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THE DEVELOPMENT OF MEASURES OF SERVICE AVAILABILITY

Volume I: Summary Report

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FINAL REPORT

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16. Abstract

Service availability is defined as the impingement of failures on passenger perceived service. The alternate technologies and applications for Automated Guideway Transit (AGT) systems require service availability measures (SAMs) to gage the impact of alternate reliability and maintainability (R/M) options and goals. The transit industry views various forms of passenger delay potential to be the appropriate parameters of service availability. The propensity of a system to induce delays is a complex function of R/M and operational characteristics. No single measure or model exists which can be uniformly applied to different technologies or applications. A methodology is presented to compute these relationships for simple loop and/or shuttle systems. More complex systems will require computer simulation procedures.

This is the first of three volumes. Volume II is a compilation of all Interim Reports submitted during this project. Volume III is a set of application guidelines for controlling service availability of AGT systems during the planning, procurement, and operation of the system.

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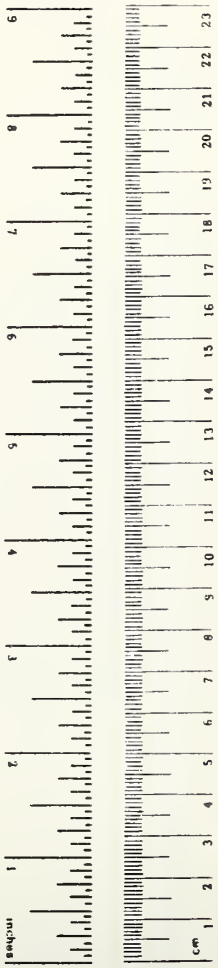
PREFACE

This three-volume set of reports constitutes the Final Report on the project "The Development of Measures of Service Availability". The project was conducted for the Transportation Systems Center (TSC) and is a part of the Urban Mass Transportation Administration's (UMTA's) "Automated Guideway Transit Technology (AFTT)" program. The objective of the project was to develop passenger-oriented measures of service availability which could be used to control the level of service provided by AGT systems throughout their life cycle.

METRIC CONVERSION FACTORS

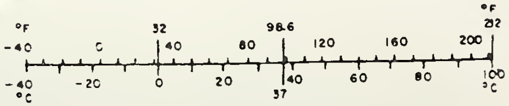
Approximate Conversions to Metric Measures

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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1. INTRODUCTION

This document is the first of a three volume set which, collectively, constitutes the Final Report on a project conducted for the Transportation Systems Center (TSC) as part of the Urban Mass Transportation Administration's (UMTA's) "Automated Guideway Transit Technology (AGTT)" program. The objective of this project was to develop measures of service availability which could be used to control the failure characteristics of automated guideway transit (AGT) system throughout their life. A corollary and equally significant objective was to develop, as necessary, a methodology for utilizing these measures during this control process.

Volume II of this report is a compilation of all Interim Reports submitted during this project; hence, it contains the details of the research effort. Volume III is the primary result of this project, a set of application guidelines for controlling service availability of AGT systems during the planning, procurement, and operation of the system.

This document, Volume I, is a summary of the research effort and results.

1.1 Background

Service availability is defined as a measure of the impingement of failures on transit system service as perceived by the passengers. This passenger service orientation has probably always been a driving force behind the establishment and maintenance of transit system failure characteristics. However, the relationship has been, in the past, qualitative. This has been satisfactory in most instances. All transit systems were generally the same; i.e., rapid transit systems, for which a significant experience base existed. Knowledgeable people in the industry could, reasonably well, identify the equipment reliability requirements for acceptable service levels as well as areas where improvement would be most beneficial with respect to improving service availability.

AGT systems, however, evolved to meet a different service requirements; frequent service, short headways, high equipment utilization, and little tolerance of failure. Furthermore, both applications and competing technologies varied widely. Hence, no experience base existed for controlling service availability. Each new system was dealt with on a case-by-case basis--each generating its own performance measures and control rationale. With this lack of a consistent viewpoint, there was little chance of accumulating an experience base; little chance of learning from existing systems to enable service improvements to be incorporated in new systems on a rational basis. Rather, what was evolving was a confusing array of performance measures, evaluation models, and definitions--forcing a perpetuation of the fragmentary treatment of service availability.

Accordingly, the project was aimed at determining and developing a degree of consistency in the control of service availability by developing a set of performance measures and application methodologies which could be applicable across technologies and applications, permitting quantitative treatment of service availability consideration in the selection, design, and application of AGT systems.

1.2 Summary Procedure

The research approach consisted of five tasks:

Task 1. Literature Review - This task was a literature review to develop the array of existing measures, models, and concepts related to service availability.

Task 2. Field Survey - This task carried the information gathering activity to the transit industry to gain the benefit of industry experience in the use of service availability measures and criteria for improved measures.

Task 3. Development of Service Availability Measures - This objective of the task was to integrate the results of Tasks 1 and 2 to select, or develop as necessary, those measures which best satisfied the needs of the transit industry.

Task 4. Development of Application Guidelines - The objective of this task was to develop appropriate guidelines for utilizing the measures selected in Task 3 during the various life-cycle phases of an AGT system.

Task 5. Service Availability Workshop - This task involved a second iteration with the transit industry, in a workshop format, to obtain critical feedback on the research results.

Initially, it was intended that each of these tasks would be performed in a sequential manner. This format was altered, slightly, as a result of interim findings. Tasks 1 and 2 determined the following:

(1) The desired parameters to be controlled by service availability considerations are related to passenger delays. The precise form of expressing levels of control and specific parameters to control vary greatly among applications; however, all are related to delay type, frequency, and/or duration.

(2) These delay parameters are not controlled directly. Rather, they are controlled indirectly by manipulating system failure characteristics via design characteristics and operating variables.

(3) Many measures and/or mathematical relationships exist which purport to relate system failure characteristics and passenger delays. These were generally discounted by the industry on the basis of questions regarding validity and application methodology. In a sense, the existence of a consistent applications methodology was a primary criterion for the selection of a service availability measure.

With these findings, Tasks 3 and 4 were combined in a fundamental investigation of the relationships between passenger delays and system failure, and means for dealing with the relationships in the practical control processes available over the life cycle of an AGT system. Early in the investigation, the following findings emerged:

(1) The relationship between passenger delays and transit system failures is a unique property of each specific system and application. System failures characteristics (i.e., failure rate and duration) are not the sole determinants of the relationship.

(2) No single quantiative formula or relationship can be applied to all system configurations and operating characteristics.

(3) It follows that no single measure is sufficient to characterize the system failure/passenger delay relationship for competing technologies in a given application or similar technologies in different applications.

As a result of these findings, the problem focus shifted away from attempting to find or define a universal measure to one of developing a methodology to derive the appropriate measures within the context of a given transport situation.

2. RECOMMENDATIONS

The following recommendations result from this research:

(1) The primary measure of system performance in terms of service availability should directly reflect passenger delay consideration. Many variations in form and value of the precise delay parameters used are possible:

Probability of incurring a delay on an average trip

Probability of incurring a station delay

Probability of incurring an en route delay

Probability of incurring an en route stoppage

Average delay associated with the above delays

Average delay encountered on average trip

Cumulative number of delays expected for an average passenger over some period of time

Cumulative delay experienced by an average passenger over some period of time

Exclusive combinations of the above.

The precise form and value of the service availability criterion are Buyer's decisions--based on his goals and insight into passenger expectation and sensitivities.

(2) The measures used for direct control of system performance requirements should be in the form of equipment failure parameters; e.g., system and subsystem failure rates and restore times.

To accommodate this dual measure utilization, a methodology has been developed to relate equipment failure characteristics and passenger delays and guidelines have been developed to integrate the methodology into the AGT service availability control process.

3. SUMMARY OF THE SERVICE AVAILABILITY CONTROL GUIDELINES

This section summarizes the guidelines for controlling service availability during the life of an AGT system. In these guidelines, the words "process" and "methodology" are taken to have specific meanings:

> Process - refers to the service availability control process
>
> Methodology - refers to the methodology for relating system failure characteristics and passenger delays.

3.1 Service Availability Control Process

The life of an AGT system can be separated into the following four distinct time phases:

(1) Planning and Preliminary Engineering Phase

(2) Supplier Selection Phase

(3) Design, Construction, and Testing Phase

(4) Operational Phase

A summary chart summarizing the highlights of the control process and the points of methodology utilization is presented in Table 3-1.

3.2 Methodology for Relating System Failure Characteristics and Passenger Delay Criteria

The key ingredient in the control process is a consistent methodology to assess the impact of system failures on passenger delays. To respond to the variety of circumstances of its intended use, this methodology must have

TABLE 3-1. SERVICE AVAILABILITY CONTROL PROCESS

PLANNING AND PRELIMINARY ENGINEERING PHASE	SUPPLIER SELECTION PHASE	DETAIL DESIGN, CONSTRUCTION, AND TESTING PHASE	OPERATIONS PHASE
Idea for System is Born	Supplier Develops System Design for Proposal	Supplier Performs Detail Design of System	Buyer Collects Operational Data to Use With Methodology
Initial Planning Accomplished	Supplier Completes List of Requested System Parameters	Supplier Builds System	Buyer Uses Methodology to Assess System Changes in Demands and Operation
Performance Measures Selected	Supplier Calculates Expected MTBF's and MTTR's of Proposed System Including Acceptance Equipments	Supplier/Buyer Suggest Changes	Buyer Uses Methodology to Monitor System Service
Selection of Service Availability Measures (Passenger Delay Parameters) is Made	Supplier Uses Methodology to Show Conformance With RFP	Supplier/Buyer Use Methodology to Evaluate Changes	
Assumptions Made of Unknown System Parameters Which Affect Passenger Delays	Supplier Submits Proposal	Supplier Performs and Buyer Witnesses System Acceptance Tests	
Methodology Used to Confirm Reasonableness of Service Availability Measures	Buyer Evaluates Proposals Using Methodology	System Operation Conforms to Acceptance Test Criteria	
Equipments/Subsystems/Systems Chosen for Acceptance Measures	Buyer Selects Supplier for System	System Accepted by Buyer	
List Made of System Parameters to Request of Supplier	Contract Negotiated Which Includes MTBF and MTTR Criteria for Acceptance as Requested in RFP		
RFP Completed and Distributed			

the capability of adapting to a variety of situations where delay criteria may vary, the level of specific knowlege regarding the failure characteristics of a system may vary, and the purpose for relating these may vary. It is within this setting that the methodology was developed.

The methodology was developed to comprehend a variety of variables which may impact delay results.

(1) Failure type - classifed by the effect of the failure on the ability of the system to deliver required capacity in the vicinity of the failure. Three types are considered: (a) failures which result in a blockage, (b) failures which result in operations at velocities less than the normal velocity, and (c) failures which result in operations with less than the required number of vehicles.

(2) Failure rate -the expected number of failures in some unit of time.

(3) Failure duration - the time during which the failed state exists.

(4) Failure location - the location of the failure relative to the general system configuration. This is important where failure tolerance is provided.

(5) System failure tolerance - the ability of the system to limit the impact of certain failure situations by bypassing or otherwise disconnecting the failure affected area. This feature determines the extent to which a specific failure disturbs total system performance.

(6) Passenger trip demands - in terms of the quantity of trip requests per unit time.

(7) Trip origin-destination patterns.

(8) System capacity - more appropriately, excess capacity to recover from failure.

(9) Options for introducing additional capacity to recover from a failure.

(10) Time of failure - This is not a primary variable but one where impact is reflected in all those above which are functions of time.

The methodology consists of several steps which sequentially "build" a delay model for any specific situation. Furthermore, station delays and en route delays are treated separately; not only because the mechanisms of delay differ, but also because the criteria for these delays may differ. Additionally, capabilities to treat variations in delay types are included (e.g., general increases in trip time, en route stoppages, delays greater than some acceptable threshold).

As implied by this list of system variables which can influence the delays experienced by passengers, the delay mechanism is very complex. In a general sense, the evaluation of each of these variables on system performance requires some form of simulation; that is, some method of imposing failures on a normally operating system and "counting" the passenger delay impacts which result. By doing this a sufficient number of times to effectively cover the range of system variables proposed, allowable values for these variables can be derived in response to a given passenger delay criterion. For complex systems, computer simulation techniques are mandatory. For "simple" systems, however, where normal operation can be "visualized", manual techniques can be used. These simple systems consist of shuttle loops, line-haul systems, connected loops, and similar types of transit systems. It is significant that the current operational AGT systems fit this category. Furthermore, it is likely that the near future systems (the Downtown People Mover Systems) will fit this category.

Because a given delay criterion can be met with a number of combinations of system parameters, the methodology developed in this program is appropriate as an evaluation tool: given a set of system failure characteristics and other delay influencing parameters, the expected delay characteristics can be derived. It is within this context that the methodology is presented.

3.2.1 Procedures for Estimating Delays at Stations. The station delay environment to which a passenger is exposed can be illustrated by a simple scenario. During normal operations, passengers enter stations in some random fashion and are transported to their destination according to the service schedule of the system. This demand and supply process constitutes the expected performance as viewed by the passenger. If the system was to experience a failure which denied service to stations, all passengers entering the stations would be delayed. At a minimum, this service denial would exist for the duration of the failure. However, even after the equipment elements of the system have been restored to normal operating conditions, passenger delays may continue to accrue at stations until the delayed passenger queues are completely dissipated. Hence, station delays accrue during the time to restore equipment to normal operation (TTR) and during the time required to dissipate the queues which developed during TTR. This latter time is termed SRT to denote "service restore time".

The recognition of this two-part delay potential is a major difference between the methodology developed in this project and existing measures, which deal only with the direct equipment downtime effects.

This service restore time (SRT) and the precise mechanisms of the queue dissipation functions at a station are complex functions of passenger demand rates, origin-destination patterns, queue discipline, and system excess capacity available to service the delayed passenger queues.

During the development of the methodology, it was found that, for the simple systems alluded to earlier, useful approximating techniques exist. Briefly, these techniques consist of subjecting the system to a "unit failure" and determining the station delay effects which result. A unit failure is defined as a failure in which the full system stops for some arbitrarily selected period of time. Relationships are then given to scale the unit failure responses (i.e, number of passengers delayed and the cumulative duration of their delay) to values expected for failures of different types, duration, and extent as would be predicted or measured in a real system situation.

3.2.2 Procedure for Estimating Delays Incurred En Route. Obtaining estimates for en route delays is considerably more straightforward than for station delays because the complex intra- and interstation queue dynamics are not present. There is no "SRT" involved in en route delay estimates.

Briefly, the procedures developed involve manually simulating failures and "counting" the number of passengers delayed en route for each type of failure expected in a given system situation. By summing these values in accordance with the expected frequency of each failure type, total system level en route delay estimates are derived.

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