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AUTOMATED GUIDEWAY GROUND TRANSPORTATION NETWORK SIMULATION

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FINAL REPORT

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16. Abstract

This report discusses some automated guideway management problems relating to ground transportation systems and provides an outline of the types of models and algorithms that could be used to develop simulation tools for evaluating system performance. The system management problems related to the routing and scheduling of both passengers and vehicles, as well as to control strategies such as synchronous and quasi-synchronous. The simulation outline provides background material for model descriptive, functional requirements, and simulation structure that can be used in future development activities.

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PREFACE

The Urban Mass Transportation Administration (UMTA) has undertaken the task of developing new technologies for public transportation. The current dominant means of public transportation are the transit bus and rapid rail systems. The development of computer and automation technology, particularly in the last decade, has led to the formulation of new public transportation concepts such as Personal Rapid Transit (PRT) and Group Rapid Transit (GRT).

In order to explore these potential developments, a new program has been established called the Automated Guideway Transit Technology (AGTT) program. The AGTT program has been directed towards the development of the critical technologies which will provide the foundation for the successful deployment of automated exclusive guideway urban transportation systems.

The objectives of the AGTT program are to: (a) determine what is technologically feasible and to explore the advantages and disadvantages of alternatives; (b) resolve technological controversies; (c) through sponsorship of research and dissemination of technological data develop an AGTT network simulation capability and explore performance of a variety of breadboard and test solutions to critical technology problems; and (d) develop a national knowledge base for use by system designers and developers, local planners and government officials, and to assist them in selecting and evaluating new automated guideway technologies for a variety of applications (thereby reducing the technical and financial risk involved in the development of AGTT systems.)

The work presented in this report was conducted in support of the AGTT program and relates to the development of a network simulation capability.

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1. INTRODUCTION

The Automated Guideway Transit Technology (AGTT) development program addresses the critical technologies of all automated guideway systems at three levels: a) the systems level; b) subsystem and component level; c) the wayside subsystem level.

At the systems level, two main thrusts are identified as system simulations and operational analyses; and development of guideline standards.

The determination of system level operational performance and the determination of design guidelines and requirements will provide the technical and cost data and the analytical tools (such as computer simulations) to evaluate the expected technical performance characteristics and to identify and project the various cost elements of a proposed automated ground transportation system. The development of efficient computer simulation tools will aid in the evaluation of vehicle operational service policies that may be proposed including any effects due to failures on the availability of passenger service.

Such simulation tools will assist in resolving the issues of vehicle control strategies, and will provide parametric outputs of system baseline parameters - such as, network topology, vehicle fleet size, vehicle headways, station sizing, etc. - to meet a specified range of input passenger service demands.

System level studies will be conducted and tests will be performed to develop and evaluate various methods of enhancing passenger security in automated systems and to ease the passenger/system interface. Also, studies will be conducted to determine design guidelines and requirements for the above classes of automated systems, with particular emphasis on user and non-user impacts, and passenger safety and comfort.

2. COMMAND AND CONTROL PROBLEMS

2.1 SYSTEM MANAGEMENT

"System management" can be defined as those activities within an AG system which coordinate the operation of system components, including passengers, employees, vehicles, guideways, stations, fares, informational displays, data registers, computers, etc.

System management deals with the solution of the general problems associated with the routing of occupied and empty vehicles, failure management, passenger management and other management functions associated with system operation.

The first operational step in system management is to determine the present state of the system. Relevant system state variables are the number of passengers in queue for each origin-destination trip: the location and duties of its occupants; the maintenance status of each vehicle (days and miles since last preventive maintenance); position and nature of defects in guideway, etc.

The second step is to compare the present state and to initiate control action. The desired state is that all passengers who have requested service are assigned to particular vehicles; the vehicles are enroute to the points of service; vehicles scheduled for preventive maintenance; and crews dispatched to repair the guideway, etc.

Implicit in the control action is the recognition of broad system goals. The tradeoff between increasing customer satisfaction and reducing system cost will dictate the number of passengers who must be accommodated, or the waiting time which must elapse before a vehicle is assigned to service a particular trip. This tradeoff is also involved in the decision as to whether the vehicle should service only passengers with the same origin and destination or whether it should make intermediate stops to serve passengers with other origins and destinations.

It is recognized that system goals and system management functions must be established early in the total development activity. For this reason, the proposed approach emphasizes early definition of performance measures and concepts which can be used to establish or evaluate them.

Vehicle control systems have been designed, developed and implemented for many years, starting with the train control systems of the past and moving up through the Morgantown PRT and Dallas/Ft Worth airport control systems. These systems involve various degrees of complexity; however, most of the equipment is state-of-the-art and the techniques and implementation procedures are fairly well known. When one looks at AG and close headway systems, the vehicle control requirements become much more stringent.

Most transit organizations today use vehicle management techniques in a manual mode of operation. This involves a high degree of manual decision making which is based on non-real-time decisions for control. When designing a real-time system for automated transportation systems one has to look at the functional requirements that one would need to meet the system's automation demands. The state-of-the-art in vehicle system management is at the level of manual-type control. Recent studies (implementation efforts in BART, WMATA, and the Dallas/Ft. Worth airport) are tending to advance the state-of-the-art in total vehicle management of network management. However, most of these systems are quite simple in terms of vehicle management techniques, and do not include many of the automated decisions required to provide the sophisticated network control for a deployed urban personal rapid transit system.

A true personal rapid transit system may be designed to cover a grid-type of network to provide a personal type service to the passenger. Automation in vehicle management in these systems plays an important role in performing the necessary tasks to carry out the service objectives.

Factors which must be considered in system management design are safety and reliability. The system must be designed to be fail-safe as well as fail-soft. Safety can be designed into the system using modular redundant hardware and software and/or fault tolerant computation. Most command and control approaches configured to date require some form of hierarchical, distributed system concept involving central, regional and local controllers. Demonstration of how one would configure such a system to meet the safety requirements at a reasonable cost has yet to be achieved.

One primary objective of the system management analysis is to develop methods for studying the movement of passengers and vehicles within a system. Vehicle management is intimately tied to the passenger service concept and should be studied in that context. It is clear that a wide variety of service concepts and vehicle management concepts can be invented and new models must be developed so optimum configurations can be developed. Vehicle movements can be either scheduled or demand-responsive, but the basic philosophy should be to maximize passenger service (e.g., minimize total trip time) while using vehicles in an efficient manner. The problem of developing vehicle scheduling algorithms for systems with intermediate stop service is a difficult problem and is to be addressed.

One approach to solving this problem could be directed at scheduled, intermediate stop service on fixed routes within a network. Here a performance index is defined which is directly related to trip time. To provide N station origin-destination service on a fixed route, it can be demonstrated that (N - 1) vehicle routes or paths are required. Which of the (N - 1) routes that should be eliminated may be determined by minimizing the performance index in an iterative manner.

The second approach could be directed at network configurations where the objective is to increase vehicle utilization by permitting one or more intermediate stops between a particular station origin-destination pair. This approach is applicable to either real-time, demand or scheduled type operation. A performance index is defined which is a linear component. The passenger component is a combination of waiting time and the time penalty due to stopping at an intermediate station. The vehicle utilization component is vehicle miles of travel saved by eliminating some origin-destination trips. The algorithm in simple terms may operate as follows. First, occupied vehicle and empty vehicle trips are determined based on origin-destination service. Then using an iterative process, candidate intermediate station stops are screened depending on the value of the performance index. Station stops are then selected eased on maximizing the vehicle miles of travel served at the least "cost" in terms of passenger service. This iterative process tends to increase vehicle occupancy systemwide.

Methods should also be devised for efficient vehicle management if some links are closed due to maintenance or vehicle failures. In scheduled operation, vehicles should be routed in such a manner as to satisfy passenger demands in a reasonable length of time without overlooking links or excessive dead heading. Schedules should be devised to minimize waiting due to transfer and methods for making changes in schedules based on current ridership patterns should be studied. In addition, vehicle management (and passenger management) in stations and switching between service modes should be considered.

2.2 VEHICLE CONTROL

In a demand responsive system, there are two functional aspects to the satisfaction of a passenger trip request. In a time acceptable to the passenger, the vehicle must be assigned to satisfy the request, and also in a time acceptable to the passenger, the motion of the vehicle throughout the transportation network must be scheduled and routed. Consider the integration of the scheduling with the system longitudinal control first.

Perhaps the biggest factor influencing the scheduling of vehicles as they move through the transportation network is the resolution of conflict which occurs between vehicles requiring the use of the same guideway resource simultaneously.

Many strategies have been suggested for resolving these conflicts; when vehicle or traffic management or control strategies are mentioned, this is normally what is meant.

If no central scheduling is done, so that vehicles in the traffic stream are not cleared for passage through potential conflict points before their arrival, the system is called asynchronous. There is no central scheduling in a traditional asynchronous system. In a system which functions in this manner, vehicles are launched from stations bearing passengers as soon as possible after the requests are made and the passengers are boarded. Once the vehicle is launched into the traffic stream, it proceeds under the guidance of the local controller until it reaches a point of potential conflict. At that point, the controller responsible for the intersection will determine on the basis of "first-come-first-served" which vehicle is allowed to pass through the conflict region. If the vehicle is not selected at its time of arrival, it must queue on the guideway and wait until it receives the clearance from the local controller. Many simulation strategies have been investigated in an effort to reduce conflicts arising from situations of this type. The results have been generally uneven, except that some general features are common to them all. Most strategies fail if the loading on one of the conflict links exceeds 80%. Most strategies have functioned when the loading on the conflict links exceeds 60%. Stable control of vehicles during maneuvers of this type is an entirely separate question. The strategy for resolution of conflict is the important part of the scheduling problem as related to merges.

It is possible to visualize systems which still operate in an asynchronous fashion but which have a central computing facility used for the optimization of some functions essential to an adequate service level, where centralized knowledge of network conditions might prove advantageous. An example might be empty vehicle management. If some previous scheduling of vehicle motion is done, either before or during vehicle departure, the system has some centralized control and is no longer operated asynchronously.

The most centralized computer system is known as a synchronous system. Synchronous systems evolve from a concept which assigns a fictitious series of moving headway slots to the guideway structure. These moving slots are made to progress conceptually around the guideway structure in an arbitrary fashion determined primarily by the permitted speed which the guideway allows in a given area. However, these moving slots really exist only in the memory of the control and scheduling computers. A one-to-one correlation is then made between the moving slots and the paths which cars must follow. It is usually precisely at this juncture that the conceptual distinction blurs between the scheduling, performed for efficient resource allocation, and the longitudinal controls, performed both for the preservation of safe operation and for the implementation of the resource allocation decision.

It seems possible to construct a control system for vehicle motion which will follow a mythical point in the fictitious moving slot. Such control schemes are known as point followers. If slot or point motion were properly coordinated, it might be possible to operate vehicles in an unscheduled asynchronous move using the point following technique. However, this would require the abandonment of some features of the moving slot approach, such as slot consiguity. Thus, the term "point follower" is generally taken to imply synchronous scheduling and vice versa.

On the other hand, it might be possible to devise a control law that operates primarily to preserve a safe separation between a preceding vehicle and the vehicle which is the object of control. The analog to automobile driving seems appropriate, and such control schemes are called car or vehicle followers. Although it is not necessary, vehicle follower controls have normally been associated with asynchronous scheduling. In theory, there is nothing to prevent the implementation of the vehicle follower control in a manner which keeps the vehicle in a slot until maneuvers are required, whereupon control is based on a leading vehicle in a minimum headway situation or on a preset manuever profile in others. In the moving slot concept, each car is assigned a slot which it follows faithfully from the origin of its journey to its destination. Using this type of control, the scheduling might be devised so that no vehicle has any conflict at a merge junction. If vehicle motion is controlled from a central location, the data communications required to implement such a scheme must be considered. If difficulties occur locally in the system, the central computer may have no choice except to slow the velocity of all the moving slots, and therefore, all cars in the system. This is required because of the conservation of slots. Slots can be neither created nor destroyed without potential impact in other parts of the system. If the system fails, all vehicles must come to a stop and once stopped, they must all start together again as a unit. In practice this has been achieved at Morgantown and other places by actually opening the control loop to the vehicle and allowing the vehicle to creep until it achieves enough speed to approach synchronism with the main computer timing slots. At this point, the synchronism of the system is resumed.

Several approaches have been conceived which use some variation of the synchronous approach. These have been lumped together with the terminology quasi-synchronous, but, in theory, there are many variations of the quasi-synchronous control. It is necessary to determine the common feature underlying quasi-synchronous control.

The common feature underlying all quasi-synchronous control is the type of scheduling. Scheduling in a synchronous system is controlled specifically for each vehicle. However, in a quasi-synchronous system, the scheduling is controlled only within certain limits. To achieve this, groups of slots are considered together as functional units called cycles. The control of vehicles assigned to the slots is left under the responsibility of local controllers. The local controllers, in turn, communicate with the central scheduling facility requesting that clearance be given to the motion of a car through a conflict point on a cycle basis. This implies that the scheduling machine need only reserve space in the cycle for the requested vehicle, and refuse space if the cycle is filled. Due to slot motion, the cycle is already programmed to pass through the conflict point in the correct time frame. When this is done, a vehicle is assigned only to the schedule for a particular cycle – not for a particular slot. It is the responsibility of the intersection controllers to work out conflicts based on conflicts within the cycle and to achieve smooth merging of vehicles. In order to achieve this, a second feature has been incorporated into quasi-synchronous vehicle management strategies. The feature basically amounts to adaptive control of vehicles in maneuvers in order to make possible smooth merging of conflicting vehicle strings. While this is relatively straightforward, the term slot-slipping has been assigned to the concept, since a moving system of uniformly moving slots will fall from synchronism with the vehicles when maneuvers of this type are undertaken.

It is at this point also, that the quasi-synchronous terminology becomes appropriate because synchronism is lost between the slot system and the vehicle system when this occurs. The loss of synchronism occurs only on the basis of individual vehicles; however, it does not occur uniformly over the whole network unless some sort of catastrophe has occurred. The effect of the failure might be confined to the region where the failure occurred. Since locally adaptive maneuvers could be permitted, sub-sets of vehicles might be systematically restarted at the local level and the flow increased as the vehicle performance increases commensurate with the requirements of the scheduling system.

These three fundamental scheduling approaches have little to do with many of the other traffic management functions. For example, the routing can be done in similar fashion for all three approaches. The reasonable routing strategy which can be applied to a guideway network involves a table search of a stored set of plausible paths to satisfy the trip demand.

From these patterns, the one may be selected which best fits the operating requirements and network conditions at the time. It is typical in an asynchronously scheduled system that no feedback of network conditions is brought to the local controllers. In centralized systems, network conditions can be taken into account when the route is chosen. The choice of route to satisfy a particular trip request can be considered a subsidiary problem of the scheduling, although not a separate problem — since the route selected obviously affects the schedule which can be achieved.

To determine which vehicle control philosophy is optimum for each AG system configuration is a very complex problem. One approach might be to define several types of network configurations such as line haul, line haul with feeders, simple loops, interconnected loops and area-wide networks, and then determine which type of control philosophy (synchronous, asynchronous or quasi-synchronous) is best for each AG system classification using minimum headway assumptions. This shall require using some large scale simulations. In the case of simulations, models of the vehicle shall include a model of the control system (the vehicle-control system could be modeled as a second-order dynamic system). Also models of dynamics of vehicles in stations shall include vehicle-control system dynamics. Speed transitions can have a significant impact on the length of merge/demerge ramps and intersections. The effects of speed transition zones on safety and capacity can be studied by analytical approximations and more accurately by computer simulations. Some of the issues which could be resolved in this area are as follows:

1) software requirements;
2) pros and cons of local, regional, and centralized control;
3) trade-offs between synchronous and quasi-synchronous control during normal, degraded, and emergency operation;
4) communication requirements; and
5) impact of vehicle-control system dynamics on stations, merge/demerge ramps, and intersections.

3. SIMULATION REQUIREMENTS

The following paragraph describes some requirements of a simulation package that could be developed in order to evaluate vehicle control and system management strategies. The objective of this simulation package is to provide a capability for:

1) simulating the operational characteristics of AG systems management and vehicle control functions as deployed in various urban applications,

2) simulating various longitudinal control strategies that might be employed in AG systems, and

3) evaluating the overall performance of AG systems to indicate where future development work may be required.

Ideally, the simulation would consist of a set of related discrete events stochastic models describing various aspects of urban mass transit systems. The models could serve as a sophisticated analysis tool for the evaluation of a broad spectrum of both planned and future automated guideway transit systems. They should provide a capability to simulate various generic transit systems.

The functional capabilities of the simulation package which are described in the following paragraphs are planned for implementation as a coordinated and modular set of simulation models in order to ultimately minimize core storage requirements and computer run times. This approach allows the models to share common elements to minimize or eliminate redundancy in model program code while allowing for modular flexibility. However, during the development of the system, the number of separate simulation models should be minimized in order to simplify simulation operation for the user.

The following sections encompass the model requirements.

3.1 MODEL SCOPE

The models should represent large urban systems in sufficient detail to obtain accurate estimates of the designed systems performance measures.

A scenario is required to bound the simulation study and a typical one is presented in Table 3-1. Systems to be modeled should include those having trip capacities to 30,000 trips per hour. Each trip represented in the model should be defined as one or more patrons traveling as a group having a common origin time and location, and a common destination. In this manner, common statistics on detailed performance can be maintained on a trip-by-trip basis (e.g., a histogram of trip times).

3.2 VEHICLE MANAGEMENT

Within the framework of the simulation model development, the vehicle management functions should include the type of control exercised over vehicle scheduling and dispatching, empty vehicle allocation, the entrainment of individual vehicles to increase passenger carrying capacity, given vehicle headway constraints. The following sections describe the modeling considerations for each of these functions.

3.3 VEHICLE CONTROL

The model package should include the capability to model synchronous, asynchronous, and quasi-synchronous vehicle control strategies which can employ fixed and moving block vehicle regulation strategies provided as shown in Table 3-2.

The functional characteristics of these operating policies allow reduction of the degree of detail necessary in measurement and evaluation. For example, in modeling a synchronous system where vehicle scheduling, route selection and dispatching are performed to accomplish unimpeded travel (barring anamolous behavior) from origin to destination, detailed movement of vehicles through the system in discrete time intervals need not be performed. Similarly, in fixed block systems, the position of a vehicle along

TABLE 3-1. BOUNDING SCENARIO TO SCOPE AGTT STUDY

Total trip request/hour	30,000 (maximum)
Vehicle Capacity	6 (minimum)
Number of Vehicles	5,000 single vehicles (maximum)
Headway	Fractional Second
Miles of Guideway	250 miles (minimum)
Number of Stations	150 (minimum)

TABLE 3-2. VEHICLE CONTROL STRATEGIES

Operating Strategy	Regulation Fixed Block	Strategy Moving Block
Synchronous		X
Asynchronous	X	X
Quasi-synchronous	X	X

a link can be maintained through the use of relative position within block or slot occupancy tables, eliminating the need for detailed modeling of the mechanics for vehicle position sensing and control. In the network simulation, it can be assumed that vehicle regulation can be implemented to perform space management to maintain safe stopping distances and desired headway between precisely models vehicle acceleration, deceleration, and merging operations. Appropriate information should be derived for the network simulation so that link velocity profiles can be modified as required.

The functions which should be considered for modeling basic control strategies include:

a. Synchronous Control - vehicle departures from each station are scheduled after selection of a prestored route and reservation of available slot times in all merges along the route to prohibit merge conflicts. Once dispatched, a vehicle travels to its next destination according to an appropriate velocity profile without maneuvers or rerouting.

b. Asynchronous Control - in this operational mode, vehicles are dispatched without considering the present or future state of the system. However, routes are determined prior to vehicle dispatch from prestored tables. Once dispatched, vehicles traverse their route at average link speed until congestion or merge conflicts occur, whereupon the vehicle may enter a queue. After resolution of the congested condition or merge conflict the vehicle proceeds to its destination.

c. Quasi-synchronous Control - this control mode selects a prestored route in a manner similar to synchronous control in that a prestored route is selected before vehicle dispatch. However, the route may be selected on knowledge of future traffic densities on the links, or future conditions at specific conflict points.

3.4 EMPTY VEHICLE ALLOCATION

The simulation should provide at least the following algorithms for allocation of empty vehicles. The algorithms include:

a. Buffer Pool - as a vehicle becomes empty, it is placed into a "pool" of available vehicles located at its last station or at a regional car barn. When a vehicle is needed by the system, it is obtained from the nearest, non-empty pool or from a set of locations designated by the simulation system user.

b. Continuous Circulation - empty vehicles are circulated along the guideway and are directed to stations as needed. Empty vehicle circulation occurs over preselected routes, over arbitrary (random) routes or would be distributed for circulation in certain areas of the network based on demand loads (e.g., twice as many empties may be required in the downtown areas as in remote areas).

c. Demand Dispersement - in this mode, empties are dispersed to remote stations or car barns based upon the number of vehicles already at those points and the demand pattern active in the system. The S.P. simulates only pre-specified demand patterns input by the user, to avoid problems with dynamic averaging, convergence, response time, etc., encountered in dynamic demand pattern generation.

3.5 ENTRAINMENT

Entrainment provides the ability to couple vehicles and obtain increased passenger carrying capacity without having to maintain separate vehicle headways. The simululàtion should be capable of modeling three basic methods of vehicle extrainment:

a. Static - when a station acquires empties to satisfy passenger demands, a fixed number of empty vehicles are always entrained.

b. Demand sensitive - empties only – of passenger loading warrant, two or more empties are entrained to satisfy the demand efficiency, providing that the empties can be obtained within some acceptable time period.

c. Fully demand sensitive - vehicles are entrained at stations whenever their destinations (or next stops) are identical so long as the first vehicle does not experience an unacceptable time delay. In this case partially full as well as empty vehicles are entrained.

3.6 STATION MODELING

The station simulation should functionally model stations in a detailed manner. It would provide capability for accepting parametric inputs such as detailed station design (for example, online and offline station configurations). The station modeling package should be capable of handling the following station characteristics:

1) finite capacity for arriving non-empty vehicles,

2) finite capacity for empties, and

3) unlimited passenger queueing capacities.

3.7 PASSENGER SERVICING

The simulation should provide detailed modeling of the process by which passengers are served by a proposed system since it has a direct bearing on system performance measurement (trip time and wait time). Service modeling should explicitly account for trip characteristics and the allocation of vehicle-space to demand (i.e., the service policy) as described in the following sections.

3.8 TRIP CHARACTERISTICS

A trip should consist of one or more patrons traveling as a group, with a common origin time and location, and a common destination. Trips consisting of more people than can be accommodated by a single vehicle will be subdivided into two or more trips. Thereafter, each trip should be modeled independently, with coordination and statistics reporting about the original (over-sized) trip.

The simulation should provide the capability of handling passenger transfer policies. For transfer-trips, it should be possible to obtain the number of transfers on an individual trip basis.

In addition to transfers, the simulation should provide the capability of individual trip statistics (trip times, wait times, and number of stops per trip), for subsequent presentation in the form of histograms, etc.

3.9 VEHICLE ALLOCATION TO DEMAND

The simulation should provide the capability of allocating trips to the first available vehicle that can satisfy that trip. In a system employing shared rides, a partially filled vehicle could deviate from a preselected route to satisfy a trip request at a station not on its route.

The simulation should have the capability of providing the following types of service policies by which vehicles can be allocated to meet passenger-trip requests: scheduled, demand, and periodic. They are:

a. Fixed schedule - each vehicle in the system follows a prescribed schedule of departure times from stations along its route. Trips are assigned to vehicles (and share a vehicle with other trips) consistent with destination location and times of arrival at the station.

b. Fixed schedule with limited deviation - variations from a fixed schedule are permitted within specified constraints.

c. Demand responsive - vehicles are utilized on a demand basis as trip requests are posted. (Such posting may be ahead of passenger arrival at the station in the case of a call-in system.) Vehicles may be shared or nonshared as specified by the system being modeled. The simulation should provide the capability to allocate trips to vehicles on a many-to-one, one-to-one and many-to-many basis. Routes are obtained from a prestored generated dynamically using a simple least-cost algorithm (here "cost" means such attributes as delay, distance, link utilization, etc.).

d. Demand actuated - vehicles follow a fixed route, but the frequency of vehicle arrivals at stations varies based on passenger demand. As demand varies vehicles can be added or removed from circulation to satisfy passenger trip requests.

e. Hybrid Policies - service policies that combine features of the allocation methods listed above. These policies should be able to handle such features as intermediate stops determined in real-time and should be capable of determining a transition effect from one policy to another policy.

3.10 SYSTEM DEGRADATION

The simulation should model system degradation insofar as it affects trip times to provide the analyst with a tool for evaluating a given system with respect to its dynamic behavior during the recovery period subsequent to a specific degradation. The types of degradation and their effects are described in the following two sections.

3.11 TYPES OF DEGRADATION

Two basic types of degradation should be provided: congestion and failure. Congestion degradation may occur on guideway links and at stations. Link congestion occurs when the number of vehicles on the link reaches the saturation point (as implicitly defined by the control scheme, link length, average link speed, headway, etc.). It may be caused by a link failure (which prevents vehicles from exiting a given link), by excessive queueing at a merge point, or by down-link congestion.

Station congestion occurs when too many occupied vehicles or too many empties queu at a given station. Station congestion may occur due to excessive delays in departure scheduling (especially in a synchronous, slot-reservation scheme), down-stream congestion, or too many arriving vehicles during a short time period.

Failure is distinguished from congestion in that failure is precipitated by a catastropic, random event. The simulator set will not model the exact cause of failure (e.g., wheel bearing burnout, control system outage, derailment), but rather will obtain failure occurrence from its input data, as specified by an analyst. When a failure is noted, the failing link or station will be inoperable for a period of time to reflect that maintenance personnel must reach the site of failure from their maintenance shop and subsequently repair the situation.

The simulation should assume that an analytical model has combined all reasons for failure to produce link and station failure rates aggregated across all causes.

3.12 DEGRADATION EFFECTS

The effect of degradation will depend upon whether a given vehicle has entered the affected link or station at the time the degradation occurs, whether it is enroute, or whether it has yet to be routed. Vehicles that have entered the affected area will be modeled as delayed until the condition has been cleared. For link degradation only, each vehicle shall be penalized an additional time delay to account for acceleration from the dead stop to average link speed.

The simulation should provide two alternatives for vehicles that are enroute but that have not yet entered a degraded area. They are:

a. Take no action - this will result in additional uplink congestion due to saturation of links and/or station capacity.

b. Re-route the vehicles dynamically in an attempt to bypass the affected area(s).

In the case of vehicles for which a route has not yet been selected, the simulation should assume that the system control program has timely knowledge of the degradation and will select a route so as to avoid the affected area.

If an affected area is a station, a vehicle scheduled to make a stop at that station will be routed to an alternate selected from a ranked, prespecified list. The vehicle will be routed to that station as if it were a totally interchangeable alternative to the original destination.

Table 3-3 presents the five most important functions that should be developed in order to conduct the desired simulation and to perform the required AG system evaluation.

Each exogenous model could be an analytical or simulation computer program, or a mathematical procedure. This should be determined through proper trade-off studies.

The input data pre-processing, the event simulation processing, the system status, and the output data post-processing are the functions to be contained in one computer simulation package.

TABLE 3-3. SIMULATION FUNCTIONAL REQUIREMENT

Exogenous Models	Input Data Pre-Processing	Event Simulation Processing	System Status Measures	Output Data Post-Processing
o merge	o network configuration data	o trip request	o headway	o passenger trip data
o passenger assignment	o link data	o route selection	o guideway queue length	o vehicle trip data
o route selection	o station data	o vehicle selection	o guideway capacity	o capacity data
o demand	o demand data	o vehicle scheduling		o recovery time data
o network configuration	o vehicle scheduling policy	o passenger assignment		
o station	o headway data	o trip generation		
o passenger	o longitudinal control data			
o availability	o reliability data			
o anomalous event				
o headway				
o service level				
o vehicle location				
o empty vehicle				

3.13 EXOGENOUS MODELS

The exogenous models are those models that should be developed separately from the simulator. These models are tools to conduct separate analyses independent of the event simulation. Further, they may provide basic scenario data to be inputted to the simulator. For example, the exogenous models may provide design data and information concerning the systems management aspects of the transportation system to be evaluated.

3.14 INPUT DATA PRE-PROCESSING

The pre-processing function interfaces between the user and the simulator and provides input data base management. Basically, it processes the input data (verifying and formatting) for use by the simulator. This pre-processing capability shall exist independently in two places: (1) as an integral part of the simulation computer package and (2) as an integral part of the remote terminal unit.

Table 3-4 presents a list of input data according to data type, its parametric characteristics, function; and, if appropriate, a model name. As shown, the pre-processing function allows the user to define and select the characteristics of a "real world" system. This data is then routed to appropriate processing routines.

TABLE 3-4. INPUT DATA PRE-PROCESSING

Data Classification	Input Data Parametric Characteristics	Function	Model Name (if appropriate)
1. Network Configuration -links -stations -merge/demand points -entrance/ egress ramps -acceleration/ deceleration ramp -vehicles	 location/length location/station type location location/length location/length initial location	determines network configuration layout used at run time -edits data & check formatting	Network Configuration Model
2. Link Data	vehicle velocity profile/link	pre-processor edits data and check formatting	----
3. Stations -docking -loading -unloading	time delays	"	----
4. Demand	trip demand per station	"	----
5. Vehicle Scheduling Policy	-vehicle schedule profile data -frequency of scheduling data -scheduling policy code	"	----
6. Headway	velocity o deceleration rates o delay times o collision policy code	"	----
7. Longitudinal Control Scheme	selected by input code at run time	"	----

4. EVENT SIMULATOR

The heart of the simulation processing is conducted in the event simulator. Table 3-3 identifies and orders the significant events that must occur in a functioning AG system simulation. This event flow allows a representation of the successive stages or discrete changes in the system to be developed. This approach allows diverse transportation networks to be modeled with minimal impact of the simulation package.

The basic unit of an event simulator is the discrete event which is the logical entity that controls all program operations. A proper undertanding of these events is needed to define the required models as well as their inter-relationships (since event is usually related to other events in the event list). The list of events that describes the minimal functional activity of an AGTT system is shown in Table 4-1. This set of events can be used to prepare an event graph. This graph describes the dynamic functional behavior of the system through the cause and effect relationships between the system events. Figure 4-1 illustrates the event graph for a transportation system that transports a passenger from an origin station to a destination station. This graph is useful to define the models used to generate the event as well as the boundaries between the models.

In order to define the event generating models, it is necessary to specify the basic information required to define the event. Table 4-1 presents the list of events together with the required input information and functions as well as other exogenous information and models. As shown, the function takes the basic input information and processes it using a set of logical or mathematical relationships in generating the event. As shown, this input information may itself be generated by exogenous models or trade-off analyses, each requiring a specific data base. Using this table, the functions can be defined in terms of specific models. The following sections outline and describe how each event is broken down into program models required, the input/output data

TABLE 4-1. BASIC INFORMATION REQUIRED TO GENERATE AGTT EVENTS

Event	Function	Input	Exogenous Model	Input to Exogenous Model
1. Trip Request	Double Monte-Carlo determines stations/passenger request frequency	Demand frequency per station per unit of time	reduces O-D trip data to proper format	-travel statistics O-D trips
2. Route Selection	select route from stored list	priority lists of routes	tradeoff analysis of trip time and distance	-network geometry -O-D pattern -velocity profile
3. Vehicle Selection	select vehicle based on delay constraints determined by trade-off analysis	delay constraints	cost/time/distance trade-off analyses	-network geometry -operating costs -selected route
4. Vehicle Scheduling	search time block tables for appropriate times, assign vehicles according to longitudinal control policy and operating constraints	-longitudinal control policy -operating constraints -time block tables	longitudinal control merge control	-passenger delay constraints -headway policy -vehicle control characteristics
5. Passenger Assignment to Vehicle	assigns passengers singularly, in groups, and split groups	passenger assignment policy	trip demand rate, vehicle capacity, time trade-off analysis	-vehicle capacity -demand -scheduling procedures
6. Trip Generation	moves vehicle through the system from origin station to destination station	based upon selected route and vehicle schedule		

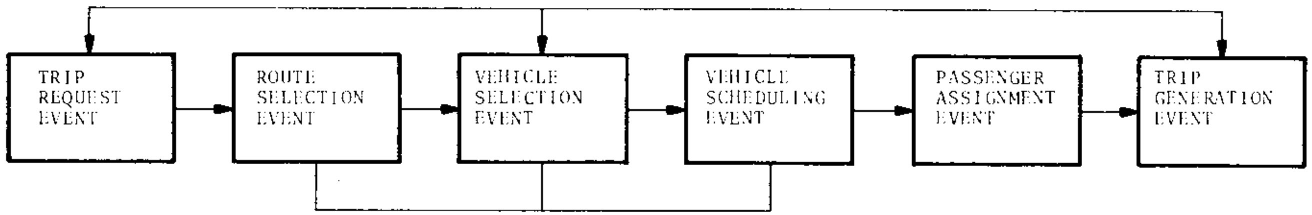

Figure 4-1. AGTT Event Graph

required, and the program models providing information to and receiving information from the event-generating models. The models are identified by name, type, and number. Model identified by a number only, are always endogenous model. These models are described in more detail in the section on Model Definitions.

4.1 TRIP REQUEST EVENT

As shown in Table 4-1, the trip request is generated using Monte Carlo procedures on the demand frequency distribution per station per unit time. Basically, the demand frequency distribution is generated by exogenous O-D travel statistics. The procedure stochastically chooses trips using the demand origin to destination distribution and demand rate profile data. The trip itself is identified in terms of origin station to destination station and destination time.

Figure 4-2 presents a further break down of this event in terms of the input data, the program models used, the output data generated and which models received this data. As shown, the input uses the demand frequency profile data generated by exogenous model No. 8 (see section on model definitions for more detail), and passenger group size data generated by exogenous model No. 12. The trip request event is stochastically generated by the demand model (endogenous model No. 8) using the double Monte Carlo procedure. This model outputs each trip request per station and the associated passenger group size. As shown, data from the demand model goes to the route selection model (endogenous model no. 7), the passenger assignment model (endogenous model no. 5), and the network control model (endogenous model no. 1).

4.2 ROUTE SELECTION EVENT

As shown in Table 4-1, the route selection event is generated by selecting a route from a list of routes pre-stored for the selection function using station origin to destination data. The list of routes are determined based on trade-off analyses of route trip time and distance for the network configuration, the vehicle velocity profile, and each station origin to destination (determined by the trip request event).

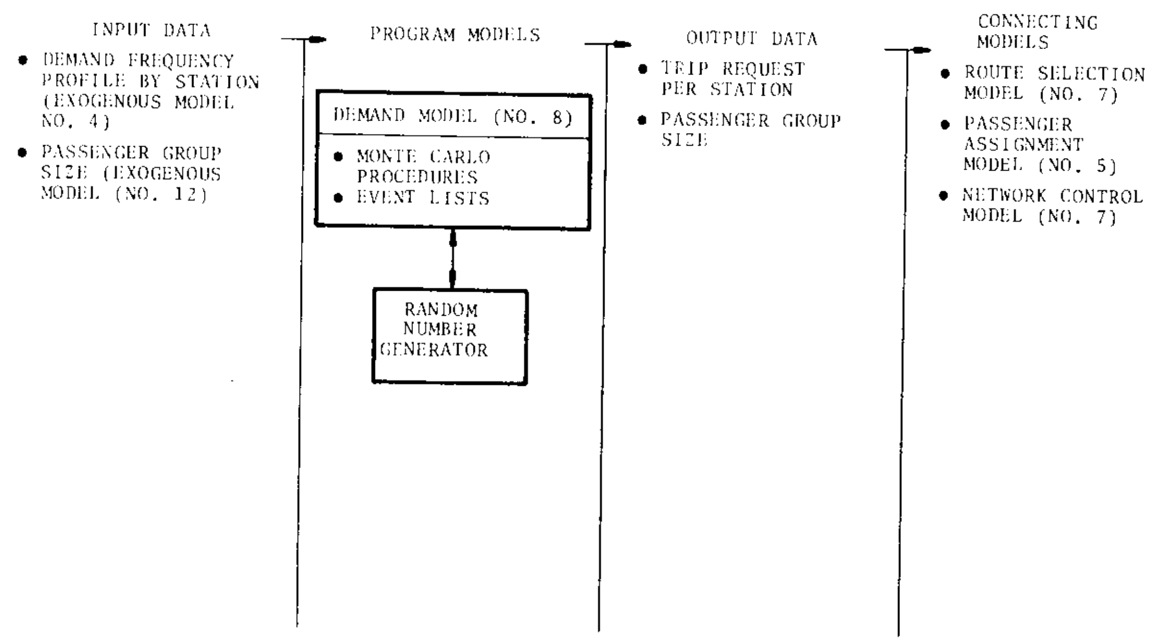

Figure 4-2. Trip Request Event

Figure 4-3 presents a further breakdown of the route selection event in terms of the input data, the program models used, the output data generated and which models receive this data. As shown, the trip request data is input data required for route selection. Also, status data from the network control model (endogenous model No. 1) and route table data generated by an enogenous model are used in the route selection model (endogenous model No. 7) to select the route specified in terms of time-block table and station numbers. This information is transmitted to the vehicle location (endogenous model No. 18), the vehicle reservation model (endogenous model No. 4), and the network control model.

4.3 VEHICLE SELECTION EVENT

As shown in Table 4-1, the vehicle selection event is generated by selecting the vehicle in the system (in a station, on route, or in storage) that best satisfies the delay constraints. The delay constraints are inputted and determined by cost/time trade-off analyses using the network geometry, operating costs, and selected route (provided by the previous event).

Figure 4-4 presents a further breakdown of the vehicle selection event in terms of input data, the program models used, and output data generated and which models receive this data. As shown, the route selection event provides input data for the vehicle selection models. Other input data is the delay constraint data and vehicle status data. The event generating models are the vehicle location model (endogenous model No. 18), the empty vehicle management model (endogenous model No. 19), and the vehicle model (endogenous model No. 9). The output includes vehicle location and identity which is transmitted to the passenger assignment model (endogenous model No. 5) and the network control model.

4.4 VEHICLE SCHEDULING EVENT

As shown in Table 4-1, the vehicle scheduling event is generated by searching the appropriate route time-block tables (generated by the route selection event) and selecting the appropriate time blocks based on the longitudinal control policy and other operating

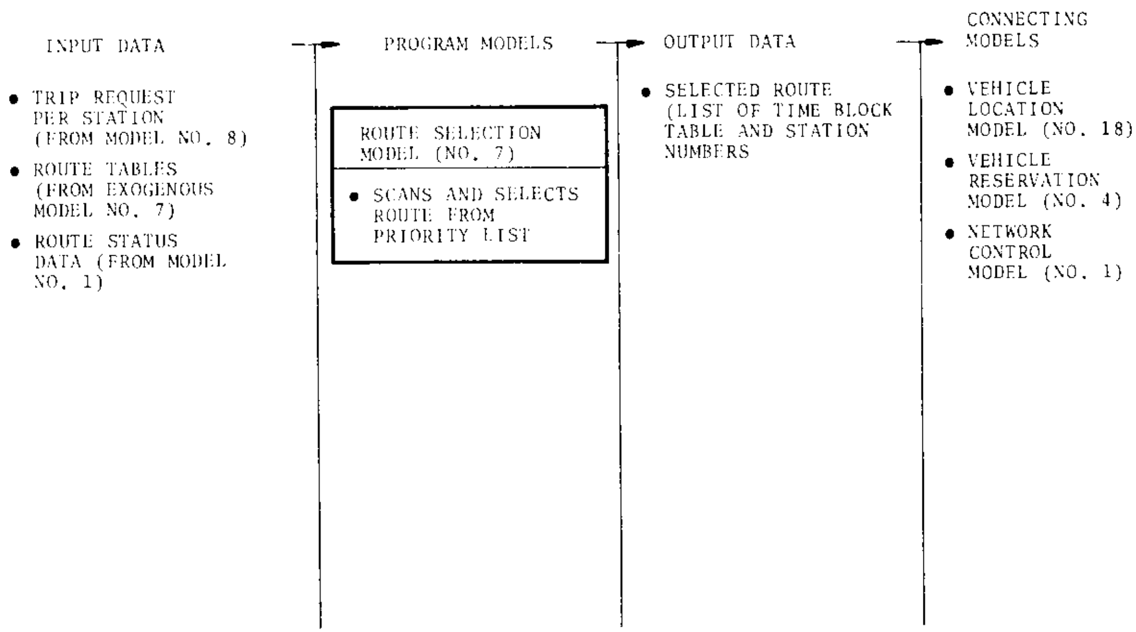

Figure 4-3. Route Selection Event

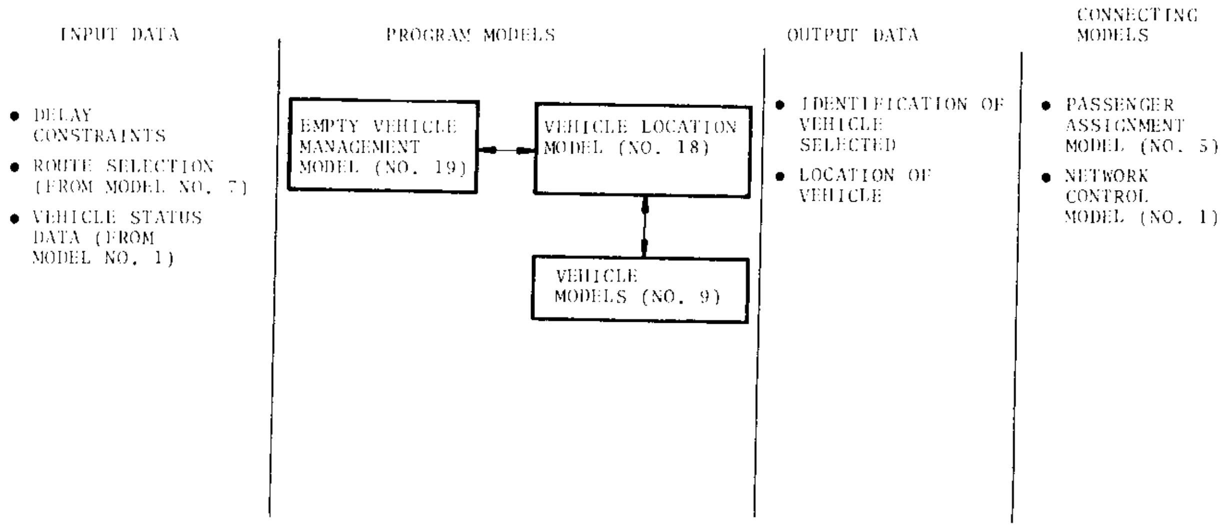

Figure 4-4. Vehicle Selection Event

constraints. This input data is provided by an exogenous longitudinal control merge model based on the passenger delay constraints chosen, the vehicle velocity and headway policy.

Figure 4-5 presents a further breakdown of this event in terms of the input data, the program models used, the output data generated and which models receive this data. As shown, after the vehicle is located and identified, the vehicle is scheduled using data generated by the vehicle selection event and the route selection event and the route selection event. The vehicle scheduling models include the vehicle reservation model (endogenous model No. 4), the station model (endogenous model No. 11) the longitudinal control model (endogenous model No. 2) and the merge control model (endogenous model No. 3). Other input data to these vehicle scheduling models include vehicle status data from the network contral model and merge data (from exogenous model No. 3) in the form of time-block tables. The event output includes block tables. This information is provided to the passenger assignment model (endogenous model No. 5), the vehicle model (endogenous model No. 9), the network control model, and the time clock.

4.5 PASSENGER ASSIGNMENT EVENT

As shown in Table 4-5, the passenger assignment function assigns passengers either singly, in groups or in split groups according to a passenger assignment policy using the exogenously derived trip demand rate data and associated trade-off studies using vehicle capacity and demand scheduling procedures.

Figure 4-6 presents a further breakdown of the passenger assignment event in terms of its input data, the program models used, the output data generated and which model receives this data. As shown, the passenger assignment event is generated by the passenger assignment model (endogenous model No. 5). Input data is derived from the trip request event, the vehicle selection event, and the vehicle scheduling event. The output is the assigned passenger aboard a vehicle. The demand model time clock is updated and the next trip request is scheduled at that station.

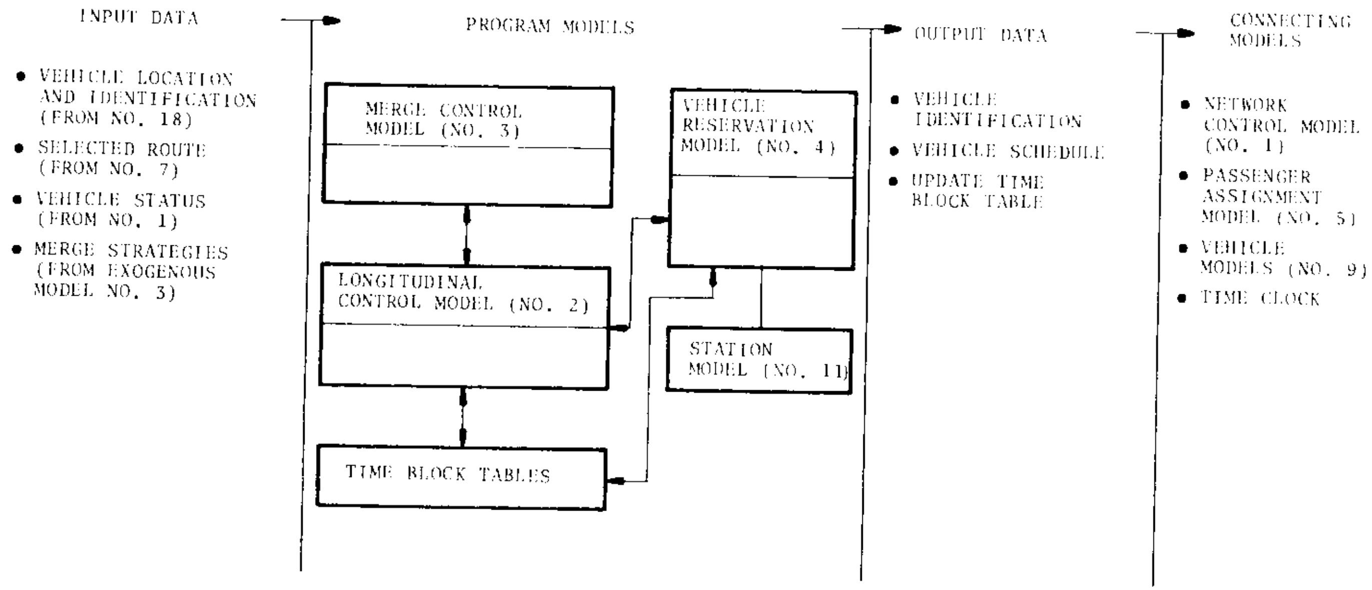

Figure 4-5. Vehicle Scheduling Event

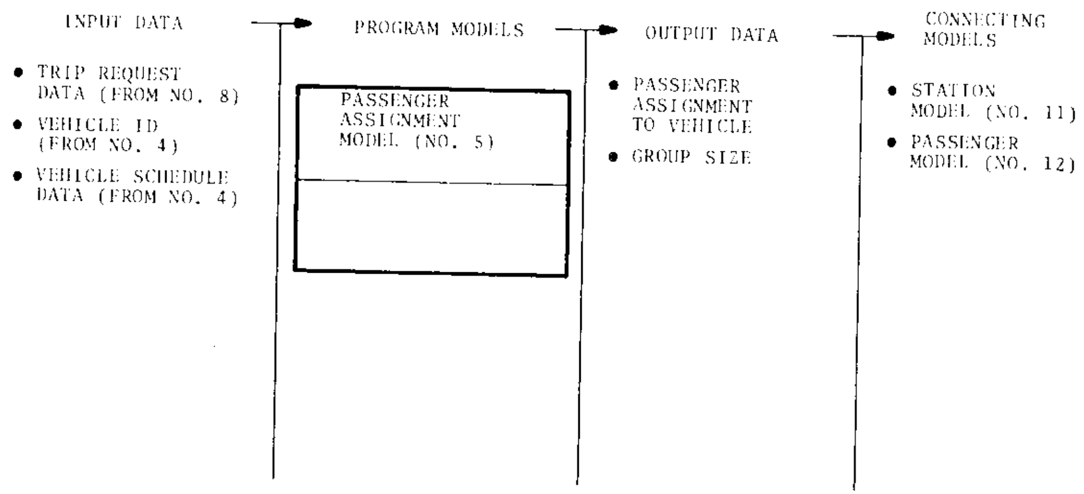

Figure 4-6. Passenger Assignment Event

4.6 TRIP GENERATION EVENT

As shown in Table 4-1, the trip generation event moves the selected vehicle through the transit system from origin to merge/demerge points, along links and through stations to the destination station based on the selected route and vehicle schedule. This event is somewhat complex and can be broken down into several event activities or trip phases which include (1) station departure (2) merge/demerge activities (3) link/route movements (4) station arrival (5) passenger departure from vehicle (including exit and transfer activities) and (6) vehicle re-scheduling. These activities and their relationships are presented in chart form in Figure 4-7. As shown, this breakdown allows the models to be specified. Using these models, a flow chart (Figure 4-8) can be constructed showing the inter-relationships between the event generating models. As the models include the following endogenous models: (1) the station model (2) passenger model, (3) merge model (4) vehicle models, (5) empty vehicle management models and (6) the network control model. The input to these models is obtained from the network control model. The output of this event is a completed station to station vehicle/passenger group trip. The vehicle is then rescheduled and routed by the empty vehicle management model.

4.7 SYSTEM STATUS

The status of the event simulation shall be continually monitored by the network control model as shown in Figure 4-8. This model interfaces with all other endogenous models and controls their use in the simulation. (See Figure 4-9 for status of the system.)

4.8 OUTPUT DATA POST-PROCESSING

The post-processing function provides output data management, interfacing between the simulator and the user, output data management provides data reduction (i.e., summary statistics), user-oriented tabular reports, as well as appropriate graphs and charts. Post-processing capability shall be provided by both simulation

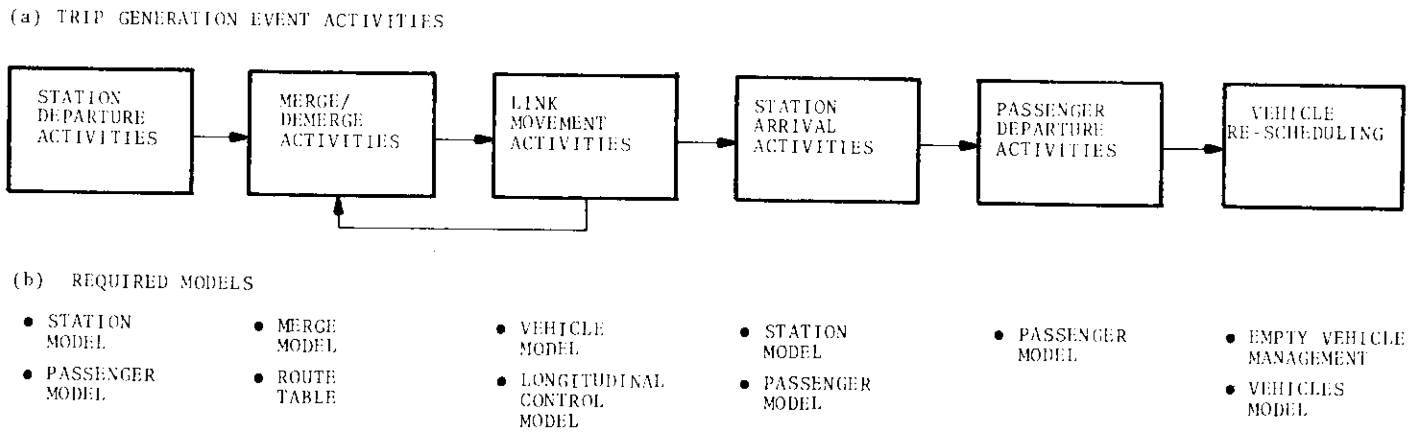

Figure 4-7. Activities and Models Required for Trip Generation Event

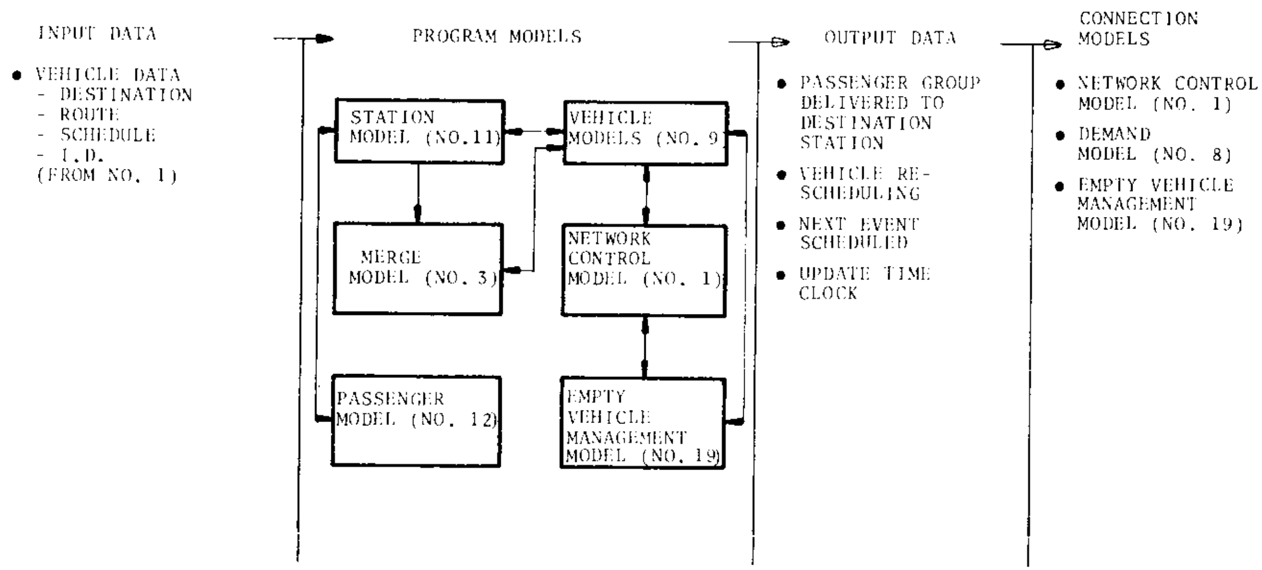

Figure 4-8. Trip Generation Event

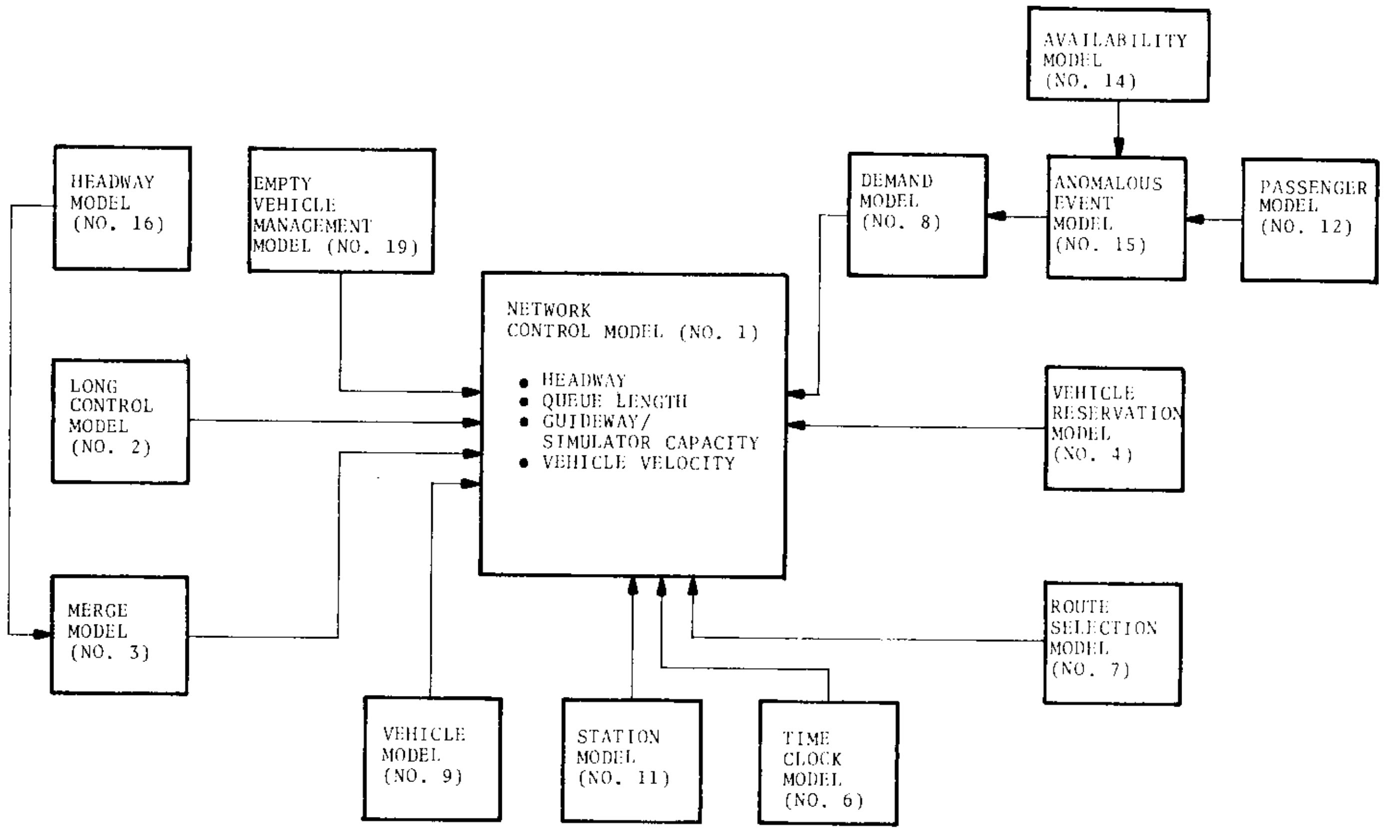

Figure 4-9. Status of System

computer package and the remote terminal. Table 4-2 presents a list of output data that shall be provided, including the type of processing conducted and output format required.

TABLE 4-2. OUTPUT DATA POST-PROCESSING

Output Data	Output Processing	Model
1. Passenger Data -trip time -delay time -waiting time -passenger flow	o averages o variables o frequency distribution in histogram format o mathematical functions o graphs o tabular format	post-processing is performed by computer package and remote terminal
2. Vehicle Data -trip time -delay time -waiting time -vehicle flow -speed	"	"
3. Capacity Data station flow -link flow -merge/demerge flow -system flow	"	"
4. Recovery Time	"	"

5. MODEL DEFINITIONS

Table 5-1 lists the models to be developed as part of this statement of work. This list which encompasses both endogenous models and exogenous models and is not complete. However, it does list some of the more important models. The models can be classified as (1) operational, (2) functional, or (3) analytical. An explanation of each model type is shown in Table 5-2.

An analytical model could be developed that computer vehicle headway as a function of several parameters such as deceleration rate, vehicle length, position error and communication processing time. Assuming that it was desirable in a hypothetical system design to have 10 different mainline guideway speed requirements as a function of vehicle volume or capacity, then the output of the headway model could be expressed in a lookup table. This table would be input to a functional model which served as an interface to the network simulation program. This functional model would have the feature of allowing the lookup table to be changed parametrically at user-run-time without the use of the analytical headway model.

An operational model could be developed that would monitor the guideway capacity after each vehicle event activity and employ the functional model as required. Consequently, the operational model would be event activated, the functional model would be used as analytical model would be used before or after the simulation as desired.

A tentative description of these models follows:

1. Network Control Model - the network control model forms the basic structure of the computer simulation package. All other models directly or indirectly tie into it. It regulates the flow of vehicles over the guideway network, schedules vehicles at various merge/demerge points and stations, resolves traffic conflicts, determines guideway capacity, vehicle speed, and headway.

This is accomplished by the use of the time-block tables associated with the various guideway nodes (merge/demerge points,

TABLE 5-1. SOME OF THE MOST IMPORTANT MODELS TO BE USED IN AGTT OPERATION SYSTEM STUDIES

Model Name	Endogenous Models	Exogenous Models
1. Network Control	Operational	---
2. Longitudinal Control	Functional	---
3. Merge Control	Functional	Analytical
4. Vehicle Reservation	Operational	---
5. Passenger Assignment	Operational	Analytical
6. Time Clock	Operational	---
7. Route Selection	Functional	Analytical
8. Demand	Functional	---
9. Vehicle Model	Operational	---
10. Network Configuration	Operational	Analytical
11. Station Model	Functional	Analytical
12. Passenger	Functional	Analytical
13. Anomalous Event	Operational	---
14. Headway	Functional	Analytical
15. Service Level	Functional	Analytical
16. Vehicle Location Management	Operational	Analytical
17. Empty Vehicle Management	Functional	Analytical

TABLE 5-2. EXPLANATION OF MODEL TYPES

Operational	- Operational Models perform certain operations, function, analysis, or bookkeeping activities, according to scheduled events and/or system constraints.
Functional	- Functional Models can be parametrically represented according to one or more parameters. These parameters represent a user run-time option.
Analytical	- Analytical Models perform some mathematical computations and/or operatings before the simulation begins based on user run-time options, and pass their output to the functional models as parameters. Where practical, equivalent functional models will be included.

stations, etc.) and appropriate network parametric information. For example, for an event based simulation model, the time-block tables may be divided into various segments such as slots or headway in synchronous and quasi-synchronous control schemes, or time frames of periods in the case of asynchronous control schemes. By reserving time for a particular vehicle in the appropriate blocks associated with the nodes contained within a route to be travelled by the vehicle, the future position of the vehicle can be determined. Travel time between nodes is based on the Configuration Model, velocity obtained from the Headway Model, and any modifying constraint obtained from the Merge Model. A link is defined as the section between any two nodes and link capacities at various vehicle velocities is based on data from the headway and Merge Model.

2. Longitudinal Control Model - This model could be used to partially simulate the influence of a particular control scheme such as synchronous, quasi-synchronous or asynchronous on system performance, by using various procedures to assign vehicles to appropriate time blocks. For example, in the synchronous system, the time blocks could be divided according to headway or slot time. Times are reserved for a vehicle on a one-to-one time slot sample in appropriate time blocks along the route. However, in a slot slipping quasi-synchronous scheme, each appropriate time block is sampled according to a specific number of slots so that the feasibility of slot slipping can be evaluated. Likewise, for an asynchronous scheme, the sample size is with respect to a specified time frame.

5.1 SYNCHRONOUS TECHNIQUE

This technique employs a conflict point — time period matrix (for example, Table 5-3). The conflict points are essentially time merge points of the network. The time periods are defined such that, at most, one vehicle can use the conflict point during a time period. As the need arises for a vehicle (VI) to go from an origin to destination, a route is selected. The route is defined spatially in terms of a sequence of conflict points. For example, the route determined for vehicles V1 and V3 is defined by conflict

TABLE 5-3. CONFLICT POINTS (1)

Slots		1	2	3	4	5
Time Periods	1	V1				
	2	V3				
	3		V2			
	4			V1		V1
	5			V3	V1	
	6				V3	

TABLE 5-4. CONFLICT POINTS (2)

Conflict Point	Time Displacement
1	0
3	3
4	4

TABLE 5-5. CONFLICT POINTS (3)

Slots		1	2	3	4	5
Time Periods	1					
	2	V4				
	3	V5	V4			
	4			V4		
	5			V5		
	6					

points 1, 3, and 4: and the route determined for vehicle V2 is defined by conflict points 2 and 5. The synchronous technique demands that the vehicle satisfy a fixed chronological schedule in terms of displacement between time periods. For example, V1's route and V3's route is shown in Table 5-4. Before beginning its trip, V1 would reserve (in the matrix) point 1 at time 1, point 3 at time 4, and point 4 at time 5. When another vehicle, V3 for example, wants to reserve slots, it examines this matrix to see if another vehicle has reserved any of the slots in its route. If a slot in this route has been reserved, the algorithm tries to reserve its full route either by increasing its start time by one or more period or changing its route. Reservations are made first come, first served: that is, once a vehicle has reserved a series of slots for its route, another vehicle cannot preempt it. This described the synchronous technique.

5.2 QUASI-SYNCHRONOUS TECHNIQUE

In the quasi-synchronous technique, a non-conflicting route can be specified spatially in terms of a sequence of conflict points (as in the synchronous technique) and chronologically in terms of a series of time displacements for each conflict point (instead of one fixed displacement). Table 5-5 gives an example.

Assume V4 has reserved first. Assume the reservations are time period 2 at conflict point 1, time period 3 at conflict point 2, and time period 4 at conflict point 3. Now assume V5 wants to make a reservation along the same route. Assume further, that V5 reserved time period 3 for conflict period 1; thus, we see that V5 is allowed to "slip" a variable number of slots at conflict point 3 in order to fit in: that is, instead of a fixed set of time displacements after a start point, V5 has a series of allowable displacements (highlighted in Table 5-5 at each conflict point that it can choose from in order to fit in).

5.3 ASYNCHRONOUS TECHNIQUES

In the asynchronous technique, conflicts are resolved as they occur and not before hand as in the other two techniques (1 and 2) stated above. For example, in the quasi-synchronous example given above, V5 would be assigned to the same time interval as V4 but the conflict would not be resolved before hand. Instead, it would be resolved at point 3 when the event was scheduled to take place. The procedure for resolving the conflict would depend on the merge strategy being simulation. It might be a single block control concept based on a first, come, first serve policy or it might give priority to one lane over the other.

3. Merge Control Models - These models are used to evaluate the effects of synchronous, quasi-synchronous and asynchronous control merging strategies with respect to the system constraints (time, velocity, guideway or ramp length required) each of these control schemes produces during the merging maneuver. The models must accurately take into consideration the performance characteristics of the braking and propulsion/transmission characteristics of the vehicles employed in the system.

4. Vehicle Reservation Model - This model reserves space on the guideway for vehicles at the appropriate nodes along given routes required according to a specified longitudinal control scheme. It accomplishes this by creating an image of the time blocks, examining the blocks for appropriate unscheduled time elements and determining the earliest possible departure time without unduly delaying previously unscheduled vehicles.

5. Passenger Assignment Model - This model assigns passengers to vehicles either regularly or in groups based on a first come, first serve basis.

6. Time Clock Models - There shall be two time clocks. One to determine the occurrence of the next trip request and the other to update the time blocks accordingly.

7. Route Selection Model - This model determines the number of routes to be used in the simulation based on a minimum time path analysis that considers origin to destination demands. The routes are stored in a table and used during the course of the simulation as required.

8. <u>Demand Model</u> - To model the trip request demand on the system, the demand model stochastically generates trip requests at a rate specified by a demand profile. The demand profile is a user run-time option which can be specified for each station. The demand profile also specifies, as a function of time, the demand rate in trip requests per defined by a start time, and end time. Trip requests are stochastically generated such that the demand profile is satisfied. Each trip request is an event which is initiated by the Simulation Control Package and which utilizes the demand model to schedule the next trip request.

9. <u>Vehicle Model</u> - This model defines the vehicle for on guideway travel. The system contains one state transition vehicle model for each type of vehicle in the system and one unit vehicle model for each vehicle in the system. The unit vehicle model defines the applicable state transition model, current vehicle position, velocity, acceleration, jerk, passenger destination, vehicle status, and route data. The vehicle state transition model defines vehicle capacity, detects overloading, and calculates new vehicle position, velocity, acceleration, and jerk as a function of the interval time specified for the update, the vehicle route and status data, and the former position, velocity, acceleration, and jerk. The aforementioned data is the maximum data used for a simulation; most simulations, the vehicle position, velocity, acceleration, and jerk will be specified as conforming to the state of the assigned vehicle.

10. <u>Network Configuration Model</u> - The data base for this model defines the network configuration, as specified by the user at run time, and the initial location and identity of all vehicles on the network. Individual guideway link lengths, station location and merge/demerge points are entered by the use of run-time. From these elements, the guideway is constructed and time blocks assigned where appropriate.

11. <u>Station Model</u> - This model represents the guideway stations. There will be one state transition model for each type of station in a system and one unit model for each station in the system. Initially, stations will be modeled as interconnections of

vehicle berths and platforms, guideway to station entrance queues, station of guideway launch queues, and station passenger wait queues. The quantity and configuration of all these entities will be user run-time options. Vehicle movement will be modelled as time delays between station queues and berths. Vehicle movement time delays will consider movement interference of vehicles. To save simulation run-time, subsequent station models will utilize statistical data collected during initial simulations to stochastically model station flow. These stations will contain guideway to station entrance queues and station to guideway launch queues. The station will utilize the vehicle and more interchange models to move vehicles through the station.

12. Passenger Model - The passenger model simulates passenger actions as time delays with stochastically generated variances for each specific action. Here, the movement of a passenger onto a vehicle is modeled as a time delay. The anomalous event models can introduce an anomalous passenger action. For example, a passenger may fail to exit a bus at the proper station. The acceptance or rejection of a proposed trip by a passenger is also modeled. Rejections will be statistically generated based upon trip data received from the Management Computer Software (MCS).

13. Failure and Anomalous Event Models - These models are events which are initiated at a scheduled time. There is one state transition model for each type of failure and anomalous event in the system, and one unit model for each particular occurrence of the event or failure. The unit model defines the time of occurrence, the entity affected, and the type of failure of anomaly. The state transition model alters the affected entities unit model so as to generate the failure or anomalous event.

For example, to generate a vehicle failure, the failure event would alter the unit model of the designated vehicle to specify a failed vehicle as its state transition model.

14. Headway Model - This is an analytical model that may be used to parametrically analyze the sensitivity of the AGTT system headway and capacity performance to vehicle management and control

parameters, line velocity, vehicle braking profiles, vehicle errors and malfunctions, and velocity transition region parameters. A variety of transition regions will be modelled including: (1) the line guideway to CBD guideway transition regions, (2) guideway to merge and demerge junctions, (3) guideway segment to a turn and, (4) guideway segment to a grade. Also, the models will be used to evaluate the influence of system management and vehicle control philosophy (synchronous, quasi-synchronous, and asynchronous) on vehicle separation (or headway) as well as system capacity. The influence of on-guideway stopping (or queueing) on headway requirements also needs study.

15. Service Level Model - This model simulates the level or type of service provided by the AGTT system. It will be used to evaluate the performance effects of such service options as: fixed schedule, demand responsive schedule, origin to destination/non-stop, origin to destination, intermediate-stop. As with any given model, this model interrelates with other modes; however, it will particularly interrelate with the station configuration – i.e., off-line, on-line or fixed location, variable location – and the level of network integration – i.e., the number of passenger interchanges. The contractor shall determine the number of kinds of reasonable combinations of service levels and station configurations.

16. Vehicle Location Model - This model determines the vehicle to which a passenger is assigned by searching the appropriate time block table and selecting the next available vehicle that is going to the passenger's destination and comparing this wait and trip time to that of selecting an empty vehicle if one is available.

17. Empty Vehicle Management - This model controls the routing scheduling, and storage of empty vehicles. These functions will be compatible with the functions associated with previously listed models, e.g., network control, longitudinal control, merge control, vehicle reservation, etc. This model, in addition to control by and compatability with other models will contain characteristics and conditions uniquely associated with empty vehicle management.

The storage function will account not only for where empty vehicles might be stationarily stored but any pattern of circulating empty vehicles over the network. The routing and scheduling strategies will specifically be able to station against a given priority assignment rule ranging from first station call to station with greatest need.

5.4 CONCLUSIONS

The analyses and evaluation of automated guideway ground transportation systems required the development of a detailed event type simulation that can evaluate various systems management and vehicle control operating strategies. The simulation could have a variety of applications relating to the operational issues that pertain to such systems.

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