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SYSTEMS OPERATION STUDIES FOR AUTOMATED GUIDEWAY TRANSIT SYSTEMS

SUMMARY REPORT

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

FEBRUARY 1980
FINAL REPORT

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16. Abstract The results of the AGTT-SOS project are summarized in this report. The characteristics of 43 existing or proposed AGT systems were inventoried, and the information was used to develop a system classification structure. Classes of metropolitan and activity center demand applications were defined, and demand matrices based on survey data from representative locales were generated. A restricted number of combinations of system classes, demand types, and network types were developed as representative deployment scenarios for analysis. An extensive list of possible performance measures was developed and then condensed to an initial set of 14 system level measures. The measures were subsequently re-evaluated in light of actual analysis experience gained during the SOS project.

A comprehensive set of computer software has been developed and tested. The various computer programs permit the simulation of entire AGT systems as well as major subsystems including stations, links, merges, and intersections. The software set includes analytic models for the evaluation of demand, feeder system characteristics, cost, and availability. The set also includes interactive graphic display programs and a number of programs to aid in data base manipulation and programming. Trade-off analyses were performed to define 14 generic AGT systems representing SLT, ART, and GRT deployments in various application areas. The performance and cost of several different systems deployed in similar applications were compared to identify the impacts of system type and network topology on system performance. Control system design alternatives and performance characteristics were analyzed in the context of isolated link and merge elements. Alternative operational control strategies were evaluated in the context of a complete system.

17. Key Words Automated Guideway Transit, Downtown People Mover, Shuttle Loop Transit, Group Rapid Transit, Automated Rail Transit, Automated Vehicle Control, System Simulation, AGT System Cost, AGT System Availability, Systems Operation Studies

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PREFACE

In order to examine specific Automated Guideway Transit (AGT) developments and concepts and to build a better knowledge base for future decision-making, the Urban Mass Transportation Administration (UMTA) has undertaken a new program of studies and technology investigations called the UMTA Automated Guideway Transit Technology (AGTT) program. This program is being administered through the office of New System and Automation at UMTA whose director is Charles Broxmeyer. Duncan MacKinnon is the Program Manager for the AGTT program. The objectives of one segment of the AGTT program, the Systems Operation Studies (SOS), are to develop models for the analysis of system operations, to evaluate AGT system performance and cost, and to establish guidelines for the design and operation of AGT systems. A team headed by GM Transportation Systems Division was awarded a contract by the Transportation Systems Center (TSC) in June 1976 to pursue these objectives. Other team members are IBM Federal Systems Division (FSD), GM Delco Electronics Division, and Aviation Simulations Incorporated. The Technical Monitor at TSC for the AGTT-SOS project was Arthur Priver. He was primarily assisted by Thomas Dooley, Li Shin Yuan, and Larrine Watson, also of TSC.

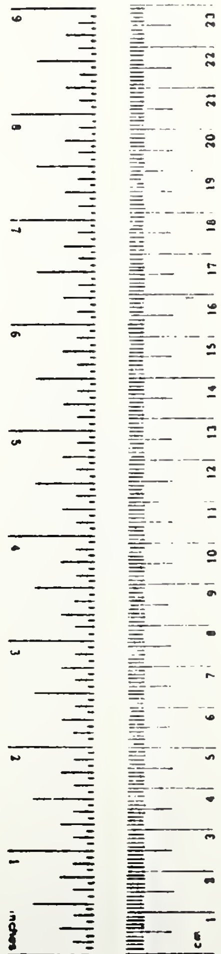
The results of the Systems Operation Studies project are summarized in this final report. The results include eight major computer programs and associated documentation, eight data base utility programs and documentation, an extensive data base, and numerous reports describing the analysis of SLT, ART, and GRT systems and alternative operational control subsystems. Individual reports which give more complete descriptions of each task in the Systems Operation Studies are referenced as appropriate throughout the report.

The Systems Operation Studies Program was completed under the direction of James F. Thompson, SOS Program Manager at GM TSD. Software development and documentation was the responsibility of Robert N. Oglesby, task leader at GM TSD. James G. Bender and Ronald A. Lee, task leaders at GM TSD, were responsible for the planning, execution, and documentation of the analysis tasks. The following GM TSD engineers contributed significantly to the completion of the SOS project: F.S.A. Alberts, J.D. Boldig, L.S. Bonderson, R.W. Cowan, J.F. Duke, A.D. Fenderson, T.M. Linden, M.J. Rizzuto, G.C. Sullo, and J.H. Waller. Software development and documentation at IBM were the responsibilities of R. Blanchard, Project Leader at IBM FSD. Major contributors to the program design and coding effort at IBM FSD were D. Cairns, D. Crehan, W. Daniell, P. Dorazio, M. Handelman, A. Melgaard, B. Nickerson, C. Pollastrino, and D. Winfield. H. Fue, Project Leader at GM Delco Electronics Division, was responsible for the development of subsystem reliability data at Delco Electronics. P. Gregoire, GM Delco Electronics Division, developed much of the reliability data used in the Systems Operation Studies. E. Joline of Aviation Simulations Incorporated was responsible for a movie which illustrates the basic capabilities and uses of the Downtown People Mover Simulation.

METRIC CONVERSION FACTORS

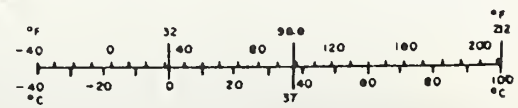
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



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LIST OF ACRONYMS

AGT	Automated Guideway Transit
AGTT	Automated Guideway Transit Technology
AP	Passenger-Based Availability
ART	Automated Rail Transit
AV	Vehicle-Based Availability
C	System Cost
CBD	Central Business District
CLIST	Command Procedures
COP	Comparison Output Processor
DDP	Deterministic Demand Preprocessor
DESM	Discrete Event Simulation Model
DOCM	Detailed Operational Control Model
DPM	Downtown People Mover
DPMS	Downtown People Mover Simulation
DPMDEM	DPMS Demand Preprocessor
DPMNET	DPMS Network Preprocessor
DSM	Detailed Station Model
E	Energy Consumption
FIFO	First-In, First-Out
FSM	Feeder System Model
GM TSD	GM Transportation Systems Division
GRT	Group Rapid Transit
GVMP	Guideway Vehicle Motion Program
HIPO	Hierarchical-Input-Process-Output
IBM FSD	International Business Machines Federal Systems Division
IGRT	Intermediate (Vehicle) Group Rapid Transit
JCL	Job Control Language
LGRT	Large (Vehicle) Group Rapid Transit
LU	Land Utilization
LUDP	Link Utilization Display Program
NBM	Network Build Module
NIA	Noise Impacted Area
PA	Air Pollution
PARAFOR	Structured Superset of Fortran
PDL	Program Design Language
PQLDP	Passenger Queue Length Display Program
PROCLIB	Library of Catalogued Procedures
PRT	Personal Rapid Transit
PS	Percent Standing
PU	Percent Unserved
SAM	System Availability Model
SCM	System Cost Model
SGRT	Small (Vehicle) Group Rapid Transit
SMSA	Standard Metropolitan Statistical Area

LIST OF ACRONYMS (con't)

SOS	Systems Operation Studies
SPM	System Planning Model
T	Transfer
TRT	Average Travel Time
TSC	Transportation Systems Center
TT	Average Trip Time
UMTA	Urban Mass Transportation Administration
UTPS	Urban Transportation Planning System
VE	Vehicle Efficiency
VTT	Average Variation in Trip Times
WT	Average Wait Time

1.0 INTRODUCTION

In June 1976, the Transportation Systems Center (TSC) awarded the Automated Guideway Transit Technology Systems Operation Studies (AGTT-SOS) contract (DOT-TSC-1220) to GM Transportation Systems Division with IBM Federal Systems Division as a major subcontractor for software development. The Systems Operation Studies is a part of a larger study of automated guideway transit technology supported by the Urban Mass Transportation Administration (UMTA). The AGTT-SOS project was a general study of the applicability and capability of automated guideway transit systems. The statement of work identified the project objectives as two-fold: "(1) to conduct comparative automated guideway system analyses evaluating the system cost, performance, and operating characteristics of a number of generic systems in representative urban network configurations, and (2) to develop and document a set of proven computer models that will allow the contractor to perform the analyses...and allow planners to perform similar analyses of automated guideway systems...." Dealing with "generic" and "representative" systems and network configurations required the development of well-defined groupings of systems, networks, and demands so that useful results with broad application could be obtained, while limiting investigations to a reasonable number of examples of system deployments.

Coupled with the need for generality was a need to provide a relatively detailed representation of system characteristics so that attributes specific to automation could be identified and evaluated. Another influence in favor of a detailed system representation was the requirement that the software tools be useful for supporting system planning and design operations for specific real deployments such as the current downtown people movers. These parallel goals of developing generalized parametric data and providing the ability to model a variety of specific applications provided the guidelines for selecting the representative applications for analysis and developing the modeling software.

This Final Report summarizes the work done by GM TSD and its subcontractors in satisfying the AGTT-SOS contract. This section of the report identifies the portion of the project that was completed by each contractor, briefly describes the major tasks, and identifies the major deliverables associated with each task.

1.1 SUBCONTRACTORS

In performing the SOS work, GM TSD employed three subcontractors to provide technical strengths in specific areas. The largest subcontract was with IBM Federal Systems Division. The subcontract covered development and documentation of the Discrete Event Simulation Model (DESM), the Detailed Station Model (DSM), and the Detailed Operational Control Model (DOCM). These computer programs are central to the SOS software set and represent a majority of the software developed. IBM FSD brought their formidable software expertise and background of Independent Research and Development work in the area of AGT system simulations to the GM TSD team and were major contributors to the successful completion of the contract.

The second subcontract was with Delco Electronics Division of GM . Delco drew on many years of military and aerospace hardware development and testing experience to compile necessary basic reliability data and to calculate subsystem reliability estimates for each of the SOS representative applications. This work established the subsystem failure rates used in the system availability analyses for each deployment.

The final subcontractor on the GM TSD team was Aviation Simulations Incorporated (ASI). ASI developed a movie using computer animation techniques which illustrates the basic capabilities and uses of the Downtown People Mover Simulation (DPMS).

1.2 AGTT-SOS TASKS

The work performed under the AGTT-SOS contract was organized into eleven major technical tasks as illustrated in Figure 1-1. The content of each of these tasks is briefly described in this section.

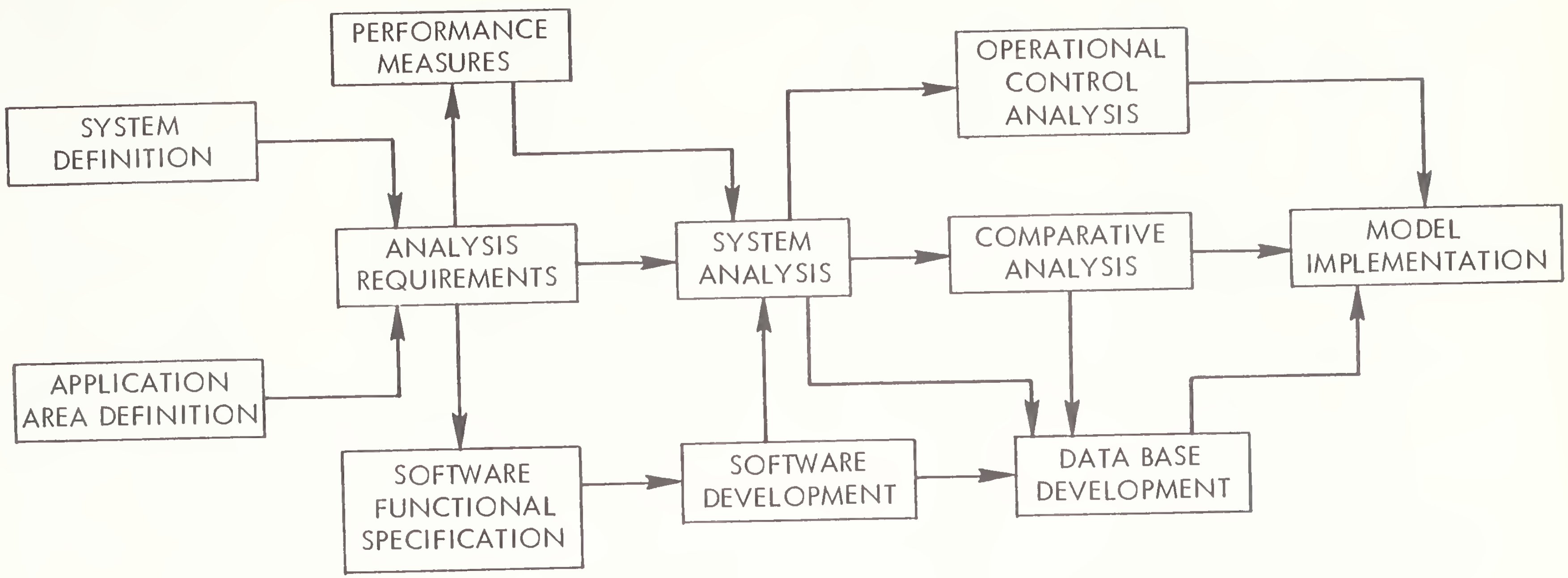


FIGURE 1-1. AGTT-SOS MAJOR TASKS

System Definition

Through a literature search and personal visits, data was collected on 43 existing, planned, or proposed AGT systems. For the sake of efficiency, all data collection work was combined under this task without regard to whether the data covered system equipment or deployment scenario characteristics. This information served as the basis for the classification of AGT systems accomplished in this task as well as the development of the set of representative deployment scenarios in the Application Area Definition Task.

A set of typical system characteristics were specified for each system class, and feeder system characteristics to be modeled in the later analysis tasks were selected. In this context, a feeder system is a manually operated public transit system whose primary function is to provide transportation between AGT stations and off-guideway origins and destinations.

Application Area Definition

Information on deployment characteristics collected in the first task was evaluated. Since each deployment scenario is defined by a demand pattern, a guideway network, and a set of system equipment, sets of representative demand types and network types were established. A subset of the possible combinations of system classes, demand types, and network types was selected and developed as representative deployment scenarios for the subsequent analysis tasks.

Analysis Requirements

One of the first analysis tasks in the Systems Operation Studies was to specify the requirements for each major analysis and to formulate an analysis plan. The plan established the sequence of analysis steps to be performed for each major analysis task. The requirements detailed the design goals, parameters to be varied, measures to be evaluated, and operating policies to be considered in the analysis of each representative deployment. In addition to defining the analysis tasks, the requirements served as a reference for the development of software functional specifications. Since it was expected that early analysis results would indicate necessary or desirable changes in later analytic work, the initial documents were updated to include revisions in approach or task content and to provide detailed requirements for review prior to starting each major phase of the analysis.

Development of Effectiveness Measures

In the initial phase of the measures development task a literature review was performed to establish an overview of previous work done in the area of system effectiveness measures. An extensive list of possible performance measures was developed which reflect the often conflicting interests of users, planners, designers, and operators. This list was evaluated and condensed to an initial set of 14 system level measures to be used in the SOS comparative analyses. During the analysis process many other more detailed parameters and measures were considered, and the SOS software set is capable of evaluating several hundred detailed measures covering most aspects of system operations. However, it was necessary to establish a small set of aggregated system level measures for better comprehension.

The final phase of this task was the reevaluation of the selected measures in light of actual analysis experience gained during the SOS project.

Model Requirements and Functional Specifications

The system information, application area characteristics, analysis requirements, and performance measures were translated into a set of computer program functional specifications which defined the set of computer programs to be developed and their relationships to each other and to the SOS data base. The data base is a collection of data files and software packages that have been brought together to assist in the development and application of the AGTT-SOS computer programs. This task also included the development of a set of software standards to control the development, documentation, acceptance testing, and implementation of the software.

Software Development

A set of models was designed and developed based on the specifications developed in the previous task. The basic software developed during the Systems Operation Studies include three analytic models and four simulation models as follows:

Analytic Models
- Feeder System Model (FSM)
- System Cost Model (SCM)
- System Availability Model (SAM)

Simulation Models
- Detailed Station Model (DSM)
- Detailed Operational Control Model (DOCM)
- System Planning Model (SPM)
- Discrete Event Simulation Model (DESM)

The DESM was further developed into the Downtown People Mover Simulation (DPMS) to meet the special needs of integration within the Urban Transportation Planning System (UTPS). Four interactive graphic display programs were designed and developed to provide enhanced input and output capability. The graphics programs include the following:

- Network Build Module (NBM)
- Guideway Vehicle Motion Program (GVMP)
- Passenger Queue Length Display Program (PQLDP)
- Link Utilization Display Program (LUDP)

Finally, a number of data base manipulation and programming aids were developed to facilitate coding and to make the programs and analysis data easier to use. These data base utilities include the following:

- Comparison Output Processor (COP)
- Structured Programming Preprocessor (PARAFOR)
- Catalogued Procedures (PROCLIB)
- Command Procedures (CLIST)
- Deterministic Demand Preprocessor (DDP)

The software development task included the detailed design of the software, preparation of Software Technical Specifications, coding and testing of the software, preparation of User's Manuals and Programmer's Manuals, and model validation.

System Analysis

The purposes of the system analysis task were to define superior systems in terms of system parameters, operating strategies, and station configurations to serve as subjects of comparison in later analyses and to develop system design guidelines. A total of fourteen AGT system deployments were analyzed in detail using the SOS software. The deployments range in complexity from single-route Shuttle Loop Transit systems to Automated Rail and Group Rapid Transit systems deployed on grid networks. System analysis resulted in the generation of performance, cost, and availability sensitivity data.

Comparative Analysis

Comparisons were made among several AGT systems deployed in Central Business District (CBD) and metropolitan area applications to study the effects of vehicle size and network topology on overall system performance, cost, and availability. The objective of the comparative analysis was to determine the advantages and disadvantages of different systems deployed in similar application areas.

Operational Control Analysis

The objective of this task was to identify the operational advantages and disadvantages associated with the use of alternative operational control strategies. The performance, cost, and operating characteristics of alternate operational control strategies were investigated. An operational control strategy consists of a compatible combination of vehicle control, headway protection, longitudinal control, merge policy, and dispatch policy. Control system design alternatives and performance characteristics in the context of isolated guideway link and merge elements were analyzed using the Detailed Operational Control Model. The Discrete Event Simulation Model was used to evaluate alternative operational control strategies in the context of an entire system.

Data Base Development

The data base development task included the structuring of the SOS data base and the maintenance of the computer files during the project.

Model Implementation

Interim and final versions of the SOS software were implemented on the computer system at Draper Laboratories during the course of the project for the use of TSC personnel. Two training sessions were conducted at TSC to help familiarize potential users with the software.

1.3 SOS DOCUMENTATION

A great deal of computer software and documentation was generated during the Systems Operation Studies. Figure 1-2 is a milestone chart which lists each major task giving the period of performance and identifying the deliverable reports associated with each task. Table 1-1 illustrates the volume of technical output produced during the SOS project in terms of software, documentation, and system simulation. The engineering manhours expended for software development and analysis are also listed in the table. A complete list of deliverable reports generated during the Systems Operation Studies project is included as Appendix A. In addition, a computer readable data base containing the software itself and analysis and test case data sets is stored on magnetic tape at GM TSD and at TSC.

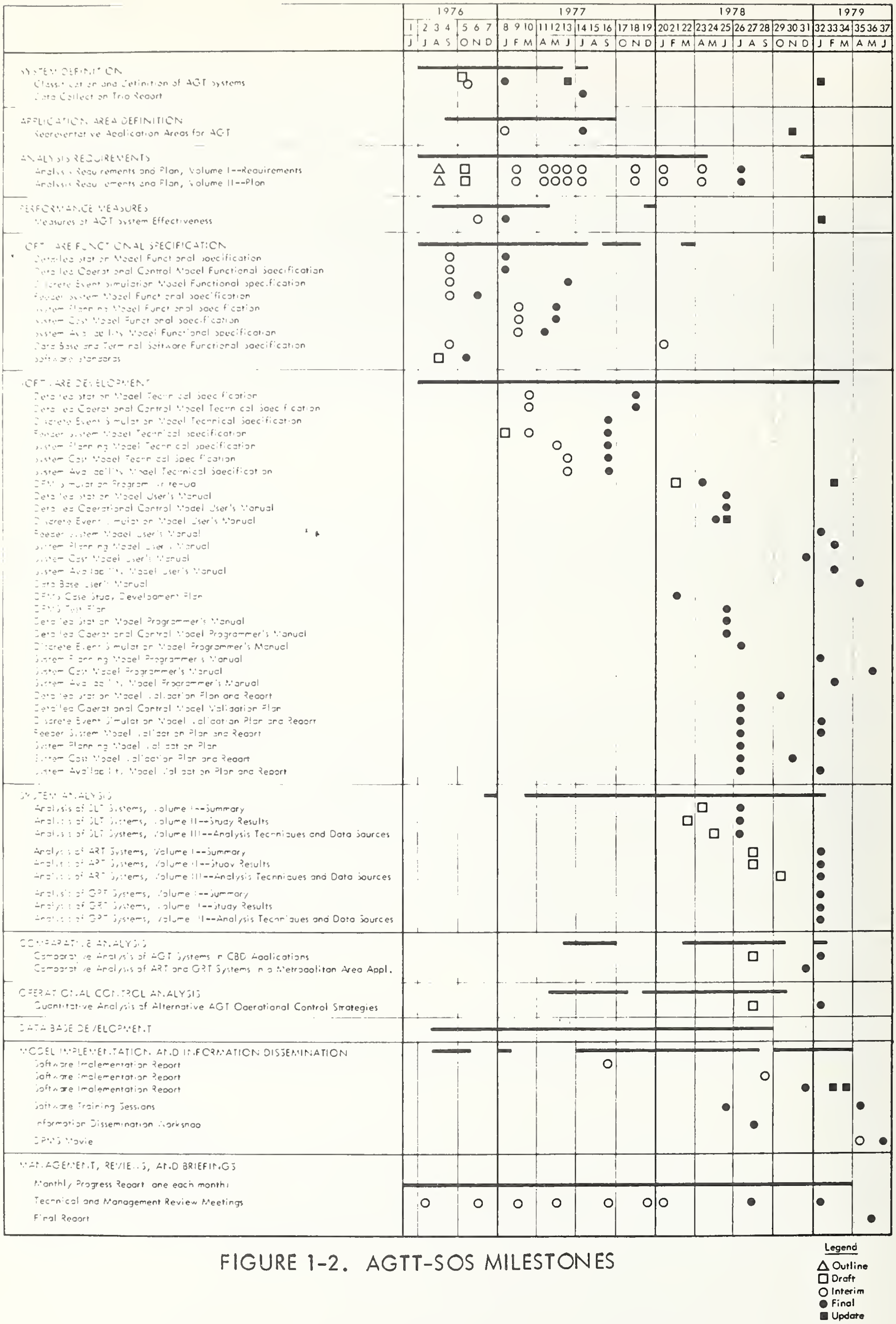


FIGURE 1-2. AGTT-SOS MILESTONES

TABLE 1-1. SOS OUTPUT SUMMARY

	Final Pages
Classification and Planning Documents	459
Analysis Plan and Requirements (total pages generated 1,162)	390
Analysis Reports	2,066
Validation Reports	223
Software Specifications	3,150
Software Manuals	3,390
Miscellaneous Reports	240
	9,918
	Lines
Total Lines of Code Including Comments	147,500
Executable FORTRAN Lines	80,000
Other Executable Code (JCL, Assembler, etc.)	1,500
	81,500
	Hours
Hours of System Operation Simulated	1,000
	Manhours
Engineering Hours Analysis	23,835.3
Engineering Hours Software GM	22,926
Engineering Hours Software IBM	23,565
Total Engineering Hours Software	46,491

2.0 CLASSIFICATION AND DEFINITION OF AGT SYSTEMS

A classification structure for AGT systems was developed to serve as a guide in selecting a variety of system types for consideration in the Systems Operation Studies. The characteristics of existing and proposed AGT systems were summarized following a data collection effort which included an extensive literature search and personal contacts with AGT system designers and operators. The summary of system characteristics served as a basis for classification and as a reference for defining nominal values and ranges of variations for system parameters. The results of these efforts are summarized in this section and reported in detail in a report entitled Classification and Definition of AGT Systems.[1] Information obtained directly from system designers, system operators, and transportation system planners through personal contacts is presented in a report entitled Data Collection Trip Reports.[2] Detailed cost and reliability data for each system type are reported in Volume III of the appropriate analysis reports.[47, 50, 53]

The classification structure developed as part of the Systems Operation Studies permits existing and proposed AGT systems to be easily and unambiguously classified into one of several distinct classes which emphasize major differences in level of service and general applicability to various urban environments. Two system parameters (traveling unit capacity and maximum cruise velocity) were selected to define the classes. Traveling unit capacity is the nominal capacity of the minimum train consist. Since in some systems two or more vehicles are permanently coupled in trains, traveling unit capacity rather than vehicle capacity was selected as a classification parameter to more accurately reflect the service capabilities of systems. Vehicle velocity influences service level through its direct effect on travel time. Maximum speed capability also implies a range of applications for which a system may be suited. Maximum operating speed rather than cruise speed is used as a classification parameter because the former describes a system capability while the latter may refer to a network constraint or deployment option.

The classification structure is illustrated in Figure 2-1. Automated Guideway Transit is divided into two main categories -- personal transit and group transit -- on the basis of the type of service provided (single party or multiple party). Three major categories are identified on the basis of traveling unit capacity: Personal Rapid Transit (PRT), Group Rapid Transit (GRT), and Automated Rail Transit (ART). GRT is further partitioned into three distinct ranges of traveling unit capacity -- Small Vehicle GRT (SGRT), Intermediate Vehicle GRT (IGRT), and Large Vehicle GRT (LGRT). The resulting five classes are further divided as appropriate into eight subclasses on the basis of maximum operating velocity. The subclasses are uniquely defined in terms of the classification parameters in Table 2-1. The range of minimum headway which is characteristic of systems in each subclass is given in the table. An example of each system class -- either a system which has been deployed or one which is under active investigation -- is also given in the table.

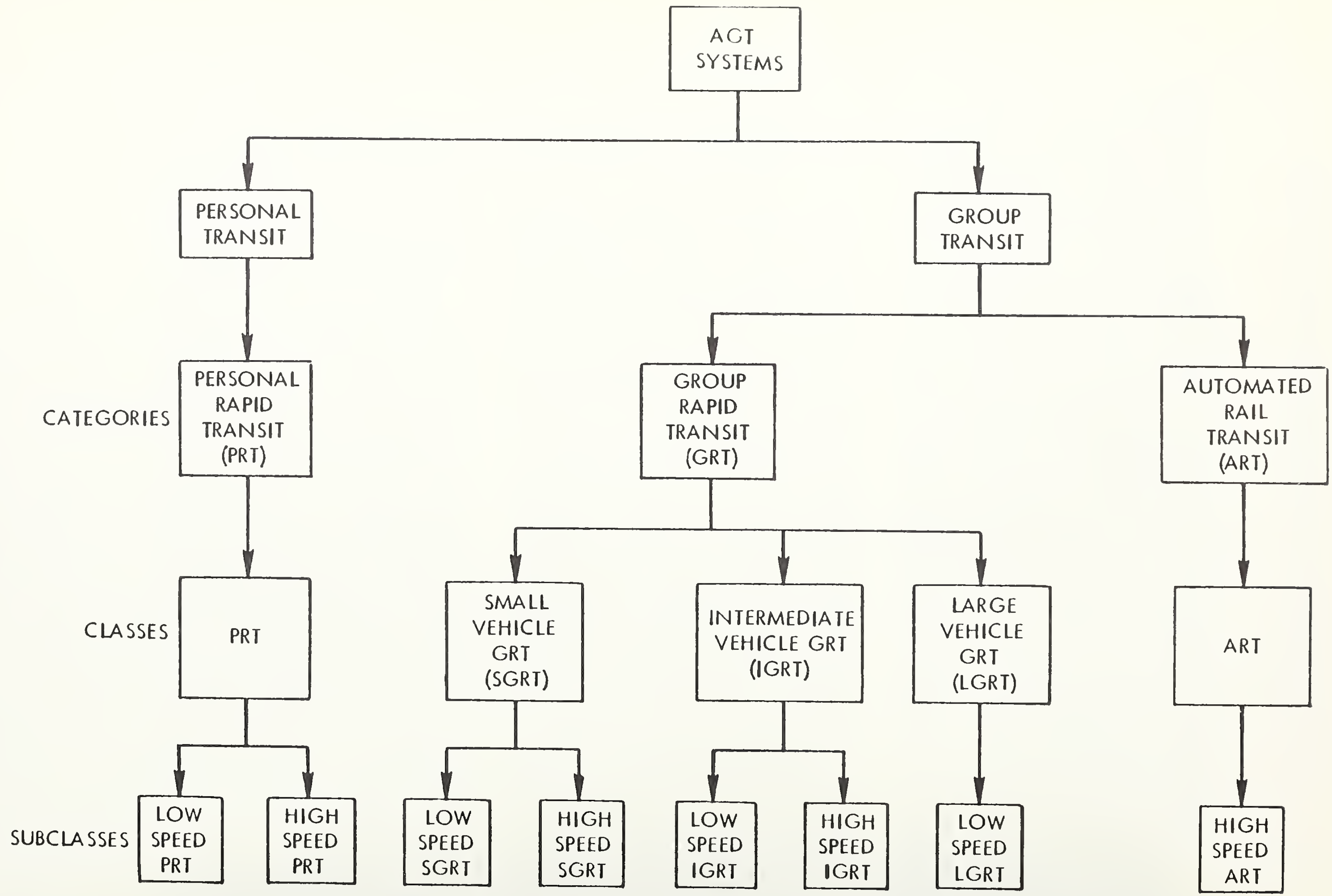


FIGURE 2-1. GM TSD CLASSIFICATION STRUCTURE

TABLE 2-1. GM TSD CLASSIFICATION STRUCTURE

Category	Class	Subclass	Service Type	Minimum Traveling Unit Capacity (Passengers)	Maximum Operating Speed (km/hr)	Characteristic Minimum Headway (s)	Example System
PRT	PRT	low speed	non-stop	3-6	13-54	3 or less	Cabinentaxi
		high speed	non-stop	3-6	55+	3 or less	CVS
	SGRT	low speed	multiple-stop	7-24	13-54	3-15	Morgantown
		high speed	multiple-stop	7-24	55+	3-15	UMTA-AGRT
	IGRT	low speed	multiple-stop	25-69	13-54	15-60	Airtrans
		high speed	multiple-stop	25-69	55+	15-90	Unimobile Transporter
	LGRT		multiple-stop	70-109	13-54	50-109	SEA-TAC
ART	ART		multiple-stop	110+	55+	60+	WMATA

Legend

PRT - Personal Rapid Transit
GRT - Group Rapid Transit
SGRT - Small Vehicle GRT
IGRT - Intermediate Vehicle GRT
LGRT - Large Vehicle GRT
ART - Automated Rail Transit

In 1975, the United States Congress, Office of Technology Assessment (OTA) published an assessment of AGT systems.[63] The report includes one of the first documented attempts at classifying AGT systems. The OTA classification structure has become, in some respects, a standard for the industry. Therefore, it is important to note that except for the omission of Shuttle-Loop Transit (SLT) as a system class the classification structure described in this report essentially parallels the OTA classification and provides a more rigorous definition of the OTA classes.

One of the guidelines followed in generating the classification structure was to separate network and deployment constraints from inherent system characteristics. According to the OTA definition, SLT systems require the simplest technology and utilize few, if any, operational switches. Although some systems employ relatively slow guideway-active switching techniques, nearly all systems that have been examined to date are capable of some degree of operational switching; and most of them could be deployed on a limited grid network with relatively minor modifications. Obviously, systems designed for operation on grid networks could be deployed on shuttle or loop networks which do not require sophisticated control technology. Therefore, the amount of switching required of a system is more dependent on network configuration than on inherent system capability.

Since any of the systems represented by the classes defined in Table 2-1 could be deployed in a shuttle-loop network, a separate class for SLT systems is not provided in the structure. However since Shuttle-Loop Transit is an important application of AGT technology, eleven SLT deployment scenarios were analyzed in detail during the Systems Operation Studies. These scenarios include various shuttle and loop deployments of GRT systems in CBD and other activity center applications.

Link capacity is another system parameter that is often considered when assessing the suitability of a system for a given application. Alternate classification schemes which utilize capacity as a classification parameter were evaluated. One alternate classification structure composed of eleven system classes was defined using link capacity and maximum cruise speed as classification parameters. While this classification scheme seems to be a reasonable one, the use of link capacity as a classification parameter does suffer from several limitations. The main limitation is that link capacity is dependent on network topology and station location (on-line or off-line) which are deployment characteristics rather than system characteristics. The limitations tend to make link capacity a less desirable classification parameter than minimum traveling unit capacity.

3.0 REPRESENTATIVE APPLICATION AREAS

The specification of deployment scenarios to serve as subjects for detailed analysis includes the definition of a system type, a demand environment, and a network. System types were selected from the system classes defined in the previous section. Demand matrices were generated using available data from particular cities and activity centers which represent selected demand types. One or more network configurations were specified for each demand environment to represent a set of network types. Estimates of on-guideway and off-guideway system performance were used in conjunction with the Feeder System Model (FSM) to map demand onto the network. The resulting station-to-station demand matrices served as inputs to the system simulation. The selection of deployment scenarios and the representation of demand are summarized in this section and presented in more detail in Representative Application Areas for AGT.[3]

3.1 TRAVEL DEMAND

Travel demands may be described in terms of four major demand characteristics. One significant travel demand characteristic is the size of the analysis area. Analysis areas vary in size from major portions of entire metropolitan areas to localized parts of small-area activity centers. Aggregate trip-making volume is a second important characteristic of demand. The average daily number of trips in an analysis area is a measure of this type. Disaggregation of demand magnitude by specifying magnitudes for each of several smaller time intervals results in a third demand characteristic--temporal variation. Disaggregation by subdividing the overall demand analysis area into smaller units and then specifying demand magnitudes between pairs of units allows demand to be described in terms of spatial variations--a fourth major demand characteristic.

An examination of these demand characteristics suggests a top-level classification of demands into two groups: metropolitan areas (or substantial portions of metropolitan areas) and activity centers (small areas of high travel intensity). Since any comparison of a demand area chosen from one group with an area chosen from the other group is expected to indicate great differences in all four of the major demand characteristics, the basis for establishing the two groups is sound. However, the variations in one or more characteristics among members within each group suggest that each group may be readily divided into more homogeneous subclasses.

Since the travel patterns in a metropolitan area are strongly influenced by the presence of one or more central business districts, a measure of relative CBD trip attraction or orientation was used as a demand classification parameter. The measure of CBD orientation used in the Systems Operation Studies is the percentage of all daily work trips in an urbanized area which terminate in the CBD. Another useful measure of spatial distribution is the relative amount of reverse commutation; that is, the proportion of central city dwellers who work in the suburbs. If high and low values are considered for each of the two measures of spatial distribution, the following four basic demand types are defined:

Low CBD Orientation, Low Reverse Commutation
Low CBD Orientation, High Reverse Commutation
High CBD Orientation, Low Reverse Commutation
High CBD Orientation, High Reverse Commutation

In this context, "high" refers to a characteristic measure above the mean value for the 35 largest Standard Metropolitan Statistical Areas (SMSA) in the United States, while "low" refers to a value below the mean. The mean values are 10.06 percent for CBD orientation and 8.49 percent for reverse commutation. The first demand type, in which both measures are low, suggests a metropolitan area potentially more difficult to serve with capital-intensive transit systems than the other three types. Therefore, the last three demand classes were used in the SOS project to define the range of metropolitan area demands to be considered for AGT system deployment.

Activity center demands can be classified according to the nature of travel within the activity center. Circulation type demands tend to be evenly distributed over the activity center while line-haul type demands tend to have a few relatively large production or attraction zones. In addition, central business districts are of particular interest due to the number of cities in which a Downtown People Mover system is currently being planned.

For activity center travel demand models, the opportunity exists to utilize data from areas in which AGT systems are presently operating. West Virginia University at Morgantown, West Virginia, was selected as a representative Activity Center Line-Haul travel demand situation. In this case station-to-station demand projections for the six station system were used to estimate demand for the three station system that was initially deployed. A set of demand matrices which define travel demand among the three stations for each 15-minute interval during the service day was used to model the Activity Center Line-Haul demand. Actual turnstile counts from the Airtrans system at the Dallas/Fort Worth Regional Airport were used to formulate an Activity Center Circulation demand model. In this case a station-to-station demand matrix for each 30-minute interval during the 24-hour operating day was generated.

Candidate cities for the two CBD demand models were limited to those selected to implement Downtown People Mover systems in the near and intermediate future. Houston was selected as the representative application area on which to base the CBD Line-Haul demand. The downtown people mover system proposed by the City of Houston is essentially a line-haul service between multimodal transfer points and employment sites. The demand is represented by three matrices (a.m. peak, off-peak, and p.m. peak) and scale factors to approximate hourly variations in demand magnitude. Detroit was selected as the representative application area on which the CBD Circulation demand was based. The DPM system proposed by the City of Detroit would primarily serve a circulation function for secondary trips made within the CBD. In this case the demand is represented by one matrix and hourly scale factors. In order to permit direct comparisons of system deployments designed for different demands, three values of daily demand magnitude for the CBD Circulation application and two values for the CBD Line-Haul application were specified. The three values of demand for the CBD Circulation application represent pessimistic, optimistic, and average demand projections for a single lane loop deployment (39,450, 65,500, and 52,475 passenger trips per day, respectively). The high demand for the CBD Line-Haul application was obtained by arbitrarily doubling the values originally projected for that application (25,600 and 51,200 passenger trips per day).

Representative metropolitan areas were selected from among the 35 largest SMSAs in the United States on the basis of journey-to-work data, land area, population, and availability of travel demand data. The city selected to represent each metropolitan area demand type is:

Low CBD Orientation, High Reverse Commutation — Detroit
High CBD Orientation, Low Reverse Commutation — Washington, D.C.
High CBD Orientation, High Reverse Commutation — Cincinnati

Available transportation survey data was aggregated to form peak and off-peak period travel demand matrices. Hourly demand variations were modeled by applying scale factors to the appropriate demand matrix.

In the Systems Operation Studies the temporal distribution of demand was modeled as a series of discrete step changes in magnitude at 15-, 30-, or 60-minute intervals depending on the application. An attempt was made to assess the value of modeling demand as a more continuous function of time. The discrete event simulations developed during the AGTT-SOS project generate an input stream of passengers based on demand input according to a Poisson process. The Detailed Station Model was used to generate two passenger arrival streams using the same random number seed but different input demand profiles--one in which the demand level changes abruptly at 15-minute intervals and another in which the transition between 15-minute intervals is smoothed by incrementing the demand in 2-minute intervals. In addition, passenger arrival streams were generated using the 15-minute step method but with different initializations of the random number generator. The two approaches (stepped and smoothed) resulted in apparently similar but statistically different demand profiles being generated by the Poisson process.[62] However, variations in the passenger arrival streams caused by using different random number seeds appeared to be more significant than the variations caused by smoothing the demand input. Therefore, the simpler demand representation (i.e., use of step changes) was used in the Systems Operation Studies.

3.2 NETWORK CONFIGURATION

Each operationally distinct portion of a network may be classified as one of three simple network types:

1. Shuttle — A guideway on which bidirectional motion occurs during normal operation and which is defined by a single path connecting two distinct end points.

2. Loop — A guideway on which motion is unidirectional during normal operation except possibly on short segments at stations or at ends of runs, and which is defined by a closed path.

3. Grid — Any guideway on which vehicles are presented with a choice of paths during normal operation.

Only one vehicle or train may be operated on a simple shuttle network, and no headway protection or merge control is required. More than one vehicle may be operated on a simple loop or grid network, and headway control is required to prevent collisions. In the case of a grid network, some form of merge control must be used.

3.3 REPRESENTATIVE SYSTEM DEPLOYMENTS

The representative system deployments analyzed in the Systems Operation Studies are identified in Table 3-1. The selected combinations of system class, application area, and network type represent a wide variety of AGT deployment scenarios which provided opportunities in SOS to compare the performance and cost of different system technologies and network configurations in similar applications. Schematics of the various network configurations identified in Table 3-1 are presented in Section 7.0 of this report.

TABLE 3-1. REPRESENTATIVE APPLICATION SCENARIOS

SYSTEM TYPES		DEPLOYMENT SCENARIO								
		LOW SPEED							HIGH SPEED	
		ACTIVITY CENTER LINE-HAUL	ACTIVITY CENTER CIRCULATION	CBD CIRCULATION			CBD LINE-HAUL		METRO AREA HIGH CBD HIGH REVERSE	METRO AREA LOW CBD HIGH REVERSE
				LOW DEMAND	MEDIUM DEMAND	HIGH DEMAND	LOW DEMAND	HIGH DEMAND		
SLT	SGRT						L1 (SLT 10)			
	IGRT		LMC (SLT 2)	SS (SLT 7)	L1, L2 (SLT 3)(SLT 4)	L1 (SLT 5)				
	LGRT	PS (SLT 1)				L1 (SLT 6)	LM, L1 (SLT 8)(SLT 9)	L1 (SLT 11)		
ART									LH (ART 1)	
GRT	SGRT									G (GRT 3)
	IGRT								LH (GRT 2)	

PS - PARALLEL SHUTTLE
SS - SERIAL SHUTTLE
L1 - ONE-WAY LOOP
L2 - TWO-WAY LOOP
LC - COLLAPSED LOOP

LM - SIMPLE MULTIPLE LOOP
LMC - COMPLEX MULTIPLE LOOP
G - GRID
LH - LINE-HAUL

4.0 ANALYSIS REQUIREMENTS AND PLAN

One of the first analysis tasks in the Systems Operation Studies was to specify the requirements for each major analysis and to formulate an analysis plan. The requirements served not only to define the analyses but also as a reference in the development of software functional specifications. The System Analysis Requirements and Plan, Volume I - Requirements [4] and Volume II - Plan [5] were updated before the start of each major analysis task to permit review by the Government prior to execution of the analyses. The Analysis Requirements document (Volume I) identifies the relationships among the various analysis tasks and describes the system deployments to be analyzed in terms of demand environment, network configuration, and major system characteristics and alternatives. Volume I also defines the procedure to be followed for each system-level analysis by identifying the analysis steps to be followed and the alternatives to be considered. Requirements are established for the following system-level analyses:

- System trade-off analysis
  - Shuttle loop transit
  - Group rapid transit
  - Automated rail transit
  - Personal rapid transit
  - Feeder system alternatives
  - Failure management alternatives
- Comparative system analysis
- Alternative operational control strategy analysis

The Analysis Plan (Volume II) is a top-level planning document that provides an overview of the analysis tasks which comprise the Systems Operation Studies. The document presents a summary of the objectives of each analysis task, a schedule for completion of each major task, and an estimate of the resources to be allocated to each analysis.

Both the Analysis Requirements and the Analysis Plan were dynamic documents which were updated often as the analyses progressed. The purpose of the updates was to permit the experience gained in performing the early analysis to influence the planning for later analysis tasks. As a result, the original outlines (submitted in August 1976) were expanded and updated ten times before the final Analysis Requirements and Plan were delivered in August 1978. The final versions of the documents reflect the plan for completing the SOS analyses as of April 1978--they do not include modifications to the plan that were made after that date.

5.0 MEASURES

A set of operational goals and effectiveness measures that permit evaluation and comparison of AGT systems within a system class and among system classes for a given application were developed to support the Systems Operation Studies. The initial set of measures was developed by considering overall system objectives and compatible measures used in other studies or in system specifications. Based on experience gained while performing system analysis, the initial set of measures was modified by deleting some measures which were found to be of limited value and by adding others which proved to be more useful than had been originally expected.

5.1 INITIAL SET OF MEASURES

There are four primary interest groups involved in the transportation decision-making process: users, non-users, operators, and the community as a whole. These groups are not meant to partition the individuals involved but rather to indicate different perspectives on the transportation issue. A particular individual may view a transportation question from more than one perspective. Also, the Government may be considered a fifth group interested in all four perspectives. Each group seeks transportation system alternatives which satisfy different goals. Since a variety of goals must be considered, a variety of effectiveness measures are required to establish how well a given AGT system deployment meets the goals. Choosing measures for a particular goal in effect defines subgoals for that goal. For example, selecting "improve quality of travel" as a system goal implies a set of subgoals such as "decrease average travel time", "minimize transfers", etc. The degree to which each of the subgoals is achieved may be used as a measure of system effectiveness. Figure 5-1 displays the relationships between interest group perspective, goals, and subgoals defined by specific measures of effectiveness. The figure also identifies with symbols the initial list of measures proposed for system-level comparisons. The symbols in Figure 5-1 are identified in the paragraphs that follow.

Average Trip Time (TT) - This measure is the average origin to destination time for all passengers who complete trips during the period simulated including system access time, out-of-vehicle wait time, in-vehicle travel time, and egress time.

Average Variation in Trip Times (VTT) — The variation in trip time gives an indication of schedule reliability and is especially important to passengers with trip time constraints.

Percent Standees (PS) — This level of service measure is the ratio of standing passenger hours to total passenger hours.

Transfers (T) — Two measures relating to transfer requirements are of interest: the fraction of passengers requiring transfers and the average number of transfers per passenger.

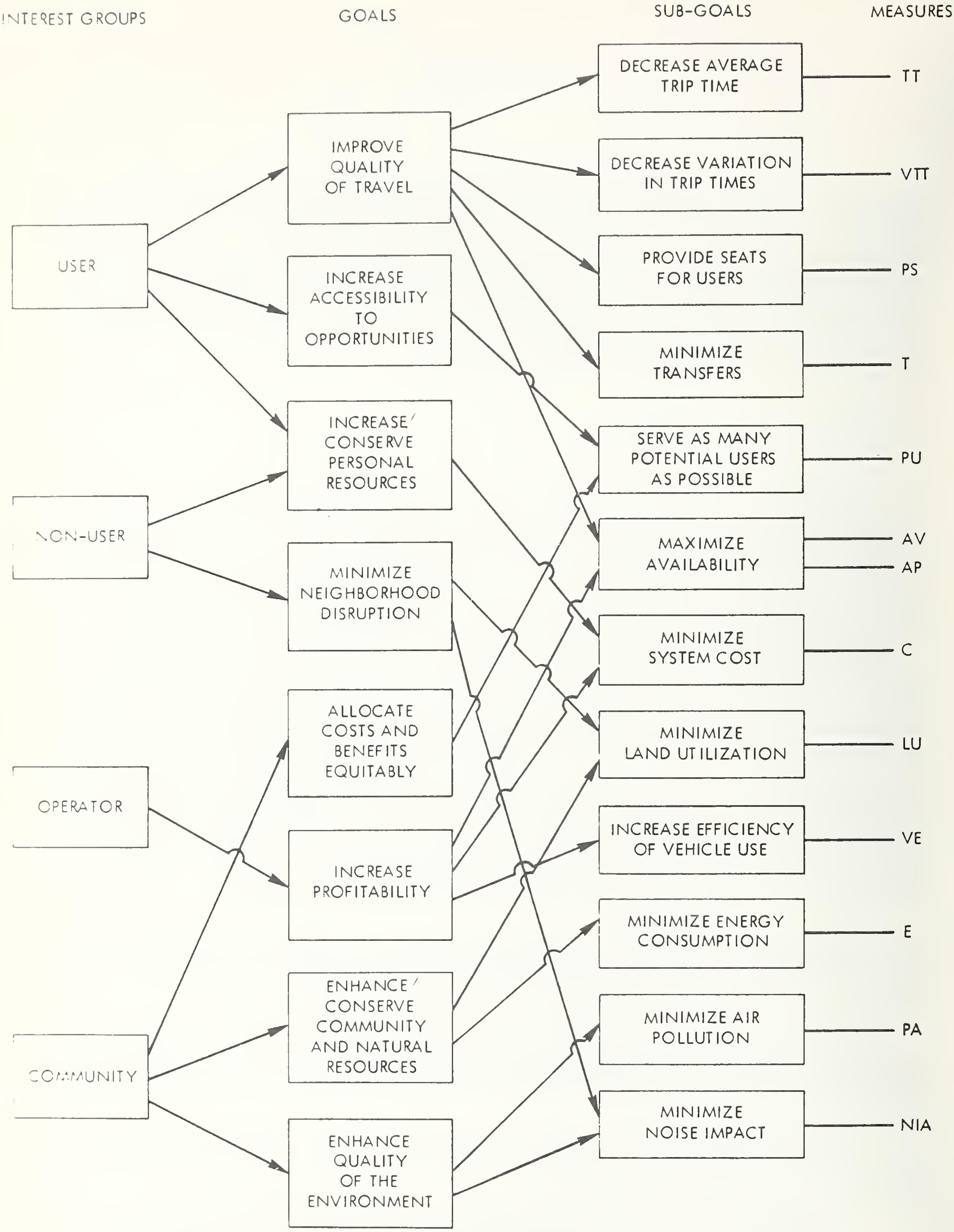


FIGURE 5-1. RELATIONSHIP OF MEASURES, GOALS, SUBGOALS, AND INTEREST GROUPS

Percent Unserved (PU) — This measure is calculated by the Feeder System Model as the percentage of total demand between zones that are not assigned to station pairs, i.e., demand which could be served by the AGT system only by accessing and egressing the same station.

System Availability (AV, AP) — Two definitions of availability, vehicle-based availability and passenger-based availability, were used in the Systems Operation Studies. Vehicle-based availability is defined by

$$AV = \frac{\text{Vehicle Operating Time (Normal)} - \text{Vehicle Delay Time (Failure Induced)}}{\text{Vehicle Operating Time (Normal)}}$$

Passenger-based availability (AP) is based on the premise that if a passenger is not delayed more than some threshold amount, then he perceives the system as operating normally. Passenger-based availability is defined as follows:

$$AP = \frac{\text{Number of Passengers Served (Reference)} - \text{Number of Passengers Delayed above Threshold (Failure)}}{\text{Number of Passengers Served (Reference)}}$$

A value of 5 minutes was selected as the delay threshold for use in the Systems Operation Studies, but the System Availability Model automatically calculates values of availability for a range of threshold values.

System Cost (C) — Capital cost associated with initial system implementation, base year variable cost (operating and maintenance cost), and life cycle cost over a 40-year period were considered as measures of system cost.

Land Utilization (LU) — Since the cost of land was not considered in the estimates of capital cost, the total amount of land required for stations, guideways, and maintenance facilities was considered as a separate measure.

Efficiency of Vehicle Use (VE) — Three measures of vehicle efficiency were initially proposed for consideration in the Systems Operation Studies. The first, vehicle load factor, is a distance-weighted measure of vehicle utilization defined as follows:

$$\text{Vehicle Load Factor} = \frac{\text{Total Passenger Miles}}{\text{Vehicle Capacity} * \text{Total Vehicle Miles}}$$

Percent occupancy is a time-weighted measure of vehicle utilization defined as follows:

$$\text{Percent Occupancy} = \frac{\text{Passenger Hours on Vehicles} * 100 \text{ Percent}}{\text{Vehicle Capacity} * \text{Vehicle Hours}}$$

Finally, vehicle trip productivity is defined as:

$$\text{Vehicle Trip Productivity} = \frac{\text{Total Number of Passengers Served}}{\text{Vehicle Capacity} * \text{Total Vehicle Hours}}$$

Energy Consumption (E) - The measure of energy usage is the total amount of energy consumed by the system including energy for vehicle propulsion, vehicle auxiliaries, guideway heating for snow removal, heating and cooling of stations and other buildings, and electrical energy required for lighting and control.

Air Pollution (PA) - The air pollution measure is the total amount of the following five pollutants generated either directly or indirectly by the AGT system: hydrocarbons, carbon monoxide, oxides of nitrogen, sulfur dioxide, and particulates.

Noise Pollution (NIA) - The effect of noise from an AGT system on the surrounding community is expressed in terms of the area adjacent to the guideway within which the day-night sound level resulting from AGT vehicle operation exceeds 55 dB(A). This level of noise was selected by the Environmental Protection Agency to represent the level of noise which causes annoyance and interference with outdoor activities.

Average Number of Intermediate Stops (ANIS). - This measure is not in the original set of measures listed in Figure 5-1, but it is useful in evaluating different fixed routes or service policies. The measure is the ratio of total number of intermediate stops by passengers completing trips to the total number of passengers completing trips.

During the analysis process, it was frequently useful to inspect the performance of specific deployment elements and local areas within the deployment, or to evaluate the time history of certain performance measures. The AGTT-SOS software set provides an extensive set of disaggregate statistics for these purposes as well.

5.2 FINAL SET OF MEASURES

Over 500 individual measures of performance, cost, and availability are evaluated by the SOS system-level models (DESM, SPM, SCM, and SAM). Many of these measures have multiple values (e.g., one for each station, guideway link, route, simulation sampling interval, year in the life cycle costing period, etc.). Literally thousands of measure values can be obtained from the SOS processors and used by an analyst to evaluate virtually any aspect of an AGT deployment. Not all of the performance measures are applicable to a given deployment, and some are more useful than others depending on the deployment and the aspect of system operation that is being investigated. As a practical necessity and to achieve compatibility among results, a subset of the available measures was selected for consideration in the trade-off and comparative analyses. The initial set of effectiveness measures served as a guide in selecting the subset, but experience gained while performing the analysis led to changes in the initial set. The remainder of this section describes the measures that were found to be most useful in the evaluation of AGT system deployments.

While components of trip time (wait time and travel time) were found to be the most sensitive and important measures of system performance, the aggregate measure "average trip time" was found to be not representative of the variety of trip times which occur. The averaging of trip times over the entire system tends to mask both local congestion and locally insufficient capacity. As a result systems can have an acceptable overall average trip time but have totally unacceptable average trip times for trips from certain stations. It was found that in order to design systems with acceptable local as well as system-wide performance, more details of trip time must be examined. Consequently, trip time was disaggregated spatially by station. In addition the wait time and travel time of a trip were distinguished as separate components. In addition to average wait time for each station and for the system as a whole, a measure of maximum wait time was found to be useful. Since the absolute maximum wait time that occurs during a simulation is often quite sensitive to random variations in the demand, a 95th percentile wait time (value below which 95 percent of wait times fall) is considered to be a useful measure. This measure can be derived from DESM output data using the trip log file. In the trade-off analysis of deployments where limited guideway capacity does not permit wait time goals to be satisfied at all stations, the number of stations and the number of passengers arriving at stations where the wait time exceeds the goal were used as performance measures. Since average travel speed can be more easily related to the performance of other modes than average travel time, travel speed was used as a measure of the in-vehicle component of trip time. Average travel speed is especially useful when comparing the performance of systems deployed on different networks. Intermediate stops and transfers contribute to travel time but may have a negative effect on system ridership which is in addition to that caused by increased travel time. Therefore, the average number of intermediate stops and the fraction of passengers who must transfer from one AGT vehicle to another were considered in the comparative analyses.

Percent occupancy, the time weighted measure of vehicle utilization, was evaluated and traded off against average wait time when selecting the operating fleet size for the demand responsive GRT deployment (GRT 3). In fixed schedule deployments consideration of wait time alone is generally sufficient to select an appropriate fleet size.

In evaluating the operation of various vehicle fleets on grid networks, the average and maximum queue delay per queued vehicle and the average and maximum number of vehicles queued on guideway links were useful measures of congestion. In some cases disaggregate forms of these measures (values for each individual link) were used to identify points of congestion in the network.

Measures of system cost were used in both the trade-off and comparative analyses. Estimates of life cycle cost impacts of vehicles, guideway, maintenance facilities, vehicle energy, and vehicle maintenance were considered in the trade off analysis to help specify vehicle capacities and cruise velocities. Total capital, variable, and life cycle costs and net present values were considered in the comparative analyses. Normalized costs, especially base year variable cost per passenger and life cycle cost per passenger, were found to be quite useful in comparing alternative systems deployed in various applications.

Two values of availability were evaluated for each system deployment. They were used to evaluate the effects of increased subsystem reliability and redundancy. Comparison of system deployments in terms of availability led to some interesting conclusions concerning the apparent effects of network topology and vehicle class on system availability (Section 7.3.1). Throughout the analysis, passenger availability was shown to have a greater range of variation than vehicle availability for a given variation in system or network configuration. Since both measures typically have values near unity, consideration of one minus the availability value (1-AP and 1-AV) often provides more insight into the effect of system parameters on availability than consideration of the availability measures themselves.

6.0 SOFTWARE DESIGN AND DEVELOPMENT

6.1 INTRODUCTION

A set of models was designed and developed based on the needs of the SOS analysis tasks. Besides serving the needs of SOS the models were designed to be useful in other applications as well. All of the major elements of each AGT system under consideration are represented in the set of models. Three analytic models, the Feeder System Model (FSM), System Cost Model (SCM), and System Availability Model (SAM); and four simulation models, the System Planning Model (SPM), Discrete Event Simulation Model (DESM), Detailed Station Model (DSM), and Detailed Operational Control Model (DOCM) have been developed. The DESM was further developed into the Downtown People Mover Simulation (DPMS) to meet the special needs of integration with the Urban Transportation Planning System (UTPS). Four interactive graphic display programs were designed and developed providing the user with convenient input and output tools. The graphics programs include the Network Build Module (NBM) which enables the user to enter and edit network, route definition and station designation information directly from maps or a CRT display; the Guideway Vehicle Motion Program (GVMP) which displays the dynamics of vehicles at merges as output from the DOCM; and the Passenger Queue Length Display Program (PQLDP) and the Link Utilization Display Program (LUDP) which accept output from the DESM to display dynamic temporal variations in boarding queue lengths at stations, and in guideway link utilization, respectively. In addition, a number of data base manipulation and programming aids were developed including, principally, the Comparison Output Processor (COP) which retrieves summary statistics from various model runs for the purpose of graphically comparing alternate AGT system attributes; and the structured programming preprocessor (PARAFOR) which has the advantage of eliminating the need for "go to" statements, improving code readability and increasing speed of code production. Catalogued procedures (PROCLIB) and command procedures (CLIST) were prepared to permit running of the models without extensive knowledge of job control language (JCL). A Deterministic Demand Preprocessor (DDP) was built which operates in conjunction with the DESM to provide a nonstochastic alternative in the production of trip lists. The final software packages delivered to the Government each consist of applicable code, test case data sets, a Programmer's Manual, and a User's Manual which are described in Implementation Reports.

The supporting documentation includes Functional and Technical Specifications, Software Standards, Implementation Reports, User's Manuals, Programmer's Manuals, a DPMS Case Study and Program Write-Up, an animated sound film which illustrates the use of the DPMS program, and a software demonstration slideset. In addition to these published documents there are extensive in-line coded preambles for each program member and in-line coded comments. In-line coded preambles and comments facilitate program development and maintenance and represent 45 percent of the nearly 150,000 lines of code produced. In all, 6,500 pages of software specifications and manuals were generated.

6.2 SOFTWARE DOCUMENTATION

6.2.1 Software Standards

A document entitled Software Standards[7] was produced as the basic control document defining the guidelines for the structured code, FORTRAN, and other languages used for program development; the prescribed content of all specifications and manuals; and software delivery practices and documentation including test, installation, acceptance, and validation. A user's guide to PARAFOR, the structured code-to-FORTRAN conversion routine, is also included.

6.2.2 Functional Specifications

A review was made of representative AGT systems, noting service policies, deployment scenarios, analysis requirements, and measures of system effectiveness, in order to select the set of functional requirements for the software. Those requirements are documented in a Functional Specification for each model which defines the purpose and capabilities of the model, the functions to be modeled and modeling techniques employed, the data content and format required by the model as input and produced by the model as output, and the interfaces with other models and with the data base via specific files.[8-14] The relationship among functions within the model are further defined by hierarchial-input-process-output (HIPO) diagrams.

6.2.3 Technical Specifications

After completion of the Functional Specifications, Technical Specifications were developed for each model to define the program design.[15-21] High level Program Design Language (PDL) was specified and subsequently updated to increasing depth as actual coding progressed. Final PDL is presented in the Programmer's Manuals. The description, source, assumptions, and limitations of the mathematical algorithms are presented. The algorithms evaluate the model equations and mathematical formulae specified in the Functional Specifications. A description of architecture, input files, output files and output reports, and the processing performed for each function is presented. Requirements for compatibility with other models and with the centrulized data base are detailed. The size of the software program, data storage required, execution time and hardware requirements are also presented. The test cases to be run for checkout, installation and acceptance are specified. The HIPO diagrams of the Functional Specification are updated and expanded to reflect the developed software structure. The expanded HIPO diagrams of the Technical Specification are used in the production of PDL segments which are used in the production of code. Coding was initiated concurrently with Technical Specification production. The higher level HIPO elements (in the hierarchical sense) were generally coded and made operational first, with the lower levels added subsequently in conformance with the top-down, structured programming approach. These higher level elements, called modules, typically select the tasks to be performed and the order in which they are performed, and call on the lower level elements to carry out the tasks. This approach reduces the time traditionally required for system integration, and the simplified control structure results in programs that are easier to understand, debug, and modify.

6.2.4 User's Manuals

Each User's Manual includes a description of the program's purpose, the basic methodology of the model, its options, its data requirements, and its operating procedures. The User's Manual enables a user to create input data file members for modeling specific AGT systems, to create control file members for executing the program, and to understand the output reports. The input file options establish the system state for the system being modeled. The Manual defines the method of input, the type and function of all input data, the alternative report formats for output of variables, and a summary of all input and output files. The control file procedures define the job setup alternatives for model execution. Included is a listing of catalogued procedures which minimize a user's need to be familiar with Job Control Language (JCL). The computer type, memory space, execution time, and the host computer support software requirements are presented. Complete computer listings of the sample run setups and model's output are also provided. In addition to a User's Manual for each model,[22-28] a User's Manual was prepared for the data base[29] which describes the data base software support package from a user's perspective.

6.2.5 Programmer's Manuals

The Programmer's Manuals[30-36] include the information needed by a programmer to maintain and modify the programs and provide a final detailed technical specification of the "as built" software. These manuals define the programs' purpose, functions, organization, inputs, processing algorithms, and outputs. The relationships between subprograms and overlay segments, decision tables, the structure of control and data flow, local and global variables, HIPO diagrams, PDL, and full descriptions of each subprogram are provided. Debug tools are described. The programming language and all translators and compilers required to produce object code decks are presented. The Programmer's Manuals are used in conjunction with the source code listings which are written primarily in structured (top-down) code facilitating ease of comprehension.

6.2.6 Data Base Specification

A specification was prepared to define the collection of data files and software support modules for the AGTT-SOS software.[37] This document includes a description of the requirements, modeling techniques, and files associated with the Network Build Module (NBM) and its associated Conversion Program which produces the network, stations, and route file inputs for the DESM and SPM models. In addition, the three Dynamics Modules which accept outputs from the DESM and DOCM for dynamic display are described. The Comparison Output Processor (COP) is described which is used to generate reports that assist in comparing alternative systems by retrieving and reporting performance measures from more than one simulation run. The file manipulation and command procedures for all batch and terminal operations are presented. The overall data base information flow is shown in Figure 6-1. Input and Description Files are input to the Input Processor of the particular model. The Input Processor reformats that data into Structured Data Files suitable for Model Processor use, which in turn produces Raw Statistics files that are used by the Output Processor for the production of reports and summary files.

6.2.7 Implementation Reports

Each software delivery is defined in terms of the tapes, listings, card decks, data files, and documentation in an Implementation Report.[38-42] The Report also provides program status information, a description of the installation requirements (e.g., regarding space allocations and language), and a description of the installation plan and the acceptance testing to be performed. Applicable versions of documentation such as for User's Manuals or Specifications are cross referenced. In the case of the NBM and the Dynamic Modules, the Implementation Reports also provide user's instructions and programmer's notes.

6.2.8 DPMS Program Write-Up

The DPMS is documentated in a Program Write-Up[43] which provides a summary description and methodology description for the DPMS functions and presents information on the detailed mechanics of the program operation. The content and organization of the Program Write-Up is specified by the Urban Transportation Planning System (UTPS) Standards (UMTA's Software Systems Development Program Software Standards). The Program Write-Up describes the messages, keywords, file formats, procedures, and output reports of the DPMS.

6.2.9 DPMS Case Study and User's Guide

A hypothetical Case Study was developed using the DPMS program for the simulation of a DPM system. The Case Study document[44] introduces transportation planners to the DPMS for the modeling and analysis of DPM alternatives. A base system is identified; the simulation is run; parameters are varied; the simulation is rerun; and the outputs are compared. The modeling techniques for demand, network, and system parameters and the interface between the DPMS and UTPS are defined. The Case Study, in machine readable format, conforms to the UTPS Standards for documentation. The document is designed for use in conjunction with the DPMS Program Write-Up.

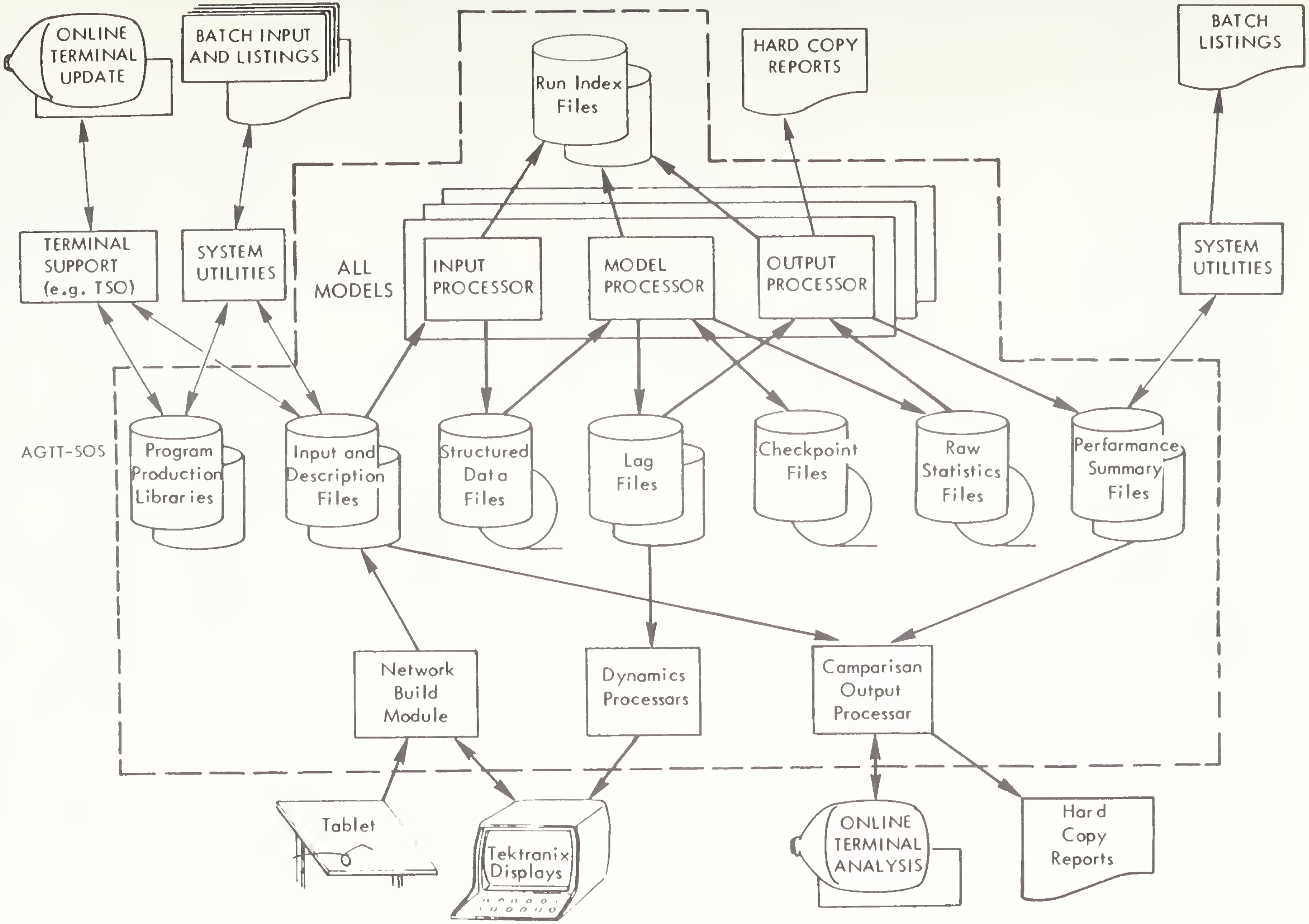


FIGURE 6-1. AGTT-SOS DATA BASE RELATIONSHIP

6.2.10 DPMS Animated Sound Film

A 16 mm sound film of approximately 25 minutes duration describes the capabilities and general operation of the AGTT-SOS Downtown People Mover Simulation Model. The film is designed to serve a broad audience interested in computer simulation as an aid to the analysis and design of DPM transportation systems. It emphasizes the advantages of simulation in developing and verifying complex system designs and shows how the DPMS model can be used to investigate the effects of alternative considerations in transit operation. Animation techniques are used extensively in the film as an effective means of presenting typical simulation results.

6.3 FUNCTIONAL DESCRIPTION OF THE MODELS

6.3.1 Overview

The computer programs developed for AGTT-SOS fall into four convenient groupings:

1. Subsystem performance simulation and evaluation

   Detailed Station Model (DSM) — A detailed simulation of the movement of vehicles and passengers in a station

   Detailed Operational Control Model (DOCM) — A detailed simulation of vehicle movements on a link, and through a merge or intersection

   Feeder System Model (FSM) — A simplified model of feeder system operation used to estimate the trips served by an AGT deployment out of a total set of transit oriented trips in an area.

2. System Performance Simulation

   Discrete Event Simulation Model (DESM) — A detailed simulation of the movements of individual vehicles and passengers throughout an AGT deployment using discrete event simulation techniques

   Downtown People Mover Simulation (DPMS) — a modified version of the DESM providing a direct interface with UTPS

   System Planning Model (SPM) — A simulation of AGT system operations in terms of average flow rates of vehicles and passengers.

3. System Availability and Cost Evaluation

System Availability Model (SAM) -- An analytic model using equipment failure rates and simulated operations data to evaluate system availability

System Cost Model (SCM) -- An analytic model using unit costs, deployment configuration, simulated operations data, and economic factors to calculate capital, operating, and life cycle costs.

4. Analysis Support Software

A set of support programs provided for graphic network input (NBM), dynamic display of vehicle motion, queue lengths and link loading (GVMP, PQLDP, and LLDP), nonstochastic demand input generations (DDP), comparison of summary statistics (COP), and preprocessing structured Fortran (PARAFOR).

This set of models allows evaluation of the performance, cost, and availability characteristics of AGT deployments. The evaluation results enable reasonable, low-risk decisions to be made about the selection or development of new Automated Guideway Transit Systems. The SOS models have been designed to analyze alternative AGT system designs for a given scenario. Figure 6-2 shows the flow of model use for analysis.

6.3.2 Detailed Station Model (DSM)

6.3.2.1 Purpose -- The DSM simulates vehicle and passenger movement within a single station. It is used to develop and verify system level station performance models and to evaluate station sizing requirements. The model determines queue sizes and travel times for interrelated processes including passage through a turnstile and the movement of vehicles through entry ramps, boarding docks, and exit ramps.

6.3.2.2 Major Inputs -- The major inputs are contained in three user-supplied files:

1. Trip demand generation data (AGT.IANDD.DEMAND) which includes factors such as interarrival time distribution, destination probability distribution, and party size probability distribution

2. Vehicle demand generation data (AGT.IANDD.DEMANDV) which includes factors such as service policy, route definition, train length distribution, interarrival time distribution, and destination probability distribution.

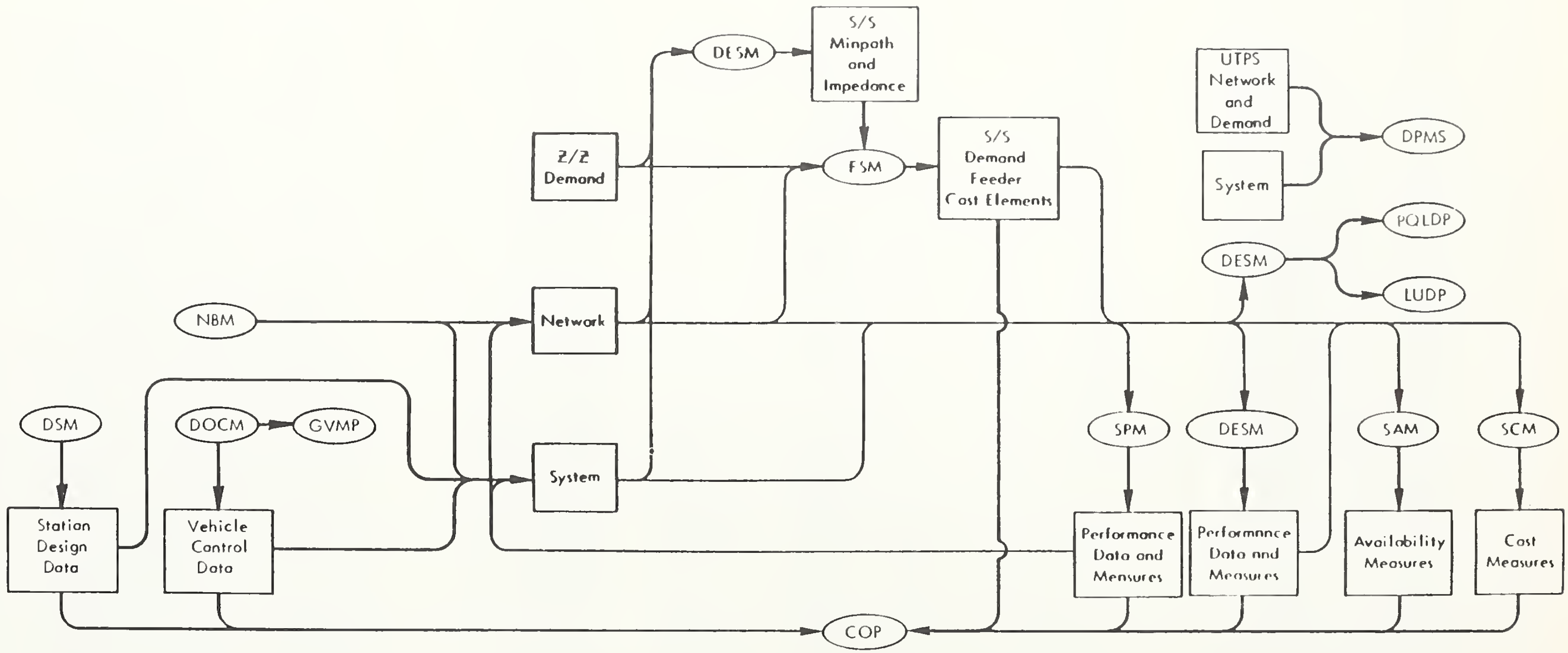


FIGURE 6-2. DEPLOYMENT ANALYSIS FLOW

3. System characteristics data (AGT.IANDD.SYSTEM) which includes factors such as the station link configuration, trip link parameters, control policies and network characteristics.

Also, the DESM file of the discrete vehicle sequence list from the guideway (AGT.STRUC.DEMANDVG) is an acceptable input to the DSM model processor for system-level station performance modeling.

The user defines the on-line or off-line station characteristics as a set of vehicle and passenger links. (Refer to Figure 6-3.) Vehicle links are used to represent upstream, downstream, and bypass links; input and output ramps and queues; and docking, storage, and modal transfer areas. An internal processor establishes the connectivity of the links based on a predefined set of possibilities, or the user can specify the connectivity. In addition to link characteristics such as capacity, travel time, and diverge functions, one or more of the following events are defined for each link as appropriate: headway, travel, board, deboard, joint board/deboard, store, and launch. Passenger links are used to represent ticketing, turnstile processing, and movement to the boarding area; passenger events are walk, process, and queue.

Failure and recovery events at vehicle or passenger link entry, or vehicle degraded operation, can be entered into the simulation at user specified times.

6.3.2.3 Major Outputs — The DSM produces two major output files:

1. Performance summary measures (AGT.PERSUM.DSM) which is input to the Comparison Output Processor (COP) for evaluating several alternative station configurations derived across several runs. The performance summary measures include, for example, vehicle load factors; rates of vehicles entering and leaving; statistics on empty vehicles; rate of trips arriving, boarding, and deboarding; and statistics of passenger and vehicle queues.

2. Trip and vehicle event log (AGT.TVF.DSM) which includes, primarily, the start time and duration of each trip and vehicle event.

The DSM determines statistics, at user specified intervals, of the number and occupancy times of vehicles, trips, and passengers for each event and queue state on each link and within the station area as a whole. The station model generates tables, plots, and histograms of statistical variables and a summary report on average and maximum numbers of vehicles and passengers on links and in queues. Summary statistics on vehicle and passenger arrivals at and departures from the station and vehicle and passenger rejections due to congestion are also calculated.

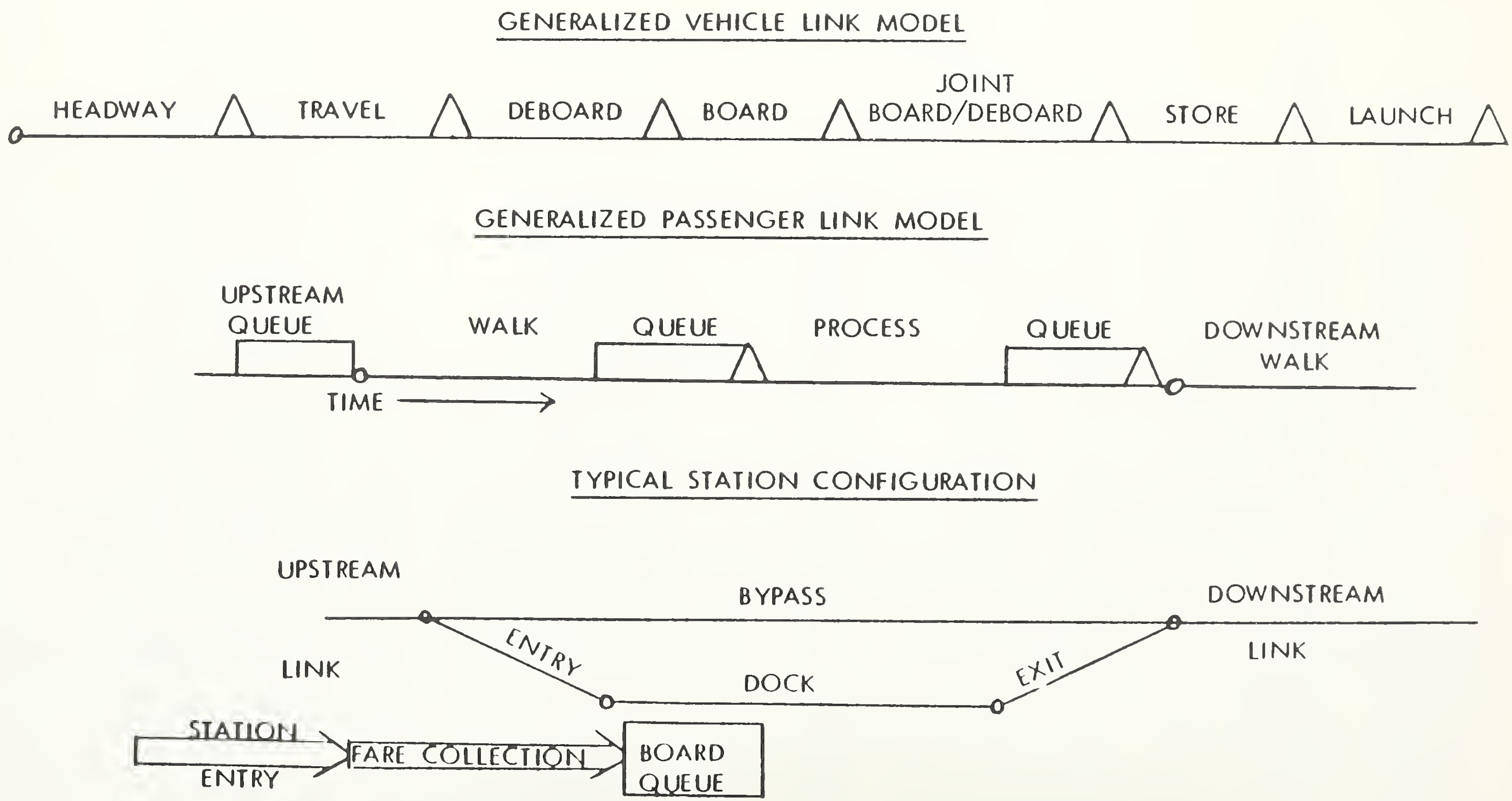


FIGURE 6-3. VEHICLE, PASSENGER, AND STATION MODELS

6.3.2.4 Methodology — The DSM is a discrete event processor that models a number of control policies including demand responsive single party and multiparty service, scheduled service, entrainment, transfer probability, empty vehicle search method, empty vehicle disposition method, and launch delay as a function of network and/or local delay.

Asynchronous events are modeled to represent failure or degradation, and recovery by station link and trip link. In the DSM, vehicle movement on a link is modeled as the time to complete each event or the time queued waiting to get to the next event. Vehicle movement between links is accomplished by tests to determine if it is safe to enter, if the link is operable, and if it has available capacity. Passenger movement is modeled similarly within the link, and movement to the next link is based on the availability of sufficient capacity. The headway event is used to ensure safe vehicle operation. An upstream vehicle is prevented from entering a link until the headway event is completed. The time to complete the headway event is the time it takes a vehicle to move one headway distance. The travel event is used to model all vehicle movements other than headway travel. Board and deboard events are modeled as random processes of the form $ax + by + c$, where x is the number of passengers boarding, y is the number deboarding. The store event is used for vehicles queued in storage. The launch event is used to model the reentry of the vehicle onto the guideway, including the case of merges with traffic on the bypass link.

6.3.3 Detailed Operational Control Model (DOCM)

6.3.3.1 Purpose — The DOCM simulates the detailed motion and interaction of automated vehicles on the three network elements shown in Figure 6-4. The DOCM is used to support the link and merge modeling in the DESM and as an independent vehicle control

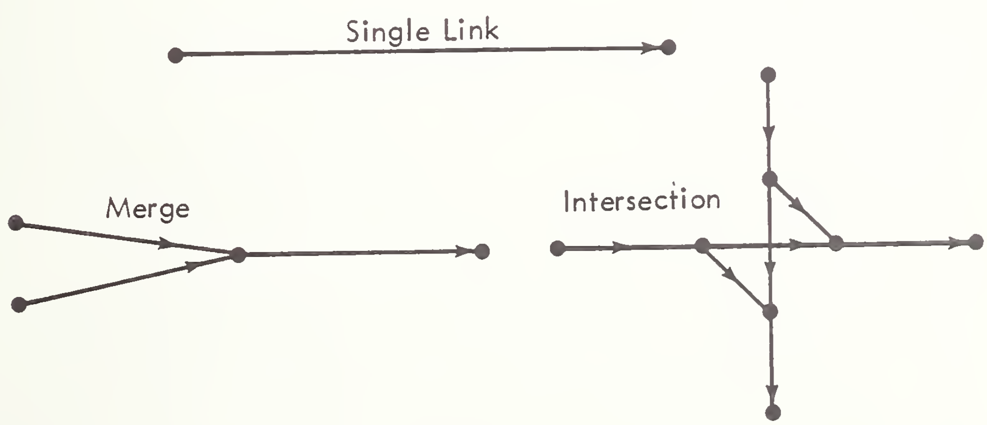


FIGURE 6-4. DOCM GUIDEWAY ELEMENTS MODELED

design tool. It models nonuniformity and noise effects of vehicle dynamics, propulsion, and braking, and sensors. The DOCM is used to evaluate alternatives including:

1. Point follower, vehicle follower, or fixed block vehicle position control
2. Fixed block or moving block headway protection
3. Synchronous, quasi-synchronous, or asynchronous merge control
4. First-in, first-out (FIFO) or priority merge strategy

6.3.3.2 Major Inputs — The major inputs are contained in two user supplied files:

1. Vehicle injection generation data (AGT.IANDD.INJECT) which includes factors for the creation of vehicles, the dynamics parameters, the sensor parameters, and headway policy.

2. Network element definition (AGT.IANDD.SYSTEM) which includes factors such as guideway definition and velocity control definition.

The user is given extensive flexibility in defining program inputs. Network elements are defined in terms of lengths, line speed profile, and fixed block locations. The environment is specified in terms of grade profile and wind time history. Limits are set for service and emergency acceleration, deceleration, and jerk. Either time-triggered or passage-triggered wayside mounted sensors or time-triggered vehicle mounted sensors to measure vehicle position and velocity can be specified. The gain and bias of each sensor can be specified, or the gain and bias may be randomly chosen from distributions defined by means and standard deviations. Random additive noise can also be specified for any measurement. The following vehicle characteristics can be individually specified or randomly chosen: injection time; input link; output link; initial velocity; mass; frontal area; maximum propulsion power; vehicle sliding, rolling, and drag coefficients; and vehicle propulsion and braking time constant variables.

6.3.3.3 Major Outputs — The DOCM produces two major output files:

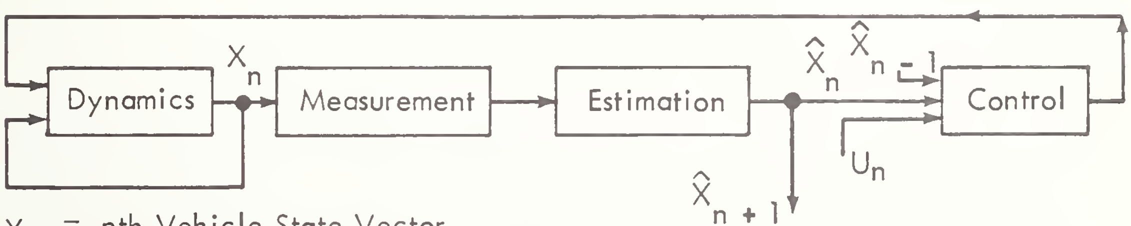
1. Performance summary measures (AGT.PERSUM.DOCM) which is input to the COP for evaluating alternative operational control factors derived across several runs. The performance summary measures include network, path, link, and vehicle related statistics.

2. Vehicle log (AGT.STRUC.DOCMVLOG) which is input to the Dynamics Processor, GVMP, and contains network definition and vehicle position records.

Reports output at user specified intervals are available for true state information, estimated state information, and control information. Asynchronous reports associated with events such as vehicle injections and ejections, merge assignments, headway violations and emergency stops are also made.

Raw statistics on system, path, control, merge and vehicle variables are subjects for time series plots, histograms, and statistical summaries by the output processor. In addition, the DOCM generates the following summary performance measures: vehicle travel times; the probability of violating headway, acceleration, and jerk limits; queue lengths; total, average, and peak propulsive and braking work done during the simulation period; and measures of merge and failure initiated congestion.

6.3.3.4 Methodology - The DOCM is a delta-time processor for the simulation of detailed operation of longitudinal control algorithms. The core of the program is the closed-loop feedback control system shown in Figure 6-5. This generalized control system can be specialized by input to define a particular vehicle control system. The DOCM models the measurement, estimation, and control command computation processes as well as the application of the control command signal to the vehicle propulsion and braking system. The control command signal or vehicle acceleration may also be open-loop specified for selected vehicles. Through numerical integration of the equations of vehicle motion, time histories of position, velocity, acceleration, propulsion energy, and brake energy for each vehicle on the network element are obtained. The user can evaluate a system by first verifying correct closed-loop operation with perfect information and all vehicles identical. The user can then evaluate the effects of imperfect information (sensor error) and nonidentical vehicles.



X_n = nth Vehicle State Vector

U_n = Reference State Vector

FIGURE 6-5. DOCM VEHICLE CONTROL MODELING TECHNIQUE

6.3.4 Feeder System Model (FSM)

6.3.4.1 Purpose — The FSM is used to map geographical zone-to-zone (Z/Z) demand onto AGT stations for input to the DESM and SPM. It is also used to compute submodal split data and feeder system performance and utilization data.

6.3.4.2 Major Inputs - The major inputs are contained in four user supplied files, and one file from the DESM:

1. Zone characteristics data (AGT.IANDD.ZN) which contains coordinates and areas for each zone
2. Station and region characteristics data (AGT.IANDD.STATION) which contains, for example, station coordinates, auto/feeder/walk speed in each region by service interval, route information, service type, and headway
3. Feeder characteristics (AGT.IANDD.CHAR) which contains, for example, the demand matrix scale factor and length of demand interval, acceptable walk distances, feeder transfer time, and performance factors for the feeder and AGT portions of a trip
4. Zone-to-zone demand matrix (AGT.IANDD.DZZ) which contains the demand for each zone pair. In addition, the FSM is designed to accept the zone-to-zone transit demand matrices used by the Urban Transportation Planning System (UTPS). This is accomplished by the AGT.IANDD.DZZ file being in compatible UTPS compressed format
5. Station-to-station performance (AGT.IANDD.SSP) which is obtained from the DESM and contains the nominal travel time for each station pair.

6.3.4.3 Major Outputs - The FSM major output files are:

1. Station-to-station demand (AGT.IANDD.DEMAND) which is used as input for the DESM and SPM and contains the demand interval and the demand for each station pair. This is illustrated in Figure 6-6, Temporal Demand Distribution, where each horizontal "__" represents a matrix of station origin-to-destination demand.

2. Performance summary measures (AGT.PERSUM.FSM) which is input to COP and contains measures for comparison of alternative feeder characteristics across more than one run. This file contains, for example, the level of demand diverted to non-AGT; level of demand accessing stations by walk, auto, and feeder; the number of feeder regions, stations and zones; and the fleet size and fleet vehicle miles.

In addition to file outputs, the FSM produces a number of reports including principally:

1. Feeder Characteristics and Program Options which lists, for example, walk, transfer, and feeder performance factors; fleet miles, hours, and size; demand using AGT, diverted, and unserviceable; region descriptions and results; station descriptions and results; and zone descriptions and results. The total feeder service mileage, operating time, and fleet size is used by the SCM to determine feeder system costs.

2. Station-to-Station Performance which lists nominal travel times for each station pair (reflecting the DESM input).

3. Station-to-Station Demand which lists for each demand interval the demand for each station pair.

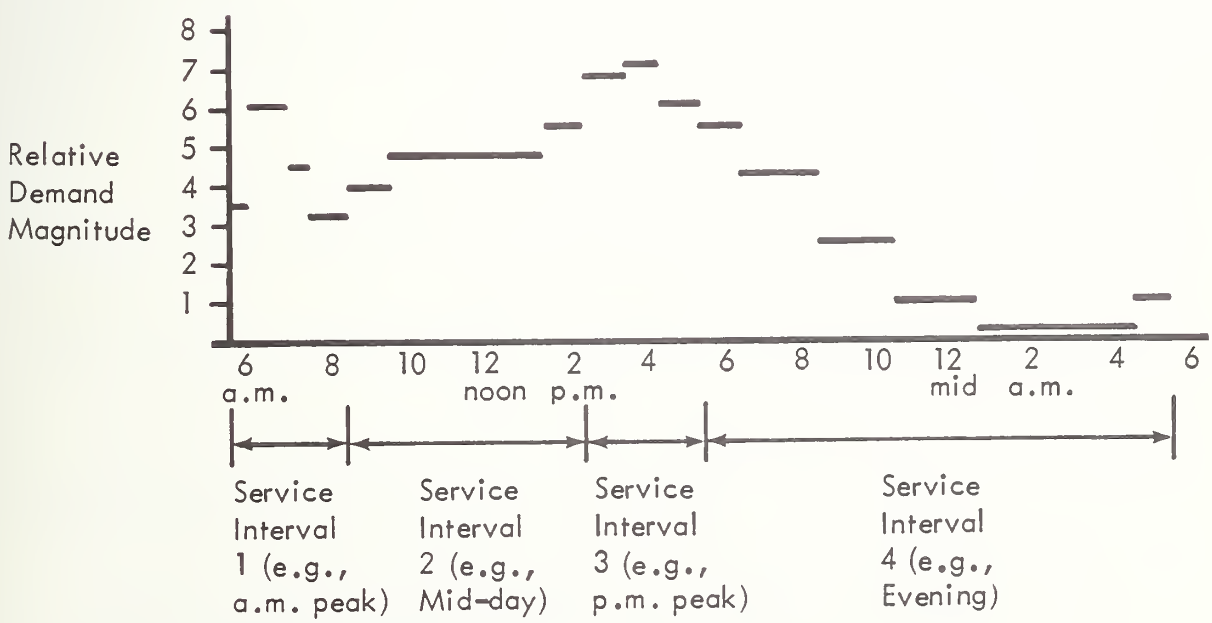


FIGURE 6-6. TEMPORAL DEMAND DISTRIBUTION

6.3.4.4 Methodology – The FSM represents the area served as a set of geographical zones. For distance calculations, the demand is considered to move from zone centroid to zone centroid. The FSM groups zones and stations to form service regions for assignment of common feeder attributes within a region.

To determine the demand at each station, the FSM finds the station pair which provides the best zone-to-zone travel time given a particular type of feeder service and an estimate of AGT station-to-station travel time. The best travel time path runs from origin zone centroid to origin station, to destination station, to destination zone centroid. Zone pairs which are assigned the same AGT station for both origin and destination are classified as unserviceable by AGT and the associated demand is not mapped onto the AGT system. The zone pair/station pair association function also compares feeder/AGT and feeder only performance for a given zone pair. A diversion curve based on travel times is used to assign a portion of the zone-to-zone demand to the AGT system. Following the assignment of demand to stations, the zone-to-AGT station and AGT station-to-zone portion of the zone-to-zone trip is split among walk, auto, and feeder transit submodes based on time and distance acceptability factors. The FSM calculates for each service interval and region the on-vehicle, off-vehicle, and total travel time for each submode. The feeder service is specified by route lengths, spacing, headways, speeds, and service type (either fixed route, demand responsive, or subscription). Although the FSM is not fully a modal-split model, it can be used to evaluate the relative merits of alternative station locations by comparing the levels of demand attracted by alternative deployments. After the submodal split function has allocated serviceable transit demand to the submodes, the performance modeling function computes on and off vehicle trip times.

The modeling technique of the FSM is illustrated in Figure 6-7 where the network is input as zones, station locations, and station-to-station impedences. Feeder characteristics are specified, and the FSM maps demand onto the AGT system and applies factors to perform submodal split. The station-to-station demand is output for DESM and SPM, and feeder performance is summarized.

6.3.5 Discrete Event Simulation Model (DESM)

6.3.5.1 Purpose – The DESM is a general purpose model designed to simulate:

1. The operation of an AGT system deployment over a complete network of guideway links and stations within a given time domain
2. The effects of various operational strategies and service policy options on overall system performance
3. Time varying demand situations
4. The interaction effects of vehicles and passengers competing for system resources.

6.3.5.2 Major Inputs – The major inputs are contained in four files:

1. Network definition data (AGT.IANDD.NETWORK) which is an output file from the NBM, or may be user created. The file contains start of link and end of link node number, station entry indicator and link length for each guideway link in the network.

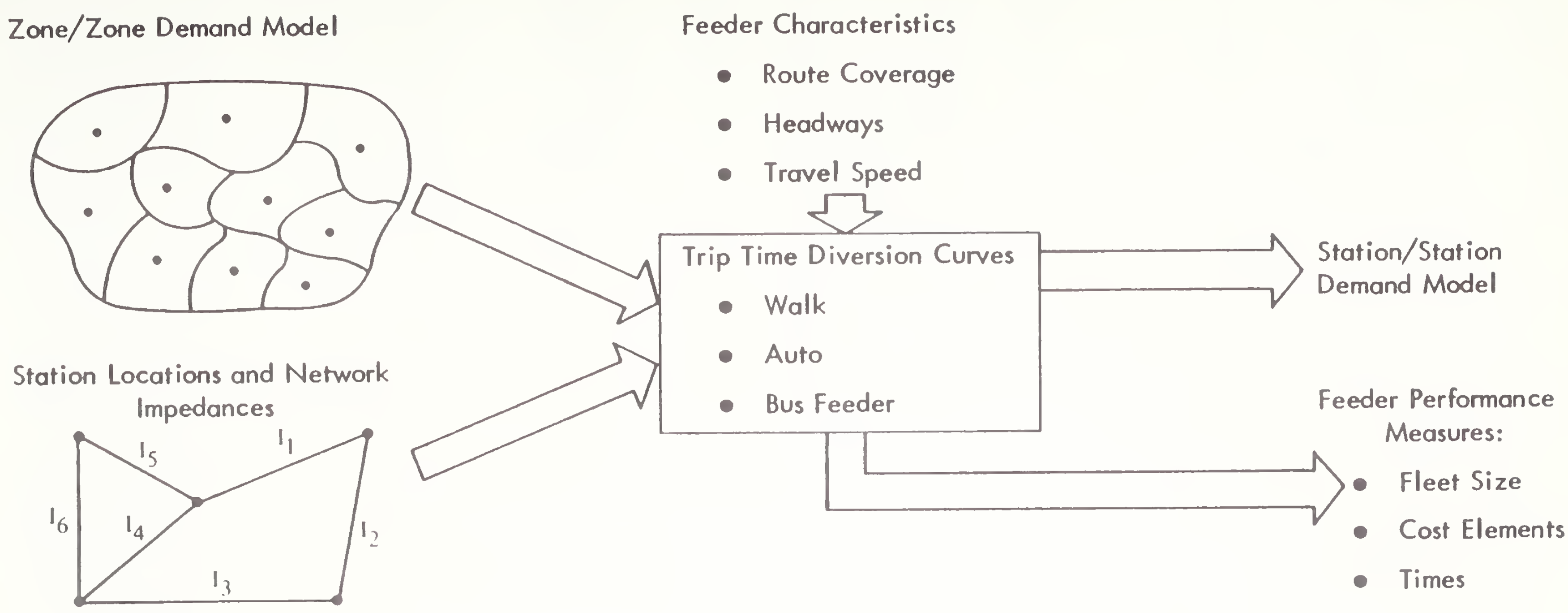


FIGURE 6-7. FSM MODELING TECHNIQUE

2. Station-to-station demand (AGT.IANDD.DEMAND) which is an output file from the FSM, or may be user created. The file contains the matrices of number of passengers traveling from origin to destination, the associated time period, and party size information.

3. System characteristics data (AGT.IANDD.SYSTEM) which is partially output by the NBM, and the remainder is user created. The file contains all parameters defining the system to be simulated, including, for example, the nominal speed by link or for all links, walk time for transfers, station board/deboard times, vehicle capacity, route assignments (NBM), route groups, transfer list, station type, demand stop indicator, and transfer policy selection.

4 Runtime data (AGT. IANDD. RNTIM) which contains simulation control information, demand scaling information, nonzero-time data such as failure/recovery instructions, and output requests.

6.3.5.3 Major Outputs - The major outputs include the following six major files:

1. Station statistics log (AGT.STRUC.DESMSLOG) which provides queue information to the dynamics program, the Passenger Queue Length Display Processor

2. Link statistics log (AGT.STRUC.DESMLLOG) which provides utilization information to the dynamics program, the Link Utilization Display Processor

3. Completed trips data (AGT .STRUC.TRIPLOG) which is input to the SAM to provide the delay consequences of failure

4. Vehicle arrival log (AGT.STRUC.DEMANDVG) which is input to DSM for the specification of each vehicle arriving at a station, and for specification of each trip on board the vehicle

5. Station-to-station performance (AGT.IANDD.SSP) which provides the nominal travel times for all station pairs input to the FSM

6. Performance summary measures file (AGT.PERSUM.DESM) and report which provides summary statistics related to the overall system; summaries across all links, stations, and routes; and level of service measures such as average travel time per completed trip.

In addition to these major files and the performance summary report, the DESM produces a large number of other reports including time series listings, plots, statistical summaries and histograms. The user can choose from a large number of measures: resource utilization such as fleet size and total vehicle hours, performance measures such as average trip length and travel speed, and level of service measures such as average wait time and number of transfers.

6.3.5.4 Methodology - The DESM is a general purpose event model designed to simulate the operations of specified AGT systems over a complete network. The transit systems that can be modeled range from personal rapid transit (PRT) to automated rail transit (ART) using networks ranging from simple shuttles or loops to fully connected grids with guideway link combinations which include merges, diverges, and grade-separated intersections. Station representations can range from simple to complex with the specific event processes being defined by the user.

The DESM input processor transforms the network definition, trip demand, and level of service data input by the user into a format to provide for efficient operation of the model processor. The model processor contains the discrete event simulation architecture which provides the time dependent processing of all functions associated with trip management and station, vehicle, and guideway operations. The interaction of these functions over time can cause queues of patrons in stations and propagation of vehicle congestion on the guideway and in stations. The model processor accepts asynchronous commands for time dependent inputs such as trip requests, fleet size changes, and introduction of failures and other external stimuli. The model processor collects, summarizes and formats statistical data at user-specified intervals on the completed events, current operational status, and queues at various levels of detail (system, station, route, link, vehicle, and trip). The output processor is used to retrieve the statistical output from the model processor. The output processor also calculates simulation period performance summary measures and both prints a report and writes a file for later comparison with the results of other simulation experiments.

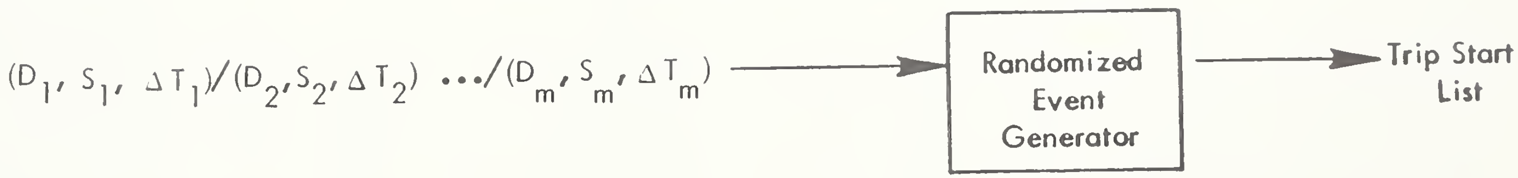
In the discrete event approach to modeling, system operation is represented as a list of events or transactions which are scheduled to occur in the future. Each system entity, such as a vehicle or passenger, is represented by its next event on the list. Each event is processed in time sequence. Processing consists of determining what the next event for that entity will be and when it will occur. Each new event is entered into the appropriate time position in the future events list. If conditions within the system preclude the execution of an event, a queuing mechanism is invoked which allows that event to be delayed until the inhibiting condition is cleared permitting the event to be then entered on the future event list.

Modeling of failure occurrences and delay until the onset of recovery is provided for by user commands. The reason for failure is not modeled; rather, the effect of failures on links, stations, and/or vehicles is modeled. Statistics on the effects of a failure, such as the number of passengers affected by the failed entity (during the failure and its recovery) and the average delay related to the failure, is calculated by comparing a DESM failure run with a nonfailure run using the SAM.

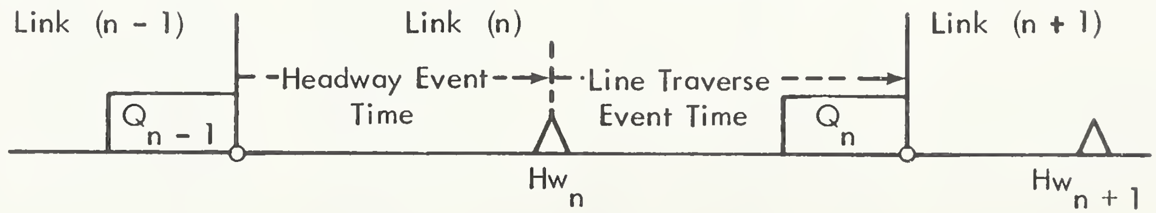
Passenger demand is represented by trips generated from a distribution which is based on either a user-input station-to-station demand matrix or one generated by the FSM. The model can accept a series of matrices (Dm), each having a different magnitude (Sm), spatial distribution, and applicable time interval (ΔTm). (See Figure 6-8 a)

In the DESM, a fleet of vehicles circulates over a specified guideway network according to a selected service policy and provides transportation service on an individual patron basis. Simulation functions associated with patrons include arrival at a station, assignment of a vehicle to service the trip request, waiting for the assigned vehicle, and boarding and deboarding. The travel portion of the patron activity is modeled in conjunction with vehicle travel. Vehicles move along the guideway network and through stations according to a user-selected system management strategy. The strategy consists of individually selected policies for type of service, berth assignment, entrainment, empty vehicle allocation, path selection, dispatch, longitudinal control, position regulation, and merge control. Other system characteristics, such as vehicle capacity, nominal speed, and headway, are also included factors in the simulation of system performance.

(a) DEMAND MODELING



(b) VEHICLE MOVEMENT MODELING



Q_n = Exit Queue From Link (n)

Hw_n = Indicator for Headway Event on Link (n)

FIGURE 6-8. DESM TRIP AND VEHICLE MODELING

The guideway network is represented in the DESM by a set of links and nodes. A link is the model representation of a portion of the guideway which can be considered uniform in its characteristics.

For internal manipulations, a link is further divided into a headway zone, link travel segment, and an exit queue as shown in Figure 6-8 b. Q_n is the exit queue, and Hw_n denotes the end of the headway event. The headway zone is where the entrance checks are made. The link segment is where vehicle traverse time is computed, and the exit zone is where the simulated vehicles are queued if entrance to the subsequent link is impossible due to congestion. This subdivision of the links facilitates an orderly simulation of the interactions between software entities. A node of the network is either a decision point (e.g., merge point) or simply the junction of two links. A station is represented in the same manner (by links and nodes) as the network, but the station representation includes both passenger boarding queue and vehicle links.

6.3.6 Downtown People Mover Simulation (DPMS)

6.3.6.1 Purpose - The DPMS is a modification of the DESM which enables a UTPS interface, provides additional output reports, and limits user options to those required for analysis of the operation of an AGT system in a downtown people mover environment.

6.3.6.2 Major Inputs - In the DPMS configuration, input is simplified. The user treats the Input Processor, Model Processor and Output Processor as a single job for execution rather than as three separately controllable programs. System characteristics data are input as described in paragraph 6.3.5.2, DESM Major Inputs, except that (a) the NBM output is not assumed, and (b) the DPMS offers a compressed set of input parameters as part of heavily commented default data files and a limited set of modeling options. Options for DPMS, for example, include fixed routes and scheduled service whereas DESM also permits real-time path selection and demand responsive service.

Demand data is input from a UTPS demand file in compressed format to a Demand Preprocessor, DPMDEM, which then outputs the demand file required for further DPMS processing (AGT. IANDD. DEMAND).

Network data is input from UTPS network files to a Network Preprocessor, DPMNET, which then outputs the network file required for further DPMS processing (AGT. IANDD. NETWORK).

6.3.6.3 Major Outputs - The major outputs include:

1. Station-to-station performance data in UTPS merged matrix data sets (J-file) and an accompanying report which provides total, average, standard deviation, maximum and minimum for a number of parameters such as wait time for each origin station to destination station pair, and grand totals across station categories

2. A DPM report of summary statistics including system wide, station, link, and route measurements and measures unique to downtown people mover analyses

3. A large number of other reports including time series listings, plots, statistical summaries and histograms. The user can choose from a large number of measures: resource utilization such as fleet size and total vehicle hours, performance measures such as average trip length and travel speed, and level of service measures such as average wait and number of transfers.

6.3.6.4 Methodology - The DPMS is a modification of the DESM, adding two input preprocessors which translate from the UTPS file structure to the DESM input requirements, one new output file, a new output report, and default control files that restrict user alternatives to the DPM application environment. The DPMS methodology is detailed in paragraph 6.3.5.4, DESM Methodology.

6.3.7 System Planning Model (SPM)

6.3.7.1 Purpose - The SPM is a coarse flow model of AGT vehicles and passengers on links and in queues. The SPM is used to establish the effects of network configuration, demand, system configuration, and management strategies on vehicle utilization and level of service parameters and to report the passenger and vehicle flows throughout the network.

6.3.7.2 Major Inputs - The major inputs are contained in eight files, three of which are obtained from NBM output, and one from FSM output:

1. Network definition data (AGT.IANDD.NETWORK) which is output from the NBM, or may be user created. The file contains start of link and end of link node number, station entry indicator and link length for each guideway link in the network.

2. Station definition data (AGT.IANDD.SPMSTNS) which is output from the NBM, or may be user created. The file contains the nodes associated with each station by station number.

3. Routes definition data (AGT.IANDD.SPMRTES) which is output from the NBM, or may be user created. The file contains the sequence of nodes comprising each route, and the initial number of vehicles on each route-link.

4. Station-to-station demand data (AGT.IANDD.DEMAND) which is an output file from the FSM, or may be user created. The file contains the matrices of passengers traveling from origin to destination, the associated time period, and party size information.

5. Demand characteristics data (AGT.IANDD.DMCHAR) which is user created, and contains the scale factor to be applied to each demand matrix, and the end-time at which the demand matrix will end/change.

6. Trajectories data (AGT.IANDD.SPMTRAS) which is input by the user, and contains for each trajectory (passenger path from origin to destination) the route number, route starting node, origin and destination station, and the fraction of the demand which will use that trajectory.

7. Passenger initial loading (AGT.IANDD.PASSLD) which is input by the user and contains the initial placement of passengers on vehicles and in station queues for each route-link and for each destination.

8. Link attribute data (AGT.IANDD.LKATTR) which is input by the user and contains merge policy, the maximum vehicle flow rate, and associated intervehicle spacing.

6.3.7.3 Major Outputs - The SPM outputs are contained in standard reports. The SPM reports the rate of flow and number of vehicles on each route-link combination, the number of passengers on vehicles and at stations for each route-link-destination combination, and the link and station queue transit times for each link and route-link. In addition, for each route-link combination the model reports vehicle and passenger kilometers, vehicle load factors, vehicle occupancies, and percent standing. For each route the model reports the hours, passengers served, and vehicle trip productivities.

Finally, the model reports the station-to-station trip times between all station pairs. The system planning model outputs are reported at user specified intervals to provide the user with a presentation of key system-operation measures as a function of time for all parts of the network.

6.3.7.4 Methodology - The various functions modeled by the SPM are as follows:

1. Demand-The SPM is driven by the mean rate of passenger arrivals.

2. Service Policy-Only fixed route is modeled, but not all stations along a route need to be serviced.

3. Passenger Flow Management-Passenger flows are divided according to the predetermined passenger-route assignment provided by the analyst and apportioned to the appropriate queues.

4. Station Configuration-On-line or off-line stations are considered.

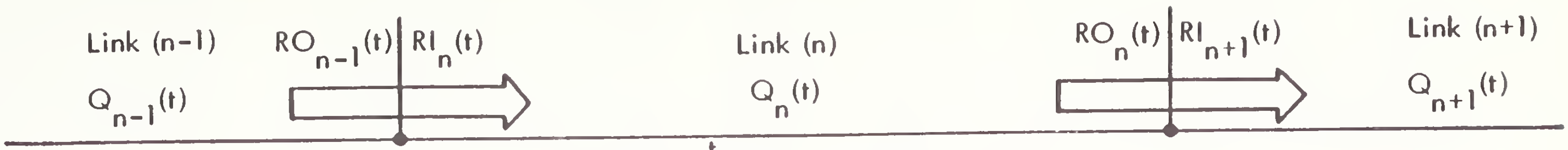
5. Network Configuration Capabilities-Networks are modeled in terms of nodes and unidirectional links. Each node may have up to three connecting links which must include at least one entering and one exiting link.

6. Merge Control Policies-Priority or first-in, first-out (FIFO) merge policies are considered.

The SPM models the flow of passengers and vehicles using the fluid approximation for queues in which the contents of a queue at time t is given by the initial state at t_o and the integral of the difference of the input and output flow rates between t_o and t. A second-order Runge-Kutta approximation is used to perform the integration. In modeling vehicle flow, the links represent queues with vehicles as queue content; in modeling passenger flow, the station waiting areas and the vehicles represent queues with passengers as queue content. (See Figure 6-9)

6.3.8 System Availability Model (SAM)

6.3.8.1 Purpose - The SAM is a system-level model which provides measures of vehicle and passenger availability. Maintenance and standby fleet sizes required to support the operational fleet are also determined.



Where

$$Q_n(t) = \int_0^t \left[RI_n(\tau) - RO_n(\tau) \right] d\tau$$

$$RI_n(t) = RO_{n-1}(t)$$

$$RO_n(t) = \frac{Q_n(t)}{\Delta T_n}$$

ΔT_n = Time to traverse link (n) at present density

FIGURE 6-9. SPM MODELING TECHNIQUE

6.3.8.2 Main Inputs - The major inputs are contained in two files, one of which is supplied by the DESM:

1. Trips Logs (AGT.STRUC.TRIPLOG) which are produced by the DESM and contain for the nonfailure reference case and for the failure case, information on vehicle and passenger travel time for each trip, travel distances, transfer time, and number of passengers for each trip.

2. Failure Rate and Maintenance Time Data (AGT.IANDD.RNTIM) which are produced by the user, and contain data such as failure rates by subsystem, the average time to repair and to service a vehicle, reliability region characteristics, the delay thresholds and print control cards for selected report generation

6.3.8.3 Major Outputs - The SAM produces one major file output and a number of standard reports:

1. The performance summary measures file (AGT.PERSUM.SAM) which is input to the COP provides summary measures such as standby, maintenance, and total fleet size, number of service bays required, and vehicle and passenger availability.

2. Other major reports present information on failure rates, trips delayed, vehicle delay times, passenger availability, vehicle availability and maintenance fleet.

6.3.8.4 Methodology - The model provides the capability to evaluate parametrically availability measures as a function of network, system and demand characteristics by considering the effects of failure on operation, failure response strategies, hardware reliability and maintainability, and level of parts quality and redundancy.

Passenger availability is defined as the percent of total completed trips delayed less than a specified threshold. Vehicle availability is defined as the percent of total vehicle operating hours that the vehicles are not delayed by failures. The maintenance fleet is the expected number of vehicles in maintenance for regular service or failure reasons. The standby fleet is the number of vehicles needed to assure with a certain probability that a vehicle will be available to replace a failed vehicle.

Passenger availability is calculated as follows. The failure rates are specified as a function of subsystem (vehicle, station, guideway, control), cause of failure, reliability level (off the shelf, mil-standard, redundant, etc.), and failure type (stoppage, degraded operation). A standard day's scenario is described (for several distinct demand periods and regions) to establish the values of the causal variables. The causal variables used are vehicle operating hours, number of passengers through stations, system elapsed time, number of vehicles through stations, vehicle kilometers, the number of stations, and guideway kilometers. The number of passengers delayed greater than specified thresholds is determined by the SAM by comparing DESM trip logs generated for failure/recovery situations with those of the nonfailed case for the specified scenario. The trip logs contain trip origin and destination, departure and arrival times, number of transfers, and the number of people traveling together. The expected failures for the scenario are determined from the failure rate and the causal factor values. For example, the number of failures at stations is a function of the station failure rate, the passenger flow through stations, system elapsed time, the number of stations, and the vehicle flow through the station. The expected number of delays above threshold are calculated by multiplying the number of expected failures by the fraction of passengers delayed above threshold for those types of failures. Passenger availability is calculated using the total number of trips and the expected number of passengers delayed above the specified thresholds. Vehicle availability is determined without regard to threshold, but rather considers the hours of delay as a consequence of failure in comparison with nonfailure conditions.

The standby fleet size is determined as a probability function. This probability is a function of the active fleet size, the vehicle failure rate, and the number of service bays and their service rates. A standby fleet is set to achieve a specified probability that the standby fleet is adequate, e.g., 95 percent that a vehicle will be available when required. The average number of vehicles in maintenance (the maintenance fleet) is the number receiving routine servicing plus the number expected to be in maintenance to repair a failure.

Up to five alternative reliability levels for a given system can be analyzed in a single SAM run. In addition to varying the reliability levels, the user can also specify up to ten passenger delay thresholds. Each delay threshold will have a direct effect on passenger availability by varying the number of passengers considered by the model to be significantly delayed.

Presented schematically in Figure 6-10, SAM Evaluation Technique, the failure rates by subsystem are combined with the parameters of nominal operation and, from the DESM, the delay consequences. Maintenance information is also provided such as average time to complete a repair or a service action, and the model then outputs the measures of passenger and vehicle availability and the maintenance fleet size estimate.

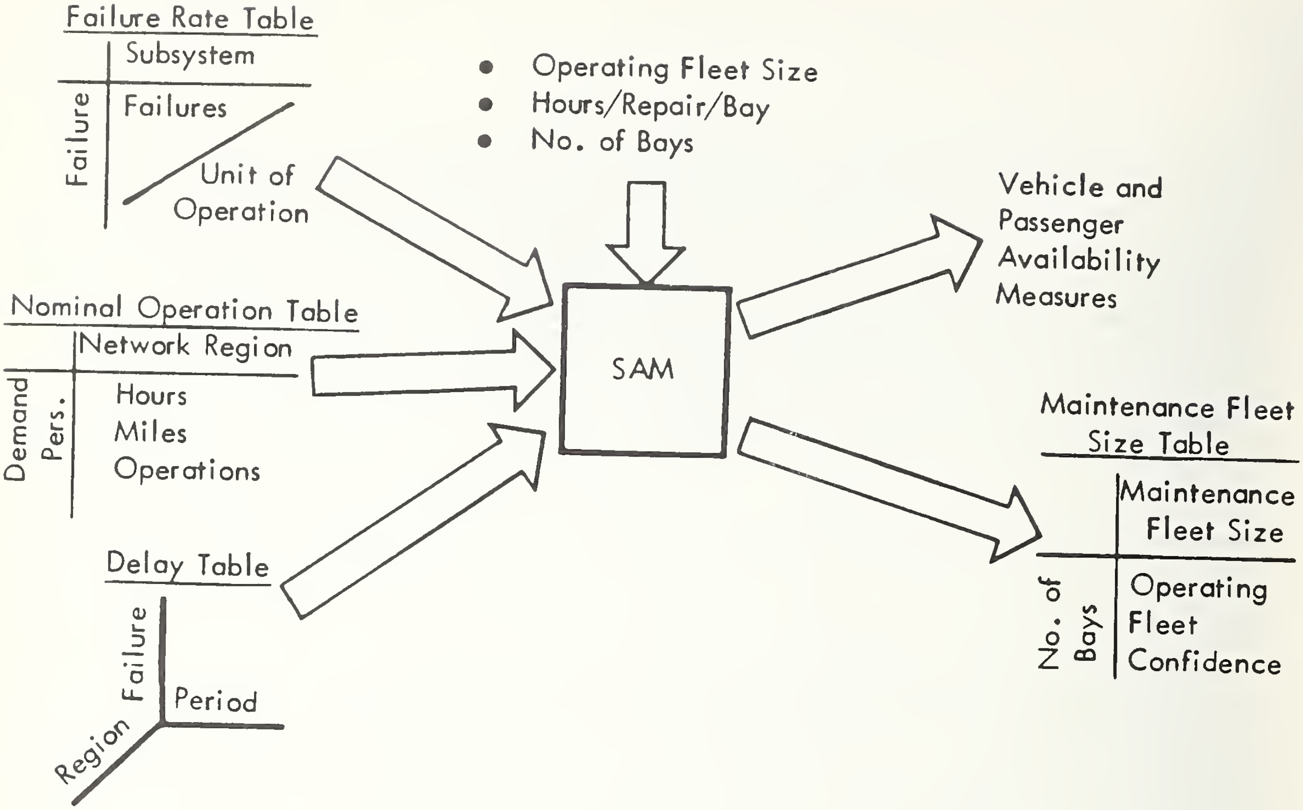


FIGURE 6-10. SAM EVALUATION TECHNIQUE

6.3.9 <u>System Cost Model (SCM)</u>

6.3.9.1 <u>Purpose</u> - The SCM is an interpretive program that determines life cycle cost measures taking into account charges for interest, replacement, and annual operating and maintenance.

6.3.9.2 <u>Major Inputs</u> - The major SCM inputs include three files for the data on which the cost equations operate, and, as an interpretive program, the equation set in one additional file:

1. Data equations file (AGT.IANDD.SCMEQU) contains the categories for the life cycle cost process and the equations for those categories.

2. Deployment data values file (AGT.IANDD.SCMDPLY) contains the cost items that are site specific. These include guideway data, such as the length of elevated single lane urban guideway; passenger station data, such as the number of turnstiles in each station; support facilities, such as central control buildings; annual vehicle operations, such as number of passengers and vehicle kilometers; feeder service data, such as passengers and vehicle kilometers; and inflation factors.

3. System data values file (AGT.IANDD.SCMSYS) contains the unit costs and technology items which are specific to system type. These include vehicle and guideway unit costs and vehicle propulsive unit energy.

4. Common data values file (AGT.IANDD.SCMCOM) contains costs and factors general to all systems and deployments. These include building and equipment costs, such as cost per ticket machine; nonpropulsive unit energy requirements, such as BTU/m^2/yr for air conditioning; unit pollution data, such as grams of CO per kwH; and general cost factors, such as percent of total vehicle cost for spare parts.

6.3.9.3 Major Outputs - The SCM produces one major file output and a number of standard reports:

1. The performance summary measures file (AGT.PERSUM.SCM) which is input to the COP, and provides summary measures selected by the user from among items presented in the standard reports.

2. Eight standard reports which provide information on land utilization, energy consumption, pollution, capital costs at purchase, cumulative capital costs to date, annualized cost, cumulative amortized cost to date, and present values.

6.3.9.4 Methodology - The SCM has a unique architecture for cost calculations. It consists of: (1) a general purpose processor capable of performing cost modeling functions in a general purpose tree data structure and (2) a data base element (input) which contains the tree and tree traversal control tables which represent the equations to be used. Since the equations can be altered as a model input, several cost models can be developed by the user.

The SCM calculates the cash flow process for financing and operating an AGT system. The SCM calculates the life cycle cost of an AGT system by computing the effects of capital, operating, and maintenance expenditures throughout a specific life cycle period. Several environmental measures are also calculated by the SCM - namely, energy consumption, pollution, and land use requirements. The SCM has been constructed so that the feeder system attributes associated with an AGT system can be included in the life cycle cost analysis.

Estimated data for input items can be varied to determine their effect on the transit system's life cycle cost. For example, the SCM is programmed so that vehicle maintenance cost is calculated by adding a cost per vehicle kilometer (for preventive maintenance), and a cost per failure (for failure maintenance) to determine a total vehicle maintenance cost. The number of failures per vehicle per year can be varied resulting in a new life cycle cost for the transit system.

6.3.10 Analysis Support Software

6.3.10.1 Graphics Support Programs - The Network Build Module (NBM), the Guideway Vehicle Motion Program (GVMP), the Passenger Queue Length Display Program (PQLDP), and the Link Utilization Display Program (LUDP) comprise the four graphics support programs.

The NBM provides an interactive method of entering graphical network representations for the SOS models. The guideway, the station locations, and the vehicle routes are entered from a map using a graphics tablet or from the CRT display using a joystick-cursor. The resulting file is transmitted from the Tektronix 4081 terminal via phone lines to the IBM 370 by means of a Transfer Program, and there it is automatically converted to the proper format for SOS model input by means of a Conversion Program. The network consists of nodes connected by vehicle-travel links. Links are specified as to direction (may be bidirectional). The location of stations is specified, and routes are specified as a circular sequence of links with indicated station stops.

The GVMP operates on a file produced by the DOCM. That file is transferred from the IBM 370 to the Tektronix 4081 by means of the Transfer Program. At the Tektronix 4081, the GVMP creates a dynamic display of vehicles moving along the link, merge or intersection. Features such as the rate of display, thresholds of interest, and the generation of hard copy are under user control.

The PQLDP operates on a file produced by the DESM. That file is transferred from the IBM 370 to the Tektronix 4081 by means of the Transfer Program. At the Tektronix 4081, the PQLDP creates a dynamic display of passenger queue lengths at the various stations throughout a network. The PQLDP reads the background network from a file at the 4081. Features such as the rate of display, thresholds of interest, and the generation of hard copy are under user control.

The LUDP operates on a file produced by the DESM. That file is transferred from the IBM 370 to the Tektronix 4081 by means of the Transfer Program. At the Tektronix 4081, the LUDP creates a dynamic display of link utilization throughout a network. The LUDP reads the background network from a file at the 4081. Features such as the rate of display, thresholds of interest, and the generation of hard copy are under user control.

6.3.10.2 Additional Support Programs - A number of data base manipulation and programming aids were developed including, principally, the comparison output processor (COP), which retrieves summary statistics from various model runs for the purpose of graphically comparing alternate AGT system attributes, and the structured programming preprocessor (PARAFOR), which has the advantages of eliminating the need for "go to" statements, improving code readability and increasing speed of code production. Catalogued procedures (PROCLIB) and command procedures (CLIST) were prepared to permit running of the models without extensive knowledge of job control language (JCL). And, a deterministic demand preprocessor (DDP) was built which operates in conjunction with the DESM to provide a nonstochastic alternative in the production of trip lists.

7.0 TRADE-OFF ANALYSIS

The primary objective of the system trade-off analysis is to define a superior system configuration for each deployment in terms of system parameters, operating strategies, and station configurations. The superior systems are specified as a result of trade-off analysis so that performance goals are satisfied at approximately minimum cost. Other major objectives of the analysis include the generation of performance, cost, and availability sensitivity data for variations in system design and the development of system design guidelines.

In this section of the report the 14 deployments that were analyzed are identified along with the performance goals that were used as design criteria. The use of the SOS software to support the trade-off analysis is then summarized. Finally, the results and conclusions of the system trade-off analyses are presented. More complete discussion of the methodology and results of the trade-off analysis are presented in the following task reports:

Analysis of SLT Systems [45, 46, 47]

Analysis of ART Systems [48, 49, 50]

Analysis of GRT Systems [51, 52, 53]

7.1 REPRESENTATIVE SYSTEM DEPLOYMENTS

The representative system deployments that were considered in the trade-off analysis are identified in Table 3-1. The network configurations used for the Activity Center Line-Haul (SLT 1) and Activity Center Circulation (SLT 2) applications are illustrated in Figure 7-1. Figure 7-2 illustrates the three network configurations that were studied in the CBD Circulation application. The single lane loop and multiple loop networks that were considered in the CBD Line-haul application are shown in Figure 7-3. Figure 7-4 illustrates the grid network configurations that were considered in the metropolitan area applications. The line-haul grid network in the upper portion of the figure was analyzed in conjunction with an ART and a GRT system in the High CBD Orientation, High Reverse Commutation application. The network consists of dual lane guideway and the stations are all on-line. The more fully connected grid network shown at the bottom of the figure was analyzed in the context of an SGRT system in the Low CBD Orientation, High Reverse Commutation application. Except for the single lane loop in the CBD (indicated by directional arrows), the guideway is dual lane with off-line stations. All intersections are full interchanges.

A major output of the trade-off analysis is the definition of a nominal representative system deployment for each of the 14 AGT system/network/demand combinations that were considered. A nominal system is defined as one that achieves or closely approaches specified performance at approximately minimum cost. The performance and availability goals used for the trade-off analyses are presented in Table 7-1.

SLT 1 — SHUTTLE NETWORK IN THE ACTIVITY CENTER LINE-HAUL APPLICATION WITH A LOW-SPEED LGRT

SLT 2 — MULTIPLE-LOOP NETWORK IN THE ACTIVITY CENTER CIRCULATION APPLICATION WITH A LOW-SPEED IGRT

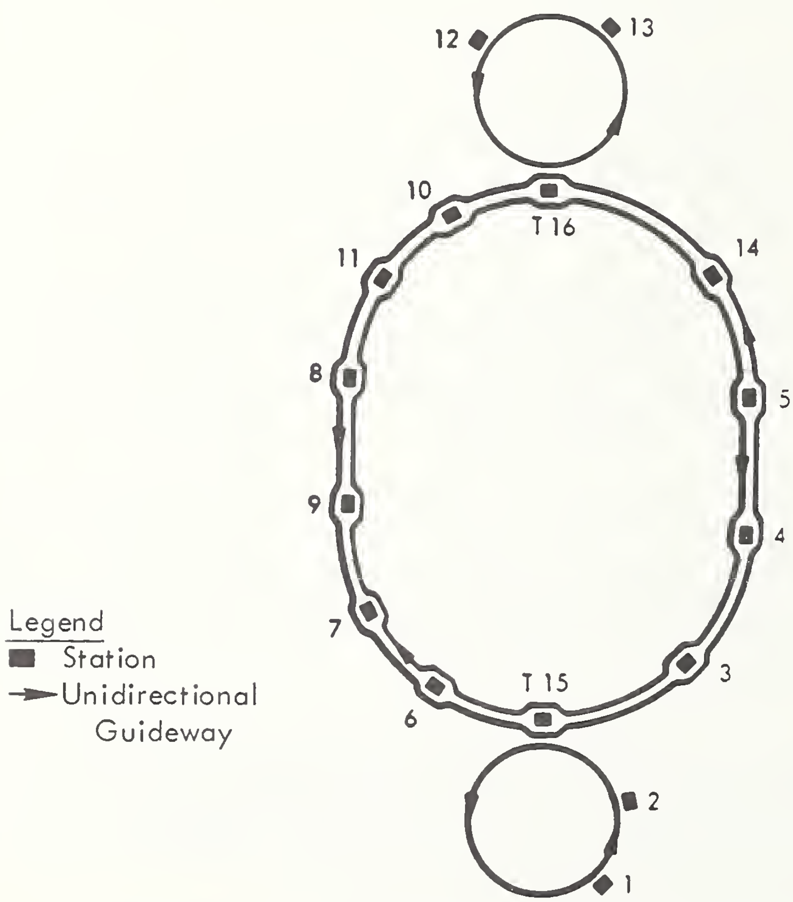


FIGURE 7-1. NETWORKS FOR ACTIVITY CENTER APPLICATIONS

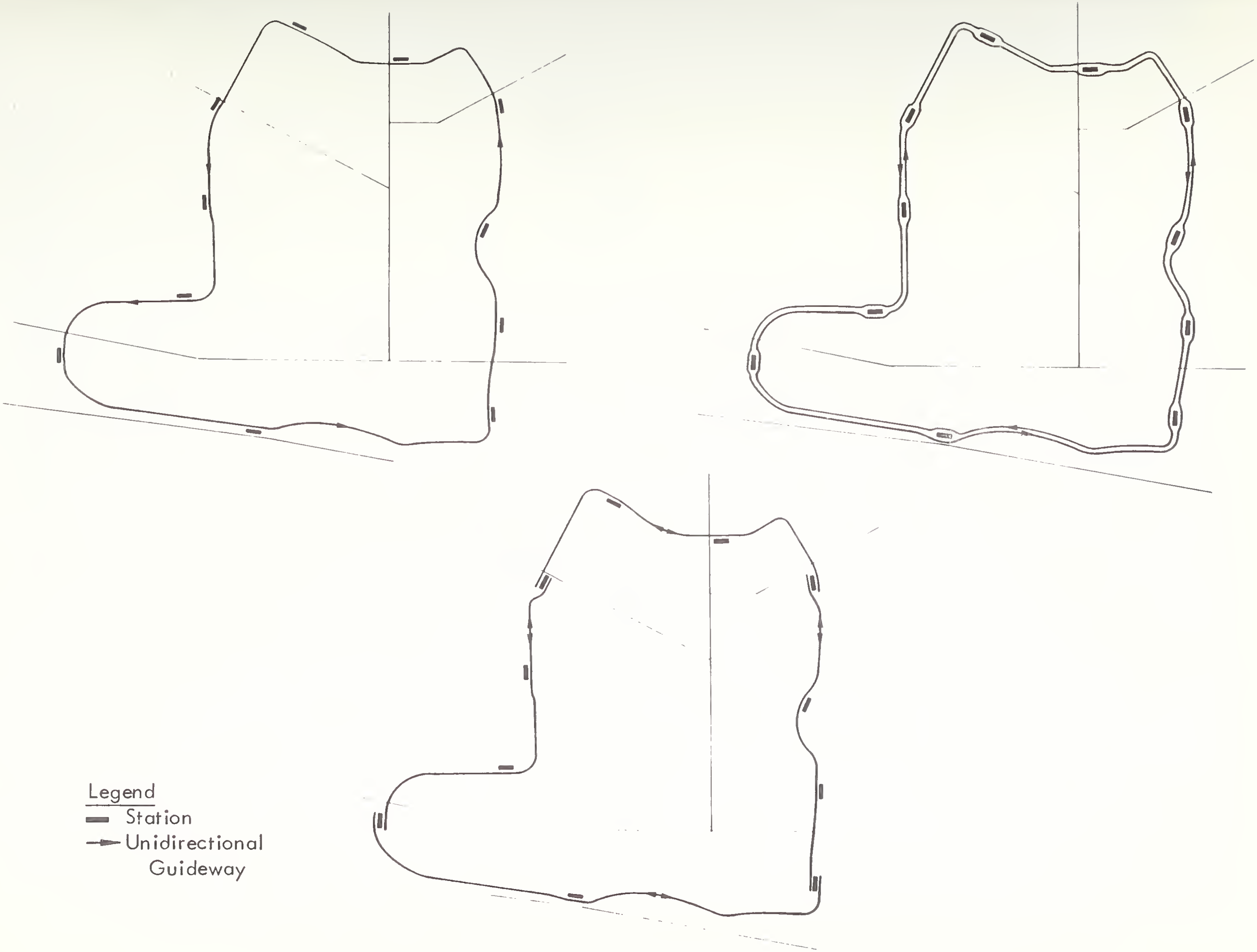


FIGURE 7-2. NETWORKS FOR THE CBD CIRCULATION APPLICATION

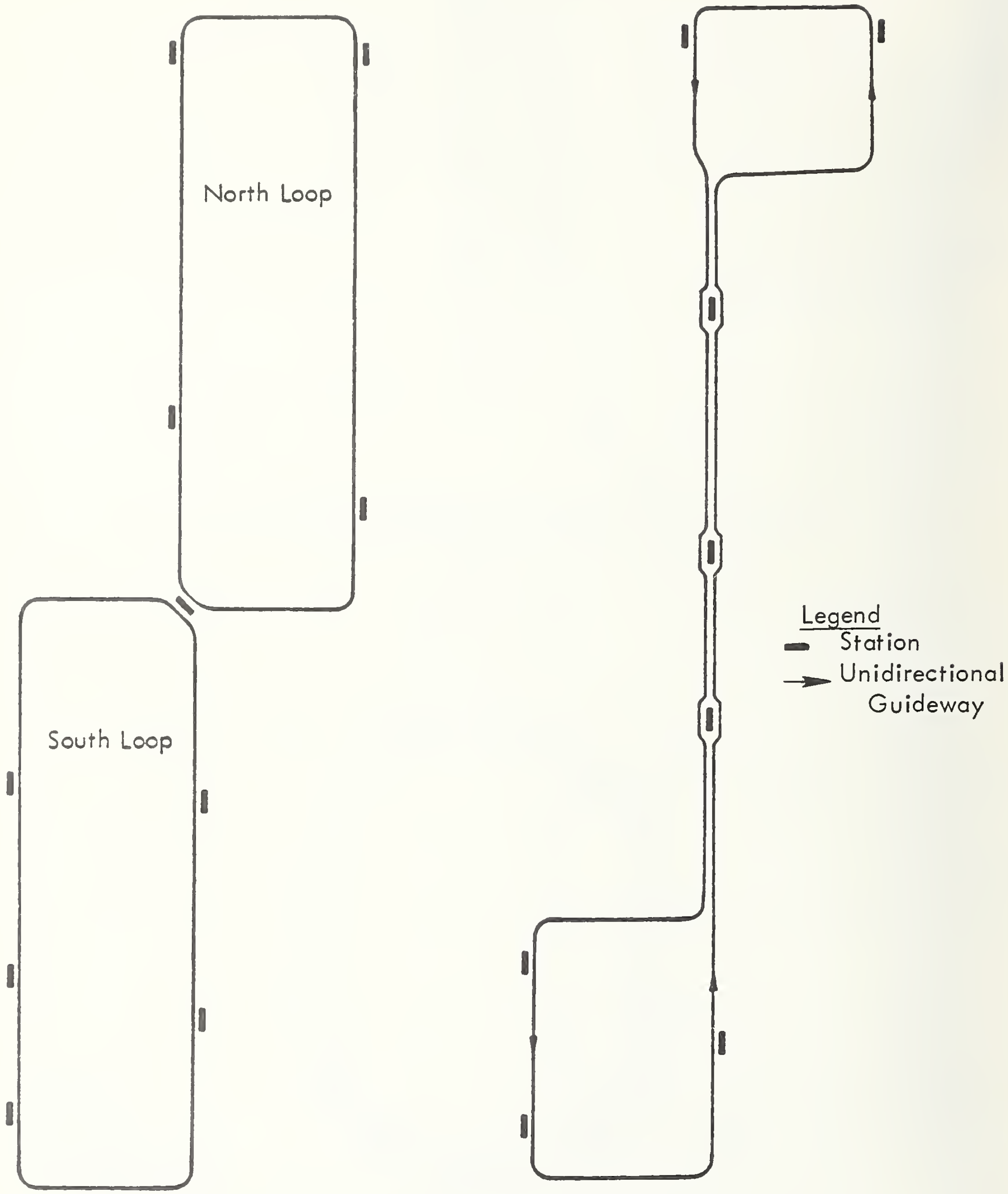


FIGURE 7-3. NETWORKS FOR THE CBD LINE-HAUL APPLICATION

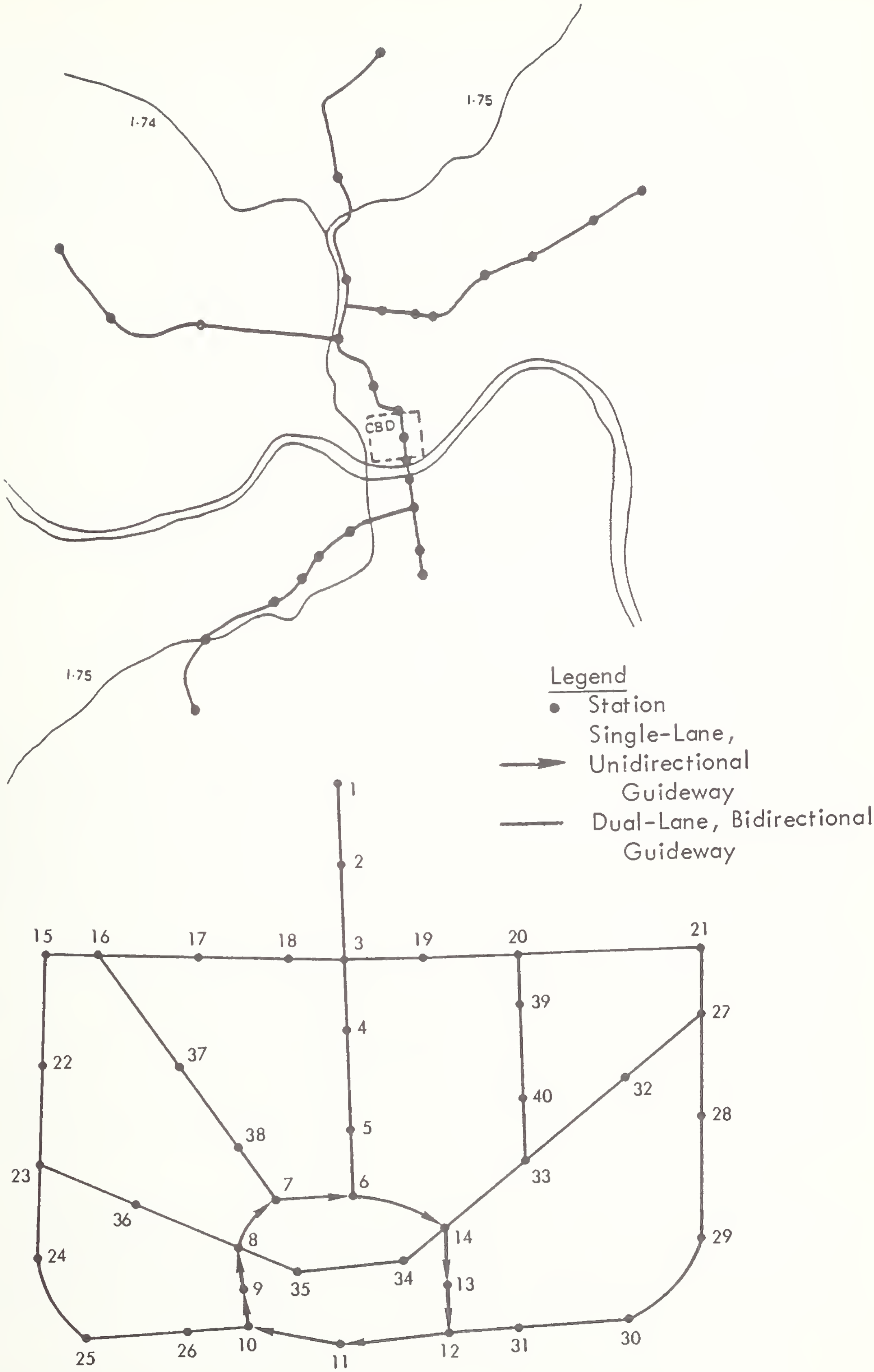


FIGURE 7-4. NETWORKS FOR THE METROPOLITAN AREA APPLICATIONS

TABLE 7-1. PERFORMANCE/AVAILABILITY GOALS FOR AGT DEPLOYMENTS

	SLT	ART	GRT
Average Wait Time (s)			
Peak	240	180	180
Off-Peak	240	300	180
Maximum Wait Time (s)			
Peak	540	480	480
Off-Peak	540	600	480
Average Travel Speed (m/s)	3.5 - 6.0	8.5	8.5
Vehicle Availability	0.994	0.994	0.994
Passenger Availability	0.996	0.996	0.996

7.2 ANALYSIS METHODOLOGY

The overall flow of analysis was partitioned into three major steps: initial system definition, subsystem analysis, and system trade-off analysis. The first step involved the initial definition of the deployment and generation of station-to-station demand. The second step included analysis of vehicles, stations, and control systems to determine subsystem characteristics necessary for the trade-off analyses. Failure management and reliability analyses were also conducted. The results of these subsystem analyses are reported in Volume III of the SLT,[47] ART,[50] and GRT[53] analysis reports. Finally, a trade-off analysis was performed on each of the 14 representative system deployments to define system configurations for peak and off-peak period operation. Trade-offs were conducted which involved vehicle capacity, number of cars per train, operating headway, cruise velocity, routing alternatives, and empty vehicle management strategies for demand responsive service. Also evaluated were system costs, availability, and performance sensitivities to demand variations and vehicle seating capacity. The results of the trade-off analyses are reported in Volume II of the SLT,[46] ART,[49] and GRT[52] analysis reports.

Figure 7-5 illustrates the manner in which four system-level processors were used to support the system trade-off analyses. The figure also shows the general flow of data from one part of the analysis to another. The following discussion identifies iteration loops which were executed in the analysis of AGT deployments as well as others which could be considered in future trade-off analyses.

The analysis process depicted in Figure 7-5 begins with the use of the Feeder System Model (FSM) to generate station-to-station demand matrices for each deployment. Inputs to the FSM include zone-to-zone origin-destination demand data, a network description in terms of station coordinates relative to zone centroid locations, feeder system

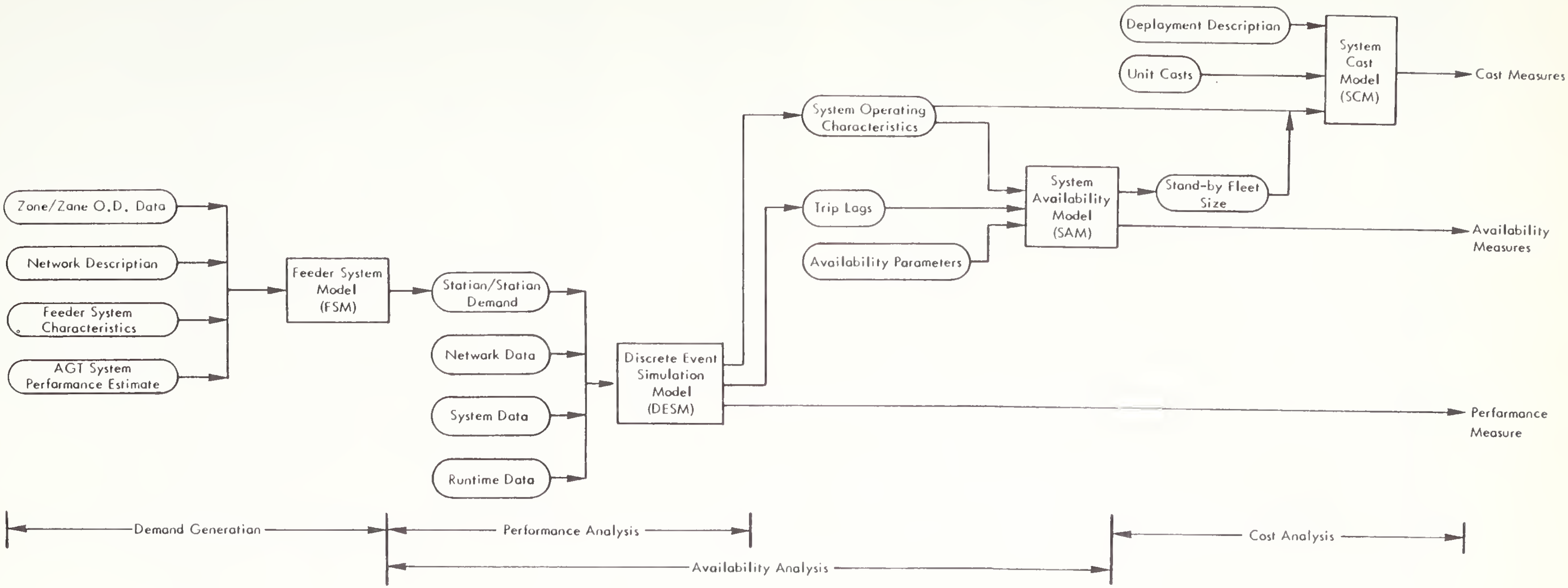


FIGURE 7-5. USE OF AGTT-SOS SOFTWARE FOR SYSTEM ANALYSIS

characteristics, and an estimate of station-to-station trip time for the deployment under consideration. The outputs of the FSM are station-to-station demand matrices for all demand periods.

The results of the subsystem analyses were used to define system configurations which have potential for satisfying system goals. The trip size distribution data were added to the station-to-station demand files. Networks and systems were defined in terms of DESM inputs, and DESM simulation control parameters were specified. The DESM was run a number of times for each deployment to determine the combinations of vehicle capacity, train consist, operating headway, and cruise velocity which satisfy the wait time and travel speed goals for each major demand period of the service day. The system configuration which satisfies the performance goals at approximately minimum cost was selected as the nominal configuration for each deployment. The DESM was also used in the availability analysis to generate trip logs from which passenger delay information relating to various failures was obtained. The portion of the system analysis which involved the use of the DESM produced three general types of outputs: values of performance measures for the nominal system and for systems resulting from parameter variations about the nominal, system operating characteristics used to define inputs to the System Cost Model (SCM) and the System Availability Model (SAM), and the trip logs which define the trip time of individual passengers during periods of normal system operation and system failure.

Both the DESM and the SAM were used in the availability analysis. In addition to the system operating characteristics and the trip logs generated by the DESM, the SAM requires as input the values of several availability parameters such as subsystem reliabilities, failure recovery times, and vehicle maintenance data. The SAM generates as output the system availability measures and the standby fleet size required to achieve those values of availability.

The System Cost Model was used to evaluate capital and variable costs, land utilization, energy consumption, and pollution. In addition to system operating characteristics based on DESM outputs and the standby fleet size generated by the SAM, system description and unit cost information are required as inputs to the SCM. The SCM was used to evaluate cost measures for the nominal systems and in many cases for alternate systems resulting from the seating capacity sensitivity study. Detailed unit cost data which are required as input to the SCM were compiled as a result of an extensive literature survey. Special consideration was given to data describing deployed systems such as Airtrans and SeaTac. Capital cost estimates include the cost of guideway construction, passenger station construction and equipment, AGT vehicles, central control facility construction and equipment, maintenance facility construction and equipment, power distribution installation, and guideway snow melting system installation. The costs do not include right of way acquisition cost, site modification costs, or project management costs. Variable cost estimates include the cost of vehicle and facility maintenance, energy, labor for operations such as station attendants and system control personnel, and administration.

Several possibilities for iteration in the design process can be identified by considering the analysis flow depicted in Figure 7-5. Since system performance measures are an output of the analysis process and an estimate of system performance is a required input to the demand generation task, it may be desirable in some cases to iterate on the entire analysis process. In general, a demand estimation model which is more sensitive than the FSM to modal split parameters should be used if this type of iteration is considered necessary.

The sensitivity of availability measures to various availability parameters, principally to variation in values of subsystem reliabilities, was investigated in several analyses by making repeated runs of the SAM. However, the relationship between improved reliability and unit costs was not investigated. Although this is an important aspect of an availability analysis, budget and schedule constraints in the System Operations Studies precluded the detailed subsystem design and analysis required to establish these relationships. Studying the effects on availability of alternate failure response strategies and, therefore, different failure recovery times requires that a large number of DESM and SAM runs be made. Numerous runs of the DESM are required to generate trip logs which establish the passenger and vehicle delays associated with each type of failure in each demand period. The SAM is then used to evaluate the availability measures. If the deployment description or standby fleet is changed, then the SCM must also be rerun to evaluate system cost measures.

7.3 RESULTS AND CONCLUSIONS

7.3.1 Shuttle Loop Transit Analysis

The major output of the SLT trade-off analyses is the definition of 11 representative SLT systems deployed in a variety of application areas. These system deployments served as the basis for the SLT comparative analysis in which the performance of different systems deployed in similar applications was evaluated. A summary of important system characteristics and measures of performance, cost, and availability for the 11 SL T deployments is presented in Table 7-2. Each of the nominal SLT deployments described in the table satisfies the performance and vehicle availability goals specified in Table 7-1. A passenger availability goal of 0.996 based on a 5-minute delay threshold was established for all deployments. The six single lane loop deployments do not satisfy the passenger availability goal when component reliabilities corresponding to commercial-grade electronic parts are specified. All but three deployments (SLT 3, SLT 5, and SLT 10) can satisfy the goal when military-grade electronic parts or redundant design of electronic subsystems is considered. It is expected that component reliabilities could be sufficiently increased by the combined use of redundant design and high quality parts so that these systems would satisfy the goal. Each deployment satisfies the wait time goals on an overall system basis. In addition, the CBD deployments have been specified so that the maximum and average wait times associated with the most congested station also satisfy the goals. The total fleet size in the table for each deployment includes the standby vehicle fleet required to ensure that a spare vehicle will be available in the event of a failure. The average wait time and average travel speed are system-wide averages obtained for the peak demand

TABLE 7-2 (1 OF 2). SUMMARY OF NOMINAL SLT DEPLOYMENT CHARACTERISTICS

Deployment Description						System Description		Performance Measures						
Deployment	System Type	Network Type	Daily Demand	No.of Stations	Guideway Lane Km	Vehicle Capacity	Total Fleet Size	Average Wait Time (s)	Average Travel Speed (m/s)	Maximum Average Percent Standing	Maximum Average Wait Time* (s)	Vehicle Load Factor	% Occupancy	Trip Productivity
Activity Center Line-Haul SLT 1	LGRT	Shuttle	12,683	3	6.8	70	5	185	10.5	87	341	0.336	47.1	6.25
Activity Center Circulation SLT 2	IGRT	Multiple-Loop	8,608	16	25.4	40	9	233	6.7	0	503	0.152	23.6	1.42
CBD Circulation														
SLT 3	IGRT	Loop	52,133	11	3.7	58	20	85	4.6	37	484	0.488	64.6	5.87
SLT 4	IGRT	Dual Lane Loop	68,797	11	7.4	62	26	117	4.0	27	500	0.304	51.8	5.14
SLT 5	IGRT	Loop	65,252	11	3.7	58	24	83	4.7	39	514	0.470	63.8	5.86
SLT 6	LGRT	Loop	65,252	11	3.7	109	12	72	5.0	85	491	0.476	62.8	6.24
SLT 7	IGRT	Shuttles	39,036	11	3.8	55	14	210	4.2	38	313	0.392	55.8	5.91
CBD Line-Haul														
SLT 8	LGRT	Multiple Loop	24,235	10	3.6	109	8	184	5.2	81	386	0.214	21.2	3.64
SLT 9	LGRT	Loop	25,580	8	3.6	100	9	147	5.4	76	374	0.213	22.6	3.88
SLT 10	SGRT	Loop	25,580	8	3.6	24	35	94	5.7	25	321	0.289	39.8	5.55
SLT 11	LGRT	Loop	51,160	8	3.6	100	17	140	5.4	77	375	0.430	33.8	6.06

* The values given for SLT 1 and SLT 2 are average maximum wait time. The values given for the other deployments are the maximum values of the average wait time per sampling interval at a specific congested station.

TABLE 7-2 (2 OF 2). SUMMARY OF NOMINAL SLT DEPLOYMENT CHARACTERISTICS

Deployment Description			Cost Measures*							Normalized Cost Measures						Availability Measures	
										Base Year Variable Cost ($)			Life Cycle Cost ($)				
Deployment	System Type	Network Type	Land Utilization (m^2)	Noise Impacted Area (m^2)	Annual Energy Consumption (Million kw-h)	Base Year Capital Cost ($Millions)	Base Year Variable Cost ($Millions)	Life Cycle Cost ($Millions)	Net Present Value ($Millions)	per Passenger	per Passenger Km	per Vehicle Hr	per Passenger	per Passenger Km	per Vehicle Hr	Vehicle Avail-ability	Passenger Avail-ability**
Activity Center Line-Haul SLT 1	LGRT	Shuttle	19 869	20 111	3.6	15.0	0.131	73.5	17.9	0.350	0.270	15.11	0.483	0.363	211.23	99.9	99.9
Activity Center Circulation SLT 2	IGRT	Multiple Loop	54 668	10 390	3.1	25.1	0.453	128.2	32.1	0.141	0.055	6.47	0.995	0.387	45.72	100.0	99.7
CBD Circulation																	
SLT 3	IGRT	Loop	10 066	7 180	10.1	17.1	0.414	106.0	25.1	0.027	0.022	9.03	0.169	0.138	57.72	99.9	99.2
SLT 4	IGRT	Dual Lane Loop	18 394	11 366	16.3	25.6	0.651	154.2	37.0	0.032	0.043	10.04	0.187	0.257	59.51	99.9	99.6
SLT 5	IGRT	Loop	10 571	11 000	11.5	18.8	0.497	116.5	28.1	0.025	0.021	8.63	0.149	0.122	50.54	99.9	99.2
SLT 6	LGRT	Loop	12 780	45 000	11.6	18.3	0.378	110.1	26.1	0.019	0.016	13.14	0.141	0.114	95.56	99.9	99.4
SLT 7	IGRT	Shuttle	10 858	5 708	11.4	16.5	0.450	101.5	24.2	0.038	0.042	12.50	0.217	0.235	70.48	100.0	99.8
CBD Line-Haul																	
SLT 8	LGRT	Multiple Loop	12 146	61 000	4.8	14.4	0.301	84.9	20.3	0.041	0.043	16.43	0.292	0.303	115.98	100.0	99.8
SLT 9	LGRT	Loop	11 793	54 000	4.0	14.0	0.269	82.4	19.6	0.035	0.039	13.57	0.268	0.295	104.05	99.9	99.5
SLT 10	SGRT	Loop	9 676	11 567	4.8	15.3	0.411	108.3	25.6	0.054	0.044	7.15	0.353	0.291	47.01	99.8	99.0
SLT 11	LGRT	Loop	12 790	77 000	6.5	18.8	0.432	121.3	28.0	0.028	0.030	13.41	0.198	0.220	95.38	99.9	99.3

* Dollar amounts are expressed in constant 1977 dollars. Life cycle costs are based on a 40 year period and a 10 percent interest rate. Net present values are based on a discount rate of 10 percent.

** Passenger availability is based on a passenger delay threshold of 5 minutes.

period. The maximum average wait time listed in the table for CBD Circulation and CBD Line-Haul deployments is the maximum value of average wait time per sampling interval for a particular station. For the SLT 1 and SLT 2 deployments the value listed in the table is the average of the maximum wait time occuring at all the stations over the simulated peak period. In all cases, the value reported in the table is the one which was compared to the maximum wait time goal during the trade-off analysis. The vehicle efficiency measures (load factor, percent occupancy, and trip productivity) represent daily averages. The normalized life-cycle cost measures are calculated assuming that both the system and demand remain constant during the 40-year life-cycle period. All costs are expressed in constant base year (1977) dollars. A value of 10 percent has been assumed for both interest rate and discount rate.

As part of the study results, some guidelines were deduced from the SLT trade off analyses. First, it may be concluded that the vehicle size which results in the smallest fleet to satisfy performance goals also results in the most economical system. As may be expected, this result is dependent on the relative costs of major system components and on the sensitivity of vehicle cost to vehicle capacity.

A similar guideline can be stated for the selection of the nominal cruise velocity. The cruise velocity which results in the smallest fleet that satisfies performance goals also results in the most economical system. A corollary to this general guideline is as follows: once the smallest fleet has been established, the minimum velocity which permits the travel time and wait time goals to be satisfied should be specified to minimize system costs. There are generally two incentives for varying the operating velocity of a system. If the required vehicle fleet can be reduced by increasing the capacity of the system through an increase in cruise velocity, then the total system cost will generally be reduced even though vehicle energy consumption may rise. If an increase in cruise velocity does not permit a reduction in the fleet size, then the possibility of reducing cruise velocity should be considered so that vehicle energy consumption is minimized. However, the effect of reduced velocity (reduced flow capacity) on station area requirements must be evaluated. A decrease in flow capacity may cause station platform queues to increase in size. If station area is increased to accommodate larger queues, then system capital cost will increase. Both station maintenance costs and energy costs for heating and cooling are estimated as a function of station area. The reduction in vehicle energy costs resulting from a decrease in cruise velocity may not be sufficient to compensate for possible increases in station costs.

It was originally intended that the nominal systems be designed to satisfy system-level goals. However, it became apparent from the analyses that satisfaction of overall system goals alone can result in systems that have totally unacceptable wait times at certain stations. Furthermore, the averaging of wait times over time can tend to mask a congestion problem. While it is not generally feasible to ensure that no passenger will ever experience an unacceptably long delay during normal operation of the system, it is not, in general, sufficient to design the system on the basis of measures averaged over the entire system and over an extended period of time. Therefore, wait time goals used in designing AGT systems should be specified for a selected set of stations at which congestion is expected to occur, and average wait time values for these stations should be calculated for time periods in which queuing is expected to occur. Engineering judgment must be applied in selecting the set of stations which are to define the system design constraints. The set of key stations which is selected in the design process may consist of all stations in the network. System average wait time measures are likely to be appropriate design constraints when the demand is very evenly distributed or when the demand is quite low and the number of active vehicles is determined by the requirement that one-half headway be less than the maximum wait time goal. On the other hand, particularly large platform queues often develop at one or two stations in the network during the peak hour. Passenger queues and delays at various stations should be considered through simulation of a nominal system deployment as a first step in selecting the set of stations to which wait time goals are to be applied during the design process.

Another important result of the SLT analyses is the identification of a linear relationship between average wait time and system capacity which can be used in many cases to analytically predict the effects on wait time of variations in vehicle capacity, train consist, number of trains, cruise velocity, dwell time, and demand magnitude. The relationship can be established for SLT systems through the use of system simulation whenever system performance is limited by unusually large wait times at one particular station in the network. That is, the relationship can be established whenever the system wait time goal is expressed in terms of the average wait time at a single station, and the platform queue at that station continues to grow throughout some portion of the simulation period.

The relationship between average wait time and queue arrival and departure rates, which strictly applies only over periods of uniform, time-constant passenger arrival rates, can be expressed in the following form:

$$(\overline{WT} - H/2) = \frac{\Delta T}{2}\left(1 - \frac{\rho_D}{\rho_A}\right) \qquad \text{for } \rho_D \leq \rho_A$$

where

$\overline{WT}$ = Average passenger wait time at a congested station during the period ΔT

H = Average route headway

ΔT = Any interval of time during which the platform queue at the congested station is increasing

ρ_D = Passenger dispatch rate at the station

ρ_A = Passenger arrival rate at the station.

The difference between average wait time and one-half the headway is called the average queue transit time. The passenger arrival rate is known from the demand model, but the passenger dispatch rate cannot be known a priori. In general, since vehicles are partially loaded when they arrive at stations, the dispatch rate, ρ_D, is some fraction of the system flow capacity. The flow capacity, ρ_C, is the flow rate (in passengers/sec.) that the system can accommodate, and it is given by traveling unit capacity divided by the headway. If α is the fraction of total flow capacity available at this station (i.e. the arriving vehicles are 100(1-α)% full of non-deboarding passengers), then for the congested station $\rho_D = \alpha \rho_c$ and the average queue time expression becomes,

$$\overline{WT}-H/2 = \frac{\Delta T}{2} - \left(\frac{\alpha \Delta T}{2 \rho_A}\right) \rho_c \ .$$

The preceding equation establishes the functional relationship between the average queue transit time $(\overline{WT}-H/2)$ and the system flow capacity (ρ_c). There are two constants in the equation, namely, $\frac{\Delta T}{2}$ and $\frac{\alpha \Delta T}{2 \rho_A}$. In order to establish the exact relationship between the queue transit time and the system flow capacity for a particular deployment, these constants are determined empirically from simulation data.

In general, the values of the constants are different for each station in the network and for each time period for which the relative station-to-station demands are different. The wait time data obtained through system simulation must be averaged over an appropriate time period (ΔT). That period corresponds to an interval of constant demand during which the platform queue at the congested station continues to increase in length.

Figure 7-6 is a good example of the straight line relationship between average queue transit time and flow capacity. The data points represent a.m. peak hour simulation results for Station 6 and p.m. peak-hour results for Station 11 in both the SLT 9 and SLT 11 deployments. Data from these two deployments can be plotted directly on the same straight line because they use the same demand and network configuration One hour is shown to be an appropriate time interval over which to average wait time for this application in Figure 7-7. The figure illustrates that the platform queue at Station 6 continues to increase for approximately one hour.

Once calibrated using simulation data, the queue transit time and flow capacity relationship can be used as the design curve to predict the average wait time resulting from a change in flow capacity. A change in flow capacity can result from a change in vehicle capacity, train consist, or headway. Headway varies in a predictable manner with the number of trains on the route, the cruise velocity, and the average dwell time. Since the passenger arrival rate, ρ_A, appears in the design equation, the flow capacity can be scaled by the ratio of original demand magnitude to new demand magnitude to predict the effect on average wait time of a change in demand level. In summary, the average queue transit time-flow capacity relationship provides a valuable analytic tool which can be used in many applications to predict the effect on average wait time of variations in a number of system parameters.

There were other significant results observed in the SLT trade-off analyses. First, the demand stop service policy was generally found to be ineffective in the SLT applications that were studied. In general, the demand must be sufficiently low, so that the inter-arrival time of passengers is greater than the average route headway in scheduled service before the potential advantages of the demand stop concept can be realized. The off-peak demands for most of the SLT system deployments analyzed in this study were too high to adequately test the demand stop concept.

The analysis of SLT 8 identified the need for a more sophisticated demand stop algorithm which retains the potential advantages of the demand stop concept but which

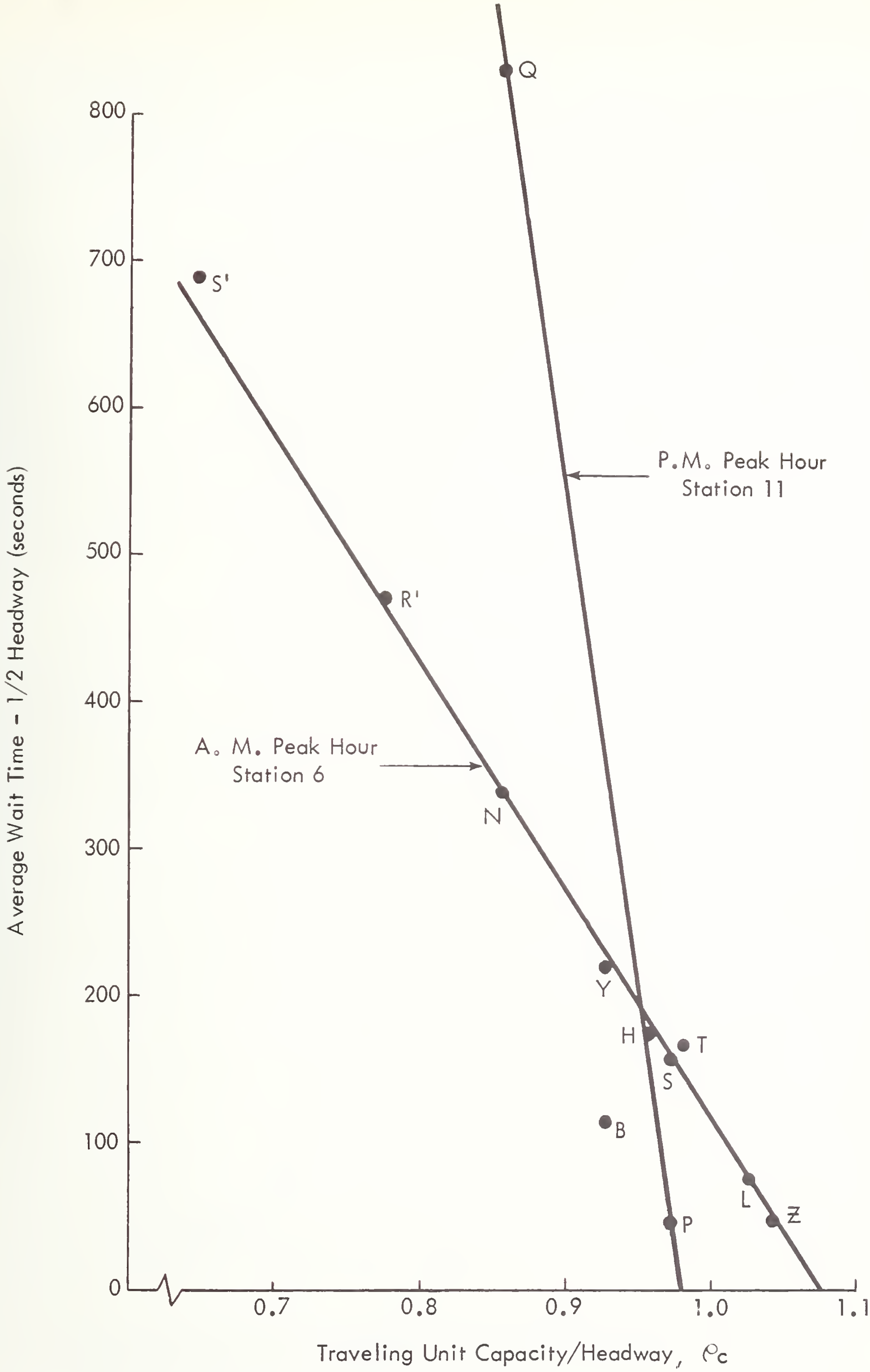


FIGURE 7-6. AVERAGE QUEUE TRANSIT TIME VERSUS FLOW CAPACITY FOR SLT 9

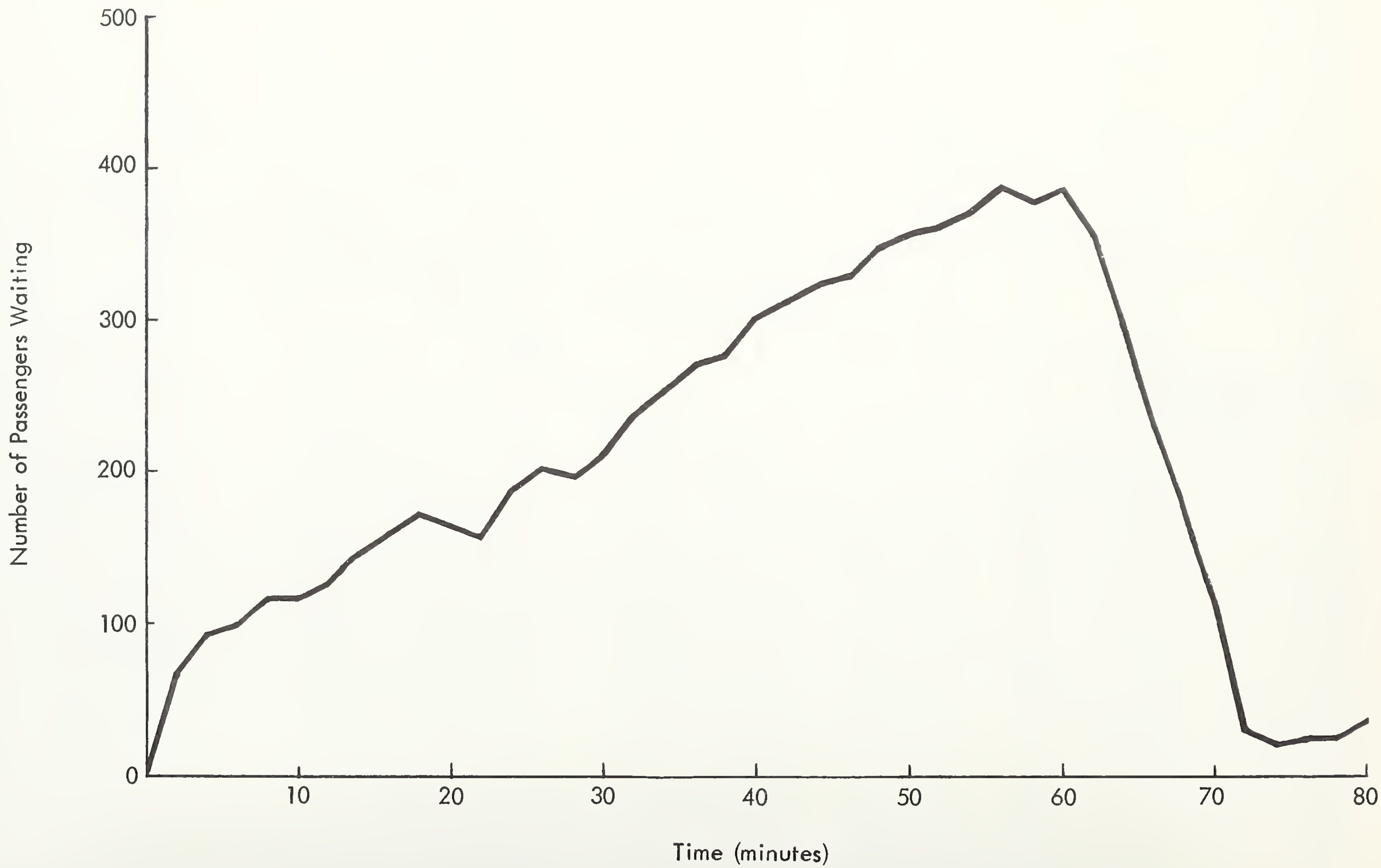


FIGURE 7-7. TIME HISTORY OF MAXIMUM QUEUE SIZE IN THE A.M. PEAK PERIOD FOR SLT 9, STATION 6

reduces the tendency of vehicles to bunch. In this analysis, two vehicles were operated on each of two loops. One vehicle by-passed several consecutive stations while the other vehicle on the loop made station stops. As a result, the two vehicles acted essentially as a two-vehicle train for the remainder of the simulation, and maximum wait times increased to a value approaching twice the nominal headway.

The SLT availability analysis results have revealed some noteworthy trends with regard to SLT type system applications. As was expected, shuttle type systems with more than one guideway produced the highest levels of passenger and vehicle availability of any of the SLT systems analyzed. The factor most responsible for the high level of performance is that only one lane of the shuttle system was failed at any given time, and, thus, only a fraction of the passenger demand on the system is affected by the failure. This suggests that systems with higher numbers of individual shuttles would provide a higher level of availability than systems with a lower number of shuttle lanes. This is borne out by a comparison of SLT 1 which serves a daily demand of approximately 9000 on two independent shuttles and SLT 7 which serves a daily demand of approximately 40,000 on four independent shuttles. Although the demand for SLT 7 is nearly 4-1/2 times greater than that for SLT 1, the number of passengers delayed increased by a factor of two.

Dual-lane loop or multiple-loop networks provide the next highest level of performance, and, again, it is primarily attributable to the fact that only a portion of the network is affected by a failure event. The dual-lane loop network of SLT 4 provides a level of passenger availability which approaches that of the shuttle type systems in the presence of a daily demand of almost 70,000 passengers, the highest demand used in any of the SLT analyses. This trend is also evidenced in SLT 2 and SLT 8 which are also multiple-loop systems.

The single-lane loop networks give the lowest levels of passenger availability as might be expected since a failure event in general will stop the entire system. There are, however, some interesting observations that can be made regarding the classes of systems considered for single-lane loop applications. LGRT systems on loop networks demonstrate higher levels of passenger availability than IGRT systems while SGRT systems provide the lowest level of availability performance on a single-lane loop network. The reliability of the various GRT vehicles considered in the SLT analysis is relatively constant. Therefore, larger fleets of small vehicles result in more frequent vehicle failures and, consequently, lower values of availability than large vehicle systems designed to serve the same demand. With LGRT systems the availability performance goal of 99.6 percent is achieved by using higher quality parts in the design of system electronics. Redundant design in the areas of high electronic parts usage offered no significant improvement over the use of higher quality parts and is thus not considered a cost effective approach to system design for LGRT systems. However, SGRT and IGRT systems deployed on single-lane loop networks require the combined application of higher quality parts and redundant design in order to satisfy the passenger availability goal of 99.6 percent.

7.3.2 Automated Rail and Group Rapid Transit Analyses

The major output of the ART and GRT analyses is the definition of the representative AGT systems deployed in two different metropolitan area applications. A summary of important system characteristics and measures of performance, cost, and availability is presented in Table 7-3.

TABLE 7-3. SUMMARY OF NOMINAL ART AND GRT DEPLOYMENT CHARACTERISTICS

Deployment Description						System Description		Performance Measures *							
Deployment	System Type	Network Type	Daily Demand	No. of Stations	Guideway Lane km	Vehicle Capacity	Total Fleet Size	Average Wait Time (s)	Average Travel Speed (m/s)	Average Percent Seated	Average of Maximum Wait Time (s)	Average Number of Intermediate Stops	Vehicle Load Factors	% Occupancy	Trip Productivity
ART 1	ART	Grid	111,359	28	93.5	190	38	151 248 153 248	11.9 11.6 11.7 11.6	100 100 100 100	410 562 412 562		0.275	0.254	0.997
GRT 2	IGRT	Grid	113,314	28	104.1	50	104	96 107 89 107	13.9 14.0 13.6 14.1	73.2 85:8 74.6 83.1	304 316 304 303	2.65 2.26 2.82 2.32	0.135	0.326	1.39
GRT 3	SGRT	Grid	154,537	40	183	15	556	111 112 107 110	12.3 12.1 12.3 14.2	84.3 86.7 86.1 98.7	903 840 983 657	1.98 1.92 1.84 1.07	0.158	0.180	1.33

* The four values refer to the A.M. Peak, Midday, P.M. Peak, and Evening demand period respectively.

Deployment Description			Cost Measures *							Normalized Cost Measures						Availability Measures	
										Base Year Variable Cost ($)			Life Cycle Cost ($)				
Deployment	System Type	Network Type	Land Utilization ($10^3 m^2$)	Noise Impacted Area ($10^3 m^2$)	Annual Energy Consumption (million kW-h)	Base Year Capital Cost ($ millions)	Base Year Variable Cost ($ millions)	Life Cycle Cost ($ millions)	Net Present Value ($ millions)	Per Passenger	Per Passenger km	Per Vehicle Hour	Per Passenger	Per Passenger km	Per Vehicle Hour	Vehicle Availability	Passenger Availability **
ART 1	ART	Grid	340.9	7,310	32.3	412.5	5.971	2,000.9	492.2	0.150	0.020	27.82	1.23	0.18	233.07	0.999	0.997
GRT 2	IGRT	Grid	236.3	554.3	57.4	209.6	9.445	1,341.5	333.7	0.228	0.034	15.82	0.81	0.12	56.16	0.998	0.986
GRT 3	SGRT	Grid	406.6	6,235	289.3	443.8	28.984	3,273.2	818.4	0.514	0.088	10.22	1.45	0.25	28.85	0.993	0.984

* Dollar amounts are expressed in constant 1977 dollars. Life-cycle costs are based on a 40-year period and a 10-percent interest rate. Net present values are based on a discount rate of 10 percent.

** Passenger availability is based on a passenger delay threshold of five minutes.

The ART deployment and both of the GRT deployments satisfy the system average wait time and average travel speed goals specified in Table 7-1. In addition, each station of the GRT 2 deployment individually satisfies the average wait time goal (180 s) and the maximum wait time goal (480 s). While the ART 1 and GRT 3 deployments provide very good service on average, the average and maximum wait times at a few individual stations exceed the goals. However, only 0.6 percent of the a.m. and p.m. peak hour demand arrives at stations where the mean of the maximum wait time exceeds the goal of 480 s in the GRT 3 deployment. The ART system and the IGRT system in the GRT 2 deployment both satisfy the vehicle availability goal, but the SGRT system in the GRT 3 deployment achieves a vehicle availability which is slightly below the goal. Neither GRT deployment satisfies the passenger availability goal when component reliabilities corresponding to commercial-grade electronic parts are specified.

Values of the first five performance measures in the table are given for each demand period (a.m. peak, midday, p.m. peak, and evening). The vehicle efficiency measures (load factor, percent occupancy, and trip productivity) represent daily averages. The normalized life-cycle cost measures are calculated assuming that both the system characteristics and demand remain constant during the 40-year life-cycle period. All costs are expressed in constant base year (1977) dollars. A value of 10 percent has been assumed for both interest rate and discount rate.

The linear relationship between flow capacity (ratio of train capacity to average route headway) and average queue transit time (difference between average wait time and one-half the average route headway) that was used to help specify Shuttle-Loop Transit characteristics was also used with limited success in the ART and GRT analyses. The usefulness of the flow capacity/queue transit time relationship is limited in the study of systems deployed on grid networks for several reasons. First, the relationship can be used only in the analysis of systems which provide fixed route service where the average route headway is known. If several routes share a segment of guideway and vehicles must merge to access the common guideway segment, then merge delays may tend to increase the variance in route headways and cause vehicles on the same route to bunch. The bunching effect may cause the average route headway to be greater than expected. Use of the relationship is further complicated if some stations, particularly ones where passenger queues tend to form, are served by more than one route. Insufficient capacity on any of the routes serving a station can cause queuing and increased wait times. Nevertheless, the flow capacity/queue transit time relationship can be used to at least obtain a first estimate of the flow capacity on each route required to satisfy a given wait time goal.

In the absence of excessive vehicle queue delays the capacity on each route of a system can be specified so that average and maximum wait times at every station are limited to values below selected goals. The minimum number of vehicles per route can often be specified precisely so that the removal of only one vehicle from a route causes a significant increase in wait time at one or more stations on the route. Alternatively, excess capacity can be provided at the expense of vehicle productivity. The average load of vehicles leaving individual stations is a useful measure which can be used to assess how closely system capacity matches the demand.

Specification of minimum fleet size for demand responsive GRT systems cannot be done as precisely as for fixed route systems. Demand responsive service is generally considered in conjunction with grid networks and relatively low-capacity vehicles. Guideway congestion is more likely to have a random but generally adverse effect on performance in these deployments than in the line-haul deployments using larger vehicles in fixed route service. In addition, since demand responsive vehicles respond to individual trip requests, the performance of these systems is more sensitive to the initial placement of vehicles than is the performance of fixed route systems. Finally, the demand responsive algorithm implemented in the DESM invariably produces high wait times at a few stations even though the system average wait time is low. With little or no guideway congestion the stations immediately downstream from high demand stations and those in low demand areas of the network are most likely to experience excessive wait times. In systems with significant guideway congestion, high demand stations in congested areas of the network experience high wait times. In some cases high demand stations utilize nearly all of the available vehicle capacity leaving very little capacity to serve passengers at downstream stations. In other cases, relatively few vehicles are routed onto some guideway links in low demand areas of the network. Empty vehicles which are dispatched to low demand stations are sometimes reassigned while enroute to serve passengers at other stations. The use of the vehicle reservation option improves both of these conditions to some extent by permitting passengers under certain conditions to reserve space on vehicles scheduled to arrive within a specified time.

The empty vehicle dispersement strategy in which empty vehicles are dispatched to the station with the most requests for empties is shown to be superior in the GRT 3 application to circulating empties on circuitous routes and to sending empties to regional storage centers. The selected empty vehicle dispersement strategy, which utilizes real time system information, is expected to be less sensitive to random variations in demand than the other available strategies. However, a more exhaustive study of empty vehicle management may lead to improved empty dispersement strategies which would help provide a more uniform level of service at all stations.

In general, the vehicle capacity requiring the smallest number of vehicles in the active fleet to adequately meet performance goals results in the most economical system in terms of total costs. However, significant performance improvements in both fixed route and demand responsive deployments can be realized by using larger fleets of smaller vehicles with relatively small penalties in energy consumption and total costs. In fixed route systems, the use of smaller vehicles can result in equal or reduced wait times even with a reduction in flow capacity because of the compensating effect of shorter headways. Thus, when smaller vehicles are substituted for large vehicles, the required increase in fleet size is not proportional to the reduction in vehicle capacity. In demand responsive systems, the increase in fleet size tends to make more empty or partially empty vehicles available to serve passengers — especially those at stations with large average wait times. This economy of scale in metropolitan area deployments means that in some cases the capital cost of the larger fleet of smaller vehicles may be less than the cost of the fleet of larger vehicles. This, of course, depends on the unit costs of vehicles and on the requirements of the individual deployment. In the case of GRT 2, the initial cost of the required fleet of 50-passenger vehicles is about 4.5 percent less than the cost of the fleet of 69-passenger vehicles. On the other hand, the cost of the 15-passenger vehicle fleet in the GRT 3 deployment exceeds the estimated cost of a comparable 25-passenger vehicle fleet by 11.6 percent. These cost differences are augmented in one case and partially off-set in the other by the fact that the guideway structure cost is less for the lighter, smaller vehicles. Variable costs, which are very sensitive to vehicle maintenance costs, are higher for the larger fleet of smaller vehicles in both cases. The net result in terms of life-cycle cost is a slight cost advantage for the larger vehicle system. The performance improvements associated with the use of smaller vehicles for the GRT 2 and GRT 3 system alternatives that were considered include decreases in system average wait time of 15 to 30 percent, decreases in the maximum number of passengers waiting in stations of 15 to 30 percent, and increases in average percent vehicle load of 6 to 10 percent.

The Input Processor of the DESM uses a compound Poisson process to generate a trip list consisting of a specific arrival time, an origin-destination pair, and a party size for each passenger group. If the trip list generated in this random manner is used to specify system capacity, then either the system is specified on the basis of one sample from a random process or the results of many DESM runs must be combined in some way to evaluate each alternative system configuration. Another approach to representing demand for system design is to use a deterministic process in which the passenger trips specified in the reference demand matrix for each station pair are uniformly distributed in time. In this way the random nature of demand need not be considered during the system design process. This approach was used in the ART and GRT analyses. To further reduce the sensitivity of the nominal systems to random variations in demand, the uniformly distributed trip lists were generated using demands which are 10 percent greater than the nominal values. This represents an attempt to specify a reasonable worst-case demand as a basis for system specification. The sensitivity of nominal GRT system performance to random variations in demand was tested by making three DESM runs for each GRT deployment with Poisson distributed demand based on the nominal demand magnitude. The total magnitude of the randomly generated demand varied by about one percent, but the spatial distribution varied enough to cause a 5 percent variation in average wait time for both deployments. Values of GRT 2 performance measures (wait times and maximum number of passengers waiting at stations) for the cases of random demand input do not exceed those for the design demand. In the case of GRT 3, while the average wait times in all three random demand cases are slightly greater than that of the design demand case, all values are well below the average wait time goal of 180 s. Thus, the use of uniformly-distributed trip lists based on 110 percent of nominal demand is a reasonable design point. The nominal systems based on this demand input are relatively insensitive to random variations in demand.

8.0 COMPARATIVE ANALYSIS

Comparisons were made among several AGT systems deployed in CBD and metropolitan area applications to study the effects of vehicle size and network topology on overall system performance, cost, and availiability. The objective of the comparative analysis was to determine the advantages and disadvantages of different systems deployed in similar application areas. The methodology was to compare values of selected measures for each deployment and to discuss the reasons for differences and similarities between the measure values. In general the data generated during the trade-off analyses were used in the comparisons. However, additional simulations were run to augment the data available for SLT deployments in CBD applications.

The results of the comparative analyses are briefly summarized in this section and are presented in more detail in the following two reports:

Comparative Analysis of AGT Systems in CBD Applications[54]

Comparative Analysis of ART and GRT Systems in a Metropolitan Area Application[55]

8.1 SINGLE LANE VERSUS DUAL LANE LOOP DEPLOYMENTS

The comparison of SLT 3 and SLT 4 (identified in Table 3-1) matches IGRT systems deployed on a single-lane, one-way loop with a similar system in the same class deployed on a dual-lane, two-way loop in the Medium Demand CBD Circulation application. The two networks, which utilize the same set of stations, are illustrated in Figure 7-2.

The performance, cost, and availability of systems were compared on the basis of eleven measures. Figure 8-1 shows the percent deviation of each measure from the average value for the two systems. Data for the dual lane loop is denoted by dots connected with a solid line (SLT 4) while the single lane loop data is denoted by triangles connected with a broken line. The graph is symmetrical because deviations from the mean for only two deployments are plotted. The first measure, WT, is the system average wait time over the operating day including both peak and off-peak period operation. The range of wait times given in the figure represent symmetric 90 percent confidence limits for the random variable, WT. The average wait time for the dual lane deployment (SLT 4) is greater than that for the single lane deployment because average headway is greater for SLT 4 even though the demand is higher. This results because the SLT 4 fleet is split between two lanes rather than being concentrated on a single guideway lane as in the case of SLT 3. The average travel time, TRT, for SLT 4 is less than that of SLT 3 because the two-way capability of the SLT 4 deployment makes travel between certain pairs of stations much shorter than the corresponding time for the single lane system. MPS is the maximum of the system average percent standing in vehicles. Even though there are some vehicles in both deployments which are fully loaded, the single lane deployment (SLT 3) with its more uniform passenger loading on guideway links has the larger maximum

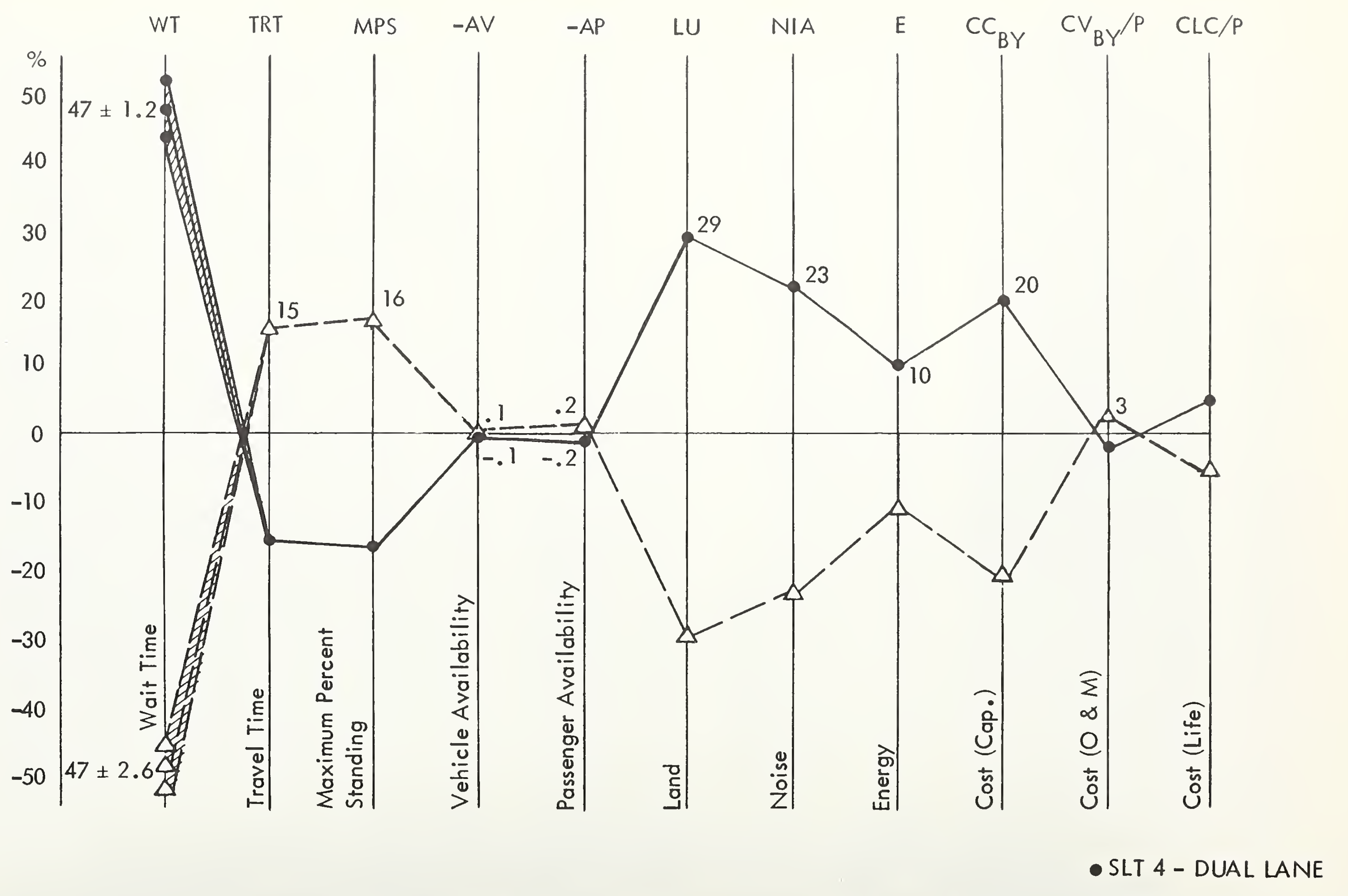


FIGURE 8-1. PERCENT DEVIATION FROM AVERAGE, SLT 3 AND SLT 4

average percent standing. The availability measures (AV - vehicle availability and AP - passenger availability) are plotted as negative values to maintain a consistent sense among the measures, i.e., lower is better. The values of availability associated with the dual lane deployment are higher than those of the single lane deployment because a single failure on SLT 4 affects only one of the two lanes whereas all vehicles are delayed by a sustained failure in the single lane deployment. The remaining measures plotted in Figure 8-1 are measures of system cost and community impact including land utilization (LU), noise impacted area (NIA), energy consumption (E), base year capital cost (CC_{BY}), base year variable cost per passenger (CV_{BY}/P), and life cycle cost per passenger (CLC/P). With one exception the dual lane deployment (SLT 4) costs more than the single lane deployment in terms of all of these measures. The dual lane deployment has a slight advantage in terms of base year variable cost per passenger. In summary, the dual lane loop deployment has higher availabilities and it has the potential to attract more demand due to its shorter travel times. However, it cost more than the single lane deployment.

8.2 IGRT VERSUS LGRT ON A SINGLE LANE LOOP NETWORK

The comparison of SLT 5 (IGRT) and SLT 6 (LGRT) matches systems having different vehicle sizes deployed on a single lane loop network in the High Demand CBD Circulation application. Both deployments have the same demand and network configuration. The 109-passenger LGRT vehicles are operated as single units while the same number of two-car trains are operated in the 58-passenger IGRT system. Hence the two systems offer almost identical route headways, wait times, and travel times. The significant differences between the systems arise from differences in maintenance costs and in the number of passengers delayed due to failures.

Figure 8-2 presents the percent deviation from average of the 11 measures used in the comparative analysis. Data for the IGRT system (SLT 5) are denoted by triangles which are connected with a solid line. The LGRT data points (SLT 6) are denoted by dots which are connected with a broken line. The LGRT deployment has slightly lower average wait time and travel time primarily because the cruise velocity of the LGRT system is slightly higher than that of the IGRT system in this application.

The difference in maximum average percent standing (MPS) is due entirely to an input assumption about the fraction of total vehicle capacity for which seats are provided. In SLT 5 (IGRT) seats are provided for 50 percent of vehicle capacity while on SLT 6 (LGRT) seats are provided for only 12 percent of vehicle capacity.

In the availability analysis, the vehicles of both systems were found to have essentially the same reliability. Since twice as many IGRT vehicles are operated in SLT 5 as LGRT vehicles in SLT 6, twice as many vehicle failures occur in SLT 5 during a day's operation. This results in higher values of availability for the LGRT deployment (SLT 6). Although the difference is not apparent in the values of vehicle availability when evaluated to three decimal places, the values of passenger availability do show an advantage for the larger vehicle system. In obtaining the availability results, it was

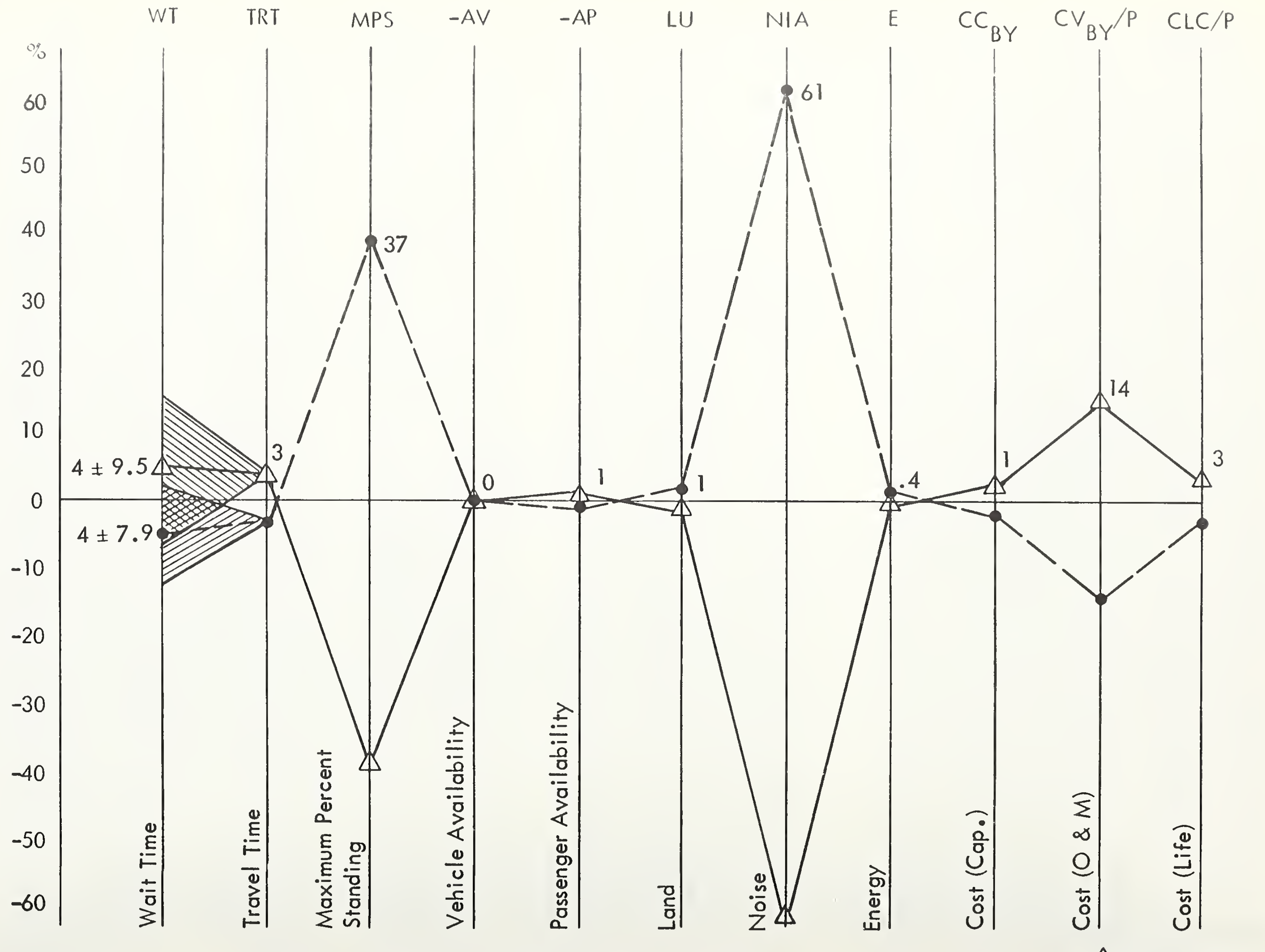


FIGURE 8-2. PERCENT DEVIATION FROM AVERAGE, SLT 5 AND SLT 6

assumed that a failure of either vehicle in a two-car train of SLT 6 which would cause a single vehicle to stop would also cause the train to stop. For some single vehicle failures, it may be possible for a two-car train to continue operation with little or no degradation of system performance. However, it is likely that system operating procedures would require the immediate replacement of the failed vehicle with a spare unit.

The noise impacted area (NIA) for the LGRT deployment (SLT 6) is greater than that for SLT 5 because the larger vehicles were found to generate more external noise.

While the LGRT deployment (SLT 6) utilizes slightly more land and consumes more energy, it costs less in terms of capital cost (CC_{BY}), annual operating and maintenance cost per passenger (CV_{BY}/P), and life cycle cost per passenger (CLC/P).

In summary, the IGRT and LGRT deployments in this application provide nearly the same level of service, but the LGRT deployment has higher availability and costs less than the IGRT deployment.

8.3 MULTIPLE LOOP VERSUS SINGLE LOOP DEPLOYMENTS

SLT 8 and SLT 9 are LGRT systems deployed on two alternative loop networks in the Low Demand CBD Line-Haul application. The networks are illustrated in Figure 7-3. Even though the multiple-loop deployment serves two more stations, it attracts slightly less demand than the single-loop deployment. This is due to the limited secondary trip demand in this application and to the negative effect of the transfer on demand attraction by the system.

The percent deviations from the average value of measures for three deployments in the Low Demand CBD Line-Haul application are shown in Figure 8-3. The relative values of measures for the multiple loop deployment (SLT 8) are denoted by triangles connected with a solid line while those for the single-loop deployment are denoted by dots connected with a dashed line. The data for the SLT 10 deployment are discussed in the next section. With the exception of availability, all of the performance and cost measure values for the single loop deployment (SLT 9) are better than those for the multiple loop deployment (SLT 8). The availability of the multiple loop system is higher than that of the single loop system because a failure on one of the two loops in SLT 8 does not affect vehicle flow on the other loop. This isolation of failure effects results in higher availability for the multiple-loop system.

8.4 LGRT VERSUS SGRT SYSTEMS ON A SINGLE LOOP NETWORK

The comparison of SLT 9 and SLT 10 is another illustration of the effects of vehicle size on the performance of a single loop SLT deployment. In this case the operating characteristics of a small fleet of 100-passenger vehicles (SLT 9) are compared with the characteristics of a large fleet of 24-passenger vehicles (SLT 10) in the Low Demand CBD Line-Haul application. The data plotted in Figure 8-3 indicate that the small vehicle system (denoted by squares) provides better performance but results in poorer availability

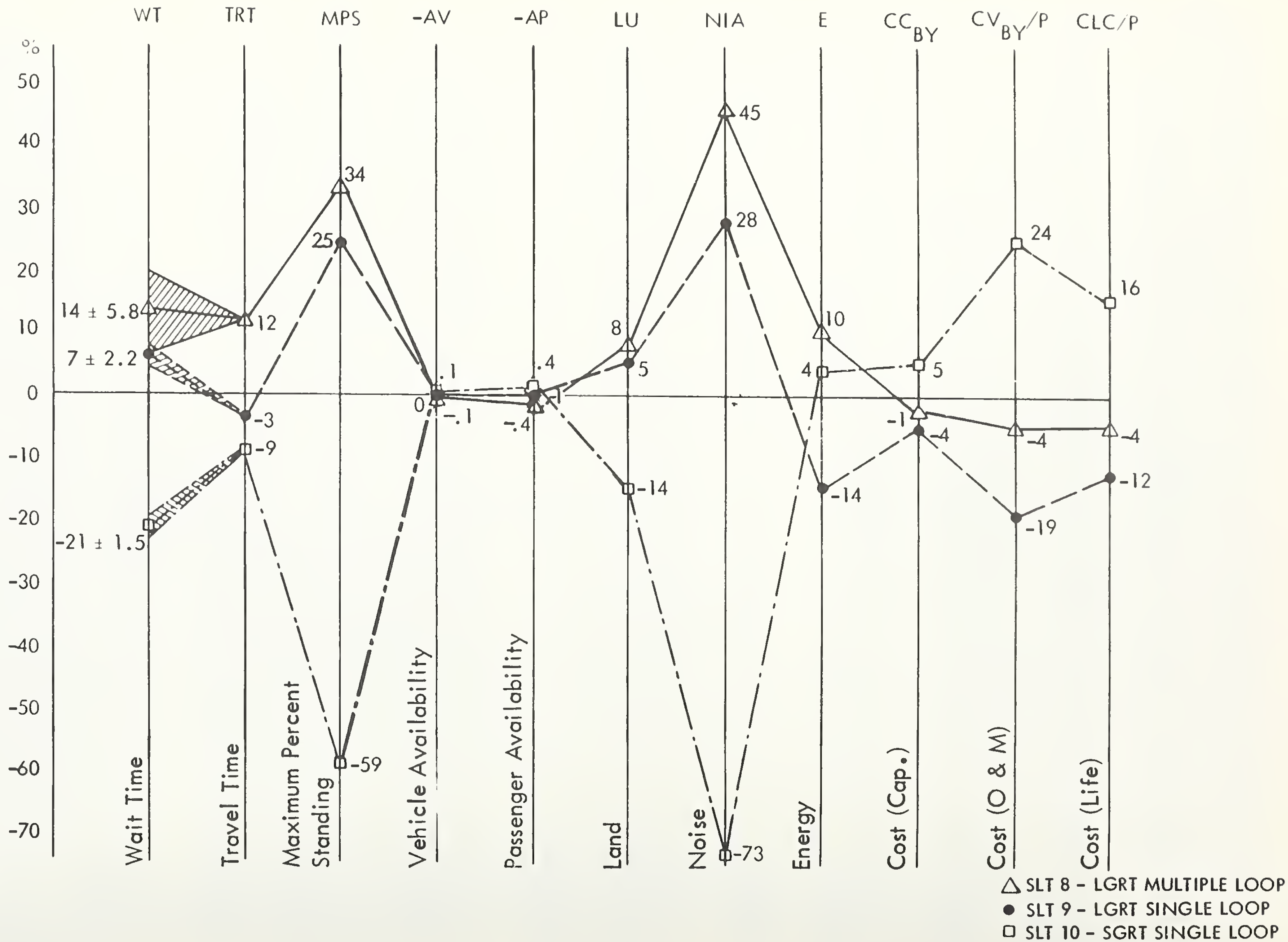


FIGURE 8-3. PERCENT DEVIATION FROM AVERAGE SLT 8, SLT 9, AND SLT 10

than the large vehicle system (SLT 9). In addition the small vehicle system requires less land and impacts a smaller area with noise, but it consumes more energy and has higher costs. In summary, the small vehicle system provides better performance than the large vehicle system in this application, but it does so at increased cost.

8.5 ART VERSUS GRT SYSTEMS IN A METROPOLITAN AREA APPLICATION

In the trade-off analyses an ART system and a GRT system were designed to serve essentially the same demand on essentially the same line-haul grid network in the High CBD Orientation High Reverse Commutation Metropolitan area application. The ART system uses large, heavy, 190-passenger rail vehicles while the GRT system uses smaller, lighter, 50-passenger rubber-tired vehicles. The operating headway of the GRT system is about one-half the headway of the ART system during peak periods. The GRT vehicles operate at a higher cruise velocity than the ART vehicles.

Figure 8-4 shows the deviation from the average value of both deployments for each of 11 measures of system performance, cost, and availability. The data show that the GRT deployment provides better service in terms of average wait time and travel time, costs less in terms of capital cost, life cycle cost, and land utilization, and impacts less area with excessive noise. The GRT system requires fewer transfers because different routes were considered in the analysis. The ART system could be reconfigured to use the GRT routes. Advantages of the ART system include lower variable costs, lower energy consumption, and higher system availability. The availability of the ART system is higher than that of the GRT system (unavailability is lower) because ART vehicles are estimated to be more reliable than the potentially more sophisticated GRT vehicles and the operating fleet of the ART system is smaller resulting in fewer failures per system operating hour.

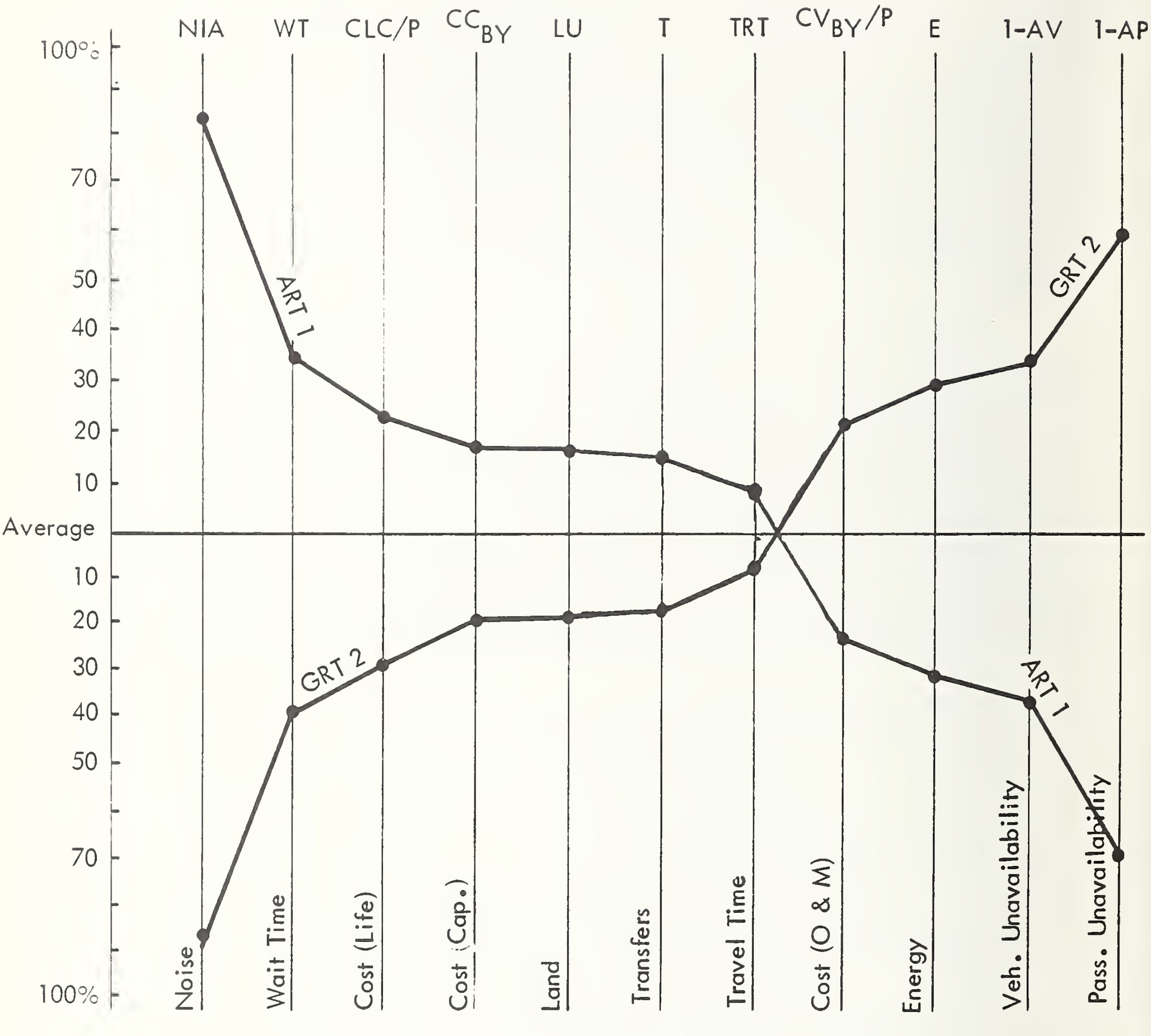


FIGURE 8-4. DEVIATIONS FROM AVERAGE MEASURE

9.0 OPERATIONAL CONTROL

9.1 INTRODUCTION

Automated guideway transit systems in general require the functions of vehicle control, headway protection, longitudinal control, merge strategy, and dispatch strategy. The specific option utilized for each of these functions in a given system constitutes the operational control strategy combination. The objective of the operational control analysis was to evaluate the performance, cost, and operating characteristics of alternative operational control strategy combinations in the context of the system types described in the Classification and Definition of AGT Systems report.[1] The entire operational control analysis task is documented in the Quantitative Analysis of Alternative AGT Operational Control Strategies report.[56]

9.2 CONTENT

The objective of the operational control analysis was met by a two-level analysis effort, an operational control subsystem analysis and an alternative operational control system evaluation. An overview of these analyses showing their interrelationship and their relationship to other portions of the AGTT-SOS program is provided in Figure 9-1.

9.2.1 Subsystem Level Analysis Content

As shown in Figure 9-1, the subsystem level analysis consisted of two major portions, an algorithm and component definition portion and a performance analysis portion. The algorithm and component definition consisted of a higher level definition of the various algorithms for controlling vehicle position, velocity, safety, merging, and dispatching along with an identification of the components and computation required to implement the algorithms. Once a specific set of algorithms was available, a performance analysis consisting of parametric analysis and network subelement experiments using the Detailed Operational Control Model (DOCM) was performed.

Parametric analysis was used to investigate the minimum operational headway for six combinations of vehicle control and headway protection, to design vehicle controllers numerically, to determine the dynamic performance and energy consumption of a single vehicle with realistic constraints on its propulsion plant, and to investigate the maneuver distance required to accomplish slot slips and advances. The DOCM was used to perform simulation experiments of a single vehicle on a link, multiple vehicles on a link, and multiple vehicles on both merges and intersections. The single vehicle experiments consisted of determining the vehicle's response and energy consumption while following a velocity profile. The multiple vehicle experiments investigated string stability, headway protection, link start-up procedures, and flow statistics for various control options.

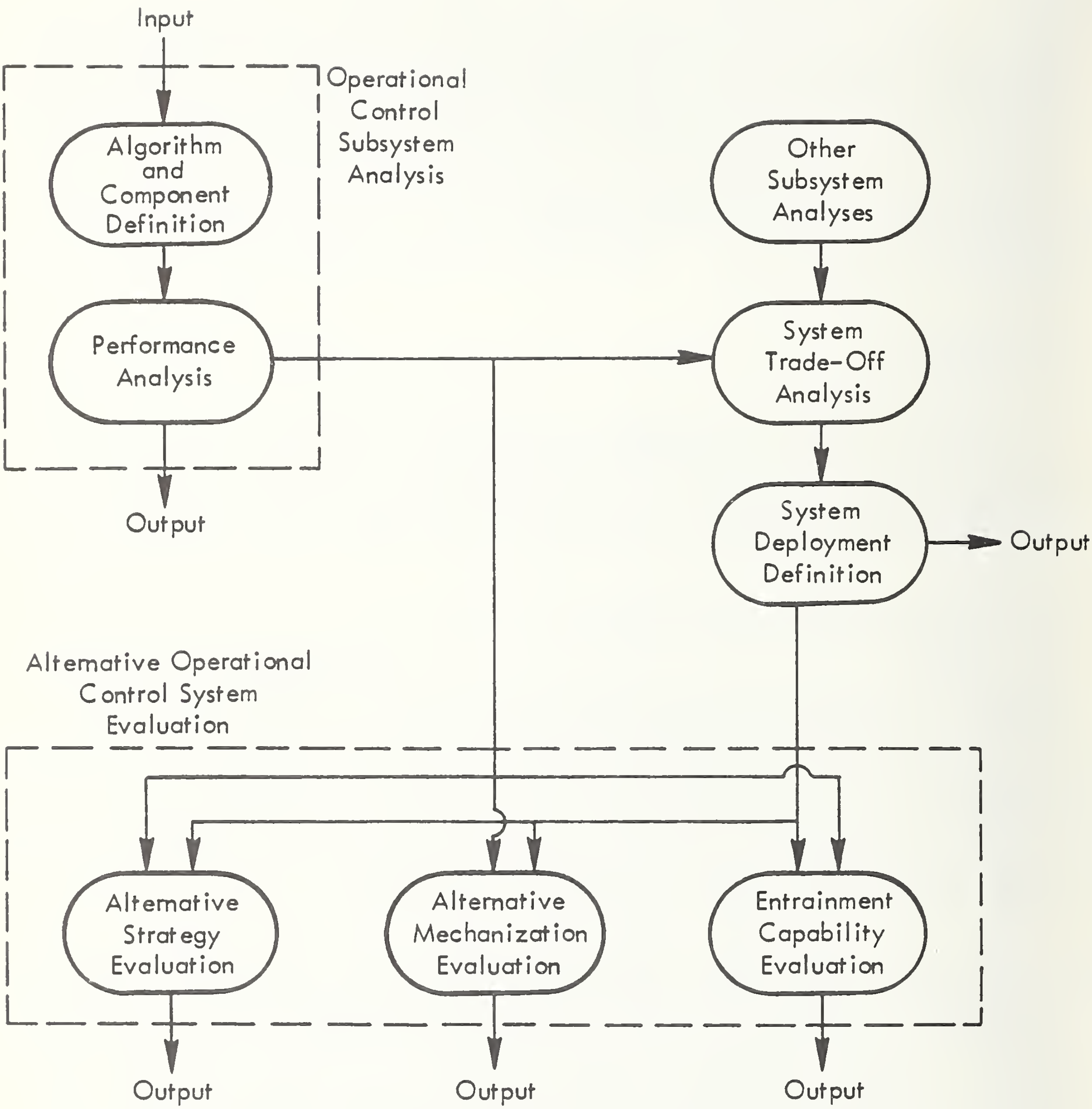


FIGURE 9-1. OPERATIONAL CONTROL ANALYSIS

9.2.2 System Level Analysis Content

The system level analysis was different from the subsystem level analysis in that alternative operational control strategy combinations were evaluated in the context of an entire system using the Discrete Event Simulation Model (DESM). As shown in Figure 9-1, this analysis consisted of three evaluation studies. The first study, the alternative strategy evaluation, considered the system performance effects of three alternative operational control strategies in the context of a single system deployment. The deployment used in this analysis is a variation of the GRT2 deployment in which 113,314 passengers per day are served on a grid network of moderate size and complexity. The GRT2 network is illustrated in the upper portion of Figure 7-4. For the purpose of this analysis, several crossovers were added to allow greater flexibility of vehicle path selection, and stations were modeled as off-line rather than on-line as in the GRT2 deployment. Demand responsive operation of a fleet of 17 passenger SGRT vehicles was analyzed. The three alternative strategy combinations were asynchronous longitudinal control with non-deterministic dispatch, synchronous longitudinal control with deterministic dispatch, and quasi-synchronous control with quasi-deterministic dispatch. The vehicle control and headway protection pair and merge strategy for use in each control combination was chosen based upon the subsystem level analysis results. The second study, the alternative mechanization evaluation, compared the software and hardware mechanizations of the alternative control strategies in the context of the same baseline system deployment. The third and last study, the entrainment capability evaluation, evaluated the system performance effects of operational entrainment both within the station and dynamically at network merges using the same baseline system deployment.

9.3 CONCLUSIONS

9.3.1 Subsystem Level Conclusions

The minimum operational headway analysis showed that the vehicle control and headway protection combination consisting of continuous moving block headway protection and fixed block vehicle follower vehicle control offers no advantage over the simpler combination using fixed blocks for both functions. In all cases, point follower control was found to require longer headway separation than vehicle follower control because of the focusing distance phenomenon during line speed changes. No combination of vehicle control and headway protection was found to offer headway separations less than about 4 seconds without requiring a safety factor less than unity and/or not considering "brickwall" failures.

Subsystem experiments with single vehicles on a link confirmed that analytic expressions descriptive of vehicle motion give velocity profiles which may be followed by the vehicle controller with good accuracy. Also, analytic expressions for vehicle propulsion energy were found to be in excellent agreement with energy usage as found from the experiments.

The vehicle follower feedback gains were chosen to analytically give string stability at 25, 15, and 5 meters per second using only one numerical value of the coefficients. Experiments with a string of vehicles at minimum headway spacing showed that the control is indeed string stable.

Link flow experiments using both point follower and vehicle follower vehicle control showed that point follower control produces energy consumption and travel times which are independent of the link utilization. In general, the point follower control uses less brake energy and less propulsion energy except at the lowest link utilization. The link travel time is also slightly more predictable with point follower control as compared to vehicle follower control.

Headway protection was experimentally confirmed for both point follower and vehicle follower control. For the vehicle follower case, substantial braking of following vehicles occurs under normal control before the headway violation triggers emergency braking. The point follower case follows the control point without braking up to the time of headway violation. Link start up procedures were also experimentally tested. A simple and efficient procedure was tested for vehicle follower control, but a good procedure was not tested for point follower control.

Merge flow experiments showed that a priority merge strategy is effective in reducing travel time on the priority path; however, the travel time increases on the other path. A FIFO merge strategy results in the minimum flow weighted average travel time and thus was concluded to be the preferred strategy, except possibly in special situations. A comparison of merging under asynchronous control and under quasi-synchronous control showed superior performance for asynchronous control for both energy usage and minimizing excess travel time. A quasi-synchronous merge experiment at high even flow rates was not successfully performed. The correct combination of headway, control parameters, and merge geometry was not found after several experiments. The results of two intersection experiments were completely similar to the merge flow results.

9.3.2 System Level Conclusions

Based upon the measures: average trip time, average trip travel speed, average passenger delay, average number of passengers waiting, and the difference of arriving and served passengers, the control combinations of asynchronous longitudinal control with non-deterministic dispatch was found to give better system level performance than the other two control combinations evaluated at the system level. The other two combinations were quasi-synchronous longitudinal control with quasi-deterministic dispatch and synchronous longitudinal control with deterministic dispatch. The asynchronous control case gave superior performance at 100, 150, and 200 percent of nominal demand except for the measures average number of passengers waiting and the difference of arriving and served passengers for the nominal demand case. Those measures were approximately the same for all three control combinations. The quasi-synchronous case outperformed the synchronous control case at increased demand, and at nominal demand the two reversed their ranking for some of the measures.

Based upon the subsystem analysis, the asynchronous control case was given a headway advantage at the system level. Experiments were also performed for which the headway advantage was removed. Asynchronous control still gave superior performance but to a lessened degree, especially for the case of 200 percent of nominal demand.

A calculation of the control related system cost of the three control combinations resulted in asynchronous control being the lowest and in quasi-synchronous control being the highest.

A system level aggregation of the hardware, computation, and software requirements identified at the subsystem level showed that the vehicle mounted, guideway mounted, and station mounted hardware, computation, and software requirements are similar for the three control cases studied. The case of quasi-synchronous control was identified as requiring higher amounts of localized control computation, and the amount of central control computation is the least for asynchronous control and the most for synchronous control. The data link structure for asynchronous control was identified as a structure of more direct communication between parts.

The comparative entrainment evaluation showed a clear performance improvement when dynamic guideway entrainment of vehicles at merges was enabled. Entrainment within stations resulted in a performance improvement only when combined with dynamic guideway entrainment to allow vehicles to divert from trains on the guideway. Even then, the result was a function of the demand level, indicating that the wait time to allow an entrainment within the station is an important parameter.

10.0 SOFTWARE VALIDATION

In addition to performing acceptance tests on all of the SOS software when it was delivered to TSC and successfully using the models to complete the analysis tasks of the Systems Operation Studies, a formal validation exercise was completed for most of the processors. While validation plans were prepared for all seven of the SOS models, schedule and budget constraints permitted the execution of only five of the plans. The following processors were validated according to the plans submitted to TSC:

Discrete Event Simulation Model (DESM)
Detailed Station Model (DSM)
Feeder System Model (FSM)
System Cost Model (SCM)
System Availability Model (SAM)

The two simulation models (DESM and DSM) were validated by comparing the model's prediction of performance to actual measured performance of an existing system under a set of well defined test conditions. The other three models were validated by comparing the model prediction to an estimate of system performance derived by some independent analytical method. The validation procedure and results were reported in memos.[57-61] The results of each validation exercise are briefly summarized in this section.

10.1 DISCRETE EVENT SIMULATION MODEL VALIDATION

The DESM was used to model the Airtrans system at the Dallas/Fort Worth Airport. The discrete event approach to large-scale system modeling provides sufficient flexibility and detail of modeling to allow an analyst to produce an efficient computer model of a complex automated guideway transit system which both qualitatively and quantitatively represents the real system. The mean round trip travel time of all nine passenger and employe routes, as calculated by the DESM model processor, were found to be statistically equivalent (using the Student t test) to the values reported for actual operation of the Airtrans system. While the standard deviations of these route travel times did not pass the validation test (statistical F test), this lack of statistical equivalence is not considered a shortcoming of the model. On the contrary, since it was recognized during the modeling process that a major cause of route time variation (variable station dwell time) was not being modeled due to lack of compatible data for the Airtrans system, it was expected that the simulation would have less variation in route times than the real system. Also, exogenous events such as vehicle stoppages due to communication breakdowns, passengers holding vehicle doors, etc. were not included in the simulation.* The time period used for

*It is possible to model these and other failures in the DESM.

comparison is one of relatively few failure occurrences in the real system, but some events undoubtedly did occur. Such events would tend to have only a small effect on mean times but a greater effect on standard deviation. The DESM successfully validated both the means and standard deviations of nine system-level performance measures obtained for simulations using Poisson generated trip lists generated by the DESM input processor against the same measures obtained for a simulation using an actual Airtrans trip list.

10.2 DETAILED STATION MODEL VALIDATION

The DSM was used to model vehicle operation in and around the Beechurst Avenue Station of the Personal Rapid Transit System located at Morgantown, West Virginia. This off-line station is the largest and most complex of the three stations initially in operation at Morgantown. The station is composed of six parallel docking lanes, two independent vehicle approach lanes, two independent vehicle exit lanes, and two station bypass lanes.

The validation approach was to compare the values of several measures determined by simulation using the DSM with actual data derived from Morgantown PRT Distance/Time Data and the Vehicle Snapshot Report obtained from Morgantown PRT operating records for April 26, 1978. The validation was based on comparing nine actual and predicted values of the following measures calculated for 5-minute intervals over a 45-minute period:

- Average vehicle in-station time
- Average vehicle deboard time
- Average vehicle board time
- Vehicle flow to the Engineering Station
- Vehicle flow to the Walnut Station
- Vehicle flow through each of the six docking lanes

The tolerance bounds associated with the average time measures were ± 15 seconds maximum deviation from the observed value. The tolerance bounds associated with the vehicle flow measures were ± 10 percent maximum deviation from observed values.

The DSM-generated values of the validation measures were found to be within tolerance limits in all cases. Such close agreement with observed data, essentially down to the individual vehicle level, strongly supports the event modeling technique of the DSM as an accurate performance emulator.

10.3 FEEDER SYSTEM MODEL VALIDATION

The output of the FSM was compared with analyst calculated results for a simple test problem consisting of five analysis zones, four stations, and three service regions in which three different feeder bus alternatives were evaluated: fixed route, demand responsive, and demand subscription. The FSM validation exercise attempted to verify the following functions of the processor:

Preliminary zone/station association
Final zone/station demand generation
Submodal split (walk, automobile, feeder bus)
Performance (travel time) calculation
Utilization (bus fleet) calculation

The important demand mapping and submodal split functions of the model were found to be operating correctly. However, some performance and utilization features of the model, which were not used during the SOS analyses, are not functioning properly. Since these features are of secondary importance, errors in this part of the model were not corrected during the SOS contract.

10.4 SYSTEM COST MODEL VALIDATION

The SCM models the cash flow process which transforms basic cost values into life cycle cost measures. Since the process of determining system cost is a deterministic one using accepted mathematical formulae, validation consisted of verifying that these formulae are properly interfaced and operate as an accurate transform device. The test problem chosen to establish System Cost Model validation is a Shuttle Loop Transit deployment operating on a multiple-loop network in a Low Demand CBD Line-haul application (SLT8). The system costs for the SLT8 deployment were calculated by the SCM based on a detailed set of input data. The resulting system cost measures obtained from the SCM were then compared with corresponding cost measures derived independently by an analyst.

The tolerance bounds for agreement between the SCM and analyst generated measures were specified as $\pm$ 1.0 percent deviation about the analyst derived values. These bounds are rather stringent since the only allowable source of difference between model and analyst values is computational round-off error. Errors may occur either in the model or in the analyst computations: in the model because it iterates through each year, summing costs (and thus introducing round-off error each time); and in the analyst's ledger because, while amortization is performed by closed form equations and requires few recorded intermediate results, the round-off error for the several existing intermediate steps is of a greater magnitude than in model rounding. In either case, the deviation between analyst and model results is expected to increase with the number of intermediate results and thus with the number of operations performed.

The results of SCM validation revealed deviations less than the $\pm$ 1.0 percent limit and a tendency for them to increase with the complexity of the computation. Values of base year costs, which are derived from simple multiplication and addition of direct input and first generation amortization, were found to differ by less than 1/1,000,000 units. When values are computed over a number of years differences on the order of 1/100,000 were found to occur. When more time is spanned and salvage values are accounted for, differences increased to the order of 1/20,000. Finally, in the calculation of present values differences were typically on the order of 1/10,000 with one difference as high as 1/125 (0.8 percent). The cost measures of this type are expected to be the worst in round-off error because present value computations involve operations on values in each of 40 years where the values themselves are the result of amortization and inflation calculations. The fact that variations were found to be more prevalent in the higher order computations reinforces the contention that all errors in transforming costs into life cycle measures can be attributed to computational round-off. In no instance was an error found to be outside the ± 1.0 percent tolerance limit.

10.5 SYSTEM AVAILABILITY MODEL VALIDATION

The SAM validation effort consisted of demonstrating that the value of vehicle availability generated by the model is comparable to the value of a similar measure of system availability calculated using data available from the operation of the Airtrans system during the period from April to December, 1976. The SAM produced a value of vehicle availability which is identical to the value reported for the Airtrans system.

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12.0 GLOSSARY

Asynchronous

Operation of vehicles under velocity control or in the vehicle-follower mode with speed changes allowed to prevent potential merge conflicts.

Automated Guideway Transit (AGT)

Computer-controlled transit system operating in demand or scheduled service on a fixed, exclusive guideway.

Automated Rail Transit (ART)

A class of AGT systems which provides multiple-stop service, carries at least 100 passengers in its minimum train consists, operates at speeds equal to or greater than 55 km/h, and generally runs at headways of more than 1 minute.

Availability-Factor Relationships

The sensitivity of the vehicle and passenger availability measures to changes in parameters which affect either system reliability or failure management strategy.

Average Queue Transit Time (TQ)

Average time required to move through a platform boarding queue during a period of congestion such as the peak hour. For a particular station the value is calculated as the difference between the average wait time and one-half the average route headway.

Capital Cost (base year)

The initial cost of deploying a system expressed in base year (1977) dollars. Capital cost is the sum of guideway construction cost, passenger station construction and equipment cost, AGT vehicle cost, central control construction and equipment cost, maintenance facility construction and equipment cost, power distribution system installation cost, and feeder system costs including vehicles, maintenance facilities, and control facilities.

Catalogued Procedure

A pre-coded set of Job Control Language (JCL) statements that is assigned a name, placed in a data set, and may be retrieved and executed by one JCL statement.

Central Business District (CBD)

The downtown retail trade area of a city. As defined by the Census Bureau, the CBD is an area of very high land valuation characterized by a high concentration of retail business offices, theaters, hotels, and service businesses, and by a high traffic flow.

Central City (CC) of an SMSA

The largest city in an SMSA. One or two additional cities may be secondary Central Cities in the SMSA.

Central City (CC) of an Urbanized Area (UA)

A city of at least 50,000 persons within closely settled incorporated and unincorporated areas that meet the criteria for urbanized ring (fringe) areas. A few UA's contain twin cities with a combined population of at least 50,000.

Central City Ring (CCR)

The portion of a Central City not included in the CBD.

Checkpoint File

A file created at a user-specified time by the Model Processor and containing all data necessary to restart the MP from that time.

Closed-Loop Control

Advancement of vehicles under generated control based upon the estimated system state.

Control Block

A specific section of guideway corresponding to a single control segment of a fixed block vehicle regulation and/or headway protection system.

Cruise Speed

The constant velocity at which a vehicle travels after acceleration and prior to braking. This velocity is usually less than the maximum design speed, but can be equal to it.

Crush Load Capacity

The maximum total capacity which a vehicle is designed to accommodate. This limitation is defined by either a vehicle weight limitation or a passenger comfort criterion.

Demand Activated Service Policy

A service policy in which routes, which may include intermediate station stops, are generated in real time on the basis of passenger demand, i.e., point-to-point routing with demand stop.

Demand Responsive Service Policy

A service policy in which non-stop routes are generated in real time on the basis of passenger demand, i.e., point-to-point routing with no intermediate stops.

Demand Stop Service Policy

A service policy in which vehicles travel on predetermined routes but stop at stations along the route only in response to specific passenger demand.

Demand Type

A system deployment parameter which specifies the demand environment on which a detailed demand model will be specified. Three metropolitan area demands and four activity center demand types are identified:

1. Metropolitan area - high CBD, high reverse commutation
2. Metropolitan area - high CBD, low reverse commutation
3. Metropolitan area - low CBD, low reverse commutation

1. Activity Center Line-Haul
2. Activity Center Circulation
3. Activity Center, CBD Circulation
4. Activity Center, CBD Line Haul

Design Load per Vehicle

The nominal passenger capacity of each vehicle including standees.

Deterministic

A strategy by which all merge conflicts are resolved before launch, and barring failures, each vehicle is assured of traversing the network in a predetermined time.

Dial-A-Ride Service

Transit service operated by generating vehicle paths in continual response to demand.

Downtown People Mover (DPM)

An AGT system deployed in a CBD environment, or the UMTA demonstration program to implement such systems.

Empty Vehicle Management (EVM)

A set of strategies which govern the disposition of active, empty vehicles not assigned to a fixed route nor enroute to service a passenger demand. Alternative strategies include:

Circulation

Vehicles are circulated on the network until needed to satisfy a demand. The distribution of circulating vehicles may be based on historical demand or on current demand patterns.

Station storage - historical

Vehicles are routed to stations for storage based on historical demand data.

Station storage - real time

Vehicles are either stored in the station when they become empty or are routed to other stations and stored based on current demand patterns.

Event Model

A representation of an entity (a subsystem or process) in terms of discrete states of the entity and the time required to change from one state to another for use in a discrete event simulation.

Feeder System

A manually operated public transit system whose primary function is to provide transportation between AGT stations and off-guideway origins and destinations.

Fixed Block

A longitudinal control or headway protection mechanization wherein blocks are hardwired to the guideway and each block transmits velocity or braking commands to the vehicle based on the occupancy of preceding blocks. For longitudinal control, the commands may be altered by central or local control. For headway protection the blocks transmit either braking or velocity limit commands to vehicles which establish upper bounds for any other commands.

Fixed Route Service

Transit service operated on predetermined paths.

Flow Capacity (ρ_c)

A measure of system capacity in terms of passenger spaces per second past a point; the ratio of traveling unit capacity to average route headway.

Fully Connected Grid (FG)

A grid network in which vehicles proceed directly from one station to any other station without retracing any one-or two-directional portion of the guideway.

Global Variables

Variables stored in a common area and known by one name to all segments included in the program.

Grid

Any guideway on which vehicles are presented with a choice of paths during normal operation.

Grid Transit (GT)

A transit system deployed in any demand environment which uses an FG or PG network and has more extensive operational switching capability than an MSLT. Generally shorter headways result than in MSLT. This category includes PRT systems and many systems which are often referred to as Group Rapid Transit (GRT).

Guideway Interface

The vehicle components which contact the guideway for support. Usually the interface is wheels but in some cases it is an air or magnetic levitation force.

Headway

A frequency of service measure: the mean time between vehicles passing a point along a route of known configuration.

Headway Equation

An analytic function which expresses the relationship between minimum headway and system parameters such as traveling unit (vehicle or train) length, cruise speed, acceleration, communication delay, and expected position error.

Intermediate Vehicle Group Rapid Transit (IGRT)

A class of AGT systems which provides multiple-stop service and carries from 25 to 69 passengers in its minimum train consist. Low speed IGRT systems have a maximum operating speed of 13 to 54 km/h and tend to run at 15 to 60 s headways. High speed IGRT systems operate at speeds greater than 54 km/h and at headways which usually fall between 15 and 90 s.

Intersection

An X-type merge with 2 input links, 2 output links, 4 ramp links, 4 through paths, and either 2 or 4 queuing areas.

Large Vehicle Group Rapid Transit (LGRT)

A class of AGT systems which provides multiple-stop service, has a minimum train consist capacity of 70 to 109 passengers, operates at a maximum speed of 13 to 54 km/h, and usually runs at headways of 30 to 90 s.

Lateral Control Interface

Vehicle and guideway components that interface to control the vehicle's lateral movement.

Loop

A guideway on which motion is unidirectional during normal operation (except possibly at short station segments or at ends of runs) and which is defined by a closed path.

Loop of Closed Geometry (S)

A simple loop as defined above which encircles no area.

Macro

A standard code segment that is generated in-line at compile time by specification of a single statement.

Maximum Operating Speed

The maximum speed at which a vehicle can travel. This limit is imposed by vehicle and propulsion system design constraints.

Merge Strategy

A strategy for resolving merge conflicts. Three strategies are considered:

1. FIFO (first-in, first-out)
2. Prescheduled
3. Priority

Metro Shuttle Loop Transit (MSLT)

A transit system deployed in a metropolitan environment and having high speed capability but no or limited operational switching capability. The network may be of any type. If it is a grid network, however, the switching is of limited capability. This category includes most guideway transit systems currently deployed in metropolitan areas.

Minimum Traveling Unit

The minimum number of vehicles with which a train can operate. For some systems the minimum traveling unit is a single vehicle.

Minimum Traveling Unit Capacity

The nominal capacity (not crush capacity) of a single vehicle times the number of vehicles in a minimum train consist.

Moving Block

A headway protection mechanization wherein an emergency protection zone which moves along with the vehicle is established around each vehicle. Emergency braking commands are issued to the traveling vehicle whenever its emergency protection zone infringes upon that of a leading vehicle.

Multiple Loop (ML)

Any network consisting of two or more loops and requiring that passengers transfer from a vehicle constrained to one loop to a vehicle constrained to another loop if they wish to travel between two points not served by a single loop.

Network Element

Either a link, merge, or an intersection modeled in the DOCM.

Network Type

A system deployment parameter which specifies network configuration. Seven network types are identified:

1. Shuttles (S)
2. Loop of closed geometry (L)
3. Open loop, one-way (L1)
4. Open loop, two-way (L2)
5. Multiple loop (ML)
6. Partially connected grid (PG)
7. Fully connected grid (FG)

Nominal Capacity

Vehicle capacity including seated and standing passengers as specified by the manufacturer according to a passenger comfort criterion. The average area allotted to each standee is generally at least 2.5 square feet.

Non-deterministic

A strategy by which potential conflicts at merges are not considered before launch but are resolved locally in the vicinity of each merge.

Off-Vehicle Feeder Travel Time for Access

The mean time per person enroute to a specific AGT station for delay or non-vehicle travel (including any walking to feeder route or waiting for feeder bus, transferring between vehicles, parking a car, or walking all the way), while going from zone centroids to a specific station.

Off-Vehicle Feeder Travel Time for Egress

The mean time per person enroute from a specific AGT station for delay or non-vehicle travel (including waiting at stations for bus, walking from route to destination, transferring between vehicles, or walking all the way), while going from a specific station to zone centroids.

On-Vehicle Feeder Time for Access

The mean time per person enroute to a specific AGT station spent aboard a feeder vehicle (including feeder bus or private auto), while going from zone centroids to a specific station.

On-Vehicle Feeder Travel Time for Egress

The mean time per person enroute from a specific AGT station spent aboard a feeder vehicle (including the feeder bus or private auto), while going from a specific station to zone centroids.

Open-Loop Control

Advancement of vehicles by user-specified control independent of system state.

Open Loop, One-Way (L1)

A single loop encircling an area and providing one-way circulation.

Open Loop, Two-Way (L2)

Two loops deployed side-by-side encircling an area and providing two-way circulation.

PARAFOR

A superset of FORTRAN utilizing PL/1 macros to add structured programming facilities to standard FORTRAN.

Partially Connected Grid (PG).

A grid network which does not qualify as a Fully Connected Grid (FG).

Partitioned Data Set

A type of file organization in which independent groups of sequentially organized records, called members, are on direct-access storage.

Path

A sequence of guideway links used by a vehicle to travel between two points on a network.

Personal Rapid Transit (PRT)

A class of PRT systems which provides non-stop point-to-point service, has a minimum traveling unit capacity of 3 to 6 passengers, and runs at very short headways, usually 3 s or less. Low speed PRT has a maximum operating speed of 13 to 54 km/h, while high speed PRT has a maximum operating speed exceeding 54 km/h.

Platoon Movement

Simultaneous advancement of a row of vehicles or trains.

Practical Minimum Headway

The minimum headway at which vehicles can operate under normal conditions.

Prescheduled Pathing

A vehicle pathing strategy in which the primary path from origin to destination is predetermined and specified for all station pairs.

Precision Stopping Tolerance

The tolerance within which a vehicle can stop at a given point.

Quasi-deterministic

A strategy by which merge conflicts are not resolved prior to launch, but information about the future state of the network is used to launch vehicles at times that provide a high probability of efficient merging.

Quasi-synchronous

Operation of vehicles under point-follower control but with change of control points allowed to resolve potential merge conflicts by advancing or slipping one or more slots.

Reliability Block Diagram

A diagram that illustrates what equipment or combinations of equipment are required for successful system operation.

Representative System

A collection of values for the following system characteristics and strategies:

1. Vehicle characteristics
2. Guideway characteristics
3. System management strategies
4. Reliability characteristics
5. Cost characteristics

Representative System (continued)

The range of values are chosen to be interrelated in such a way as to represent a general class of state-of-the-art systems for the purpose of conducting system analyses within the SOS program.

Representative System Deployment

A specific combination of a representative system, demand type, and network configuration defined for the purpose of conducting system analyses within the SOS program.

Response Time

A frequency of service measure which is the mean time between a request for and the arrival of a dial-a-ride service vehicle.

Ripple Movement

Advancement of vehicles and trains one at a time for a row of stationary vehicles/trains.

Route

A designated set of destinations, usually defined by stations, to which a vehicle must travel. The path, or links, to be traversed between any two destinations is not necessarily specified as part of the route definition.

Routing Strategy

A strategy which identifies routes for vehicles/trains. Two alternatives are fixed routing and real time select routing. Real time routing is used only with demand responsive service and demand activated service, while fixed routing is employed for demand stop and fixed route service policies.

Rural and Scattered Urban (R&SU)

The remaining rural and urban portions of counties not included as part of the urbanized ring of the UA, but still within the boundaries of the SMSA. Thus, with the exception of the New York and Los Angeles SMSA's, the SMSA consists of two components - the UA and the Rural and Scattered Urban. Both New York and Los Angeles Urbanized Areas (UA's) extend into counties outside the boundaries of the SMSA.

Scheduled, Real Time Pathing

A vehicle pathing strategy in which the primary path from origin to destination is selected from among specified alternatives just prior to departure from the origin station on the basis of current traffic conditions on the network.

Sector

An area serviceable by one vehicle in subscription service during a prescribed time interval for a specific demand density.

Service Type

Either non-stop (personal transit) or multiple-stop (group transit) service.

Shuttles (S)

A guideway on which bi-directional motion occurs during normal operation and which is defined by a single curve connecting two distinct end points. Also, any network consisting of two or more simple shuttles, either following the same path or different paths.

Shuttle Loop Transit (SLT)

A low speed AGT system deployment in an activity center demand environment having any non-grid type of network. Thus, SLT system deployments require no operational switching but may require passenger transfers.

Small Vehicle Group Rapid Transit (SGRT)

A class of AGT systems which provides multiple-party service, has a capacity of 7 to 24 passengers in its minimum train consist, and usually operates at headways between 3 and 15 s. Low speed SGRT has a maximum operating speed of 16 to 54 km/h, and high speed SGRT a maximum of over 54 km/h.

SOS Data Base

A collection of data files and software packages that have been brought together to assist in the development and application of the AGTT-SOS computer programs.

Standard Metropolitan Statistical Area (SMSA)

A county or group of counties containing at least one city (or twin cities) with a population of 50,000 or more, plus adjacent counties which are metropolitan in character and integrated economically and socially within the central city.

Switching Mechanism

The mechanism, located either on the vehicle or the guideway, by which vehicles/trains are switched.

Synchronous

Operation of vehicles under point-follower control with no changes allowed in control points during a given guideway trip.

Theoretical Minimum Headway

The minimum headway at which two vehicles can travel, assuming there are no merges or on-line stations.

Total Value Capital Cost

The sum of all capital costs except interest expense over the life cycle period expressed in base year dollars.

Urbanized Area (UA)

An area containing a central city (or twin cities) of 50,000 or more population, plus the surrounding closely settled incorporated and unincorporated areas which meet certain criteria of population size and density (urbanized ring). UA's differ from SMSA's in that UA's exclude the rural portions of counties composing the SMSA's, as well as places that were separated by rural territory from the densely populated fringe around the central city. The components of the UA's include the central city, as defined above, and the urbanized rings, as defined below.

Urbanized Ring (UR)

Various areas contiguous to a central city or cities, which together constitute its urbanized ring, or "urban fringe," as termed by the Census Bureau.

Variable Cost (base year)

The annual cost of operating and maintaining a system expressed in base year (1977) dollars. Variable costs include maintenance costs, energy costs, and administrative costs for both the AGT and feeder systems.

Vehicle Capacity

When used in correlations of vehicle dimensions and cost to capacity, nominal vehicle capacity is assumed. However, the system simulations interpret vehicle capacity as the maximum number of passengers who can occupy a vehicle at one time.

APPENDIX A

AGTT-SOS DOCUMENTATION

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
76045	Outline		Analysis Plan	8/76
76046	Outline		Analysis Requirements	8/76
76051	Spec.	Interim (Final: 77008)	Detailed Station Model Functional Spec.	9/76
76052	Spec.	Interim (Final: 77009)	Detailed Operational Control Model Func. Spec.	9/76
76053	Spec.	Interim (Final: 76065)	Feeder System Model Functional Spec.	9/76
76054	Spec.	Interim (Final: 77057)	Discrete Event Simulation Model Func. Spec.	9/76
76055	Spec.	Interim	Data Base and Terminal Software Func. Spec.	9/76
76056	Report	Draft (Final: 76056A)	Software Standards	--
76056A		Final	Software Standards	10/76
76062	Report	Draft (Final: 77002B)	Classification and Definition of AGT Systems	10/76
76062A		Interim (Final: 77002B)	Classification and Definition of AGT Systems	10/76
76063	Report	Draft	Analysis Plan	10/76
76065	Spec.	Final	Feeder System Model Functional Spec.	11/76
76067	Report	Interim (Final: 77004A)	Measures of AGT System Effectiveness	11/76

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
77002	Report	Final: 77002B	Classification and Definition of AGT Systems	1/77
77002A	Report	Final: 77002B	" " (Change No. 1)	6/77
77002B	Report	Final	" "	1/79
77003	Report	Interim (Final: 77054A)	Representative Application Areas for AGT	1/77
77004	Report	Final: 77004A	Measures of AGT System Effectiveness	1/77
77004A	Report	Final No. 2	" " "	2/79
77005	Spec.	Interim (Final: 77043)	Availability Model Func. Specification	2/77
77007	Spec.	Interim (Final: 77048)	Cost Model Functional Specification	2/77
77008	Spec.	Final	Detailed Station Model Functional Spec.	1/77
77009	Spec.	Final	Detailed Operational Control Model Func. Spec.	1/77
77010	Spec.	Interim	System Planning Model Functional Specification	2/77
77010A	Spec.	Update	" " "	5/77
77012	Report	Final	System Analysis Requirements and Plan, Vol. II (Plan)	2/77
77012A		Update	" " "	7/77
77012B		Update	" " "	1/78
77012C		Update	" " "	4/78
77012D		Final	" " "	7/78

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
77014	Spec.	Interim	Feeder System Model Technical Specification	1/77
77014A		Update	" " "	3/77
77014B		Update	" " "	9/77
77019	Report	Interim	System Analysis Requirements and Plan, Vol. I (Reqts.)	2/77
77019A		Update	" " "	5/77
77019B		Update	" " "	7/77
77019C		Update	" " "	1/78
77019D		Update	" " "	4/78
77019E		Final	" " "	7/78
77032	Spec.	Interim	System Planning Model Technical Spec.	5/77
77032A		Update	" "	9/77
77033	Spec.	Interim (Update: 77081)	Detailed Station Model Technical Specification	3/77
77034	Spec.	Interim (Update: 77082)	Detailed Operational Control Model Tech. Spec.	3/77
77043	Spec.	Final	Availability Model Functional Specification	4/77
77048	Spec.	Final	Cost Model Functional Specification	5/77
77054	Report	Final (Final: 77054A)	Representative Application Areas for AGT	7/77
77054A	Report	Update	" " "	11/78

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
77055	Spec.	Interim	Cost Model Technical Specification	6/77
77055A		Update	" " "	9/77
77056	Spec.	Interim	Availability Model Technical Specification	6/77
77056A		Update	" " "	9/77
77057	Spec.	Final	Discrete Event Simulation Model Func. Spec.	6/77
77059	Report	Final	Data Collection Trip Reports	7/77
77074B	Report	Final	System Availability Model User's Manual	2/79
77077A	Manual	Final	Data Base User's Manual	4/78
77081	Spec.	Update	Detailed Station Model Technical Specification	11/77
77082	Spec.	Update	Detailed Operational Control Model Tech. Spec.	11/77
77083	Spec.	Interim	Discrete Event Simulation Model Technical Spec.	9/77
77085	Report	--	Implementation Report (for 9/77 Software Delivery)	9/77
78002	Report		Minutes of AGT/SOS Briefing of December 19, 20, 21, 1977	1/9/78
78003	Spec.	Interim	Data Base Specification	1/78
78007	Paper		AGT/SOS Presentation at Conference on Automated Guideway Transit Technology Development, Feb. 28 - Mar. 2, 1978 - J. Thompson	2/78

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
78008	Report	Draft (Final: 79020)	AGT/SOS Downtown People Mover Program Write-Up	2/6/78
78008A	Report	Update (Final: 79020)	Downtown People Mover Simulation Program Write-Up	4/78
78014	Report	Final	AGT/SOS Analysis of SLT Systems, Vol. II - Study Results (Vol. I - Summary, Vol. III - Analysis Techniques and Data Sources)	7/78
78023	Report		Case Study Development Plan	2/78
78043	Report	Draft (Final: 78043A)	Analysis of SLT System, Vol. I-Summary	3/78
78043A	Report	Final	Analysis of SLT Systems, Vol. I-Summary	7/78
78052A	Manual	Final	Detailed Station Model User's Manual	6/78
78053A	Manual	Final	Detailed Operational Control Model User's Manual	6/78
78054A	Manual	Final: 78054B	Discrete Event Simulation Model User's Manual	5/78
78054B	Manual	Final	" " "	6/78
78059A	Report	Final	Analysis of SLT Systems, Vol. III-Analysis Techniques and Data Sources	7/78
78068A	Report	Update	Downtown People Mover Simulation Test Plan	6/78
78094	Manual	Final	Detailed Station Model Programmer's Manual	6/78

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
78094-1	Report Appendix	Final	Detailed Station Model Programmer's Manual	6/78
78095	Report	Final	Detailed Operational Control Model Programmer's Manual	6/78
78105	Report	Interim (Final: 79005)	Comparative Analysis of AGT Systems in CBD Applications	8/78
78111	Report	Final	Discrete Event Simulation Model Programmer's Manual	7/78
78115	Report	Draft (Final: 79012	Analysis of ART Systems, Vol. I - Summary	8/78
78116	Report	Draft (Final: 78116A)	Analysis of ART Systems, Vol. II - Study Results	8/78
78116A	Report	Final	" " "	1/79
78117	Report	Draft (Final: 78117A)	Analysis of ART Systems, Vol. III - Analysis Techniques and Data Sources	10/78
78117A	Report	Final	" " "	1/79
78129	Report	Interim (Final: 79003)	Quantitative Analysis of Alternative Operational Control Strategies for AGT	8/78
78162	Report	Draft (Final: 79005)	Comparative Analysis of AGT Systems in CBD Applications	8/78
78165	Report	Final	Implementation Report for Software Delivery	9/78
78170	Manual	Final	System Cost Model User's Manual	12/78
78177	Report	Final	Analysis of GRT Systems, Vol. II- Study Results	1/79

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
78184	Report	Final	Comparative Analysis of ART and GRT Systems in a Metropolitan Area Application	12/78
78200	Report	Final	Software Delivery Implementation Report	12/78
78200A	Report	Final	December 1978 Software Delivery Implementation Report with Feb. 1979 Supplement - Network Build Module Programmer's Notes	2/79
78200B	Report	Final	December 1978 Software Delivery Implementation Report with Supplements: (1) Network Build Module Programmer's Notes (2) Network Build Module User's Example	3/79
79001	Memo		Discrete Event Simulation Program Validation	12/78
79003	Report	Final	Quantitative Analysis of Alternative AGT Operational Control Strategies	1/79
79004	Report	Final	Analysis of GRT Systems, Vol. III-Anal. Tech. and Data Sources	1/79
79005	Report	Final	Comparative Analysis of ART Systems in CBD Applications	1/79
79006	Report	Final	Analysis of GRT Systems, Vol. I - Summary	1/79
79009	Manual	Final	System Cost Model Programmer's Manual	5/79

EP #	DOCUMENT TYPE	ISSUE	TITLE	DATE
79010	Memo		Feeder System Model Validation	1/79
79012	Report	Final	Analysis of ART Systems, Vol. I - Summary	1/79
79013	Manual	Final	Feeder System Model User's Manual	1/79
79020	Report	Final	Downtown People Mover Simulation Program Write-Up	2/79
79022	Manual	Final	System Availability Model Programmer's Manual	2/79
79023	Manual	Final	System Planning Model User's Manual	2/79
79026	Memo		System Availability Model (SAM) Validation	1/79
79027	Manual	Final	System Planning Model Programmer's Manual	1/79
79046	Report	Final	Summary Report	6/79

APPENDIX B

REPORT OF INVENTIONS

Work performed by GM Transportation Systems Division under contract DOT-TSC-1220, in the area covered by this report, resulted in no inventions or improvements of inventions.

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