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THE AVAILABILITY SIMULATION OF AGT SYSTEMS

Charles R. Toye

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FINAL REPORT

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16. Abstract

This report discusses the analytical and simulation procedures that were used to evaluate the effects of failure in a complex dual mode transportation system based on a "worst" case steady-state condition. The computed results are an availability figure of merit and not an absolute prediction with associated confidence levels of system availability. The advantage of this procedure is that it avoids the use of a dynamic network traffic flow simulation which is both costly and time-consuming.

The availability calculation of a complex ground-automated transportation system such as that described in the urban deployment scenario of the Urban Mass Transportation Administration (UMTA) dual mode transit program is most understandable when expressed in terms of the fraction of system time lost due to either passenger or vehicle delays. This involves both system reliability and maintainability, including the number of system failures per time interval, their effects, and corrective action times required to avoid vehicle delays.

In a dual mode transportation system, vehicles are capable of operating on conventional streets in a manual mode, and also, on specially constructed guideways in a completely automated mode.

The objective of this dual mode program is to combine the best automated transit such as the Personal Rapid Transit (PRT) system currently being demonstrated in Morgantown, West Virginia with the best aspects of modern bus technology. The dual mode concept combines two methods of operation; a driver-operated mode on surface streets of highways and an automated mode of fixed guideways.

The analytical and simulation approach taken encompasses fault tree and failure mode and effect analyses. The novel aspect of this approach is the use of the Monte Carlo technique to determine the physical location of failed vehicles in the system (on or off the guideway, in station berths, or at various merge/demerge sectors).

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PREFACE

In a dual mode transportation, vehicles are capable of operating on conventional streets in a manual mode, and also, on specially constructed guideways in a completely automated mode.

During September 1973, UMTA awarded three contracts for the design phase of a Dual Mode Transit System (DMTS) development program. The awards were made to the Rohr Corporation, Chula Vista, California; General Motors Corporation, Warren, Michigan; and to Transportation Technology, Incorporated, Denver, Colorado.

The three companies will be engaged in the first phase of UMTA's dual mode program designed to apply new technologies to the improvement of existing means of mass transportation. The program is directed towards reducing traffic congestion and improving personal mobility within medium-to-large urban areas.

The objective of this dual mode program is to combine the best automated transit, such as the Personal Rail Transit (PRT) system currently being demonstrated in Morgantown, West Virginia, with the best aspects of modern bus technology. The dual mode concept combines two methods of operation: a driver-operated mode on surface streets or highways and an automated mode on fixed guideways.

This report discusses the analytical and simulation procedures that were used to evaluate the effects of failure in a complex dual mode transportation system based on a "worst" case steady-state condition. The computed results are an availability figure of merit confidence levels of system availability. The advantage of this procedure is that it avoids the use of a dynamic network traffic flow simulation which is both costly and time-consuming.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

This report discusses the availability procedures that were given to the contractors who were selected to participate in Phase I of the UMTA Dual Mode Program. The procedures were to be used as guidelines for the contractors in determining a relative availability figure of merit for their proposed system designs. An availability estimate is usually derived during the concept development or design phase of a system. In a ground transportation system, such as Dual Mode, it involves the calculation of either passenger or vehicle delays based on the system's reliability and maintainability, including the number of system failures per time interval, their effects, and corrective action times required to avoid delays. In Phase I of the Dual Mode Program, the emphasis was placed on vehicle delays derived from a "worst" case steady-state analysis. This avoided the use of a dynamic network traffic flow simulation which is required for the computation of passenger delays and deferred until an advanced development effort can be undertaken.

The approach taken encompasses fault tree and failure mode and effect analyses. The novel aspect of this approach is the use of the Monte Carlo technique to determine the physical location of failed vehicles in the system (on or off the guideway, in station berths, or at various merge/demerge sectors).

The requirements of the Phase III (urban deployment) scenario are discussed with respect to types of stations, guideway sectors, passenger flow and network configurations.

In a dual mode transportation system, vehicles are capable of operating on a conventional street in a manual mode, and also, on specially constructed guideways in a completely automated mode.

In the manual mode, a driver will operate the vehicle in suburban residential or business districts. These surface routes will serve as collector lines and will feed into access stations. There, the driver will leave the bus and the vehicle will be placed in the automatic mode. In this mode, the mini-bus will be routed on completely automatic guideways through the heavier traveled urban

corridors and the central business district.

This combination of manual and automatic operation will permit flexible routing and distribution capable of changing to suit daily or seasonal variations in passenger demand throughout an urban area. The systems also envision demand-responsive operations for nearly direct point-to-point routing.

Phase I of the Dual Mode Transit System development covered concept and system design with special attention being paid to improving the quality of transportation while minimizing initial capital investment installation time and operating costs.

In many respects, the availability techniques used in the aerospace industry for the evaluation of large complex electro-mechanical systems cannot be directly applied to automated guideway transportation systems. When a large electronically controlled aerospace system exhibits a catastrophic failure, the entire system aborts its mission. Such a system usually has only one mission. Its system complexity is derived from numerous subsystems integrated toward one single objective. As a result, an availability estimate states the percentage of time the system is expected to complete is mission. In a very broad sense, an AG (Automated Guideway) system has one mission: to transport people. However, each individual trip or each individual user, has his own mission and therefore, could be considered as an independent system. Trips need not be interrelated or interdependent. Over the course of a day an AG network could become a galaxy of systems.

Therefore, an availability figure of merit derived for an AG system normally doesn't indicate the percentage of time that the system operated and the percentage of time the system was shout-down. It reflects the percentage of times undue delays will not occur. The unreliability percentage indicates the percentage of time delays will occur. How to measure these characteristics is an important problem that must be considered. High availability in an AG system depends in part upon:

a) efficient abnormal operating procedures;
b) efficient failure management procedures;

c) effective vehicle recovery strategies;
d) optimum location of recovery crews;
e) properly designed guideway facilities;
f) proper use of fault detection equipment;
g) enforced maintainence schedules.

As a result, availability analysis in AG systems has an added dimension of system management which most complex electro-mechanical systems do not have. This, in fact, could be the overriding factor in achieving an acceptable availability level. What level is obtained determines the user service level that can be offered. What constitues an acceptable availability level is another problem that needs investigation.

Consequently, new evaluation procedures were recommended to the Dual Mode contractors which proved to be highly successful in determining an availability figure of merit. These procedures generally consisted of:

a) dividing the system into similar kinds of major hardware and software subsystems and components as determined from its functional characteristics,

b) determining the number of vehicles per section based on speed, percentage of vehicle/guideway occupancy, and a steady-state passenger-seated flow rate,

c) conducting an appropriate FMEA based on the system design, reliability, maintainability, and safety practices,

d) determining the various failure permutations, combinations, and system interactions, and

e) performing the necessary calculations and data presentations.

The Monte Carlo technique was employed to determine which subsystems failed, at what time, and where in the network vehicle delays occurred. The procedure is given as follows:

a) Subsystems and components must be related to the guideway network in order to determine where in the network

a delay occurs. For example, guideway sectors and associated peripheral subsystems and components should be assigned to corridors by number. For each type of guideway sector (including berths in the stations) vehicle positions should also be numbered.

b) Failure rates for the major subsystems and components can be calculated from the reliability apportionment analyses stated above. The relative frequency of a failure of a particular subsystem with respect to other types of subsystems can be determined.

c) The Monte Carlo technique can utilize the relative frequency of occurrence to determine which subsystem failed. A computer can easily perform this task.

A double Monte Carlo procedure could be used to designate component failures. The first procedure would select which of the major subsystems the failure(s) occurred in and the second would assign component failures within subsystems. Consequently, two frequency distributions of events are required.

The event probability models that were developed to estimate failure occurrence and the type of scenario that is required to perform the simulation is discussed.

2. SCENARIO

In order to obtain some uniformity between contractor's availability calculations during the Dual Mode Phase I effort, a hypothetical urban deployment scenario commonly referred to as the Phase III scenario was developed. The network geometry is shown in Figure 1 (reference 1).

Specifically, the analytical network (reference 1) assumed for all availability calculations consisted of six radial corridors, each 10 miles long with two one-way lanes and the equivalent of 10 stations, feeding a CBD network which is 2 miles wide by 3 miles long with 22 miles of one-way guideway and 20 stations. Each corridor station pair was the guideway interchange for a Dial-A-Bus (DAB) zone. Each zone was the origin for the same number of trips as any other zone. The corridor station spacing was 2 miles.

It was assumed that the system will satisfy a demand of 30,000 trip requests per hour with a nominal of 5,000 and a maximum of 10,000 per corridor. The assumed operating cycle was:

1) 5,000 passengers/hr/corridor guideway sector for 6 hours per day;
2) 1,000 passengers/hr/corridor guideway sector for 18 hours per day;
3) 10,000 passengers/hr/CBD guideway sector for 6 hours per day;
4) 2,000 passengers/hr/CBD guideway sector for 18 hours per day;

The analysis covered a 7-day week for 3 consecutive years.

The off-guideway assumptions included:

a) the passenger flow rates associated with each entrance/egress station was related to an appropriate Dial-A-Bus Zone;
b) the length of the DAB Zone was 10 miles, and six equally spaced stops were made per zone;

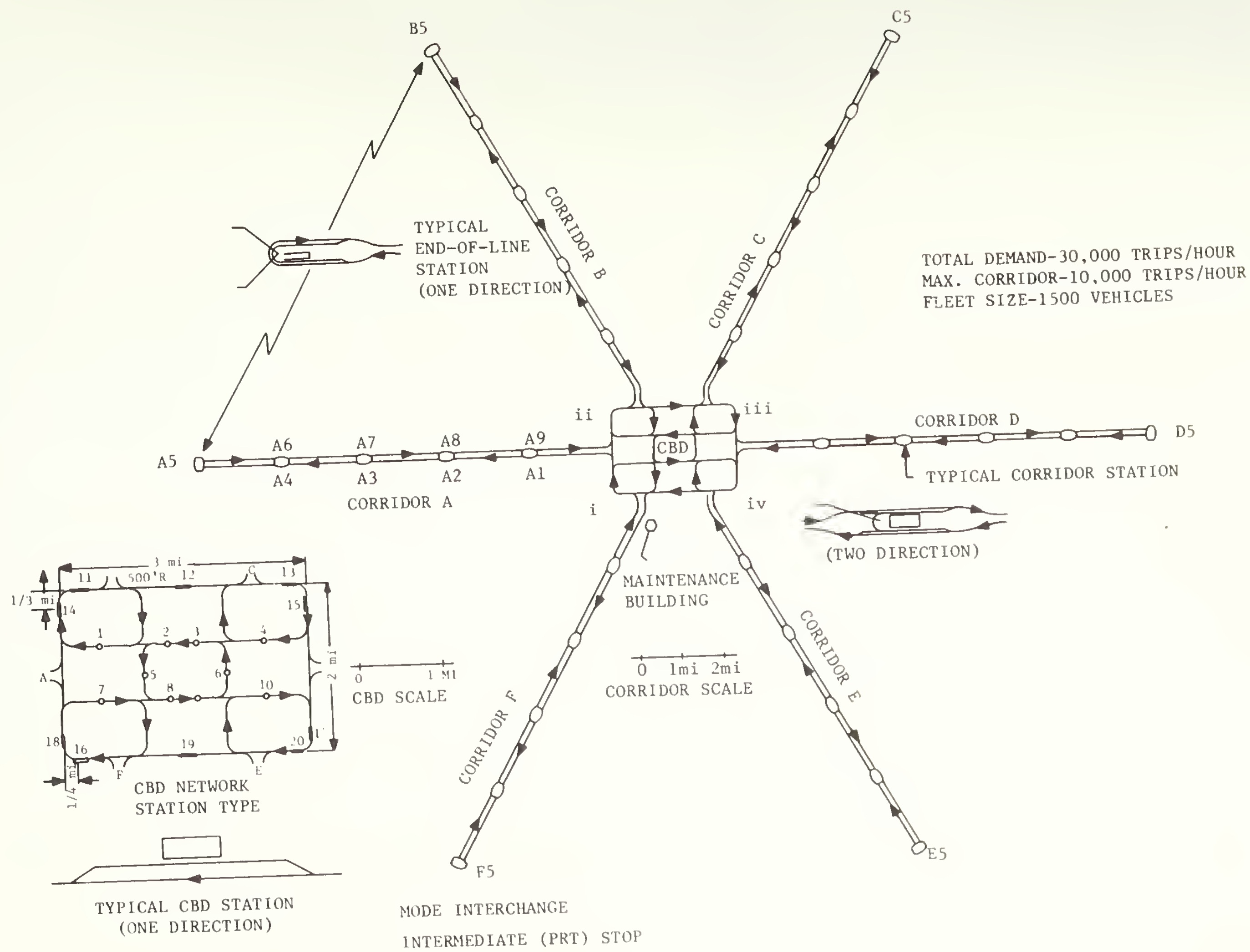


Figure 1. Phase I Scenario

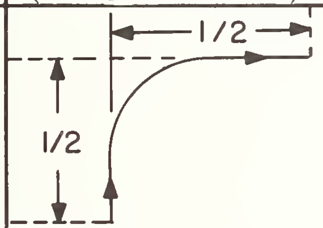
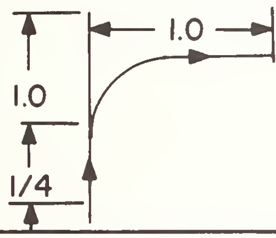
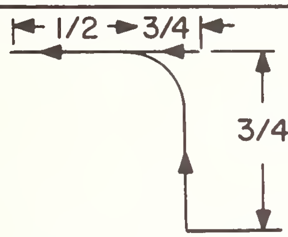
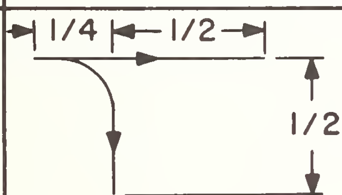
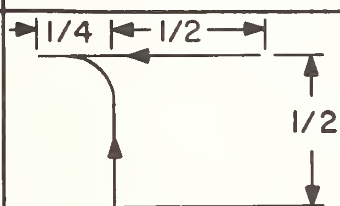
c) the vehicle speed was 30 miles per hour for both Dial-A-Bus and by-pass guideway operations.

The distribution assumed for numbers of vehicles and operating times was derived by each contractor from his particular system characteristics such as given as follows:

CBD	RUSH	392 Veh for 6 hrs.	=	2352 Veh. Hours
CORR	RUSH	588 Veh for 6 hrs.	=	3528 Veh. Hours
DAB	RUSH	490 Veh for 6 hrs.	=	2940 Veh. Hours
CBD	SLACK	78 Veh for 18 hrs.	=	1404 Veh. Hours
CORR	SLACK	118 Veh for 18 hrs.	=	2124 Veh. Hours
DAB	SLACK	98 Veh for 18 hrs.	=	1764 Veh. Hours
Total Operating Time per day				14,112 Veh. Hours

Some typical sector merge configuration found in the CBD area are shown in Table 1 (reference 1).

TABLE 1. CBD SECTORS USED IN COMPUTATION

SECTOR NUMBER	SECTOR DRAWING (DIMENSIONS IN MILES)	QUANTITY USED	DESCRIPTION
1		4	This sector illustrates a 90 degree turn with no merge or demerge points.
2		2	This sector illustrates a demerge section.
3		2	This sector illustrates a merge section.
4		2	This sector illustrates a demerge section.
5		2	This sector illustrates a merge section.
6		2	This sector illustrates a connecting section.

3. PROCEDURE

In designing a complex automated ground transportation system such as Dual Mode it is necessary to assure that an acceptable level of service is designed for. A convenient method to accomplish this is in terms of system availability. Availability for this type of system can be expressed as the percent of time a system is expected to be available for service, including interruptions which may result from system failures, relative to the time the same system without failure would be available. This can be expressed either in terms of vehicle or passenger availability.

The purposes of the study from the contractors viewpoint (reference 4) were to maximize the Dual Mode system availability by:

a) establishing an appropriate availability goal to assure substantially uninterrupted and sustained service against a Phase III scenario;

b) using that goal, through a computer program, as the basis for apportioning failure rates and delay times;

c) requiring the subsystems and the operational and recovery strategies to meet the apportioned failure rates and delay times, for example, by the incorporation of redundancies where necessary.

In establishing an availability goal, it was considered necessary to provide a high level of passenger service while minimizing the occurrence of vehicle stoppages on the guideway. Both requirements were considered essential in the development of the system availability goal.

To establish an availability goal it was first necessary to define the proposed Dual Mode concept in terms of its major subsystems. The major subsystems were further defined in terms of typical component hardware that could accomplish the function of the subsystem. Failure rate data were then obtained/established for subsystem components using, where possible, empirical failure rate data from similar components used in comparable applications

or by using MIL-HANDBOOD-216A as a guide to predict expected component failure rates.

Figure 2 (reference 2) shows the elements of a conceptual system and Figure 3 (reference 4) gives a typical block diagrams of the basic component.

From an availability analysis point of view, the FMEA is perhaps the most crucial aspect of the analytical procedure. It requires detailed engineering design review with emphasis on safety, reliability and maintainability. Table 2 (reference 5) is a typical format that was used in the FMEA.

Once the failure modes have been established, then reliability failure rates can be apportioned. The assignments of failure rates is usually accomplished by an iterative process that a) determines failure rates based on past performance of related designs, b) includes design reviews of vital functions, and c) appropriates values based on performance requirements and trade-off analysis. Table 3 (reference 6) shows some results of this apportionment procedure that was used for the Dual Mode Program.

The following sections on availability calculations, vehicle delay per failure, the availability computer program, and delay time rational are taken from reference 4 and discuss the general concepts that were used in the availability study.

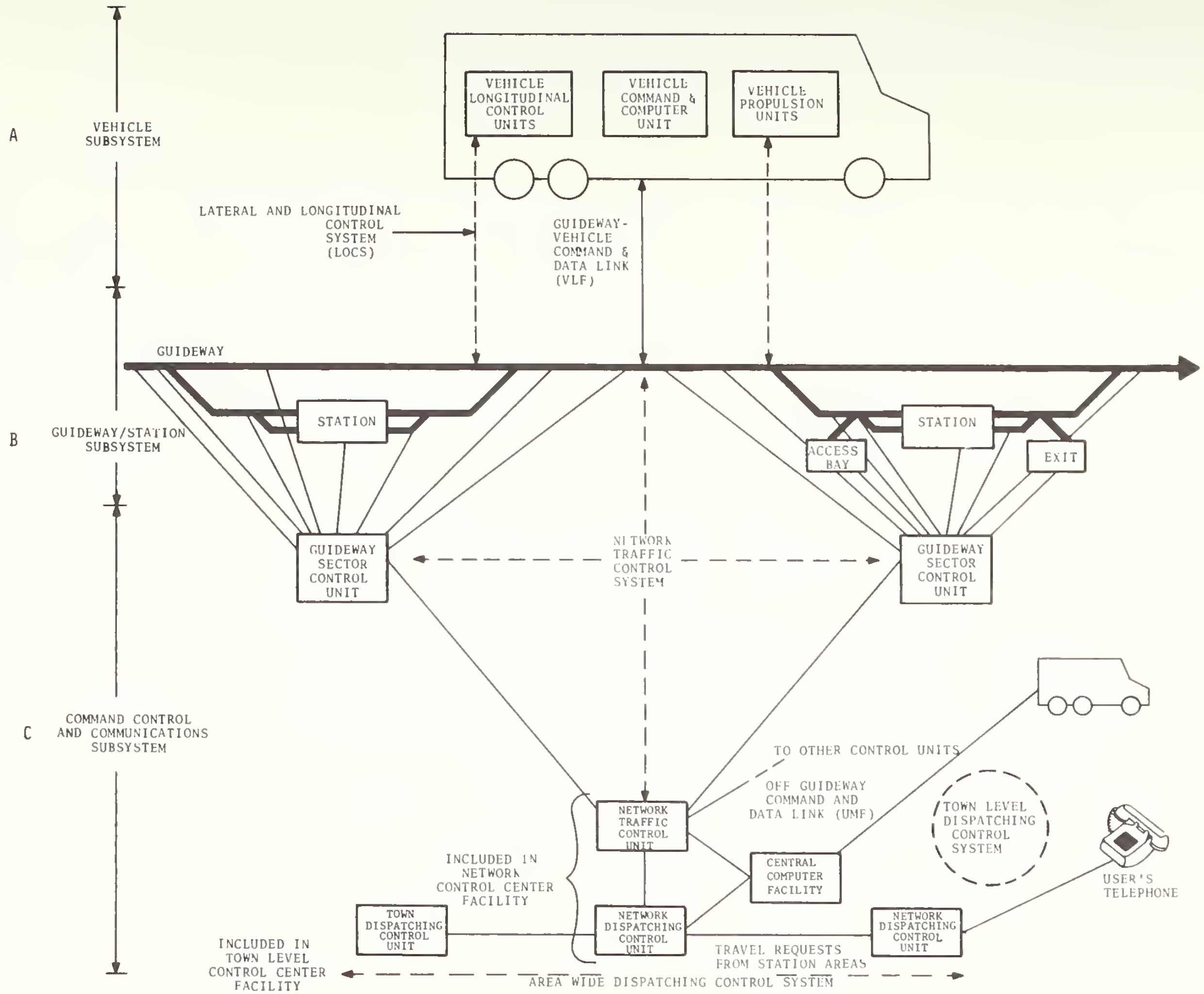


Figure 2. Dual Mode Transit Subsystem

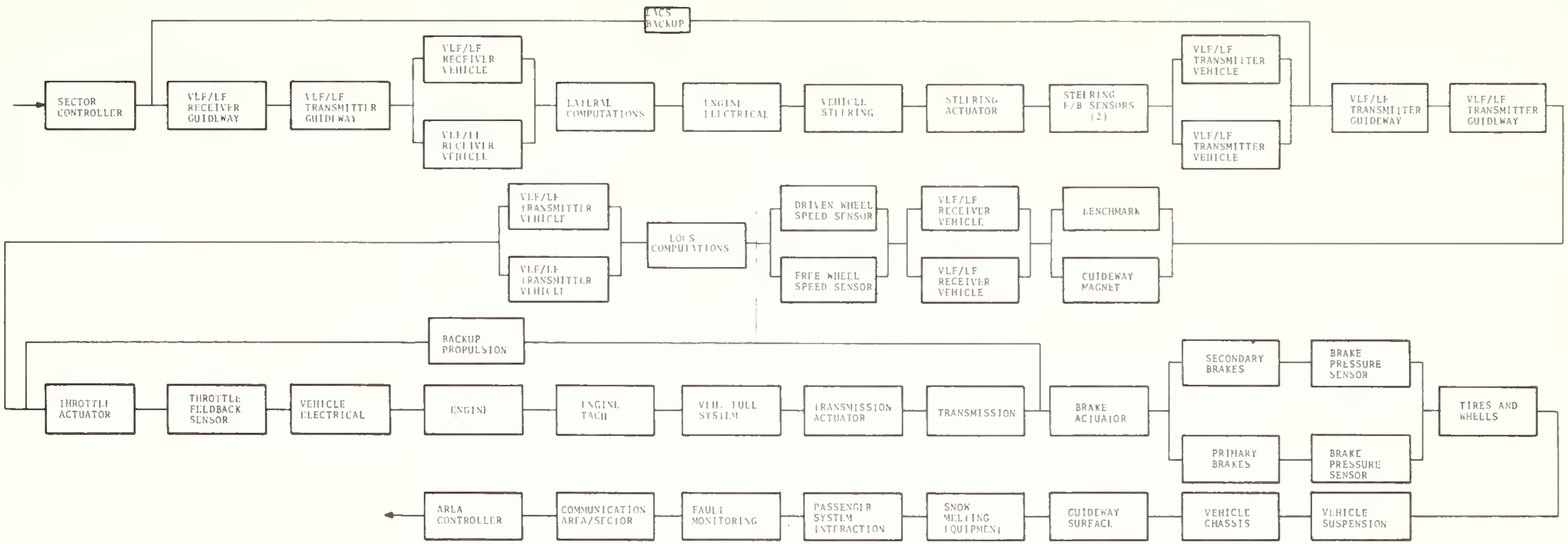


Figure 3. On-Guideway System Configuration

TABLE 2. TRANSPORTATION TECHNOLOGY, INC., FAILURE MODE AND EFFECT ANALYSIS

PROJECT DUAL MODE
SUBSYSTEM STATION
ASSEMBLY BUS HANDLING EQUIPMENT

SHEET 26 OF 28
PREPARED BY E. Hagensto-
APPROVED BY R. Dreith
DATE 5-31-74 REP. None

ITEM IDENTIFICATION AND FUNCTION	DRAWING NUMBER	REF. DESIG.	FAILURE MODE	POSSIBLE CAUSE	INTERMEDIATE EFFECT OF FAILURE	FAILURE EFFECT ON	METHOD OF DETECTION	COMPENSATION AND CORRECTIVE ACTION	COMP TIME	PROB OF FAIL.	FAIL. CLASS	REMARKS
Bus Check Station Provides a gate for automobile & bus check in to the station. It also provides sensing of vehicle size & weight denies entry if bus/auto is beyond acceptable transporter limits.			Improper gate operation Loss of bus/auto access to station.	Mechanical gate or switch failure. Failed sensor indicates bus/auto out of acceptable limits	Loss of bus/auto access to elevator or ramp to docks.	Station Minor degradation. System Possible passenger delays cause minor system degradation	Maintenance required.	Maintenance required.			4	
			Permits erroneous access of out-of-limit bus/auto to station.	Failed sensor.	Station elevator or dock blocked due to oversize vehicle. (See remarks.)	Station Degradation due to loss of dock or elevator. System Possible passenger delay causes minor system degradation.	Indication of elevator or dock/vehicle anomaly provided at CCS.	Maintenance required.			4	Critical functions to be implemented in a failsafe manner. Elevator & dock prevent acceptance of oversize/undersize bus/auto. Overweight bus/auto would probably stall vertical suspension of transporter, resulting in dock loss condition.
Elevator Provides for raising & lowering buses/autos to and from assigned loading dock. Multiple elevators & ramps provide access to docks.			Loss of, or improper elevator operation.	Elevator mechanism or control failure.	Loss of elevator bus/auto reassigned to another dock; uses alternate elevator or ramp.	Station Possible passenger delay. System Minor degradation due to reduced station throughput capacity.	Operator observation & indication at CCS.	Maintenance required.			4	Critical functions to be implemented in a failsafe manner.

TABLE 3. RELATIVE FREQUENCIES OF FAILURE

DMTS SUBSYSTEM COMPONENT	FAILURE OCCURRENCE (Nf)	FAILURE RATE (f106)	PERCENT TOTAL FAILURES (f:f)
Brakes	247	49.40	21.8
Tires	136	27.20	12.0
Wheels	3	0.60	0.3
Power Train	167	33.40	14.7
Steering	4	0.80	0.4
Electrical	211	42.20	18.6
Suspension	107	21.40	9.5
Environmental Control	39	7.80	3.4
Body	43	8.60	3.8
Doors	43	8.60	3.8
Windows	25	5.00	2.2
Interior	57	11.40	5.0
Axles	1	0.20	0.2
Fuel	23	4.60	2.0
Oil	26	5.20	2.3

4. AVAILABILITY CALCULATIONS

The availability of the DMTS was defined in the UMTA Dual Mode Contract, Statement of Work Section, by the following relationship:

$$\text{Availability} = \left(1.0 - \frac{\text{sum of delays of all vehicles in operation}}{\text{sum of operation time of all vehicles}}\right) \quad (1)$$

The calculation of vehicle delay time is the primary factor in estimating an availability figure of merit. Delay time is produced by vehicles that have failures and by those that are involved in guideway stoppages due to other vehicles failing. The total vehicle delay time is a function of the following two factors:

- Vehicle failure rate = (failures/kilometer)
- Vehicle delay per failure = TTD (total time delay/failure)

The philosophy of calculating availability as indicated in reference (4) based on dividing system operation up into segments which can be assumed to have constant vehicle flow rates. For constant vehicle flow conditions, a vehicle stopped on the guideway will be assumed to produce a specific amount of delay time. The frequency of failures in the various segments can then be multiplied by the associated vehicle delay to arrive at delay per unit of time (a day). Equation 2, below, describes the parameters used to define availability for this analysis technique.

$$\text{Availability} - 1.0 - \frac{\sum_{i=1}^{4} DT_i}{\sum_{i=1}^{4} OT_i} \qquad (2)$$

where

$$DT_i = \left[(\lambda v_i)(N_i)(T_i) \right] \left[TTD_i \right] \quad \text{(vehicle hr./day)}$$

$$OT_i = (N_i)(T_i) \quad \text{(vehicle hr./day)}$$

λ = failure rate (failure/km)

v_i = average velocity (km/h)

N_i = number of vehicles in operation

T_i = operating time period (hr)

TTD_i = delay time per failure (vehicle hr/failure)

The subscript i on the parameters denotes the different guideway operation segments. These different conditions are time of day (peak or slack system passenger load) and region of guideway network (CBD or corridor).

The subscripts are assigned as follows:

1 = CBD during rush hours, peak load

2 = CBD during off-rush hours, slack load

3 = Corridor during rush hours, peak load

4 = Corridor during off-rush hours, slack load

The total system availability was, therefore, determined from the sum of delay and operating times for the four different conditions.

5. VEHICLE DELAY PER FAILURE

Given a vehicle has had a system failure on the guideway, it is necessary to determine the number of vehicles delayed and total delay time generated by this single vehicle failure. For this analysis, guideway operation has been divided up into four segments, each of which is assumed to have constant vehicle flow as described above. For example, all CBD lanes at peak load times will be considered to have a constant flow of 10,000 passengers per hour. This 10,000 passengers per hour value was part of the scenario. With these flow assumptions and a few others, it was possible to write a fairly simple model of a guideway failure.

The additional assumptions on which this analysis is based are listed below:

a) A potentially delayed vehicle is one that at time t_o (time of vehicle failure) has been scheduled for a trip across the blocked link.

b) After t_o and before the link blockage is cleared, no new vehicle trips are scheduled over the blocked link.

c) After time t_o, all vehicles proceed without altering their paths, and those scheduled to cross the blocked link slow down as they approach the blockage and park at some close spacing.

d) No links are blocked other than the one containing the failed vehicle.

The conditions that exist at the time of failure (t_o) consist of a flow of vehicles ($\mathring{N}_o$) over the link and a set of vehicles (N_o) scheduled to cross the link. After t_o the flow of vehicles decreases because no new trips are being scheduled. This flow rate decrease is assumed to be linear with time and reaching zero at t_n (the time when the furthest vehicle in the N_o set reaches the blockage).

At time t_c the failed vehicle will have been cleared and the link will be open for the stopped vehicles to move away. The stopped vehicles will, however, not be able to simultaneously startup because

at the minimum they must be separated by one headway because all downstream merges to the next station stop must be prescheduled. Therefore, during high system load, a significant time may be required to restart a queue of vehicles stopped on the guideway. The rate at which vehicles leave the blockage area ($\mathring{N}_{out}$) was assumed to be constant with time because it is a function of guideway traffic (percentage of downstream merge slots available). The variable t_{cc} is used to represent the time when the link is completely clear.

Equation 3 below describes the number of vehicles in the queue (N) as a function of flow rates and time.

$$N = \int_{o}^{t} (\mathring{N}_{in} - \mathring{N}_{out}) d_t \qquad (3)$$

where:

t = time after t_o at which the queue contains N vehicles.

The amount of time delay (TD) associated with each vehicle in the queue must be determined to establish total time delay (TTD) for a single failure. The TD for a delayed vehicle is a function of when the vehicle enters the queue. That is, the first vehicle in the queue must wait the amount of time required to clear the failed vehicle ($t_c - t_o$). Successive vehicles will have time delays (TD) and described below in equation 4. The time delay is zero for vehicles entering after t_{cc}, which is the time that the blockage is completely clear.

$$TD = (t_c - t_o) - t + \frac{N}{\mathring{N}_{out}} \qquad (4)$$

Knowing the flow of vehicles ($\mathring{N}$) into the blockage area as a function of time and the time delay (TD) associated with these vehicles, the total time delay (TTD) caused by a single vehicle stoppage can be calculated. Equation 5 describes TTD as a function of $\mathring{N}_{in}$ and TD.

$$TTD = \int_{o}^{t_{max}} TD\ (\mathring{N}_{in}) d_t \qquad (5)$$

where t_{max} is the smaller of t_n and t_{cc}. That is, if all N_o vehicle queue up before t_{cc} then $t_{max}=t_n$.

TTD is therefore the total time delay caused by a single vehicle stoppage on the guideway and provides the last input to equation 2 above.

6. AVAILABILITY PROGRAM

The computerized system availability program (reference 4), de veloped for the Dual Mode Transportation System, was designed so as to utilize input of component failure rates, class of failure and location; and, based on expected delay times, establish a Dual Mode system availability prediction. Failure rates were assumed constant, and the reliability of the system was to obey the exponential function:

$$R = e^{-\lambda_s t}$$

where λ_s is the system failure rate and t is the time at which the reliability is measure.

Using a Monte Carlo process and the failure rates for identifiable components of the system, a time at which each component might be expected to fail could be calculated. This was accomplished by first selecting a random number between 0 and 0.9999 + and setting the selected value equal to the probability of failure. The probability of an item failing can be written as:

$$U = 1 - R$$

where U = unreliability of a component
R = reliability of the component

Using the exponential reliability function yields:

$$U = 1 - e^{-\lambda_c t}$$

where λ_c is the component failure rate. Letting U equal the random number selected by the Monte Carlo process, the above expression can be solved for t, the component operating time at which the probability of failure value is reached.

This process is repeated for each identifiable component failure rate in the system and results in probable component failure times, based on the random number selection. The failure times are then used to establish which component shall fail and at what time the next component failure will occur. The process is then repeated to determine which component next fails and when. This procedure provides a weighting factor in the program, where the occurrence of

failures for high failure rate components will be proportionately higher than the failure occurence of low failure rate components. The component failure is then evaluated for its influence on system delay time. For simplicity in the program structure, the area computer (one unit), sector computer (assumed 70), benchmarks and guidance loops (assumed 768), and the guideway, whose failure rates are dependent on the number of units involved and the system operating time, have been included by using equivalent vehicle operating time failure rates.

To effect control in the program, two times bases, system time and vehicle time, are used. System operating time considers the Dual Mode system as a single unit, i.e., one 24-hour day of operation results in 24 hours of system operation. Vehicle operating time is used to generate the cumulative or accrued time on vehicle mounted components, i.e., 1500 vehicles in the system, operating for one hour, would result in 1500 hours of vehicle or vehicle mounted component operating time.

In addition to identifying subsystem components and determining their failure rates, three failure rate categories were established: on-guideway failures, off-guideway failures, and failures which could occur both on and off the guideway. The four special case failures noted above (area computer failure, sector computer failure, guidance loops and benchmark failures, and failure of the guideway and its associated snow melting equipment) are separately evaluated in the program because of their unique influence on system operation. System operation is divided into a repeating cycle of: three (3) hours rush period, six (6) hours nonrush period, three (3) hours rush period, and twelve (12) hours nonrush. The program determines the specific component failure and the time at which the failure occurs, and then the accrued vehicle operating time of the next failure is established.

A random number process is again used to establish where in the Dual Mode system the previously established failure occurred. To accomplish this, the system is divided into three (3) failure areas: the Central Business District (CBD), the radial corridors (CORR) extending outward from the CBD, and the DIAL-A-BUS (DAB)

zone which is off guideway and is serviced by driver-operated vehicles. The percentages of time a vehicle spends in each area is used as a weighting factor for the random number process. The CBD is comprised of 20 miles automated guideway, the corridors contain 120 miles) of automated guideway, and the DIAL-A-BUS area is comprised of 700 miles of off-guideway streets. Using the vehicle capacity and flow rates specified in reference (1), the above parameters result in an average of 14,154 vehicle operating hours per day. Twenty-seven percent of this time is accrued in the CBD, 40 percent in the corridors, and 33 percent of this in the DIAL-A-BUS zones. The program is organized such that a selection of a random number between 0.000 and 0.265 would result in a failure in the CBD, values between 0.266 and 0.667 represent failures in the corridors, and values from 0.668 to 1.000 represent failures in the DIAL-A-BUS zones. The specific component failure and where it occurred, along with the time at which the failure occurred, are then used in selecting the proper delay time constant to be included in the availability computation. A top level (reference 8) program flow chart is shown in Figure 4.

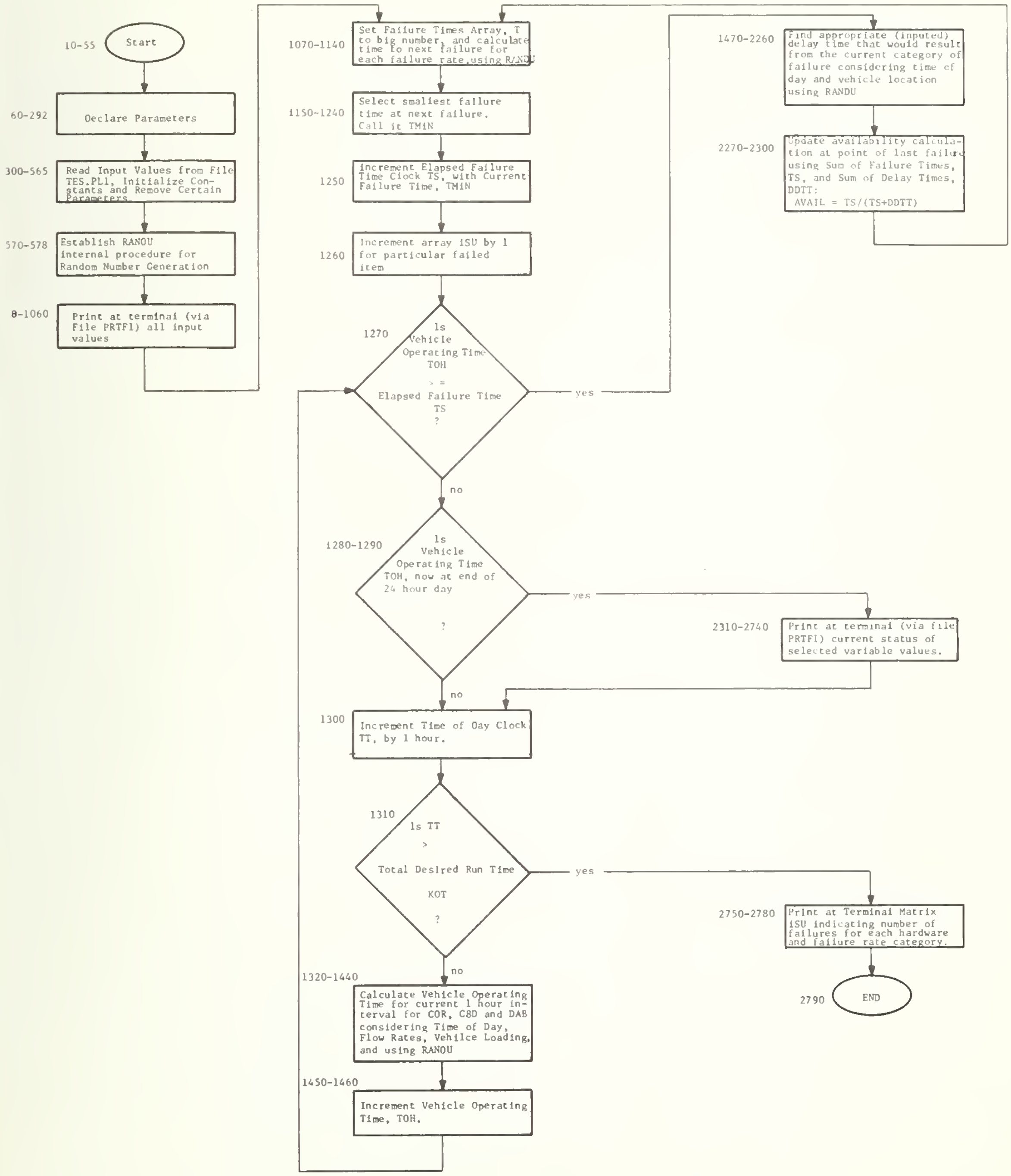


Figure 4. Availability Program Flow Network (DMTVSAS.PL1)

7. DELAY TIME RATIONALE

The delay time constants are based on operational stratagems for each class, area, and time of failure expected to be experienced by each identifiable subsystem component. Delay times were identified for the two operating periods, rush and nonrush, are times caused by a vehicle stoppage, a Class A failure.

The on-guideway Class B failure delay times shown were based on the assumption that the component failure would result in the vehicle slowing to half speed and exiting at the first available station, in this case, the next station. Failures were also assumed to occur halfway between stations, and following vehicles were required to slow to the extent required to maintain safe headways.

The on-guideway Class C failure delay times were estimates of the system delay caused by dispersing the passengers of a failed vehicle into the system. Since it was assumed that the failed vehicle could maintain guideway speed but must be removed at the next station, vehicle delays due to slowing down were not encountered for this situation.

Comparisons developed that may be deemed necessary in the future is to be performed under other technology development program. However, the original Dual Mode Program had a Phase II development effort planned, that among other items, was to expand on availability. Therefore, some flexibility was given to the contractor as to the scope and amount of detail required for the Phase I availability effort. Consequently, during Phase I not all the contractor took the same approach. Table 4 compares the procedures developed by the three contracts (demoted contractor A, contractor B, and contractor C). Contractor C didn't use an iterative procedure or the Monte Carlo Technique during Phase I but was planning these activities for Phase II.

TABLE 4. AVAILABILITY PROCEDURES

	CHARACTERISTICS	CONTRACTOR A	CONTRACTOR B	CONTRACTOR C
I	SUBSYSTEM CLASSIFICATION	BY FUNCTIONAL REQUIREMENTS	BY MAJOR HARDWARE COMPONENTS	BY MAJOR HARDWARE COMPONENTS
	A LEVEL OF DETAIL	COVERED ALL REQUIREMENTS	DETAILED BREAKDOWN OF SUBSYSTEMS	GROSS CLASSIFICATION
II	FAILURE RATE SOURCES	IN-HOUSE EXPERIENCE	MIL STANDARDS	MIL STANDARDS/PUBLISHED TRANSIT DATA
	A SUBSYSTEM FAILURE RATE DERIVATION	BY APPORTIONMENT AND DESIGN REVIEW PERFORMED ITERATIVE ANALYSIS.	1) BY ASSIGNMENT FROM DATA SOURCES ITERATIVE ANALYSIS INDICATED TOO LOW AVAILABILITY GOAL 2) APPORTIONMENT AND DESIGN REVIEW	BY ASSIGNMENT FROM DATA SOURCES ANALYSIS INDICATED TOO LOW AVAILABILITY GOAL. NO ITERATIVE ANALYSIS PERFORMED
III	FAILURE MODE AND EFFECT ANALYSIS (FMEA)	PERFORMED ON COMPLETE SYSTEM. IDENTIFIED FAILURE MODES CONTRIBUTING TO VEHICLE DELAYS	IDENTIFIED ONLY FAILURE MODES CONTRIBUTING TO VEHICLE DELAYS	IDENTIFIED ONLY FA FAILURE MODES CONTRIBUTING TO VEHICLE DELAYS ON A GROSS LEVEL
IV	FAILURE MODE AND CLASSIFICATION	CLASS A - CAUSES VEHICLE STOPPAGE CLASS B - VEHICLE CAN PROCEED AT A REDUCED VELOCITY BUT MUST BE REMOVED AT NEXT STATION CLASS C - VEHICLE CAN PROCEED AT NORMAL VELOCITY BUT MUST BE REMOVED AT NEXT STATION	SAME	SAME

TABLE 4. AVAILABILITY PROCEDURES (CONTINUED)

	CHARACTERISTICS	CONTRACTOR A	CONTRACTOR B	CONTRACTOR C
V	FAILURE MODE DETERMINATION	MONTE CARLO TECHNIQUES	MONTE CARLO TECHNIQUES	USED PROBABILITY MODELS BASED ON AVERAGE VALUES
	A MONTE CARLO TECHNIQUES	USED THE EXPONENTIAL DISTRIBUTION TO DETERMINE FAILURE PROBABILITIES	DETERMINED SAMPLING DISTRIBUTION FROM FAILURE RATES TO DETERMINE FAILURE PROBABILITIES	NA
	B TIME INTERVAL OF ANALYSIS	DAILY	DAILY	DAILY
VI	CLASSIFICATION OF VEHICLE LOCATIONS	CATEGORIES CAT A - ARTERIAL BUSINESS DISTRICT CAT B - CORRIDORS CAT C - DIAL-A-BUS AREA	SAME	SAME
VII	DETERMINATION OF LOCATION OR RAILED VEHICLE	MONTE CARLO	MONTE CARLO	PROBABILITY MODEL

The present estimation of availability utilizing Monte Carlo computer techniques, will be broadened for Automated Guideway Technology (AGT) application. A time-dependent event-type simulation will be used to bound the passenger operational times and delay times for specified conditions. In addition it will be used to evaluate the abnormal operating procedures, vehicle, passenger and system recovery strategies. The system availability shall then be determined.

The effort will consist of:

a) develop an economical procedure by which vehicle/passenger delay times can be calculated for the various links, station, merge/demerge points, ramps, etc., in relationship to the network configuration, trip demand and vehicle traffic flow.

b) developing appropriate procedures by which passenger-delays encountered at the entrances and exits of AG systems due to improper system management operations such as scheduling, routing and reservation procedures can be calculated.

c) develop models to calculate

    1) vehicle flow rate in blocked segment of guideway,

    2) vehicle flow rate out of blocked segment of guideway,

    3) first vehicle removal time,

    4) time to clear blockage,

    5) number of vehicles affected,

    6) total delay time, and

    7) average delay per vehicle.

8. REFERENCES

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