as that used during generation.

### 2.1.2 Trip Management

Trip Management relates to the management of trips while they are not on vehicles. When a trip arrives, whose number of passengers exceeds the size of a single vehicle, it will be subdivided at entry to the station and treated as N sub-groups trips of fixed size as input by the user plus one other trip to accommodate the residual patrons. Thereafter, it will be treated as N+1 independent trips.

An overview of the time line of a trip (i.e., the successive delays it may encounter while not on a vehicle) and an overview of the trip handling facilities are given in Figure 1.

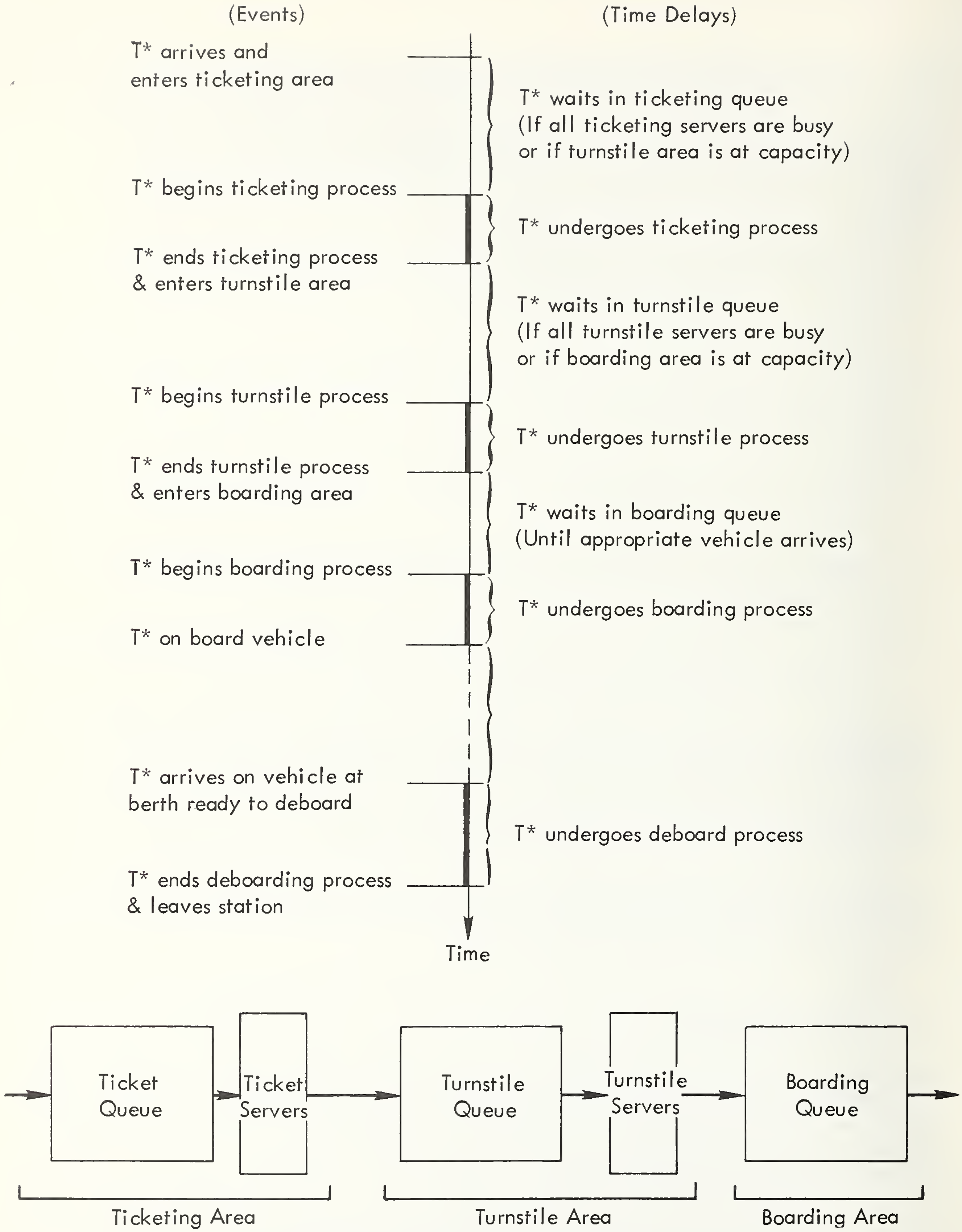



FIGURE 1 TIME LINE OF TRIP T*

When a trip arrives at a station, it will be processed by a ticketing facility. If all the ticketing servers are busy or if the next area to be entered, the Turnstile Area, is at capacity, then the trip will queue in the Ticketing Area. Following ticket processing, the trip will enter the Turnstile Area and queue there if either all the turnstile servers are busy of if the Boarding Area is a capacity. After turnstile processing, the trip will enter the Boarding Area to wait for an appropriate vehicle. Boarding trips will experience a delay time sampled from a distribution based on the number of boarding passengers and door actuation time. Deboarding passengers will experience a delay time sampled from a distribution based on the number of boarding passengers and door actuation time. In the case of a common boarding/deboarding area a delay time sampled from a distribution based on the number of boarding and deboarding passengers will model the interaction effects of the common areas.

Required transfers will be identified by the use of a user specified probability of transfer of those trips on the vehicle that are not to destinate at the station being simulated. In the DSM baseline, transfers will be assigned to the end of the boarding queue (i.e., no priority).

The capacities of the three areas are user specified and will be used to evaluate the adequacy of various station configurations. A trip will not be allowed to enter the next area unless that area is below capacity; instead, it will queue in the area it is currently in and block the processing function of that area. When an area goes below capacity, trips that have been waiting to enter will then flow into that area.

### 2.1.3 Vehicle Selection

Vehicle selection relates to the process of associating a trip with a vehicle. In the DSM baseline, two forms of service will be provided regarding the use of vehicles: demand responsive and scheduled. These service modes are defined below, together with their vehicle selection rules.

#### 2.1.3.1 Demand Responsive Service

In this service mode, vehicles are not assigned to routes but, rather, follow the routes necessary to service the trips assigned to them. Since the DSM does not contain a dynamic representation of the remainder of the network, vehicles will not continually exist in the simulation. When a vehicle leaves the station model, its transaction will be reclaimed.

Trips are assigned to vehicles when a vehicle arrives at a station berth and is available for boarding. However, when a trip arrives at the boarding queue, a search will be made for a vehicle to ensure that, in fact, a given trip will be serviced. This search procedure differs from single party and multiparty service.

For single party service, the user will select a priority ordering on the following sources:

- At the berth currently unloading or upstream of it in the station
- An empty from local storage
- An empty from elsewhere in the network

These sources will be searched in the order specified by the user. In the event it is necessary to call for an empty vehicle from elsewhere in the network, a user specified delay time distribution table will be used to determine the arrival time of an empty vehicle at the station being modeled. At this time a vehicle transaction will be initialized to represent an empty vehicle arriving on the guideway upstream of the station.

In the multiparty case, the vehicle selected has the same possibilities as the single party case, except that in considering vehicles due to arrive shortly or currently unloading, a simulated check of the compatibility of destinations will be made using a probability of a compatible vehicle entered by the user.

#### 2.1.3.2 Scheduled Service

In scheduled service, vehicles are preassigned to various circuitous routes with defined station stops. One data item in the vehicle header record from the vehicle demand file will be the route of the vehicle. Trips are assigned to vehicles when the vehicle arrives at the station berth and is available for boarding. For a trip to be considered for assignment to a vehicle, the trip's destination must match one of the assigned stops of the route of the vehicle, if the user had specified a station list for each route. Otherwise, compatibility will be determined using a user specified probability. More than one trip may board the vehicle, subject to the vehicle capacity constraint. Each succeeding trip that will be serviced will be the first assignable trip that can be accommodated.

### 2.1.4 Station Management

Station Management relates to the management of vehicles (especially occupied vehicles) within the station. Empty Vehicle Management, which determines what is to be done with an empty vehicle, will be treated in Section 2.1.5.

The management of vehicles within the station is largely controlled by the configuration of the station. In order to achieve flexibility in being able to model various station configurations, the DSM will contain a general station configuration in which components can be parametrically excluded and/or varied in size. Alternative physical layouts are modeled by changing the parameters input to the general station conficutration. For example:

- Parametrically excluding the bypass link would convert it to an on-line station

- Parametrically excluding the travel delay between the deboarding process and the boarding process would convert it from a station with separate deboarding and boarding areas to one with common areas

- Parametrically varying the number of parallel lanes and number of serial berths per lane could be used to create a station with one lane of N serial berths, M lanes of one serial berth each, or a combination

- Parametrically excluding the Input Queueing Area, Output Queueing Area, Storage Area, or Modal Entry/Exit Areas could also be used to vary the configuration of the station

An overview diagram of this general station configuration is given in Figure 2. A more in-depth view depicting the component delays that a vehicle may encounter in the baseline station model is provided in the preliminary Vehicle Time Line diagram of Figure 3. Vehicle movement through the station will conform to assigned travel time, queue delays imposed by decision logic, dwell delays, and launch delays. The various areas of the station will have user specified capacities. When an area is at capacity, vehicles in upstream areas will experience queueing delays. When the occupancy of an area drops below capacity, vehicles waiting in upstream areas will be allowed to enter. When two vehicles are serially positioned with respect to each other, the upstream vehicle may experience a queueing delay waiting for the downstream vehicle to move; when the downstream vehicle moves, vehicles upstream of it that have been waiting may also move.

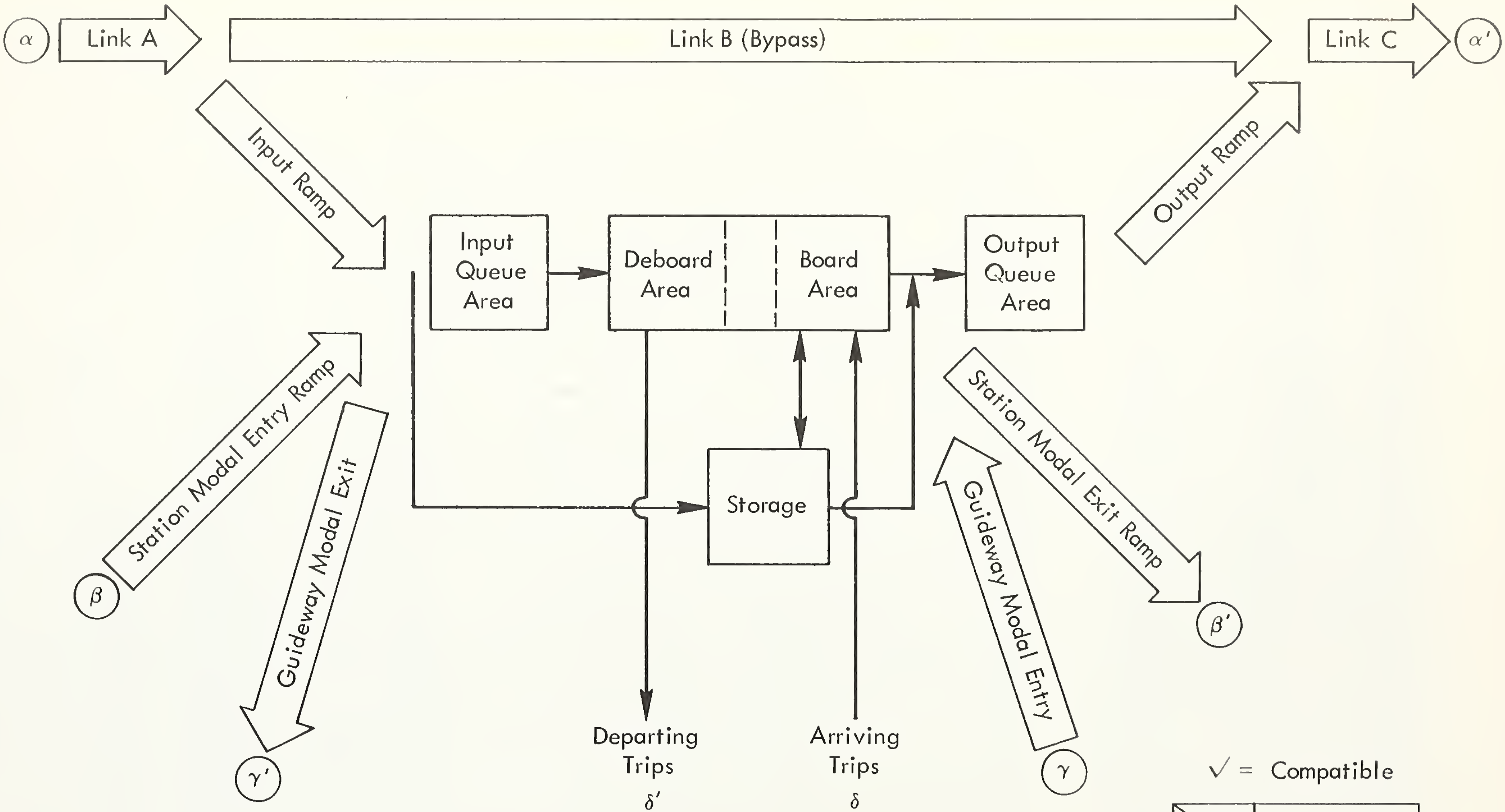
One of the more significant delays in the station is the launch delay. The factors influencing the launch delay are:

- Presence of another vehicle serially in front of the vehicle to be launched

- Schedule for the vehicle - In the case of Scheduled Service, the departure time of each vehicle on a given route will either be preassigned (fixed schedule) as a function of the vehicle's cycle or will be determined dynamically for each departing vehicle (i.e., select a departure time that is midway between the previous departure time on that route and the estimated arrival time of the next vehicle on that route). In both of these cases, if the desired launch time has passed, then the vehicle should be launched as soon as possible. In the case of demand responsive service, the vehicle should be launched as soon as possible.

- Coordinating merges in the rest of the network - Since this is a stand-alone station model, delay due to this type of factor will be modeled using a user specified delay time distribution table.

- Coordinating merge with the bypass link




√ = Compatible

| Out / In | α′ | β′ | γ′ | δ′ |
|---|---|---|---|---|
| α | √ | √ | √ | √ |
| β | √ | √ | | |
| γ | √ | | | |
| δ | √ | | | |

FIGURE 2 OVERVIEW OF STATION CONFIGURATION

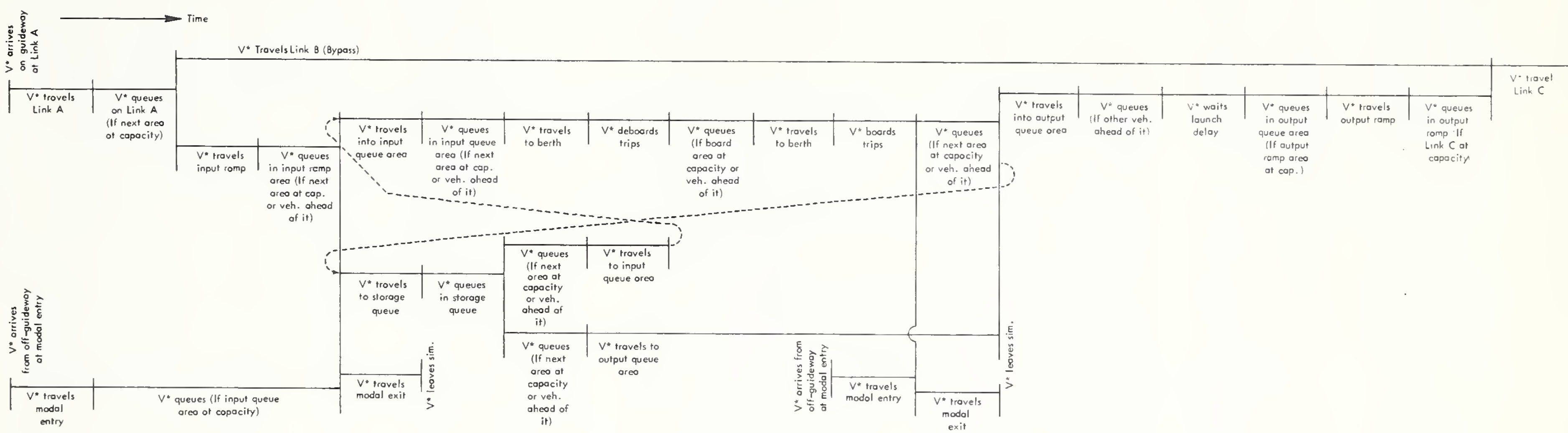



FIGURE 3 VEHICLE TIME LINE

For asynchronous, quasi-synchronous, and synchronous vehicle control, a delay will be calculated to represent the delay a vehicle would have to undergo to ensure it did not conflict with a vehicle from the bypass link at the station exit merge. This will be done by assuming a constant velocity and bypass link velocity (as specified by the user), together with the time vehicles arrived at the station entry (start of bypass link).

The preceding factors influencing launch delay will be coordinated as follows. In all cases the first factor will be observed, in that the launch delay will not be calculated until the vehicle is at the top of a serial queue and able to be launched. The other three factors will be additively included or excluded from the launch delay based on a user option.

With respect to modeling entrained vehicles in a schedule (i.e., fixed route) environment, there will be a capability to generate trains of vehicles in the demand generation process of the Input Processor. The number of vehicles per train will be specified for each route by the user (e.g., all trains on Route 1 have three vehicles, all trains on Route 2 have five vehicles, etc.). In the Event Processor, these trains will arrive on the link prior to the station, may enter the station, undergo station processing, and go out as trains. The "switchover" operation of, for example, changing all trains on a route from three vehicles to two vehicles will not be modeled for the scheduled environment.

For the demand responsive environment, when a vehicle enters the output queue area, the entering vehicle will be entrained to the vehicle serially ahead of it in the output queue lane if they have the same next stop. The launch time of a vehicle will be calculated only when the vehicle is at an output queue lane and, hence, available for launch. At launch time, if the head vehicle in a lane is entrained, then it and its followers will get launched at once. Vehicles are considered to be detrained automatically at the boarding berth and will be retrained in an output queue lane later if the criteria discussed above are met. Further, the user will be allowed to specify the number of output queue lanes either equal to the number of boarding area lanes or equal to one.

### 2.1.5 Empty Vehicle Management

Under demand responsive service, vehicles that become empty will become the responsibility of Empty Vehicle Management. Note that for scheduled service, all vehicles remain committed to routes, so Empty Vehicle Management does not become involved in that case.

In the Detailed Station Model, there will be two places to put empty vehicles: in storage of the station being modeled or elsewhere in the network (corresponding to sending it to a nearby station to service a waiting trip, to a regional storage center, or to circulate on the guideway). The user will have the option of specifying either. If the user specifies that an empty vehicle is to be sent to storage, a user specified probability will be used to simulate those instances where a vehicle would normally be sent to local storage but is now to be sent out to service a waiting trip at a nearby station. If the vehicle is to be sent to local storage, then a test will be made to see if local storage is at capacity. If the vehicle is to service a waiting trip at a downstream station, or if local storage is at capacity, then the vehicle will be directed out of the station by calculating a launch time, etc., just as with occupied vehicles.

### 2.1.6 Failure and Recovery

Station failures will be represented as explicit commands to impede the transit operation. The failure command will contain:

- Failure initiation time
- Location (link, docking area, etc.)
- Failure recovery time
- First vehicle to enter/next vehicle to exit (links, lanes, docking area)
- Degrade/complete failure

In addition, the capability to fail passenger management equipment will be provided. As a result of a failure command initially affecting a particular vehicle, that vehicle will be considered halted. At recovery time, the recovery procedure will be implemented, restoring appropriate equipment to operational status and dequeueing will be initiated to start appropriate vehicles moving. A failure affecting passengers (not vehicles) will be similarly approached. A checkpoint file will be created for the failure.

## 2.2 Input Parameters

This section lists the model input and run time variables in terms of system, configuration, trip, and algorithm related inputs. All of the input parameters are included in the input and description file of the simulation data base. The model input processor operates on this data, performing reasonableness checks and computing event oriented data for the model processor. The processed data is placed in a structured data file of the data base to be used at run time by the model processor.

### 2.2.1 System Parameters

- Event timing variables
  - Clock scale factor
  - Spacing between successive clock table entries
  - Spacing between multiple thread transactions
- Statistics sampling interval
- Run stop time

### 2.2.2 Configuration Parameters

- Link lengths
- Link connectivity
- Number of entrance queues
- Capacity of entrance queues
- Number of vehicle berthing lanes
- Number of vehicle berths per lane

- Number of exit queues
- Capacity of exit queues
- Capacity of empty vehicle storage
- Vehicle speed on links
- Vehicle speed in station
- Vehicle acceleration/deceleration/jerk
- Passenger boarding/deboarding time delay distributions
- Passenger transfer time
- Vehicle retrieval from storage time
- Launch delay distributions
- Modal interchange time
- Vehicle capacity
- Vehicle length
- Vehicle headway on guideway
- Vehicle headway in station
- Time distribution for passenger ticketing
- Time distribution for boarding area access
- Capacity of ticketing queue
- Capacity of boarding area access queue

### 2.2.3 Trip Parameters

- Vehicle arrivals
  - Time
  - Number of passengers to deboard
  - Number of passengers transferring and destinations
  - Number of passengers continuing and destinations

- Pedestrian arrivals
  - Time
  - Group size
  - Destination

- Modal interchange arrivals
  - Time
  - Number of passengers transferring and destinations
  - Number of passengers continuing and destinations

### 2.2.4 Algorithm Parameters

- Multiparty policy selection
- Berthing policy selection
- Launch policy selection
- Empty vehicle policy selection

## 2.3 Outputs

This section lists the station performance and operational characteristics data to be computed and output by the DSM. The data will be written to the data base raw statistics file periodically during each simulation exercise as defined by the sampling interval input parameter. The model output processor will subsequently access this file, retrieving parameters specified by the user, and prepare tabulations, statistical summaries, histograms, and/or plots (output format will also be selected by the user). In addition, the model output processor will compute a set of summary parameters based on the raw statistics file data and save the results in a performance summary file of the data base.

All output will be directed to a line-oriented alphanumeric device (e.g. a high-speed printer or alphanumeric terminal) in the default case. In addition, an optional capability will generate time-series plots and/or class-interval frequency distributions for display on an online vector graphics CRT or a time-sharing terminal printer with vector plotting capability.

The following parameters will be sampled at specified intervals and output to the raw statistics file. Maximum, minimum, average, and variance for each parameter will be recorded, except as noted. Both vehicle and passenger statistics will be recorded for total time in station.

- Entrance queue size
- Entrance queue dwell time
- Number of vehicles at berths
- Berth dwell time
- Berth wait time (dwell time - time required for deboard/board)
- Launch queue size
- Launch queue dwell time
- Vehicle storage occupancy
- Number of vehicles entering station (total only)
- Number of vehicles bypassing station (total only)
- Number of vehicles leaving station (total only)
- Number of entry rejections (total only)
- Number of vehicles entering storage (total only)
- Number of vehicles leaving storage (total only)
- Station dwell time per vehicle
- Modal interchange entry queue size
- Modal interchange entry queue dwell time
- Number of vehicles entering from modal interchange (total only)
- Number of vehicles leaving through modal interchange (total only)
- Number of arriving trips (total only)
- Number of arriving transfers (total only)
- Total trip demand (trips plus transfers) (total only)
- Total trips served (total only)
- Ticketing queue size
- Ticketing queue dwell time

- Boarding area access queue size
- Boarding area access dwell time
- Outbound passengers served per vehicle
- Inbound passengers served per vehicle
- Through passengers served per vehicle
- Through modal interchange (to guideway) passengers served per vehicle
- Through modal interchange (to off-guideway) passengers served per vehicle
- Number of empty vehicles requested (total only)
- Number of empty vehicles received (total only)
- Boarding area queue size
- Boarding area dwell time
- Total passenger dwell time in station
- Number of trips and passengers exiting the modeled area
- Integral of trip-time and passenger-time elapsed in modeled area for those trips leaving the modeled area

As an additional option, disaggregate trip and vehicle records will be output to a separate file. This file could then be used as a basis for post-run analyses and recreation of station events, without rerunning the DSM.

Each vehicle record will consist of the following data fields:

ID
Time of origination
Source (on guideway, off guideway, storage)
Sink (on guideway, off guideway, storage)
Time for each event

Trip records will be generated for all originating trips, all destinating trips, and all transfer trips. The trip records will include the fields identified below:

<u>Originating trips</u>

Origin time
Times for each event
Vehicle ID boarded
Number of passengers

<u>Destinating trips</u>

Time trip begins to deboard
Time for each deboarding event
Vehicle ID trip deboarded from
Number of passengers

Transfer trips

Destinating trip data
Originating trip data
Time trip joins boarding queue
Number of passengers

## 2.4 Equipment

This section describes the hardware and software requirements necessary to support the DSM. The estimates provided do not represent constraints on the model development process and only provide broad guidelines for planning purposes. The estimates given below assume a model configuration as previously defined with the capability of supporting 1,000 concurrent trips and a fleet size of 200 vehicles.

### 2.4.1 Hardware

The following computing system hardware is required as a minimum to support the DSM:

- Central Processing Unit — Must be compatible with an IBM System 370 and have at least the capabilities of a Model 145.

- High Speed Core Storage — Approximately 195K bytes of problem program core is required which includes 75K bytes for the program logic and 120K bytes for data and variables. This estimate does not include System Control Program core requirements, which can vary between 300K bytes and 2 million bytes.

- Direct-Access Storage — Storage requirements for various functional areas of the DSM are given below, in units of IBM 2314 Direct Access Storage Facility cylinders (approximately 144,000 bytes per cylinder).

| | |
|---|---|
| — Program Development Libraries | 20 cylinders |
| — Input from Data Base | 2 cylinders |
| — Structured Data File | 3 cylinders |
| — Checkpoint Files | 10 cylinders per checkpoint |
| — Raw Statistical Output | 10 cylinders per run |

- Magnetic Tape — The DSM has no explicit requirement for magnetic tape storage, but it may be a preferable medium over direct-access storage for the following files:

| | |
|---|---|
| — Input from Data Base | 2 cylinders |
| — Checkpoint Files | 10 cylinders per checkpoint |
| — Raw Statistical Output | 10 cylinders per run |

The choice of tape over disk will be based primarily on the amount of disk space available, the frequency of access required, and the operational procedures at the computing center being used. For planning purposes, a 2,400-foot reel of tape recorded at 1600 bytes/inch has a capacity equivalent to 320 cylinders of 2314 disk space.

- Unit Record Equipment -- The DSM will require a card reader for input data and a high-speed printer for output. Low volume input and output can be accomplished through a terminal keyboard/printer.

- Graphics CRT terminal - The DSM will require a CRT with vector plotting capability for output.

### 2.4.2 Software

The DSM will place certain requirements on the system support software in the areas of system control program, compilers, linkage editor, and utilities.

- System Control Program — Use of one of the following will be assumed:
  - OS/360 (Operating System)
  - VS1 (Virtual Storage 1)
  - VS2 (Virtual Storage 2)
  - VM370 and CMS (Virtual Machine and Conservation Monitor System)

  For terminal-oriented operation, the use of the Time Sharing Option (TSO) or VM/370 will be assumed.

- Compilers — The following compilers will be assumed:
  - FORTRAN IV (H Extended)
  - Assembler (H)
  - PL/1 Optimizer

  The majority of the code will be written in FORTRAN IV (H Extended), with other languages being used in minor support functions.

- Linkage Editor — Any linkage editor compatible with the selected system control program and the compilers listed above will be sufficient.

- Utilities — The availability of the standard Operating System 360/370 to perform bulk card-to-disk, tape-to-tape, data set backup/restore, and data base update will be assumed.

## 2.5 Model Interfaces

Interfaces between the DSM and other models are identified as either data interrelationships or development interactions. Data interfaces between models are facilitated by the centralized data base and the input and output processors associated with each model. There is no data passed directly from one model to another. Instead, output processors move data into a centralized data base for subsequent manipulation by analysts and retrieval by input processors of other models.

For example, the following is a list of some of the data that would be used by the DSM and developed on the basis of DESM runs:

- Launch delay time distribution
- Vehicle arrival rates
- Delay time distribution for getting an empty vehicle
- Probability of a compatible vehicle for demand responsive multiparty service
- Probability of an empty vehicle being needed at a downstream station to service a trip
- Vehicle demand file for a selected station

An example of data derived from the DSM which could be used by the DESM is the average passenger access time (from arrival to joining the trip queue).

Development interactions exist where development and analysis of the DSM help identify event representations for the DESM or system level analysis help to quantify some of the items listed above.

## 2.6 User Interface

The general structure of the DSM as shown in Figure 4 will facilitate user interface by providing flexible input and output procedures. This general structure is common to all of the coarse and detailed models.

Input and description files will be created and saved in the data base through system utilities and terminal supports. The user then interacts with the Input Processor to edit data from the data base and process run time input requirements.

The Event Processor is driven by data tables set up by the Input Processor and generates raw statistics files for use by the Output Processor. In addition, the Event Processor generates checkpoint/restart files. The structure of the Event Processor is detailed in the following Section 3.0, Modeling Technique.

Specific outputs to be presented are determined by user interaction with the Output Processor through system utilities and terminal support. The output reports may be printed at an on line terminal or on a high-speed line printer or may be displayed at an online graphics CRT.

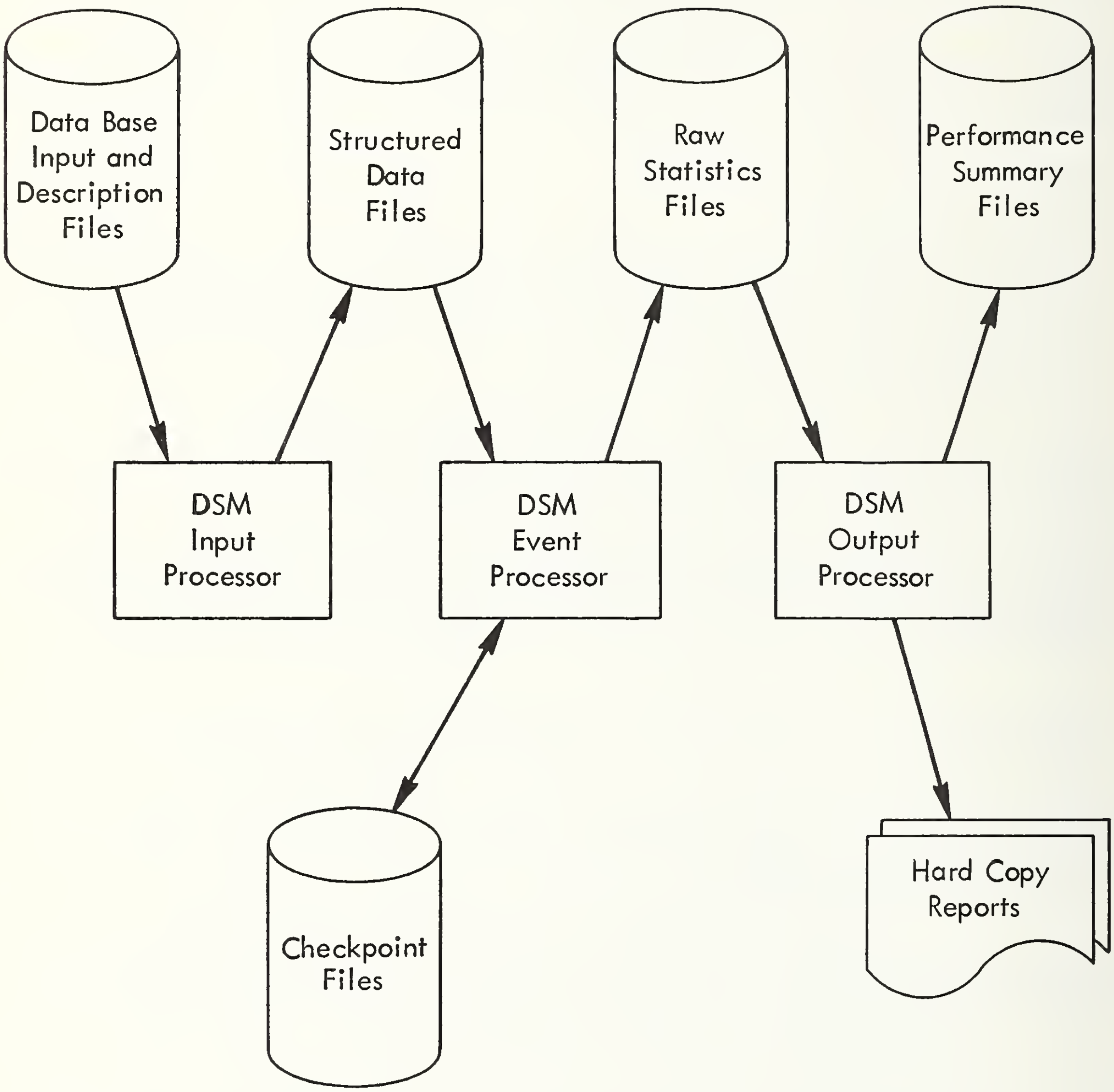



FIGURE 4 DSM GENERAL STRUCTURE

## 3.0 MODELING TECHNIQUE

The Event Processor will conform to a hierarchical structure as represented in the overview in Figure 5. This structure facilitates the flexibility needed to analyze the effect on station performance of substitution of different subsystem configurations and algorithm versions.

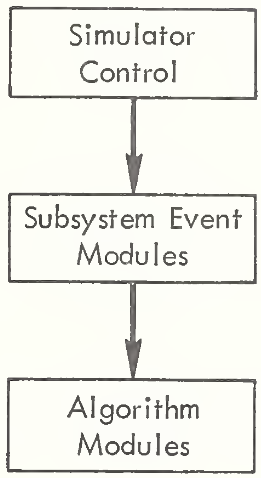



FIGURE 5 OVERVIEW OF EVENT PROCESSOR

The Simulator Control is formed by a Main Module and a set of Transaction Management Modules. The Main Module drives the Event Modules, while the Transaction Management Modules are used by the Subsystem Event Modules to perform bookkeeping functions such as event scheduling on a Future Event List and available transaction queueing in order to control the chronological flow of the DSM.

The Subsystem Event Modules model the physical and performance characteristics of the hardware. They request decisions from the Algorithm Modules and, in turn, are driven by command data supplied by the Algorithm Modules. They update Status Data for the components, trips, and vehicles as scheduled events occur that model physical changes in the hardware.

The Algorithm Modules model decisions made by the operational software as requested by the Subsystem Event Modules and based on current Status Data. They return Command Data to the Subsystem Event Modules.

Status Data for Components, trips, and vehicles are set up by the Subsystem Event Modules for use by the Algorithm Modules to make decisions. Status Data is updated by the Subsystem Event Modules to reflect the changing physical states of the hardware.

Command Data is set up by the Algorithm Modules to direct the future actions of the Subsystem Event Modules.

## 4.0 HIPO DIAGRAMS

Figure 6 represents a visual table of contents, and Figures 7 through 17 are HIPO diagrams constituting the initial design package for the DSM.

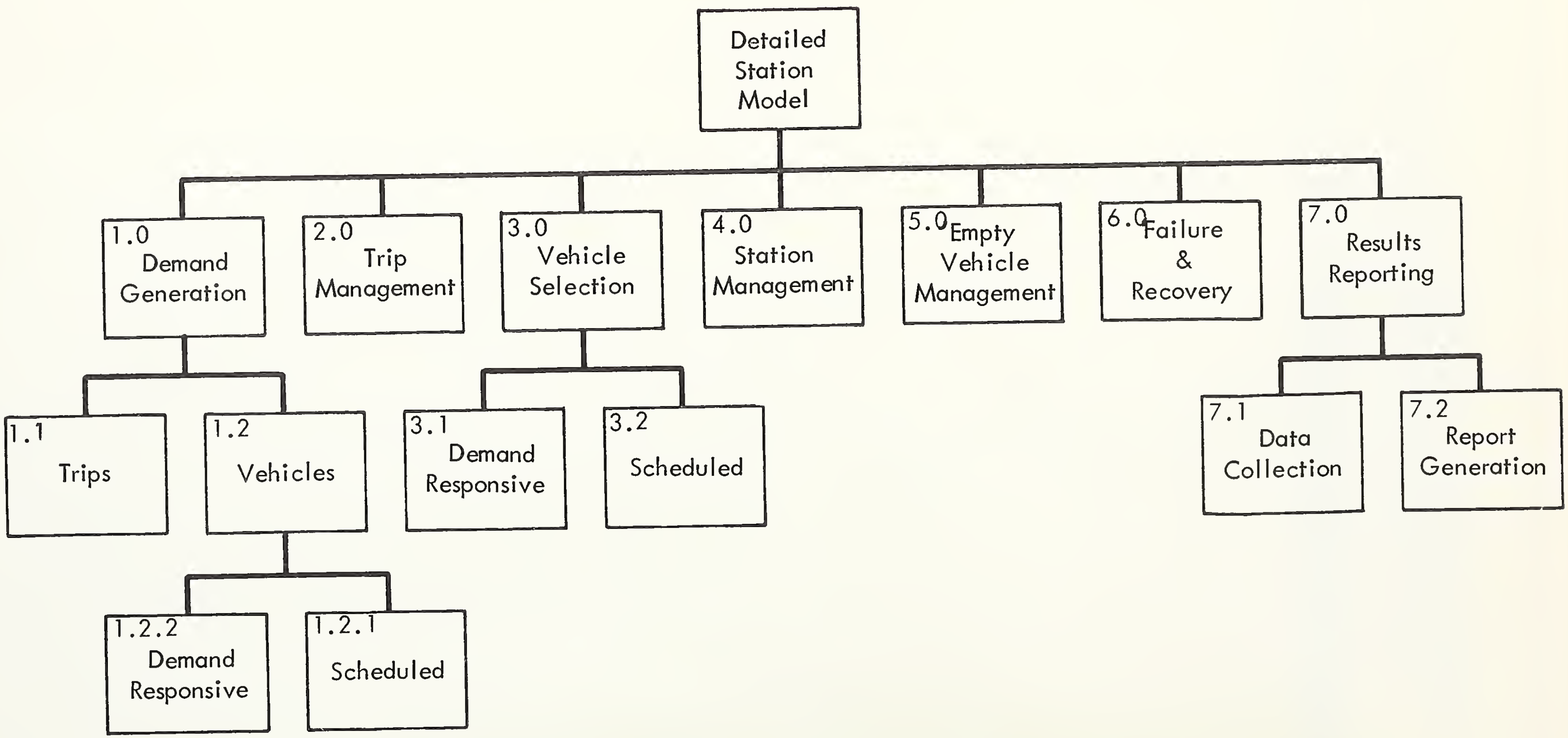



FIGURE 6 HIPO VISUAL TABLE OF CONTENTS

## 1.1 Trip Demand Generation

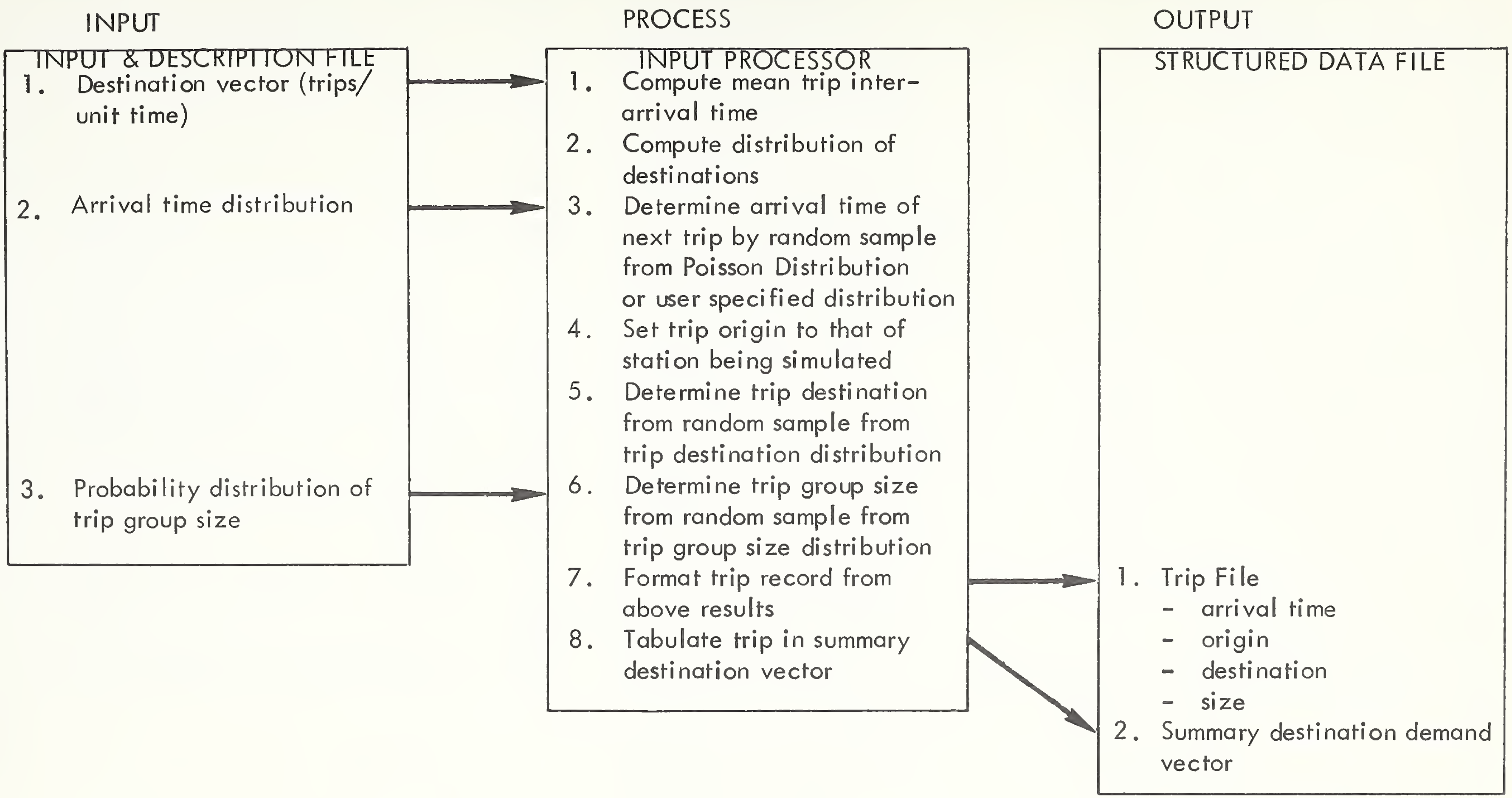



FIGURE 7 TRIP DEMAND GENERATION

### 1.2.1 Vehicle Demand Generation-Scheduled Service

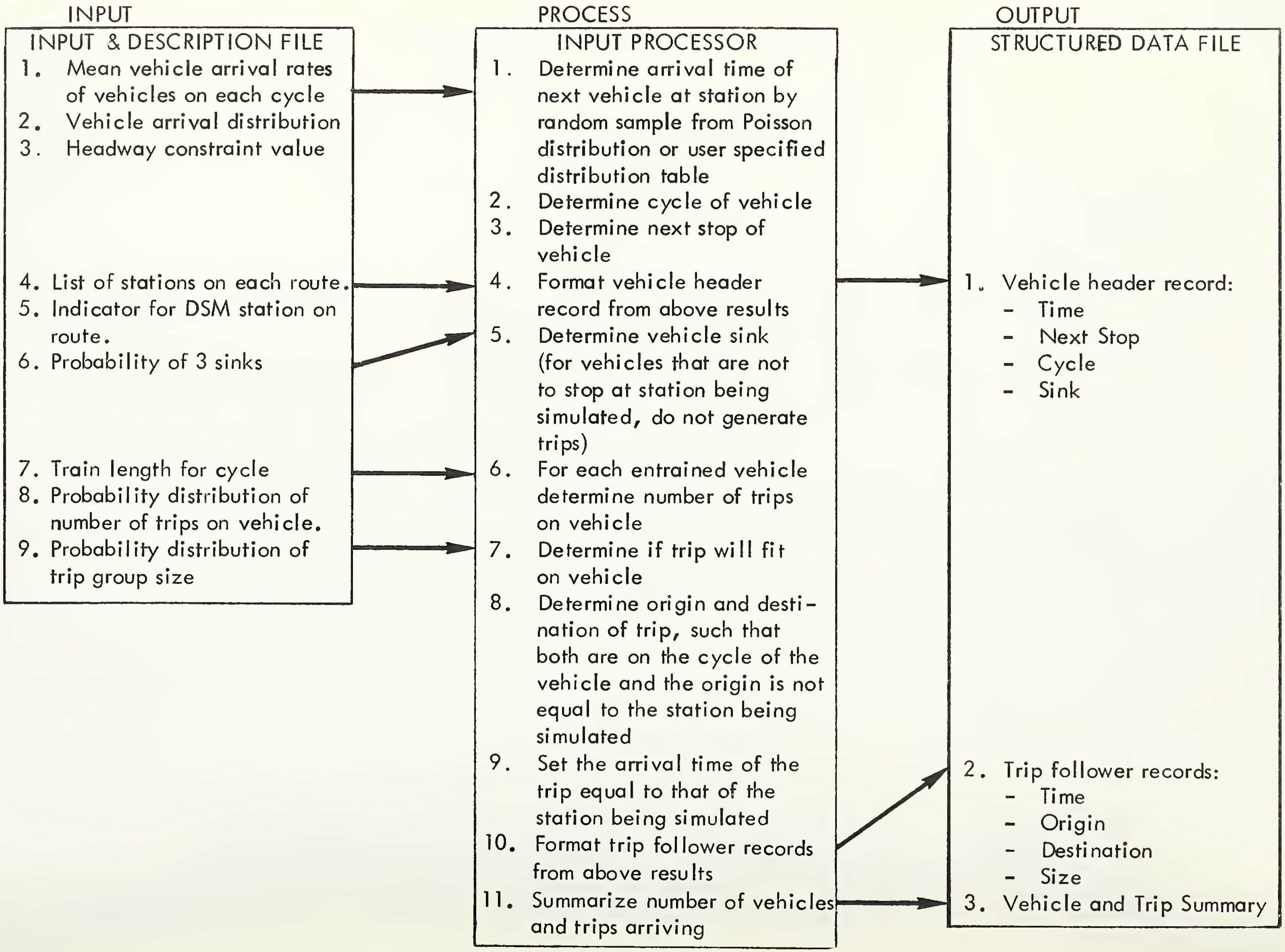



FIGURE 8 VEHICLE DEMAND GENERATION-SCHEDULED SERVICE

### 1.2.2 Vehicle Demand Generation - Demand Responsive Service

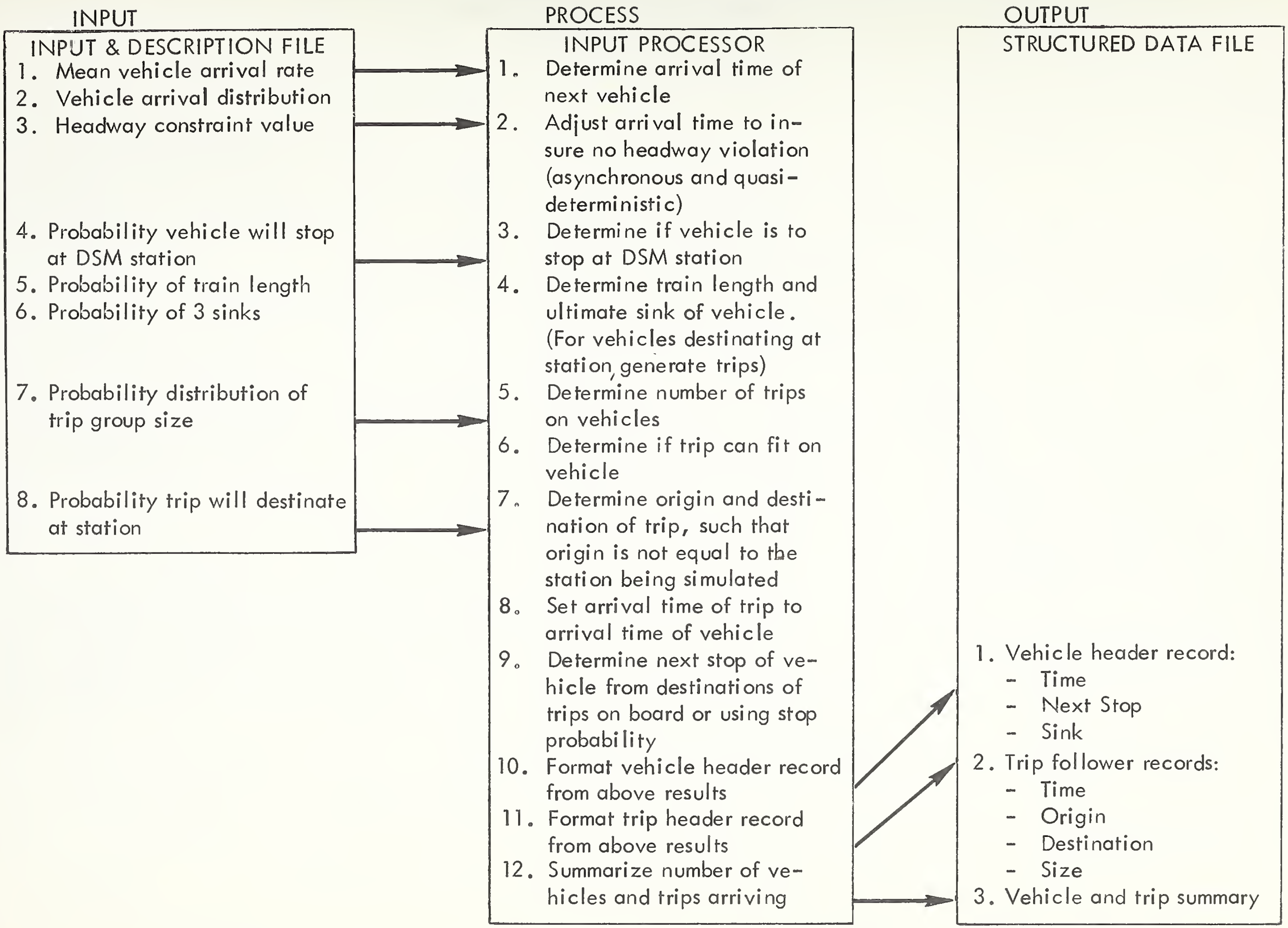



FIGURE 9 VEHICLE DEMAND GENERATION - DEMAND RESPONSIVE SERVICE

2.0 Trip Management

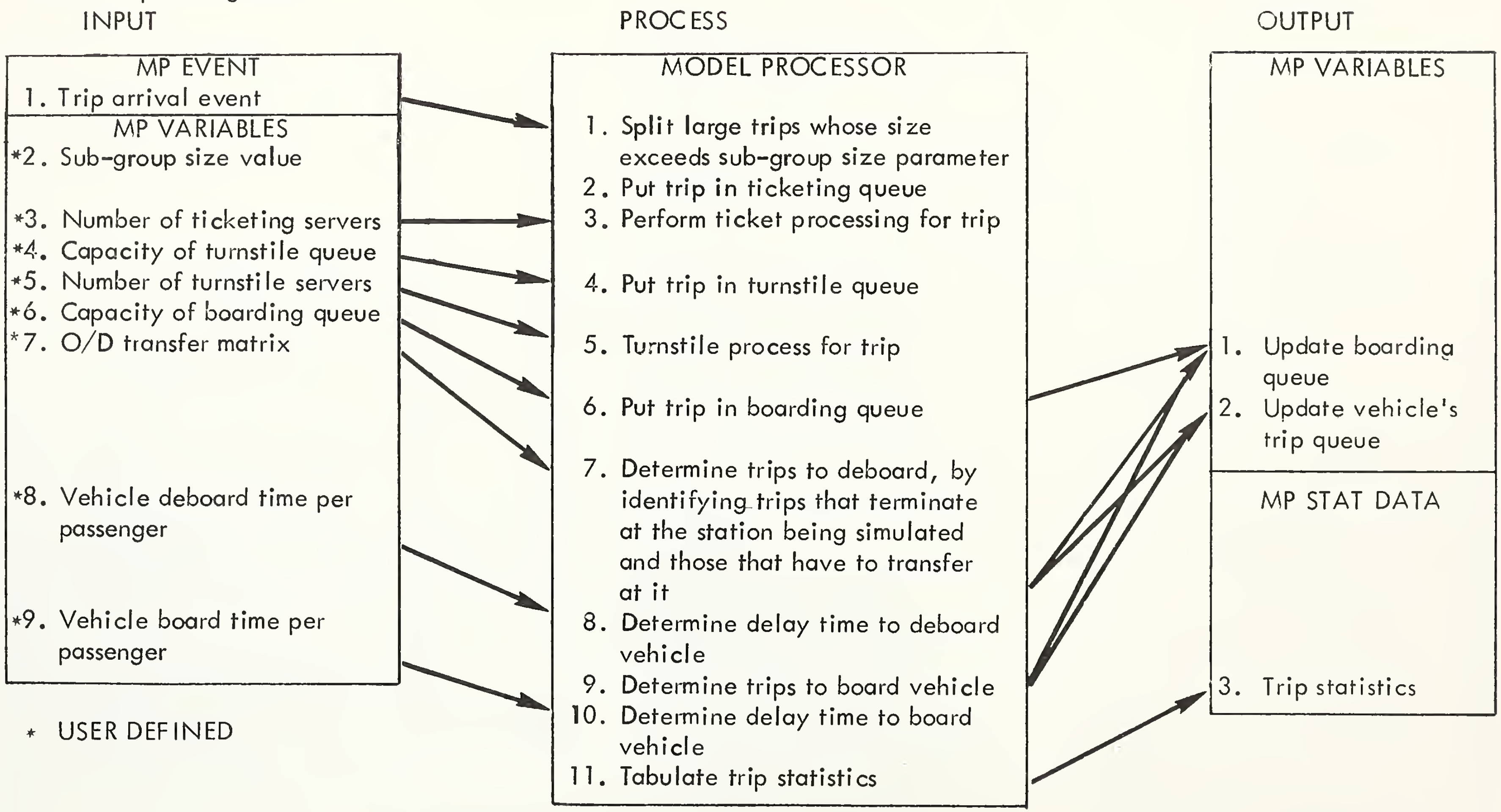



FIGURE 10 TRIP MANAGEMENT

### 3.1 Vehicle Selection - Demand Responsive Service

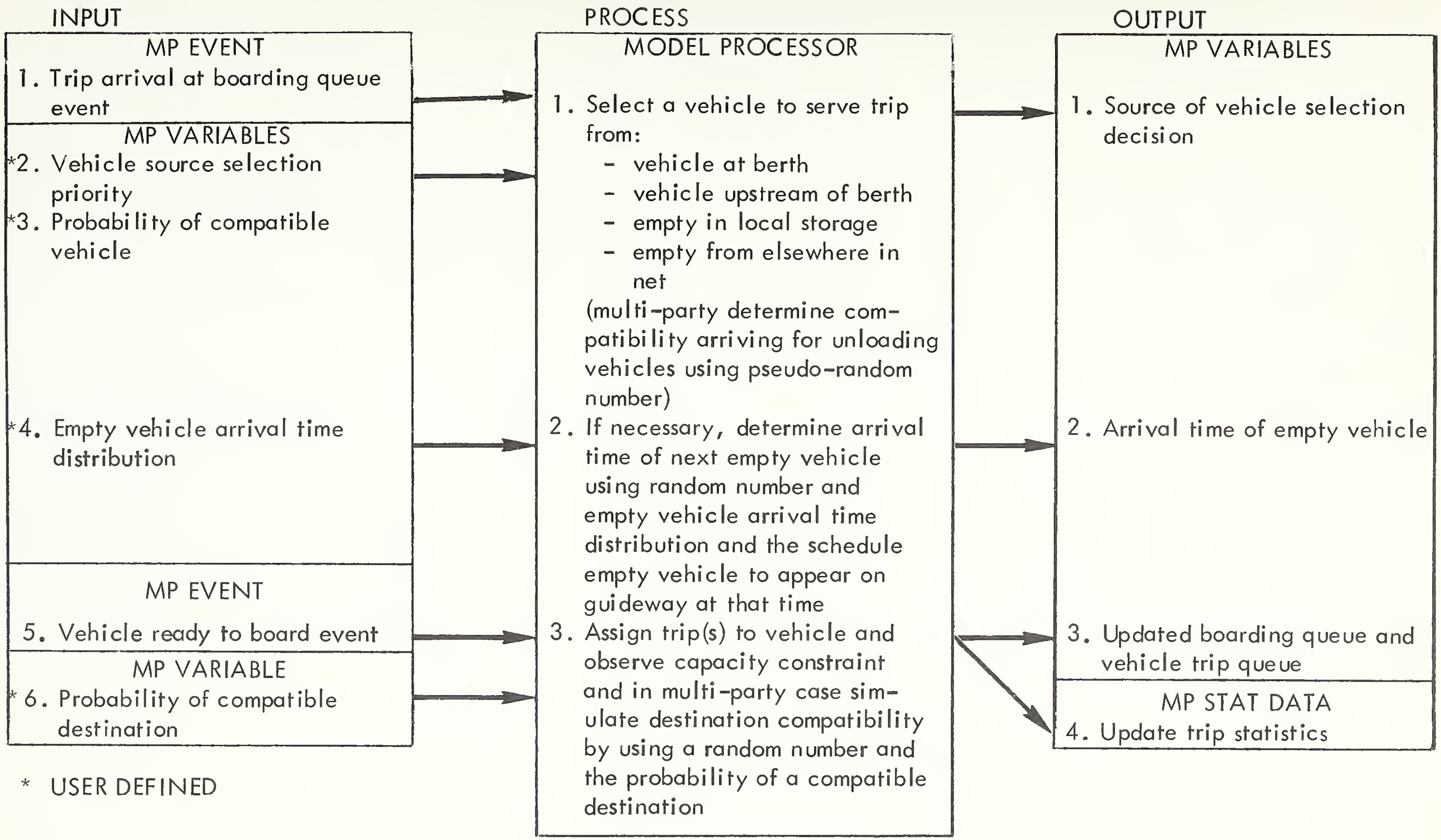



FIGURE 11 VEHICLE SELECTION—DEMAND RESPONSIVE SERVICE

## 3.2 Vehicle Selection - Scheduled Service

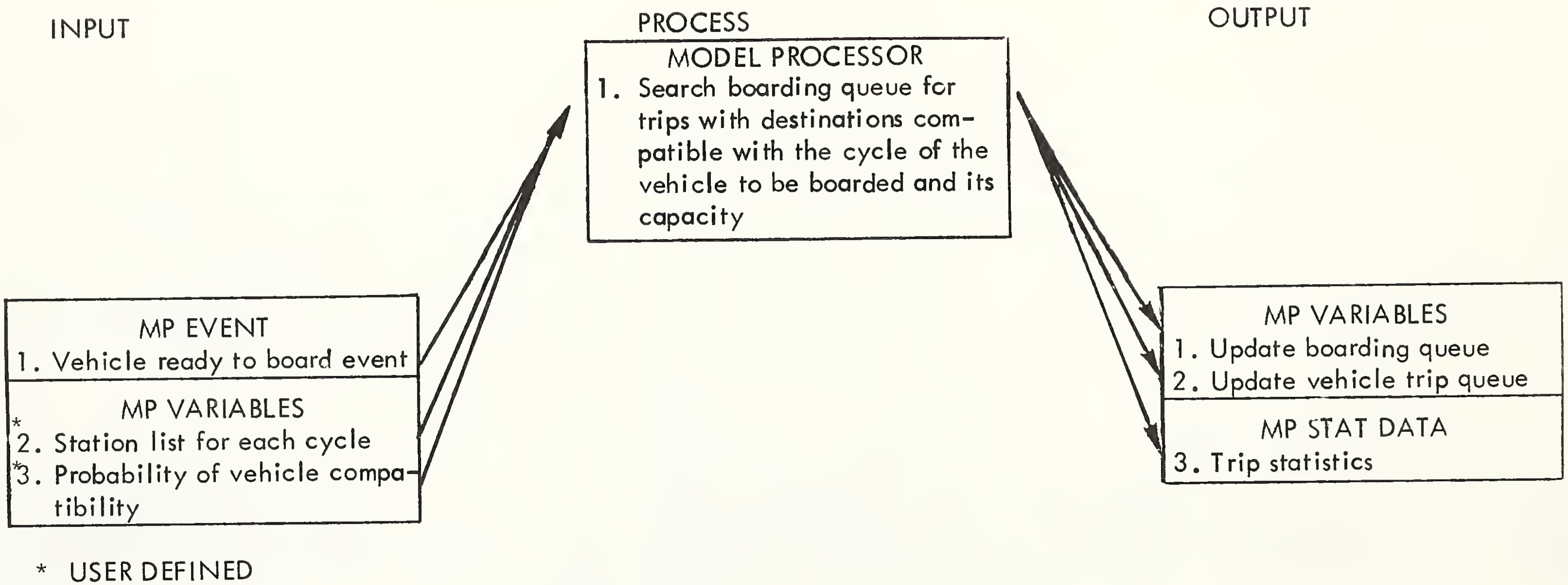



FIGURE 12 VEHICLE SELECTION—SCHEDULED SERVICE

4.0 Station Management

| INPUT | PROCESS | OUTPUT |
|---|---|---|
| **INPUT & DESCRIPTION FILE** | **INPUT PROCESSOR** | **MP VARIABLES** |
| 1. Configuration options | 1. Configure station based on user's options by excluding portions of general station model | 1. Station status |
| **MP VARIABLES** | **MODEL PROCESSOR** | |
| *2. Area capacities | 2. Model vehicle motion and queuing within station | 2. Vehicle status |
| *3. Vehicle motion characteristics | 3. Detrain vehicle arriving at dock (non-scheduled) | |
| *4. Schedule data<br>*5. Launch delay distribution table<br>6. Bypass link traffic<br>*7. Launch calculation option | 4. Calculate launch delay considering for vehicles not taking modal exit<br>- presence of other vehicles serially in front of the vehicle to be launched<br>- schedule for the vehicle, if any<br>- coordinating merges in the rest of the network - simulated using a launch delay distribution table and random numbers<br>- coordinating merge with bypass<br>- reserved based on vehicles entering the bypass link | 3. Launch Delay |
| 8. Launch delay<br>9. Next stop<br>*10. Entrainment option | 5. Entrain in output queueing area | 4. Vehicle status |

* USER DEFINED

FIGURE 13 STATION MANAGEMENT

5.0 Empty Vehicle Management

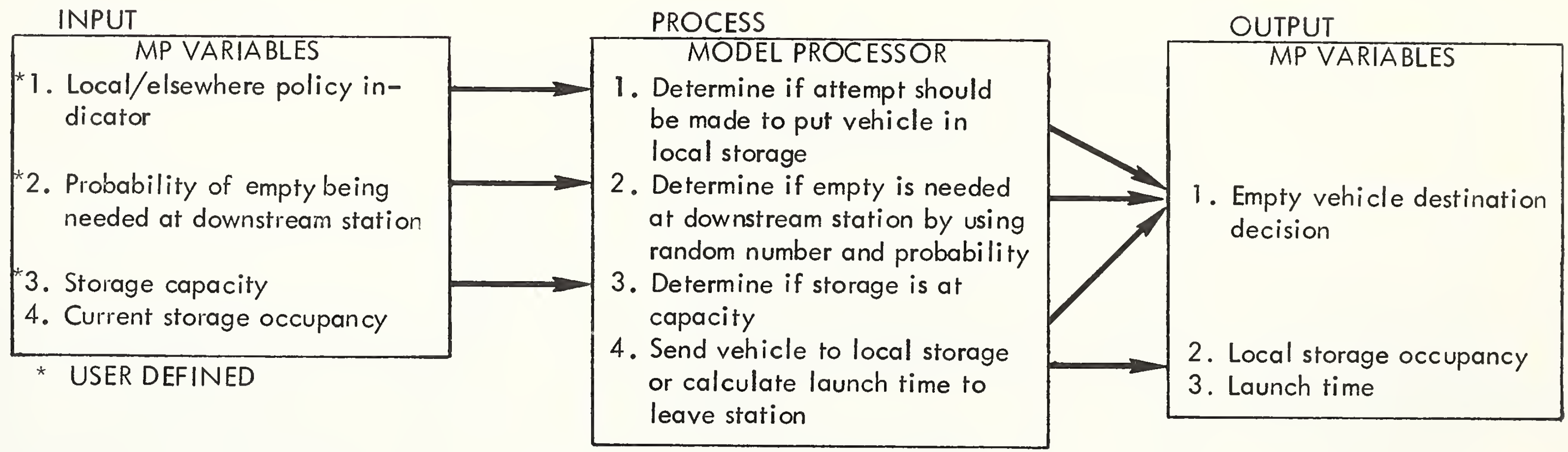
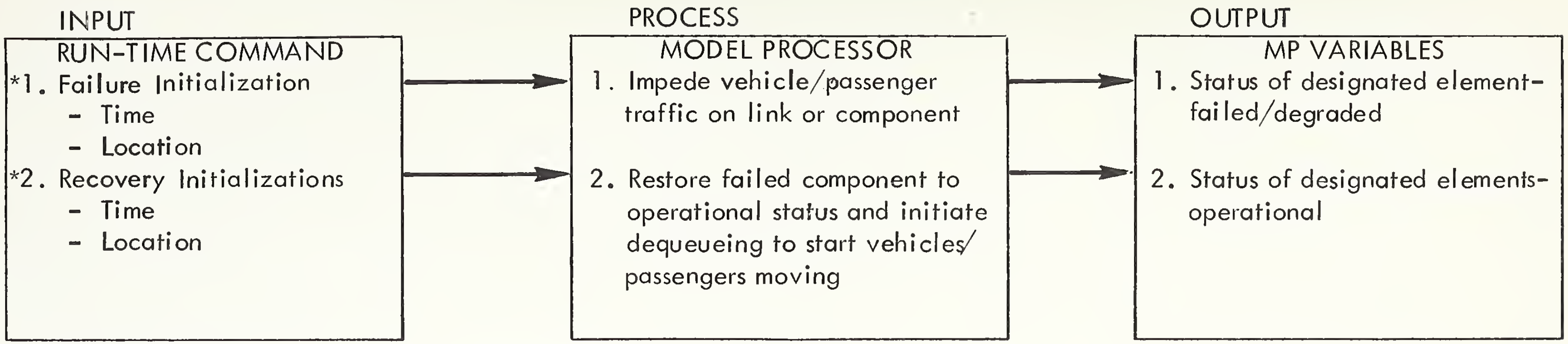



FIGURE 14 EMPTY VEHICLE MANAGEMENT

## 6.0 Failure and Recovery




* USER DEFINED

FIGURE 15 FAILURE AND RECOVERY

## 7.1 Results Reporting - Data Collection

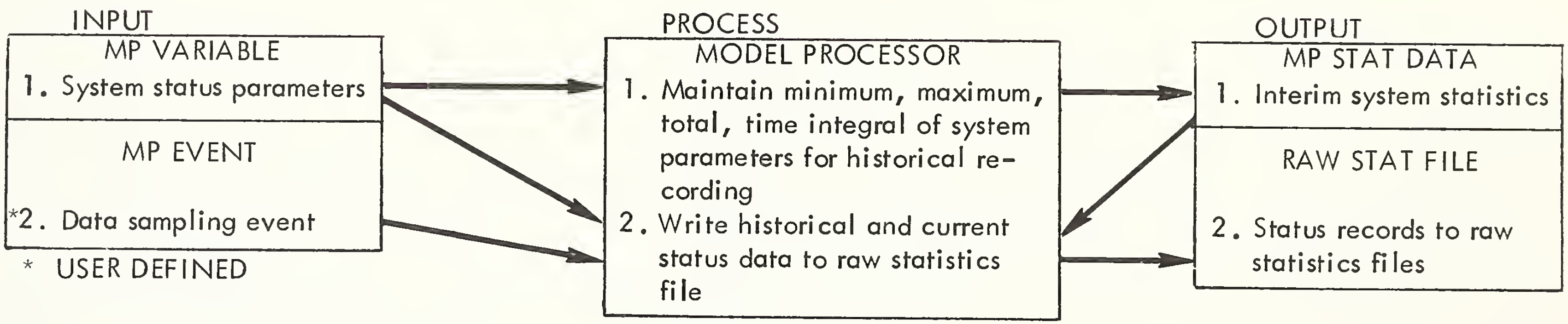



FIGURE 16 RESULTS REPORTING—DATA COLLECTION

## 7.2 Results Reporting - Report Generation

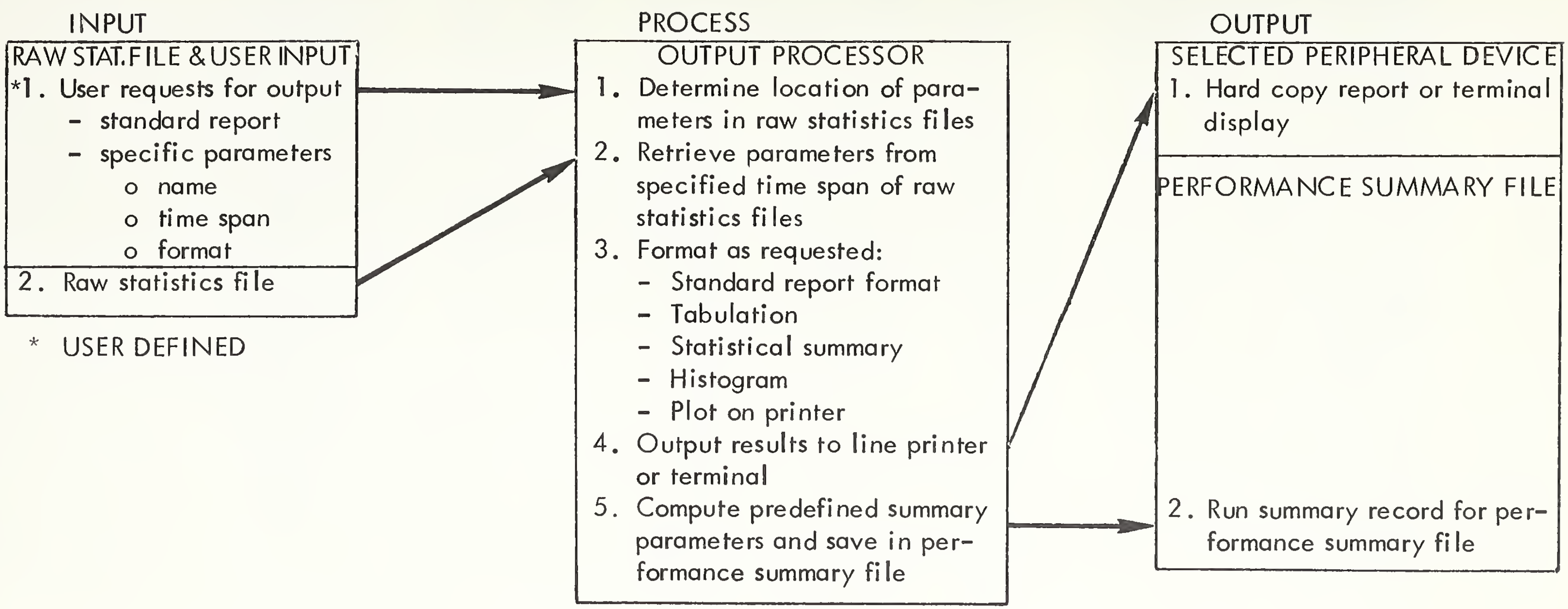



FIGURE 17 RESULTS REPORTING—REPORT GENERATION

# 5.0 VERIFICATION

Program verification is concerned with determining that the performance of the simulation models meets the requirements defined in the functional and design specifications. The verification process will start in conjunction with the integration of the individual program modules and continue through the demonstration of the completed simulation system.

Program integration and testing will be an extension of the top down software development approach. The first software element to be exercised and verified is the highest level system control logic. Then, successively lower levels of program modules will be added and exercised in the environment of the verified higher level routines. This procedure will verify the vertical communication between the levels of program modules in the simulation system.

Once the complete simulation model has been integrated, verification will continue at two levels: the module level and the system level. The verification of input preprocessor, simulation processor modules, and output postprocessor will be performed separately.

The input preprocessor will be verified manually by inspecting the data produced in response to prepared input data sets. The output postprocessor's data gathering, statistics generation, and results summarization functions will be verified manually or by using simplified stand-alone computer programs.

Module level testing of processor routines will be supported by simulation facilities which permit the tracing of an individual element (e.g., a vehicle) through the model and printing key parameters each time processing is performed on the element. Manual analysis of the trace results will establish the validity of the lowest level program modules.

System level testing will then be performed to verify that the low level functions interact properly. Test exercises will be defined, for which the results are relatively easy to predict. Such cases occur at the extremes or boundaries of the range of realistic operational conditions. A final check is made through the definition of nominal test cases which will require significant effort to predict the expected results.

A test plan will be developed which will define the procedures for complete verification of the simulation model. Separate tests will be identified for the various operational modes of the model. The plan will identify the methodology, hierarchy (sequence of testing and test interdependence), required input conditions, evaluation procedures, and expected results.

# 6.0 VALIDATION

DSM validation will be controlled by a procedure designed to demonstrate that the verified model provides a valid representation of the real world entity or state of affairs it is modeling. The validation process will provide assurance to transportation planners that the conclusions reached and data generated by these studies are realistic and can be used with reasonable conficence. In addition, one of the overall goals for validation is that test cases be sought such that at least one case exercises each model feature, and that the number of such test cases be the economical minimum that will serve this purpose.

DSM validation will comprise three steps:

1. Establishing specific criteria for the validation within the framework of the overall validation goals. What is to be an acceptable degree of correspondence between the model results and the exogenous information being compared will be specified in the validation procedure.

2. Performing the validation by one or more of the following methods.

   - Compare the model's prediction of performance to actual measured performance for an existing system under a set of well-defined test conditions

   - Compare the model's prediction of performance of the system to the results of a previously validated model

   - Compare the model prediction to an estimate of system performance derived by an independent analytical process.

3. And, reporting on how well the validation exercise met the validation goals. For example, should presently unavailable data be needed to more fully validate a certain model feature, then that needed data will be identified. Also, the degree of correspondence between predicted and actual information obtained will be interpreted for acceptability.

To the extent possible, empirical data will be the prime source of DSM validation data. However, as in the other coarse and detailed models, a multi-stage process of validation will evolve by drawing data from each of the three sources. For example, analytic data derived from queueing theory will be used to validate queues modeled in DSM.

## APPENDIX

## REPORT OF NEW TECHNOLOGY

The Detailed Station Model (DSM) provides for the first time in one program a wide range of operational and performance measures of alternative station configurations and management policies with respect to vehicle and passenger handling capabilities. This model is integrated into the unique set of System Operations Studies models developed under this contract DOT-TSC-1220; it accepts as input a stream of vehicle arrivals at a specified station computed by the Discrete Event Simulation Model. Individual passenger detailed flow is eschewed in favor of passenger transit times at queues.

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