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SYSTEMS OPERATION STUDIES FOR AUTOMATED GUIDEWAY TRANSIT SYSTEMS

AVAILABILITY MODEL FUNCTIONAL SPECIFICATION

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

JUNE 1981
FINAL REPORT

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16. Abstract

Functional requirements are specified for the System Availability Model (SAM). The SAM provides the capability for performing system-level analyses of representative AGT system hardware. It is sufficiently flexible to aid transportation system planners in AGT system selection.

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16. Abstract

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

The System Availability Model (SAM) is a system-level model which provides measures of vehicle and passenger availability. The SAM will be used to evaluate the system-level influence of availability concepts employed in AGT systems. This functional specification identifies the functions performed, the types of hardware required, and the modeling techniques employed by the SAM. This model is sufficiently flexible to aid transportation system planners in AGT system selection.

The current SOS for AGT Systems reports in this group are: Feeder Systems Model (FSM) Functional Specification (UMTA-MA-06-0048-81-1); System Availability Model User's Manual (UMTA-MA-06-0048-81-2); System Availability Model Programmer's Manual (UMTA-MA-06-0048-81-4); and Detailed Station Model Functional Specification (UMTA-MA-06-0048-81-5).

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PREFACE

In order to examine specific Automated Guideway Transit (AGT) developments and concepts--and to built 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. 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 performance and cost, and to establish guidelines for the design and operation of AGT systems. A team headed by GM Transportation Systems Division (GM TSD) has been awarded a contract by the Transportation Systems Center to pursue these objectives. The Technical Monitor for the project at TSC was Arthur Priver, who was assisted by Li Shin Yuan and Thomas Dooley.

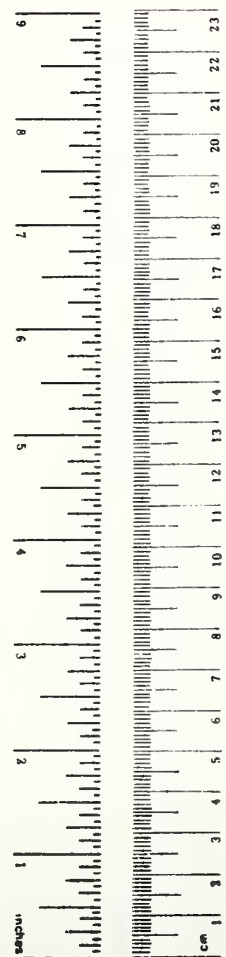
The System Availability Model (SAM) will be used to evaluate the system-level influence of availability concepts employed in AGT systems. This functional specification identifies the functions performed, the types of hardware required, and the modeling techniques employed by the SAM.

The work reported here was performed under the direction of the SOS Program Manager, James F. Thompson, at GM TSD. The research, preparation, and completion of the report was performed by James D. Boldig and Terry M. Linden.

METRIC CONVERSION FACTORS

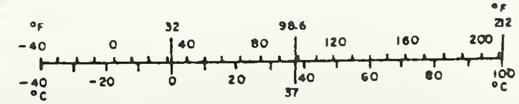
Approximate Conversions to Metric Measures

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

CBD - Central Business District

DESM - Discrete Event Simulation Model

DSM - Detailed Station Model

FMEA - Failure Mode and Effects Analysis

GM TSD - General Motors Transportation Systems Division

HIPO - Hierarchy Plus Input Processor Output

MTTR - Mean Time to Repair

SAM - System Availability Model

SOS - System Operational Studies

SPM - System Planning Model

TBD - To be Determined by GM TSD for Final SAM Functional Specification

TSO - Time Sharing Option

UMTA - Urban Mass Transportation Administration

1.0 INTRODUCTION

This document specifies the functional requirements for the AGT-SOS System Availability Model (SAM).

1.1 OBJECTIVE

The objective of the SAM is to compute system-level availability measures and maintenance and stand-by fleet sizing data for AGT systems.

One availability measure is the ratio, expressed as a percentage, of vehicle operational time to the sum of vehicle operational time and failure-induced service delay time.

A second availability measure is the percentage of passengers who do not experience delays greater than a specified acceptable threshold. A histogram enabling selection of variable thresholds will be provided.

The inclusive elements with which this model deals makes possible other availability measures.

The fleet sizing data establishes the number of vehicle within the maintenance cycle and the number of vehicles required in a ready-for-service (stand-by) mode in order to support a specified operating fleet size.

This model permits mean time between failure, mean time to restore, passenger delay threshold and vehicle availability trade-off analysis.

1.2 SCOPE

The SAM provides the capability of parametrically evaluating AGT systems for vehicle and passenger availability and maintenance and stand-by fleet size as functions of network, system, demand, considering failure response strategy, hardware reliability and maintainability, level of parts quality, and redundancy effects.

2.0 REQUIREMENTS

2.1 FUNCTIONS

The System Availability Model (SAM) provides baseline availability measurements and maintenance and stand-by fleet sizing requirements and permits alteration of the baseline parameters used in their derivation. Figure 2-1 is the functional block diagram of the SAM.

2.1.1 Vehicle Availability

Vehicle availability provides a system-level measurement of representative failure-caused delay times on a vehicle basis.

Discrete failure events are evaluated for their vehicle delay effects based on frequency of failure occurrence, demand period during which the failure occurs, and the specific network location and system type in which the failure occurs. Representative vehicle delay weighting factors are established for each failure demand period and location, and applied to baseline vehicle operating time data to arrive at the vehicle availability measurement.

2.1.2 Passenger Availability

Passenger availability is the percentage of passenger trips within a specified failure-caused delay threshold, compared to the total number of trips taken.

Weighting factors, based on failure events, demand period location, network and system are developed and applied to baseline passenger trip time data to arrive at representative trip times on an individual trip basis.

The model provides percentages-of-passengers-delayed histograms for selected delay time thresholds.

2.1.3 Maintenance and Stand-By Fleet Size

Maintenance and stand-by fleet sizing data establish vehicle support-level requirements for AGT systems.

2.1.3.1 Maintenance Fleet Size — Maintenance time factors, based on MTTR and scheduled service actions analysis, are applied to maintenance events (consequences of failure and regular service actions) to determine the vehicle maintenance fleet size as a percentage of operational fleet size.

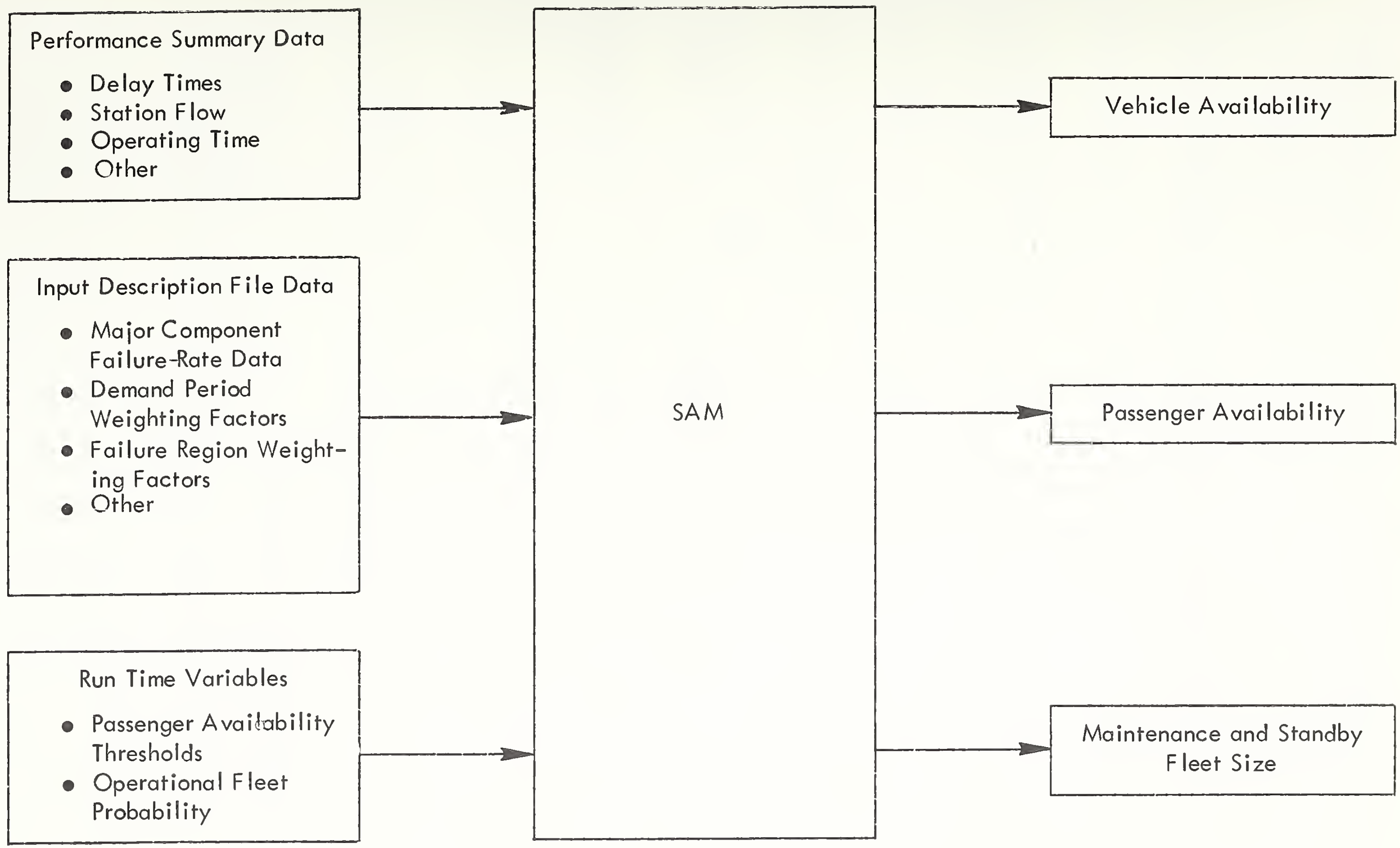

FIGURE 2-1. SAM FUNCTIONAL BLOCK DIAGRAM

2.1.3.2 Stand-By Fleet Size - The stand-by fleet size provides a system-level measurement of the number of vehicles required in a ready-for-use status to meet a specified probability level that a vehicle will be available to replace a failed operational system vehicle.

The interrelationships between the operational, stand-by, and maintenance fleet sizes as they relate to the total fleet requirements is shown in Figure 2-2.

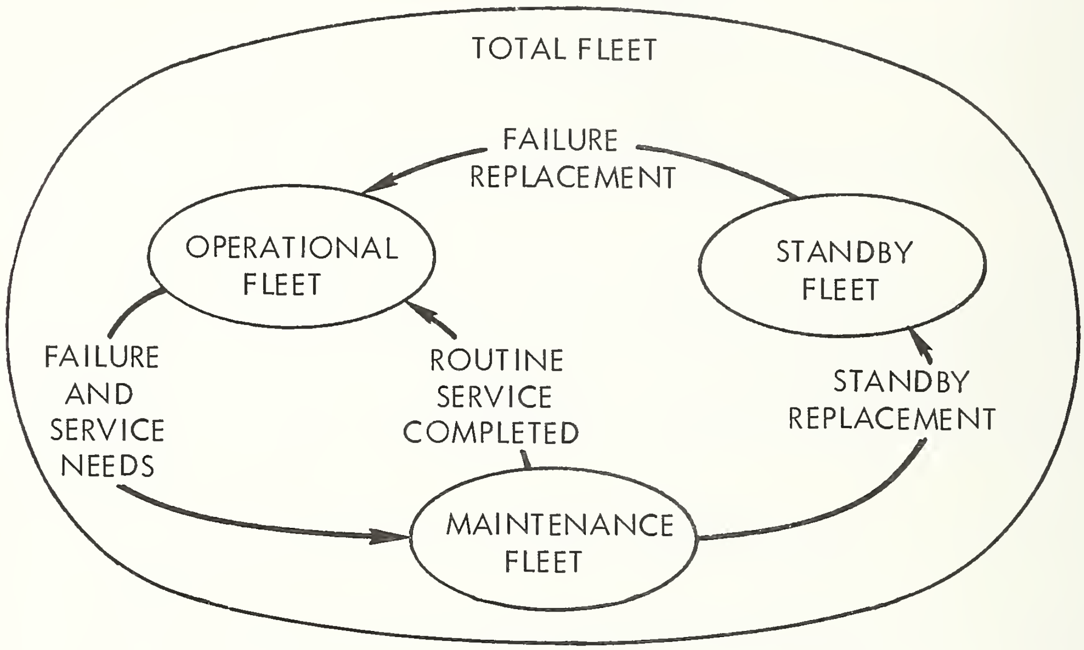

FIGURE 2-2. FLEET SIZE INTERRELATIONSHIPS

2.2 INPUT PARAMETERS

Table 2-1 presents a tabular listing of the input parameters described below.

2.2.1 Major Component Generic Failure Rates

Failure rate data establishes the failure frequency of the major subsystems within the AGT system configurations. The major subsystems include but are not limited to:

1. Vehicles

2. Guideway

TABLE 2-1 INPUT DATA

ELEMENT	SOURCE	DESCRIPTION
Major component generic failure rates	Input and Description Library, System File	Failures per 10^6 hours
Failure effects allocation factors	Input and Description Library, Systems File	Percentage
Operating time, Link loading, Average station dwell, Station flow per demand period	Performance Summary Library, DESM and SPM Files	Minutes, vehicles/link, minutes, vehicles/minute
Link speed, Link length	Input and Description Library, Network File	Kilometer/hour, kilometer
Failure region	Input and Description Library, System File	Entity identifier, region identifier
Representative delay times	Performance Summary Library; DESM & DSM, File	Minutes/events
Demand period operating time	Performance Summary Library, DESM and SPM File	Hours/demand period
Total operating time	Performance Summary Library, DESM and SPM File	Hours
Completed trip log	Structured Data Library, DESM File	Number of trips
Passenger availability threshold	Run Time Variable	Minutes
Total passengers	Performance Summary Library; DESM, DSM, and SPM File	Number of trips
Vehicle utilization	Input and Description Library, DESM File	Kilometers/hours, hours

TABLE 2-1. INPUT DATA (Continued)

ELEMENT	SOURCE	DESCRIPTION
Operational fleet size	Performance Summary Library DESM File	Number of vehicle
Station passenger loading per demand period	Performance Summary Library DESM File	Passengers
Maintenance service factor	Input and Description Library System File	Maintenance time per maintenance action
Operational fleet availability probability	Run Time Variable	Percentage

3. Stations

4. Central Management

Major subsystem failure rates are developed by a further breakdown of subsystems into major components which are assessed for their failure effect consequences based on FMEA on hardware definitions which will be developed to the subassembly or replaceable item level for representative AGT systems. The following defines the major components within each major subsystem.

1. Vehicle

   - Propulsion system/s
   - Body and chassis
   - On-vehicle control electronics
   - On-vehicle communication

2. Guideway

   - Structure
   - Power
   - Weather protection equipment
   - Wayside control
   - Wayside communications

3. Station

   - Ticketing
   - Doors
   - Lock mechanisms
   - Controller (local management)

4. Central Management

   - Communication
   - Computers

Major component failure rate data are obtained from the Input and Descriptive Library, Systems File for the SAM.

2.2.2 Failure Effect Allocation Factors

There are two types of allocation factors (failure modes):

1. The percentage of the generic failure rate that can influence traffic flow, i.e., operational failure rate

2. The percentage of operational failure rate that results in complete shutdown of the subsystem (as contrasted with partial service degradation)

The failure effect allocation factors are obtained by the SAM from the Input and Description Library, System Files, where they are associated with corresponding generic failure rate data.

2.2.3 Operating Time/Demand Period

Operating time data are provided by the Performance Summary Library, DESM File and are the time integral of vehicle operating time over a specified demand period.

2.2.4 Link Loading/Demand Period

Link loading data are provided by the Performance Summary Library, DESM File, and are the number of vehicles per network link per demand period.

2.2.5 Station Flow/Demand Period

Station flow data are provided by the Performance Summary Library, DESM and SPM Files, and are the station vehicle flow rate determined for the demand period.

2.2.6 Station Dwell

Station dwell is the average vehicle time spent at the station during the operational demand period. Data are obtained from the Performance Summary Library, DESM File.

2.2.7 Station Passenger Loading/Demand Period

These are the passenger flow data per demand period used to develop the station failure region allocation factor. Data are obtained from the Performance Summary Library, DESM File.

2.2.8 Link Speed

Link speed is a user-selected input employed to develop guideway failure region allocation factors. The data are obtained from the Input and Description Library, Network File.

2.2.9 Link Length

Link length is a user-selected input and is obtained from the Input and Description Library, Network File.

2.2.10 Failure Region Classification

Failure region classification characterizes network configurations by regions of operation wherein subsystem failures create similar "effects". Failure region classification data are obtained from the Input and Description Library, System File.

2.2.11 Representative Delay Times

Representative delay time input data obtained from the Performance Summary Library, SPM, DSM, and DESM Files, are delay time data for discrete failure events for specific failure response strategies. The data are used to develop the total delay time used in the vehicle and passenger availability computation.

2.2.12 Demand Period Operating Time

Demand period operating time is the time integral of vehicle operating times over a specified demand period. The data are a measure of total failure-free vehicle operating time and are obtained from the Performance Summary Library, DESM and SPM Files.

2.2.13 Total Operating Time

Total operating time is the sum of the demand period operating times. Data are obtained from the Performance Summary Library, DESM and SPM Files.

2.2.14 Completed Trip Log

The completed trip log provides a history of passenger trips and trip-time data. These data are obtained from the Structured Data Library, DESM File.

2.2.15 Passenger Delay Threshold

This is a run time variable which allows the model to determine the passenger availability measure of percentage of passenger trips experiencing a failure-caused delay less than the selected or specified threshold durations.

2.2.16 Total Passengers

This is the total number of passenger trips accommodated by the system over a specified period and provides the reference data required for the passenger availability computation. The data are obtained from the Performance Summary Library, DESM and SPM Files.

2.2.17 Vehicle Utilization

This is the vehicle distance traveled and operating time data obtained from the Performance Summary Library, DESM Files.

2.2.18 Operational Fleet Size

The operational fleet size is the number of vehicles required to meet the system demand requirements. The input data are obtained from the Performance Summary Library, DESM Files.

2.2.19 Maintenance Service Factors

The maintenance service factors are:

1. The average duration of the maintenance cycle for each subsystem failure type
2. The average duration of routine servicing by subsystem type
3. The average frequency of routine servicing by subsystem type

The source of maintenance service factor data is the Input and Description Library, System Files.

2.2.20 Operation Fleet Probability

This establishes the desired probability of having a stand-by vehicle ready to be substituted for a failed operational vehicle. The data are used to establish stand-by vehicle fleet sizing requirements. The data are obtained as run time variables.

2.3 OUTPUTS

The model output data (see Table 2-2) are provided by the SAM for use in internal model computations and as content in the Performance and Summary Library, SAM File. The Performance and Summary Library, SAM File, is accessed through the system utilities with Cost Model output availability versus cost tradeoffs.

TABLE 2-2. OUPUT DATA

ELEMENT	SOURCE	DESCRIPTION
Subsystem failure rate	PERFORMANCE SUMMARY LIBRARY	Failure per 10^6 hours
Subsystem failure effect rates		Failures per 10^6 hours for each subsystem failure effect
Generic failure region allocation factors 1. Vehicle 2. Station 3. Guideway 4. Central management subsystem		Percent of subsystem failures in a generic failure region for a demand period
Vehicle delay time per demand period		Minutes
Total vehicle delay per standard day		Minutes
Vehicle availability		Failure-free vehicle time per total vehicle time
Representative count of passengers above the delay threshold		Passengers
Passengers above the delay threshold per demand period		Passengers
Total passengers above the delay threshold per standard day		Passengers
Passenger threshold availability		Passengers within delay threshold per total passengers
Maintenance fleet size		Percentage of operational vehicles
Stand-by fleet size		Percentage of operational vehicles

2.3.1 Subsystem Failure Rates

Subsystem failure rates are calculated based on major component operational failure rate data (which includes design redundancies and on-vehicle "level-of-quality" effects). Resultant data provide frequency of failure occurrence data required for the failure consequence computation.

2.3.2 Subsystem Failure Effect Rates

Failure effect rates are determined from operational subsystem failure rates considering the demand and network location of failure to represent the frequencies "where and when" for each failure. This information is used in the weighting factors applied to delay times in the computation of the availability measures.

2.3.3 Generic Failure Region Allocation Factors

These regional failure allocation factors are developed based on the regional classifications for the four major subsystems.

2.3.4 Vehicle Delay Time

Vehicle delay time is the representative delay time for a specified demand period weighted for failure effect rate, failure region, and operating time.

2.3.5 Total Vehicle Delay Time

Total delay time is based on representative delay time data for discrete failure events weighted by frequency of occurrence over a standard day. The output data are used as a modifier of the vehicle operating time in the vehicle availability computation.

2.3.6 Vehicle Availability

Vehicle availability is the ratio:

$$\frac{\text{Vehicle Uptime}}{\text{Vehicle Uptime} + \text{Vehicle Downtime}}$$

Where the uptime and failure induced downtime values are arrived at by summing the times for all vehicles in the system over a finite period of time defined as a "standard day."

2.3.7 Representative Passenger Delay Count

The passenger delay count is the number of passenger trips and associated delay times which exceed the specified delay threshold for a representative failure.

2.3.8 Passenger Delay Count/Demand Period

This is the representative passenger delay count weighted by failure effects rates, failure region, and operating time. This information is combined over a standard day to obtain total number of passengers delayed.

2.3 9 Total Passenger Delay Count

Total passenger delay count is the number of passenger trips which exceed a specified delay threshold. The data are used as a modifier of total passenger trips in the passenger availability calculations.

2.3.10 Passenger Threshold Availability

Passenger availability is the percentage measurement of the number of passenger trips which are successfully completed without a failure-induced delay beyond a specified threshold.

2.3.11 Passenger Availability Histogram

This is a histogram relating the passenger availability measure to the level of threshold. One-minute threshold intervals will be available in the model with a user-selectable interval option.

2.3.12 Maintenance Fleet Size

Maintenance fleet size is the number of vehicles within the maintenance cycle in steady state operation expressed as a percentage of the total fleet size.

2.3.13 Stand-By Fleet Size

Stand-by fleet size is the number of vehicles required in a ready-for-service condition to meet a specified probability that a stand-by vehicle will be ready in case of failure of an operational vehicle, expressed as a function of total fleet size.

2.3.14 Vehicle Reliability Histogram

This is an histogram relating the vehicle generic failure rate to the percentage of the total fleet size in maintenance and stand-by. This is applied to those systems where multiple vehicle failure rates are input (as a function of vehicle electronic redundancy and level of quality) from the Input and Description Library, System Files.

2.4 EQUIPMENT

The following data are estimates of the hardware and software required to support the SAM. The estimates do not represent requirements. Rather, they are intended as broad guidelines for planning purposes.

2.4.1 Hardware

The following computing system hardware is required to support the SAM.

1. Central Processing Unit - IBM System 370 Model 145, 148, 155, 158, 165, or 168 capability is required.

2. High-Speed Random Access Storage - Approximately TBD (To Be Determined for Final SAM Functional Specification) bytes are required for the SAM itself, including TBD for program storage and TBD for data storage and scratch pad work area. Additional storage is required for the operating system and the required compilers and language translators.

3. Direct Access Storage

   a. Program development libraries: TBD bytes
   b. Input from data base: TBD bytes
   c. Structured data file: TBD bytes
   d. Checkpoint files: TBD bytes

4. Card Reader - A card reader is required.

5. High Speed Line Printer - A high-speed line printer is required for hard copy output.

6. Terminal - A terminal and associated modems for communication over standard phone lines is not required, but is very desirable.

2.4.2 Software

The following software is necessary for support and/or use of the SAM.

1. System Control Program - Use of one of the following is assumed:

   - OS/360 (Cperating System)
   - VS1 (Virtual Storage 1)
   - VS2 (Virtual Storage 2)
   - VM/370 and CMS (Virtual Memory and Conversational Monitor System)

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

2. Compilers - A FORTRAN (H) compiler is necessary for development, use, and maintenance of the SAM. A PL/1 Optimizing Compiler is necessary for development (for use in translating structured FORTRAN to standard FORTRAN) and for program maintenance.

3. Link Editors - Any link editor compatible with the selected operating system and the aforementioned compilers is sufficient.

4. Utilities - Standard Operating System 360/370 utilities are assumed for development, use, and maintenance of the SAM and are used for bulk card-to-disk, tape-to-tape, tape-to-disk, dataset backup/restore, and data base update and editing.

5. PARAFOR - PARAFOR (a structured FORTRAN to standard FORTRAN translator) is required to support development and maintenance of the SAM.

2.5 MODEL INTERFACES

The SAM input processor interfaces with the Performance Summary Files of the DSM, DESM and SPM, the DESM Raw Statistic Trip File, and the SAM Input and Description File which includes provision for run time variables.

Figure 2-3 shows the SAM general structure.

2.6 USER INTERFACE

The general structure of the SAM facilitates user interface by providing flexible input and output procedures.

Input and description files will be created and saved in the data base through system utilities and terminal supports. The user run time variables are input directly to the desired processor.

The Model Processor is driven by data tables set up by the Input Processor and generates raw statistics files for use by the Output Processor. The structure of the Model Processor is detailed in the following section, Modeling Technique.

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

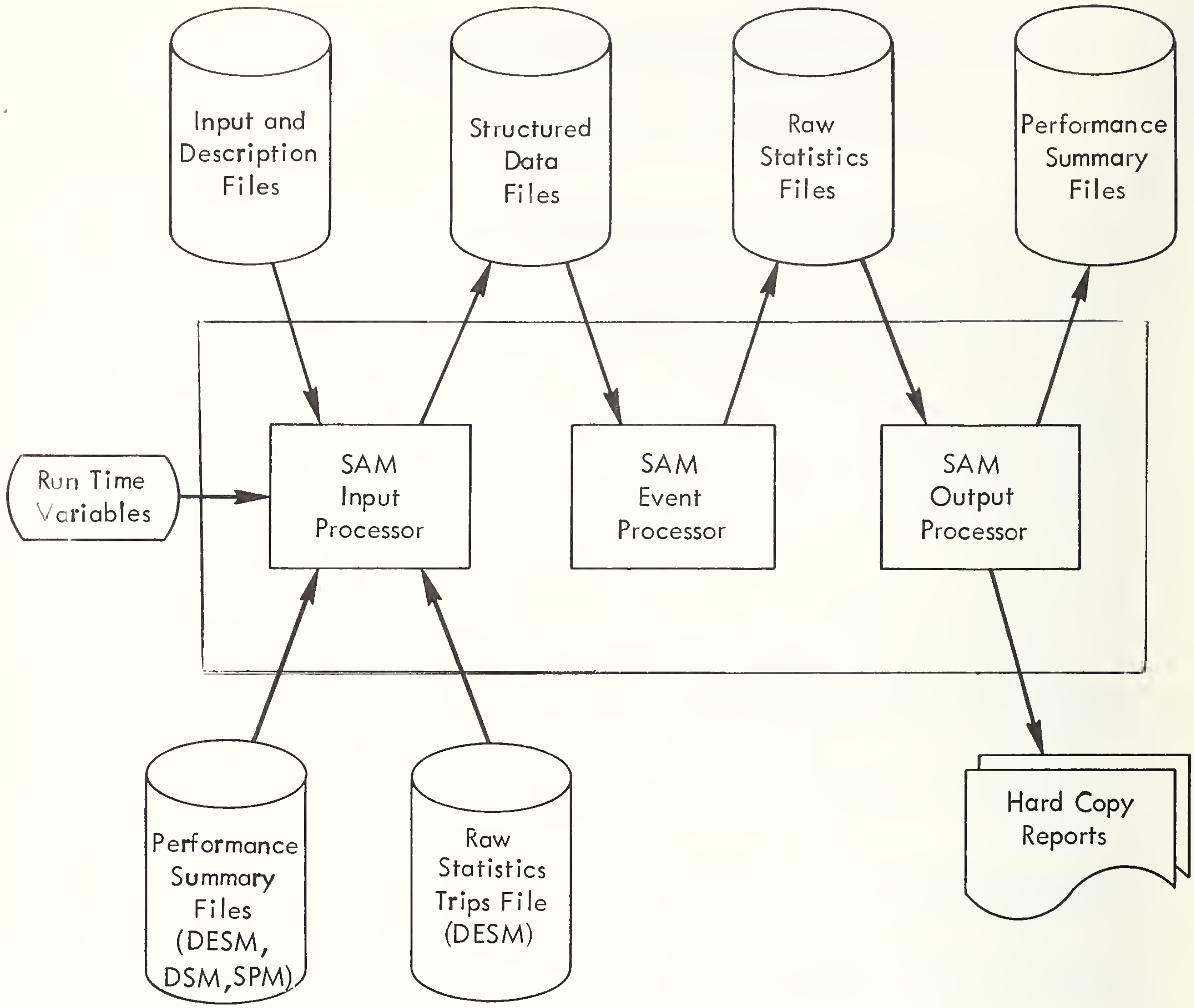

FIGURE 2-3. SAM GENERAL STRUCTURE

3.0 MODELING TECHNIQUE

Availability measures are computed using representative delays and operating times obtained with the DESM, SPM, and DSM. The SAM computes weighting factors to determine the occurrences of failures at different demand levels and within different generic failure regions.

3.1 SYSTEM REPRESENTATION

The impact of a component failure on system performance is a function of the effect of the failure in the context of system operation. Failures which yield a similar subsystem response are treated in a similar manner. Therefore, the SAM represents failures characterized by subsystem failure rate and an allocation of effects.

The impact of a failure is a function of demand. The failure-induced propagation of vehicle or passenger queues through a network or station is related to system loading. In all but the simplest systems, the relation between queue propagation, the concomitant delays, and system loading is non-linear.

Representative delays and operating times at different demand levels are inputted to the SAM from the various files. The SAM uses the failure rates and the operating time at the particular demand level to compute the number of failure instances likely to occur at each demand level for a standard day.

Failure location also affects failure impact. Therefore, the SAM represents the system as being composed of generic failure regions. These generic failure regions are defined at run time for each system modeled. The following set is an example of generic regions for vehicle failures for a Central Business District (CBD) grid with radial corridors:

1. Station entry ramp/off-line station
2. Station entry ramp/on-line station
3. Station exit ramp/off-line station
4. Station exit ramp/on-line station
5. Station dock
6. In-bound radial corridors
7. Out-bound radial corridors
8. Radial corridor/CBD grid, in-bound junction
9. Radial corridor/CBD grid, out-bound junction
10. CBD grid, outer belt
11. CBD grid, inner links

3.2 REPRESENTATIVE FAILURE EFFECT DELAY DATA

As described in Section 3.1, the failure-induced delay is a function of the failure effect on the operating system level, the demand level, and the failure location. Representative failure effect delay data for every failure, demand level, and generic service region are available through files generated by the DESM, SPM, and DSM.

3.3 SAM GENERAL STRUCTURE

The input processor (see Figure 2-3) accesses and checks data from the data base for reasonableness, completeness, and compatibility. It also processes input variables and data base overrides in order to generate structured data files for use by the model processor.

The model processor uses analytical equations to allocate failures to different effects and to determine the incidence of occurrences under different demand levels and in different generic failure regions. It then uses these data and analytical equations to compute the several availability measures. Analytical equations are also used to compute the fleet size measures.

The output processor generates hard copy reports and generates Performance Summary File content.

3.4 SAM MODULARITY

The SAM processes major component failure rate and failure location data in a modular fashion in order to generate generic system parameters which are in turn used to compute availability and maintenance and stand-by fleet sizes. One set of generic system parameters affecting availability is the set of failure effect rates which are derived from major component failure rates and failure effect allocation factors (see HIPO 1.1.1). Another set of generic system parameters affecting availability is the set of generic failure region allocation factors. The region allocation can differ for each subsystem therefore; the SAM has a model and a corresponding module for each subsystem (see HIPO 1.1.2).

The total delay, total threshold delays, and operating time are also generic system parameters affecting availability. The SAM uses the representative delay data, the failure effect rates, and the failure region allocation factors to compute delay data, which are in turn used to compute availability (see HIPO 1.1.3).

As described, the availability model separates effect rate computation, failure region allocation, and delay data computation. Further, failure region allocation is done in a separate module for each subsystem. This has been done, combined with the use of generic system parameters to interface the modules in order to allow alteration, addition, or deletion of individual subsystems without affecting the remainder of the model and to allow alteration of availability equations without affecting the failure rate and failure region allocation modeling.

The maintenance and stand-by fleet size model is separate from the availability model and is contained in its own module (see HIPO 1.3).

4.0 HIPO DIAGRAMS

Figure 4-1 is a visual table of contents of the Hierarchy plus Input Process Output (HIPO) diagrams. It also conveys the hierarchial relationship between each function of the System Availability Model. In Figures 4-2 through 4-12, HIPO diagrams are presented for each of the levels of the processes identified in the visual table of contents. The number and captions at the upper left-hand corner of each diagram refers to the process numbers in the visual table of contents. The first two digits of each of these process numbers associates the HIPO with one of the three functional steps identified in Section 2. The number in parentheses after each input refers to the section of this functional specification where the input is described (e.g., 2.2.1, 2.2.2, or 2.2.3) or to the HIPO diagram in which it is a derived output (e.g., HIPO 1.1.1, etc.). A similar reference is provided for each output listed in the HIPO diagrams to relate the output to the description in the text.

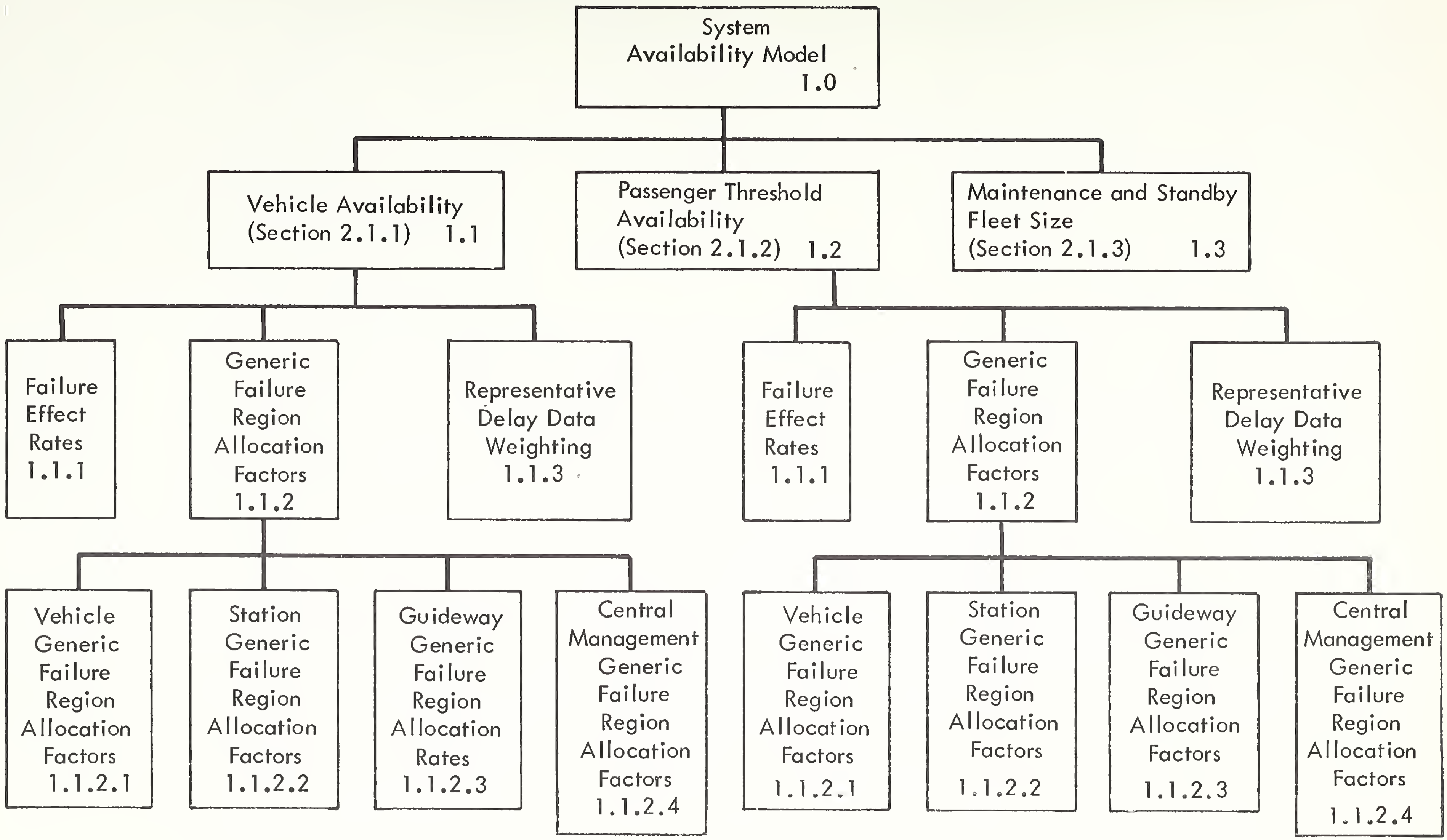

FIGURE 4-1. VISUAL TABLE OF CONTENTS

1.0 SYSTEM AVAILABILITY MODEL

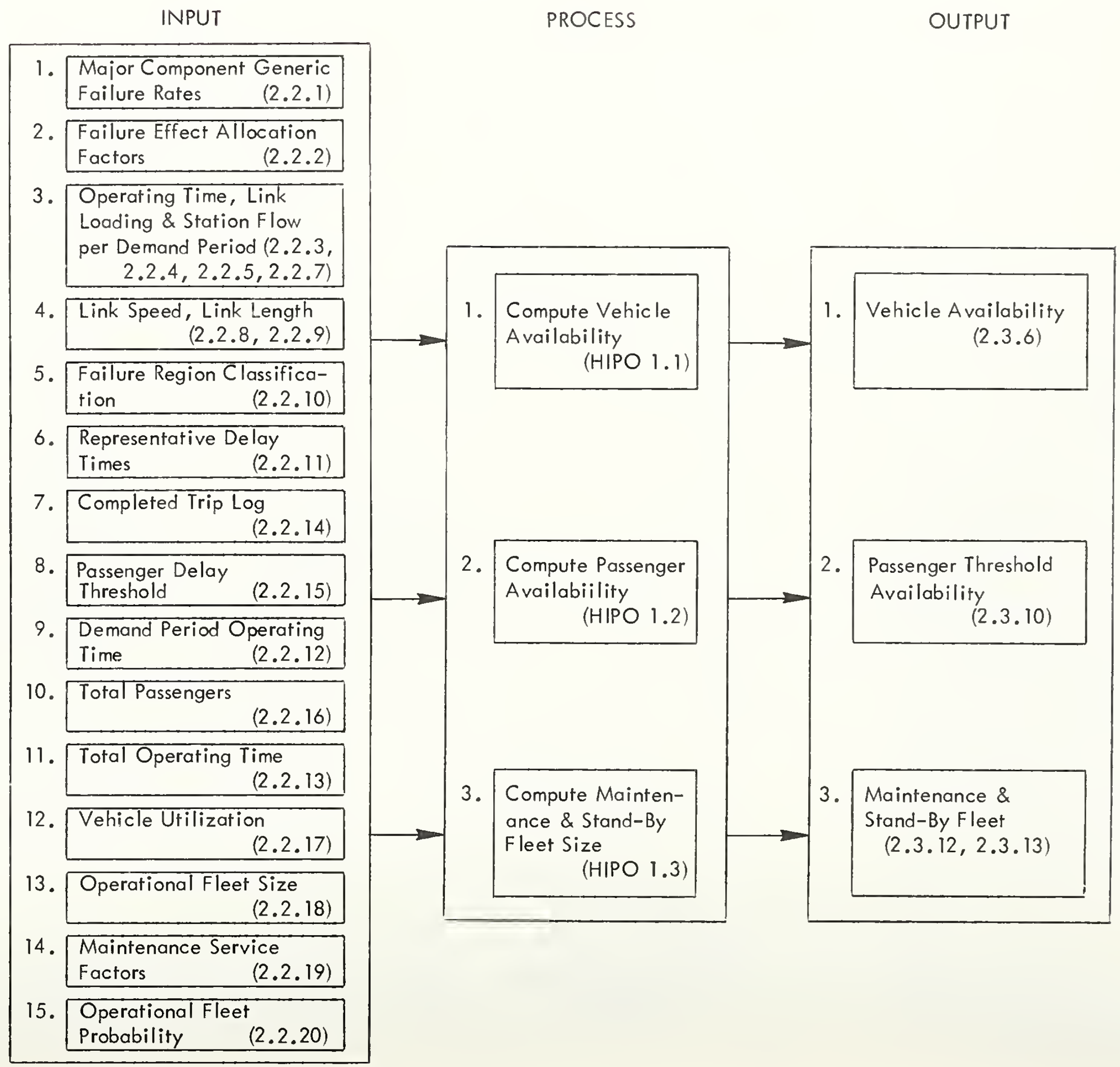

FIGURE 4-2. SYSTEM AVAILABILITY MODEL

1.1 VEHICLE AVAILABILITY (SECTION 2.1.1)

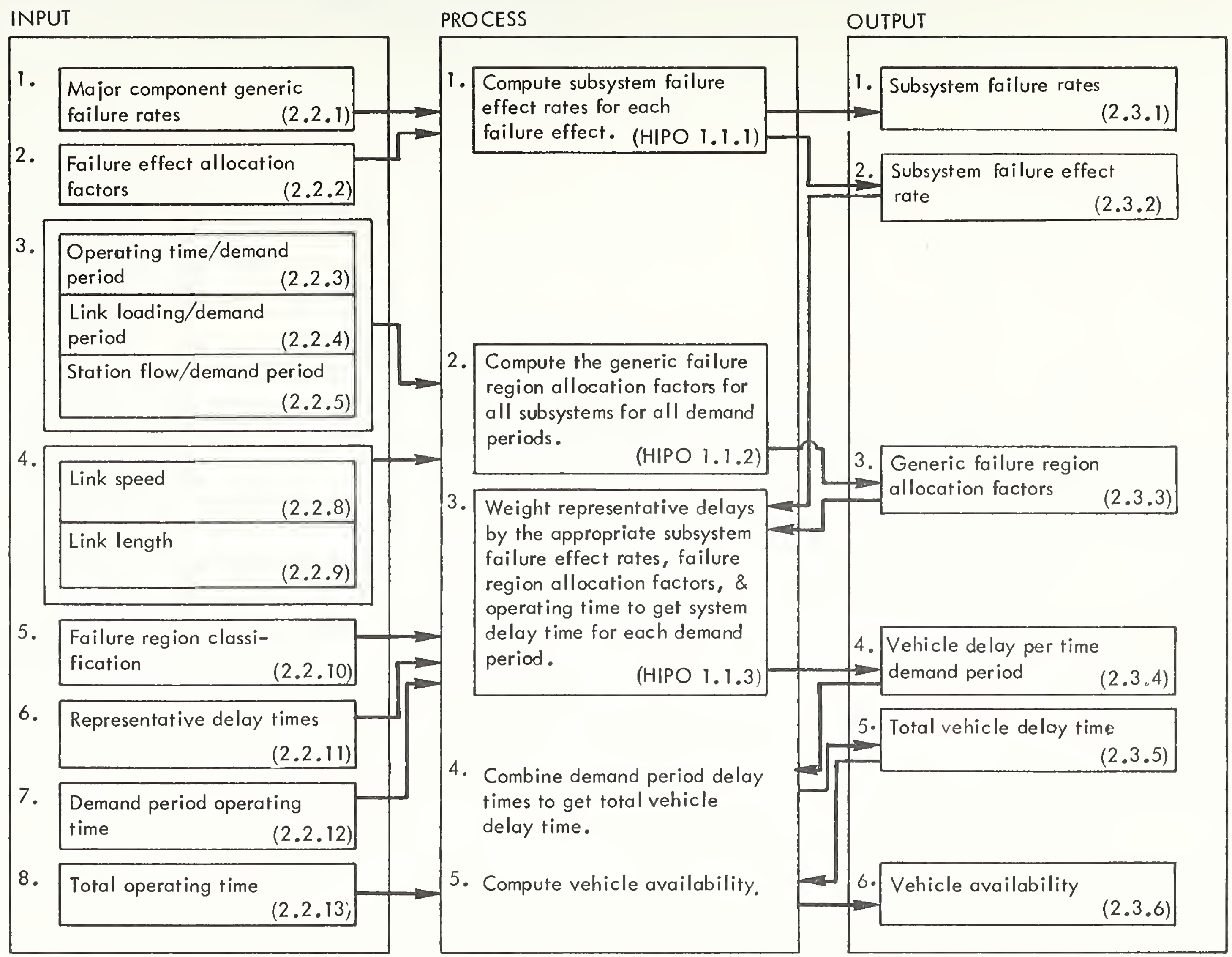

FIGURE 4-3. VEHICLE AVAILABILITY

1.1.1 FAILURE EFFECT RATES

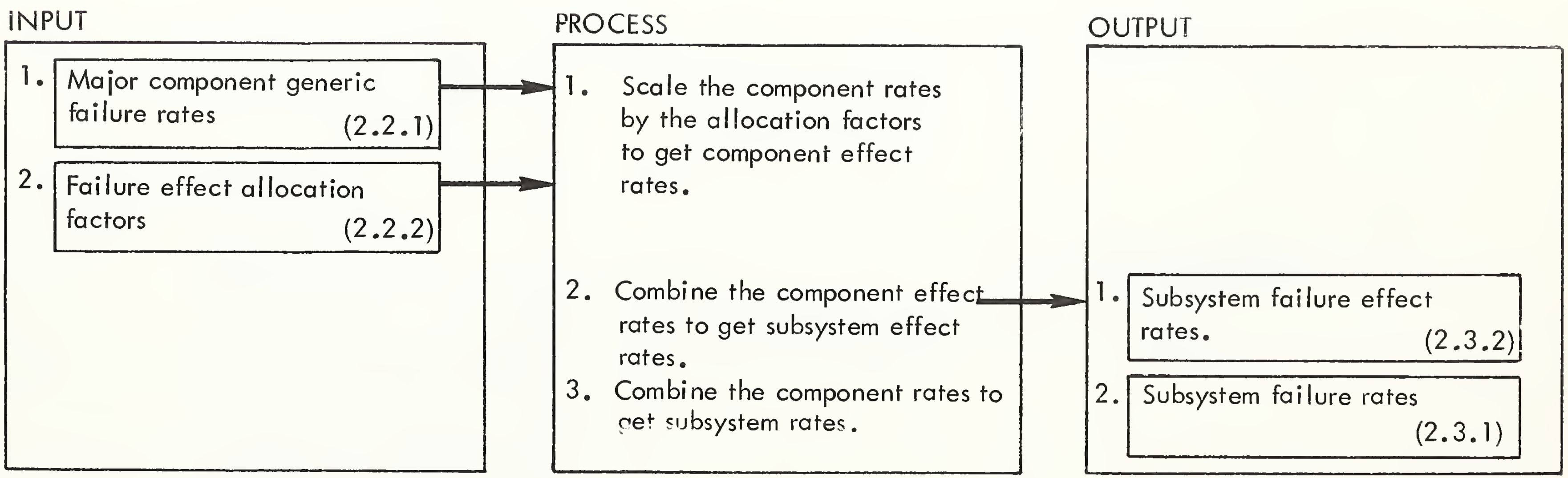

FIGURE 4-4. FAILURE EFFECT RATES

1.1.2 GENERIC FAILURE REGION ALLOCATION FACTORS

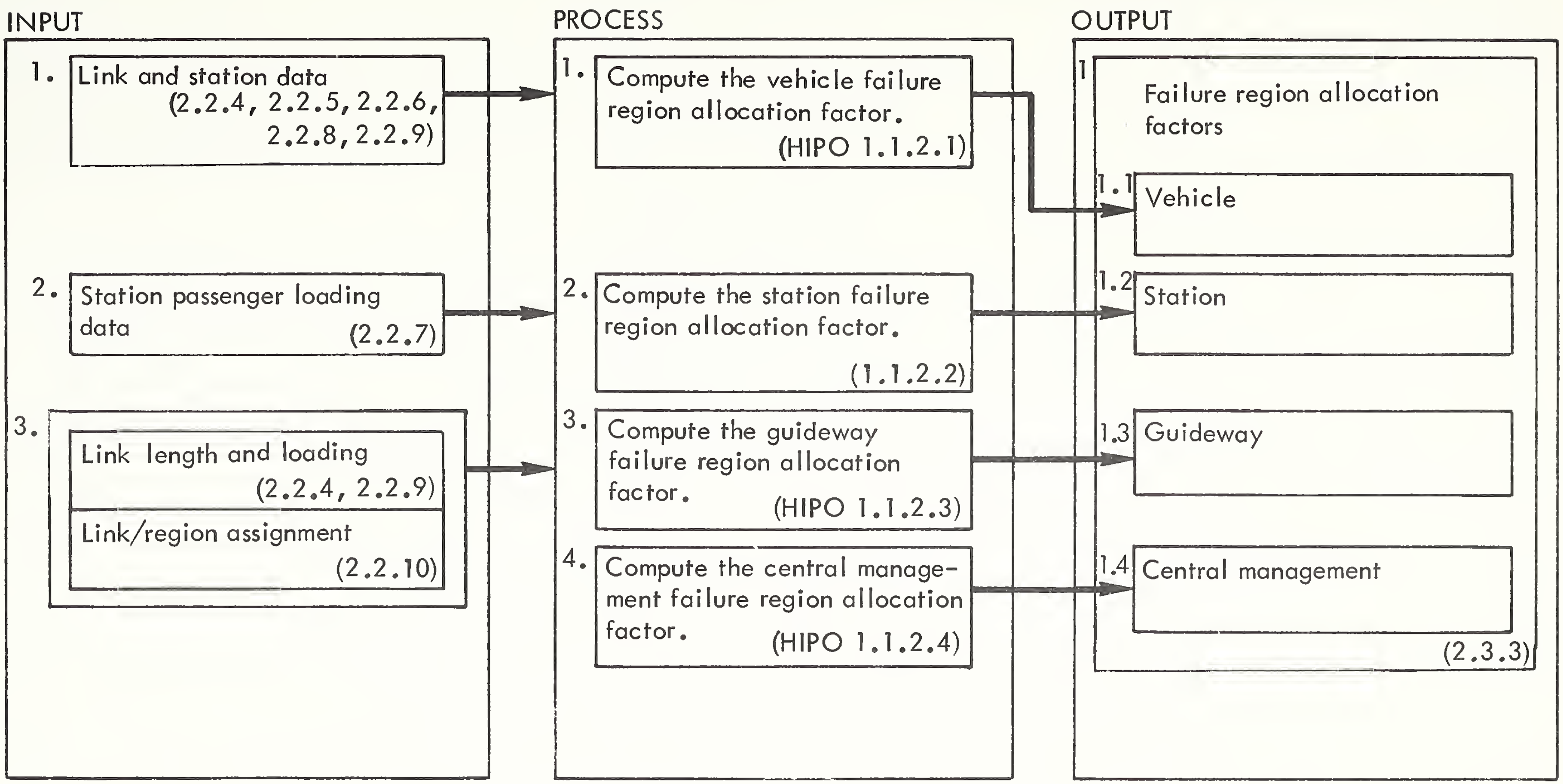

FIGURE 4-5. GENERIC FAILURE REGION ALLOCATION FACTORS

1.1.2.1 VEHICLE GENERIC FAILURE REGION ALLOCATION FACTOR

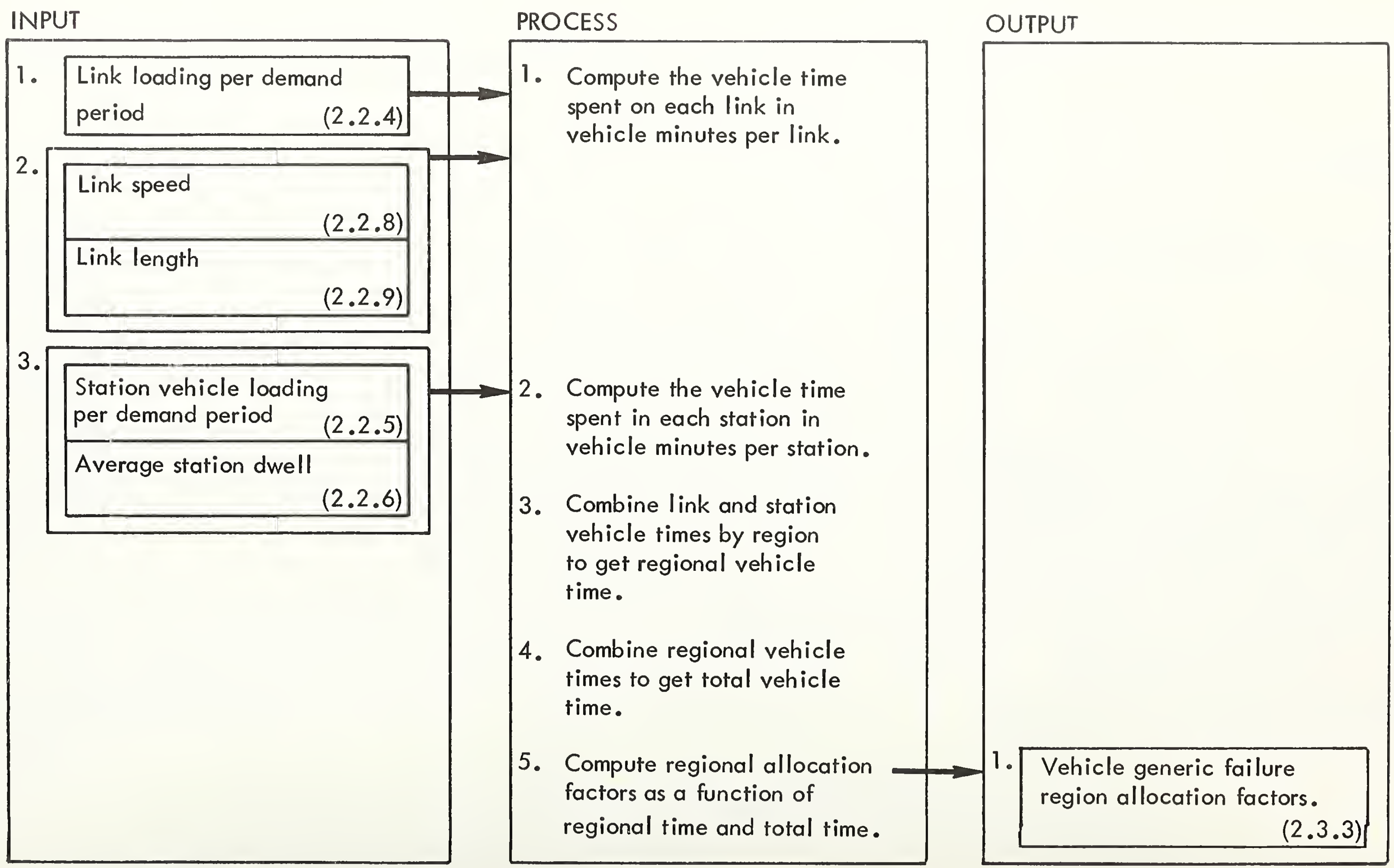

FIGURE 4-6. VEHICLE GENERIC FAILURE REGION ALLOCATION FACTOR

1.1.2.2 STATION GENERIC FAILURE REGION ALLOCATION FACTOR

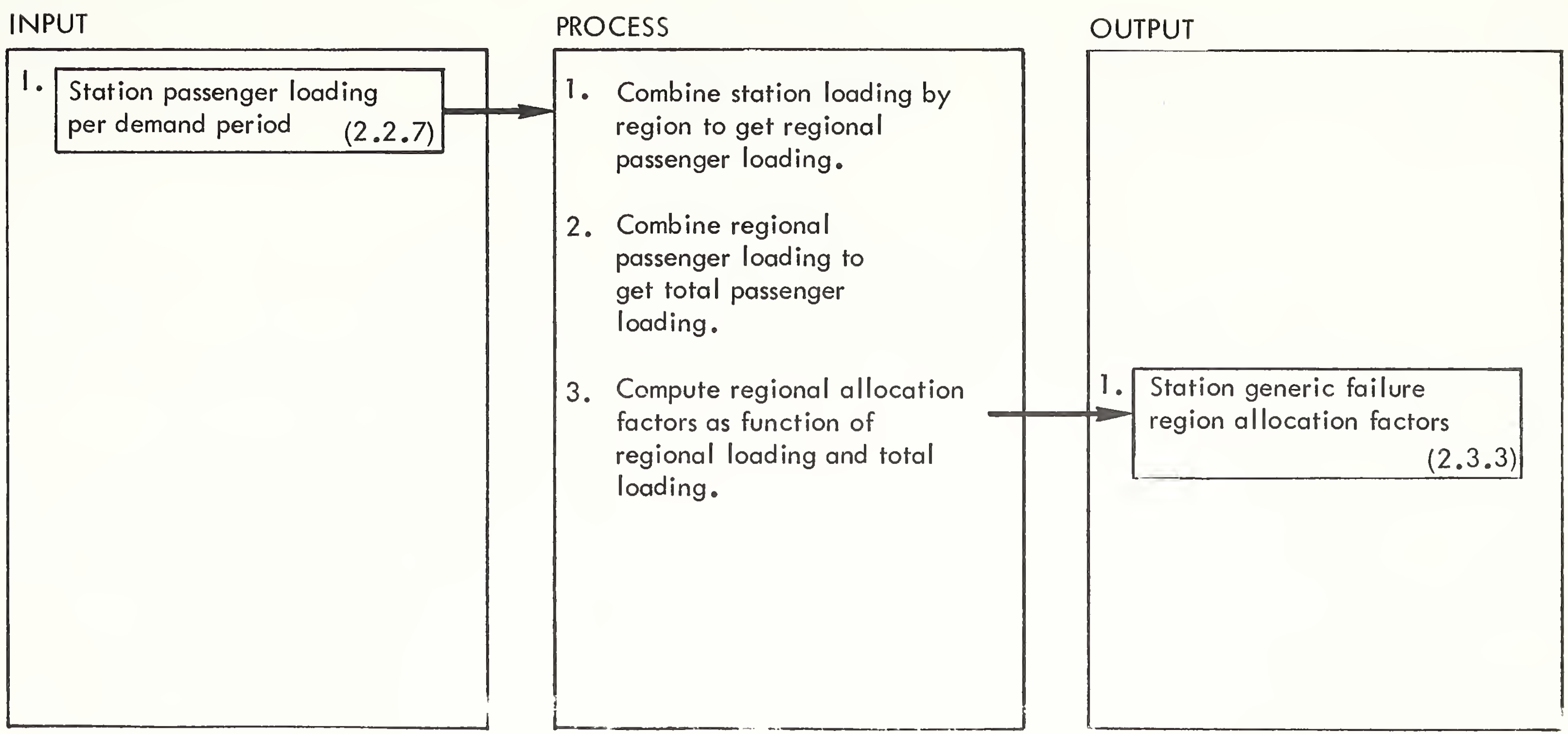

FIGURE 4-7. STATION GENERIC FAILURE REGION ALLOCATION FACTOR

1.1.2.3 GUIDEWAY GENERIC FAILURE REGION ALLOCATION FACTOR

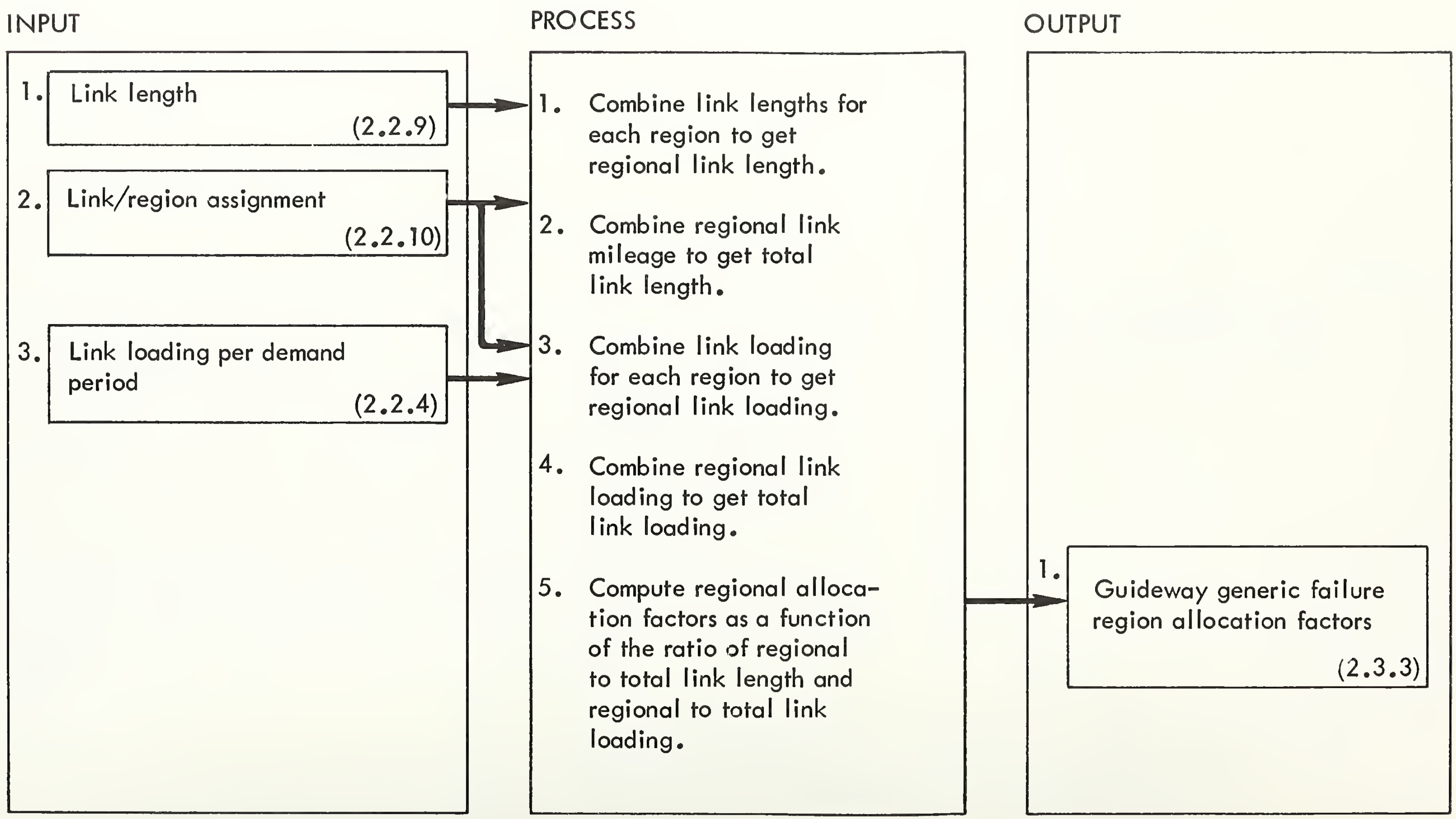

FIGURE 4-8. GUIDEWAY GENERIC FAILURE REGION ALLOCATION FACTOR

1.1.2.4 CENTRAL MANAGEMENT GENERIC FAILURE REGION ALLOCATION FACTORS

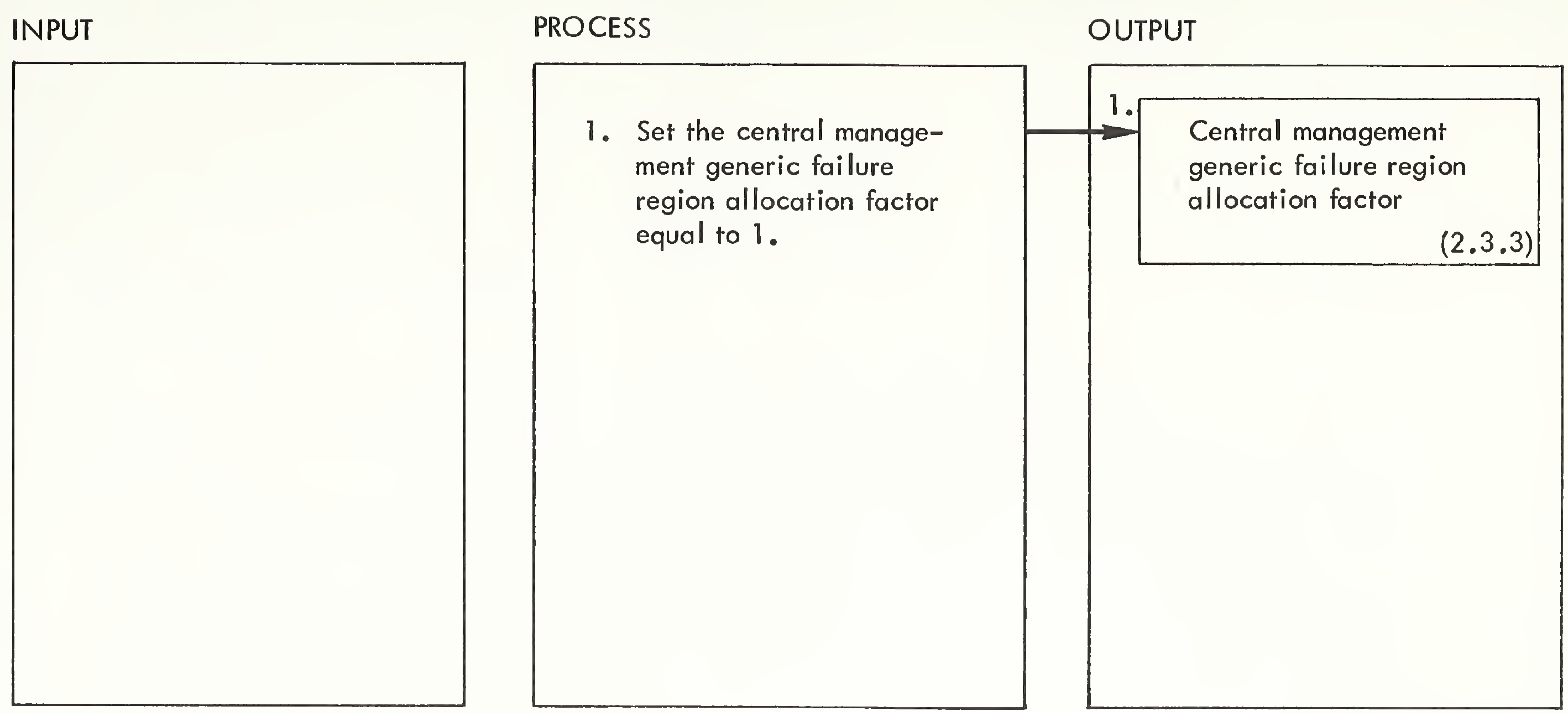

FIGURE 4-9. CENTRAL MANAGEMENT GENERIC FAILURE REGION ALLOCATION FACTORS

1.1.3 REPRESENTATIVE DELAY DATA WEIGHTING

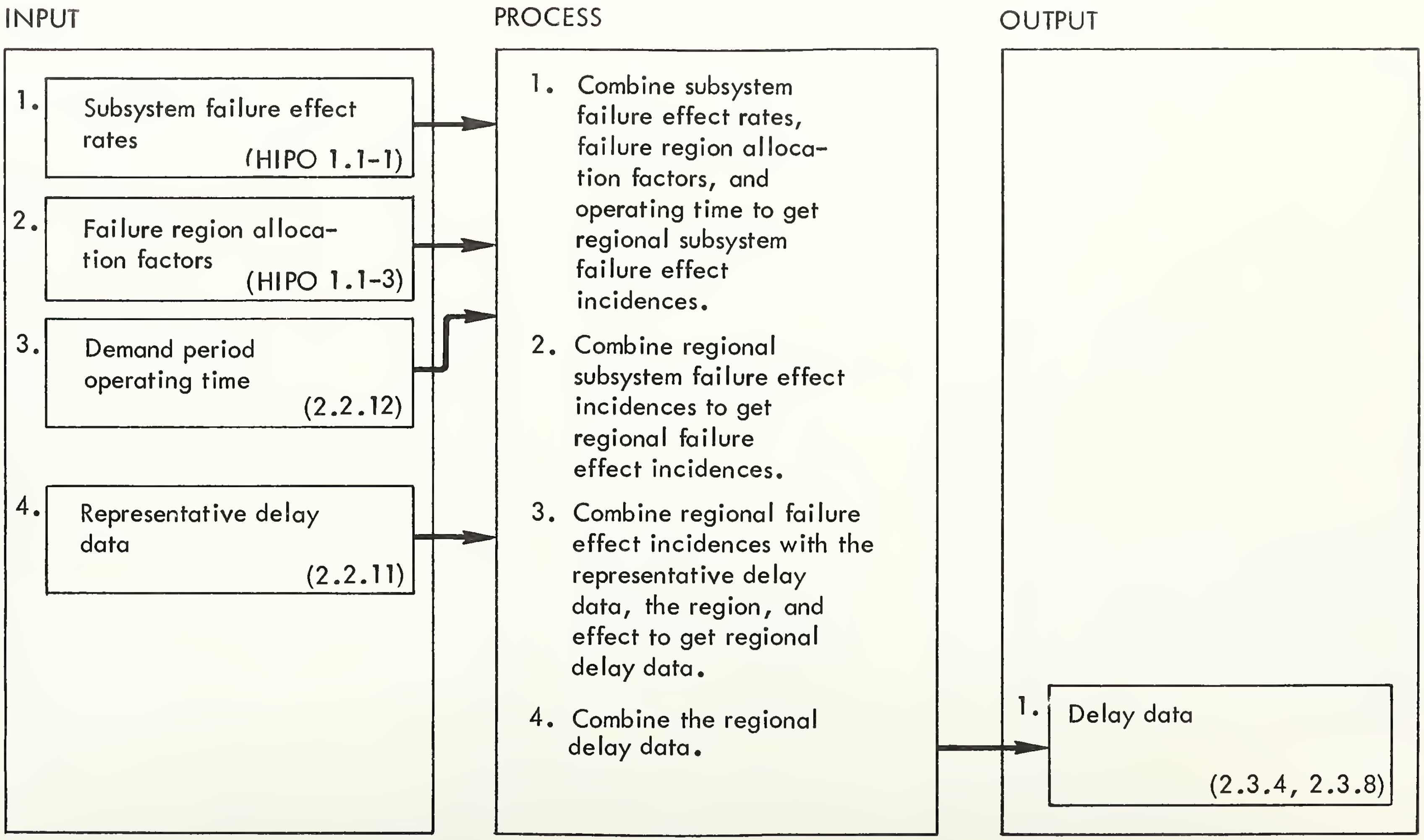

FIGURE 4-10. REPRESENTATIVE DELAY DATA WEIGHTING

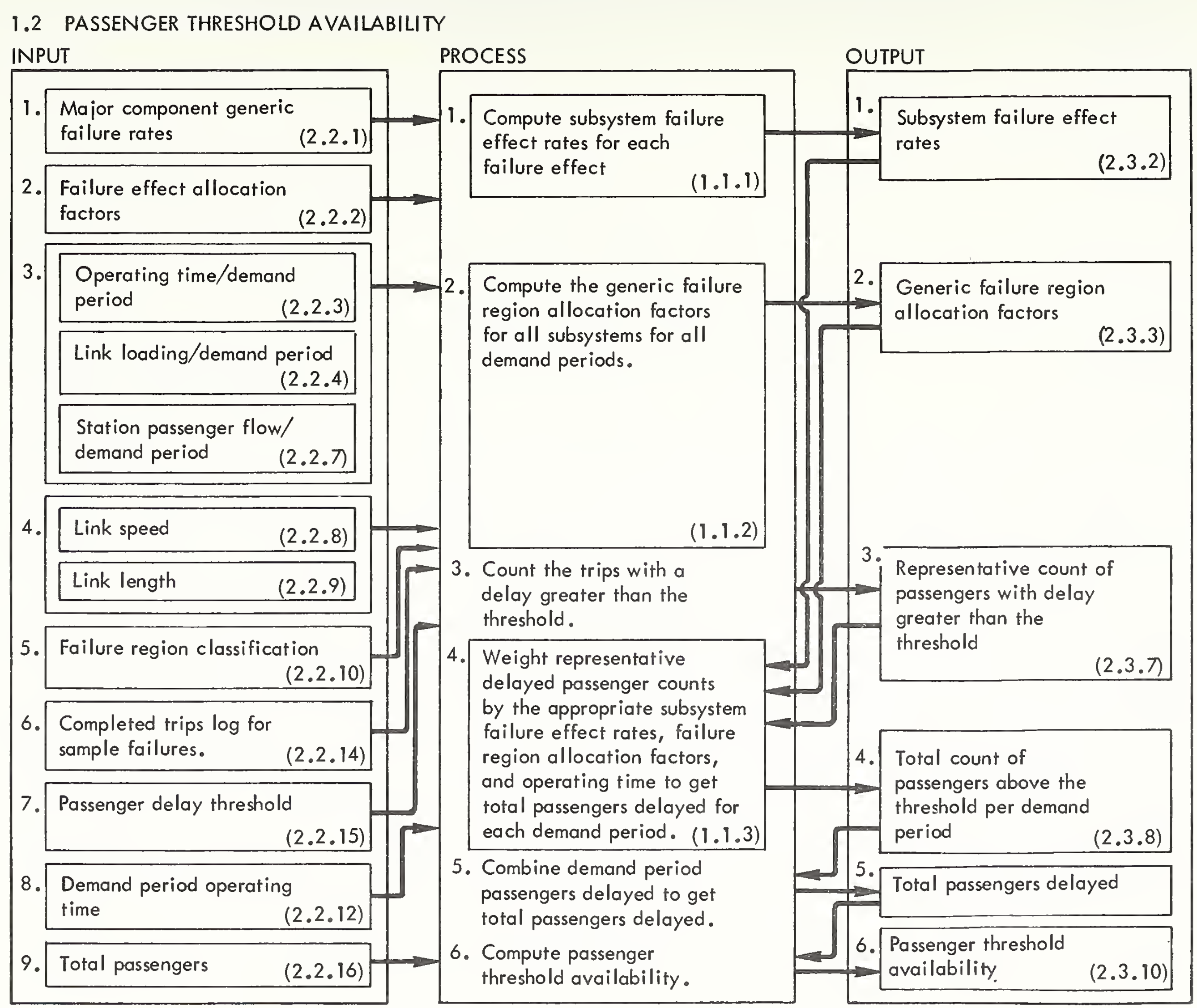

FIGURE 4-11. PASSENGER THRESHOLD AVAILABILITY

1.3 MAINTENANCE AND STANDBY FLEET SIZE

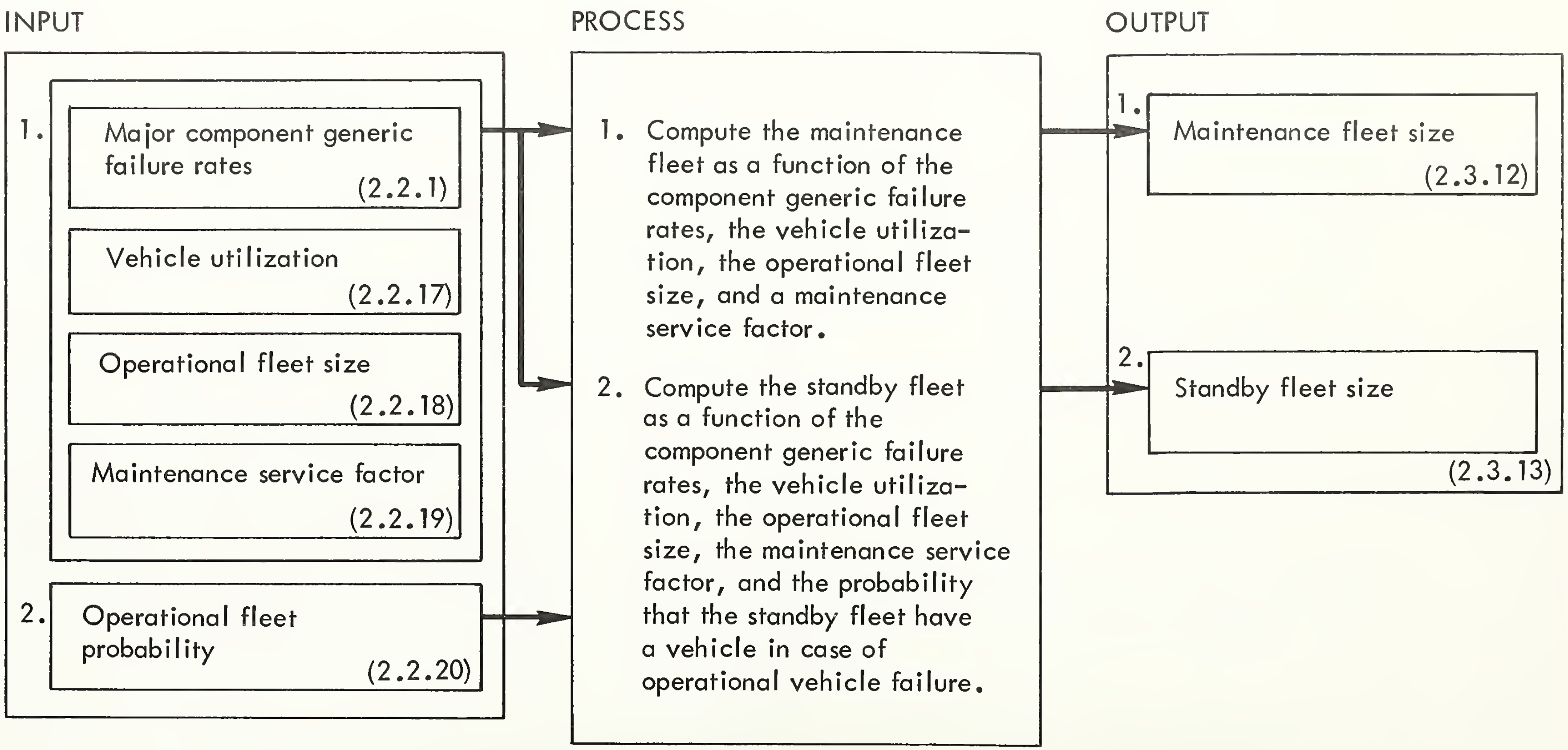

FIGURE 4-12. MAINTENANCE AND STAND-BY FLEET SIZE

5.0 VERIFICATION

The SAM verification procedure verifies that the software mechanization of the SAM model performs all functions as described in the functional specification. Formal verification procedures will be developed and executed for each SAM feature. In general, the features of the SAM are verified by comparing SAM results with hand-calculated results for several application areas and sets of failure rate data.

6.0 VALIDATION

SAM validation is controlled by a procedure designed to demonstrate that the verified model provides a valid calculation of availability and fleet size data for the real world entity it is modeling. The validation process provides assurance to transportation planners that the conclusions reached and data generated by these studies are realistic and can be used with reasonable confidence. In addition, one of the overall goals for validation is that test cases be sought so that at least one case exercises each model feature and that the number of test cases be the economical minimum that serves this purpose.

SAM validation comprises three steps:

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

2. Perform the validation by one or more of the following methods:

   - Compare the model's prediction of performance to actual measured availability and fleet size requirements for an existing system under a set of well-defined test conditions.

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

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

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

It appears that sufficient data are available from systems such as Morgantown, Airtrans, and Washington Metro to use the "existing system" comparison technique for simple networks. Previously validated model data and independent analytical techniques are necessary to complete the validation process.

GLOSSARY

Active Fleet Size

The number of vehicles in a transit system, not including a quantity which might be identified as maintenance float vehicles or spares.

Asynchronous

Vehicles operate under velocity control or in the vehicle-follower mode and are allowed to change speeds to resolve 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 110 passengers in its minimum train consist, operates at speeds equal to or greater than 55 km per hour, and generally runs at headways over one minute.

Base Year

The initial year of an analysis period.

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 with a high traffic flow.

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

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

Central City (CC) of an SMSA

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

Central City Ring (CCR)

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

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, high reverse commutation

1. University
2. Airport
3. CBD - high demand
4. CBD - low demand

Deterministic

All merge conflicts are resolved before launch, and barring failures, each vehicle is assured of traversing the network in a pre-determined time.

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:

1. 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.

2. Station Storage - Historical. Vehicles are routed to stations for storage based on historical demand data.

3. 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.

Fixed Supplier Cost

Total investment in capital equipment and facilities including the amortization of that investment.

Fully Connected Grid (FG)

A grid network in which no network constraint prevents a vehicle currently at one station from proceeding to any other station without retracing any one- or two-directional portion of the guideway.

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 a FG or PG network and has more extensive operational switching capability than a 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).

Group Rapid Transit (GRT)

A category of automated guideway transit systems which includes the following system classes: Small Vehicle GRT, Intermediate Vehicle GRT, and Large Vehicle GRT. The term GRT also refers to any deployment of a high-speed GRT system and to any grid deployment of a low-speed GRT system.

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/hr. and tend to run at 15- to 60-second headways. High speed IGRT systems operate at speeds greater than 54 km/hr. and at headways which usually fall between 15 and 90 seconds.

Large Vehicle Group Rapid Transit (LGRT)

A class of AGT systems which provides multiple-stop service, have a minimum train consist capacity of 70 to 109 passengers, operate at a maximum speed of 13 to 54 km/hr., and usually run at headways of 50 to 110 seconds.

Life Cycle Analysis Period

The prescribed number of years over which life cycle cost is evaluated.

Life Cycle Costs

The sum of all capital investment, interest, and annual variable costs incurred over the life cycle analysis period expressed in base year dollars less the salvage value of subsystem components at the end of the period.

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.

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

Minimum Traveling Unit Capacity

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

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 Type

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

1. Shuttle (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)

Non-Deterministic

Potential conflicts at merges are not considered before launch but are resolved locally in the vicinity of each merge.

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.

Partially Connected Grid (PG)

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

Path

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

Passenger Delay Threshold

A variable time value which is added to nominal passenger trip times to establish boundary levels for passenger delay analysis.

Passenger Threshold Availability

The ratio of the total number of trips with times which fall within the delay threshold to the total number of trips taken.

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 seconds or less. Low speed PRT has a maximum operating speed of 13 to 54 km/hr., while high speed PRT has a maximum operating speed exceeding 54 km/hr.

Prescheduled Pathing

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

Prescheduled Service Policy

A service policy in which vehicles travel on predetermined routes and are required to stop at specified stations along the route.

Price Inflation

Changes in the cost of a commodity or service due to actual changes in the worth of the commodity or service (i.e., not due to changes in the value of the dollar).

Quasi-deterministic

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

Quasi-synchronous

Vehicles operate under point-follower control but are allowed to change control points to resolve potential merge conflicts by advancing or slipping one or more slots.

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

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.

Route

A designated, specific path or set of links of a guideway system a vehicle or set of vehicles are assigned which indicate stops for serving passengers.

Rural and Scattered Urban (R & SU)

This consists of 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.

Service Type

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

Shuttle (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 an SLT system has 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 seconds. Low speed SGRT has a maximum operating speed of 13 to 54 km/hr., and high speed SGRT a maximum of over 54 km/hr.

Standard Day

A period of time which represents an operational or repetitive cycle of the system in terms of demand and service characteristics. This can be from any arbitrary point in time to the next point in time when the service characteristics of the system would initiate the start of a repeat cycle.

Standard Metropolitan Statistical Area (SMSA)

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

Station Dwell

The time measured from start of the vehicle doors opening to the completion of the vehicle doors closing.

Synchronous

Vehicles operate under point-follower control and are not allowed to change control points during a given guideway trip.

Time-Phased Costs

The cost of purchasing a specific commodity or service in each year of an analysis period.

Urbanized Area (UA)

An Urbanized Area contains a city (or twin cities) of 50,000 or more population (central city), 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, and exclude places which were separated by rural territory from densely populated fringe around the central city. The components of UA's include the Central City (as defined above) and the urbanized ring (as defined below).

Urbanized Ring (UR)

In addition to its central city or cities, a UA also contains various types of contiguous areas, which together constitute its urbanized ring (or urban fringe, as used by the Census Bureau).

Useful Life

The number of years over which a capital investment is amortized and after which the capital equipment or facility must be replaced.

Variable Supplier Cost

Sum of annual operating and maintenance costs.

APPENDIX

REPORT OF NEW TECHNOLOGY

The System Availability Model (SAM) provides two system-level availability measures and fleet size data for Automated Guideway Transit (AGT) systems. The first availability measure is the percentage of vehicle operational time. The second availability measure is the percentage of passengers whose wait is below a specified threshold.

The fleet sizing data establishes the number of maintenance and stand-by vehicles.

The SAM operates in conjunction with the Discrete Event Simulation Model (DESM). The DESM output provides the delay information for the SAM analysis.