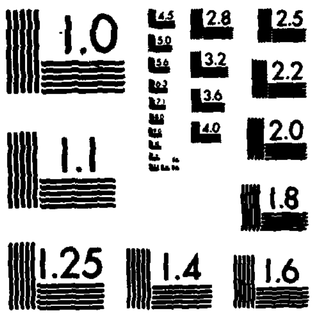
AD-A124 118 A DETERMINATION OF USAF TACTICAL MISSILE AVAILABILITY USING SYSTEM SIMULATION(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. 1/2

UNCLASSIFIED J A HALL ET AL. SEP 82 AFIT-LSSR-59-82 F/G 15/5 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A

A DETERMINATION OF USAF TACTICAL MISSILE AVAILABILITY USING SYSTEM SIMULATION

Jay A. Hall, Captain, USAF
Marie E. Niehaus

LSSR 59-82

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the author(s) and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the Air Training Command, the United States Air Force, or the Department of Defense.

AFIT Control Number LSSR 59-82

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: AFIT/LSH, Wright-Patterson AFB, Ohio 45433.

1. Did this research contribute to a current Air Force project?

   a. Yes b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Can you estimate what this research would have cost if it had been accomplished under contract or if it had been done in-house in terms of manpower and/or dollars?

   a. Man-years ________ $ ________ (Contract).

   b. Man-years ________ $ ________ (In-house).

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3 above), what is your estimate of its significance?

   a. Highly Significant b. Significant c. Slightly Significant d. Of No Significance

5. Comments:

Name and Grade	Position
Organization	Location

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR 59-82	2. GOVT ACCESSION NO. AD-A124 118	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A DETERMINATION OF USAF TACTICAL MISSILE AVAILABILITY USING SYSTEM SIMULATION		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jay A. Hall, Captain, USAF Marie E. Niehaus GS-12		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Systems and Logistics Air Force Institute of Technology, WPAFB OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication and Humanities AFIT/LSH, WPAFB OH 45433		12. REPORT DATE September 1982 13. NUMBER OF PAGES 110
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE: IAW AFR 190-17

LYNN E. WOLAVER
Dean for Research and
Professional Development

AIR FORCE INSTITUTE OF TECHNOLOGY (ATC)
WRIGHT-PATTERSON AFB, OH 45433

8 OCT 1982

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Tactical Missiles
Availability
Q-GERT Simulation
Reliability
Maintainability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Mr. Roy Wood

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Determination of weapon system availability in the USAF is a continuing problem. Availability estimates drive logistic support requirements, manpower levels, and eventually the number of weapons required to meet mission requirements. After reviewing existing analytical and computer simulation models, the authors felt there was a need for a missile-specific computer simulation model based on maintainability and reliability data which would allow USAF managers to realistically estimate weapon system availability. Using the simulation language Graphical Evaluation and Review Technique for modeling Queues (Q-GERT), the authors constructed a Q-GERT network representing a tactical missile operation scenario, using existing AGM-65A/B data. The Q-GERT simulation model combines reliability and maintainability inputs and provides a comprehensive management tool for estimating availability, analyzing the impact of fluctuating logistics support levels, reliabilities, and variations in maintenance times. The concepts behind the AGM-65 availability model can be used to model a number of USAF weapon systems with minor modifications. Based on the results of the model, it may be concluded that the Q-GERT simulation satisfies the USAF need for an availability model.

LSSR 59-82

A DETERMINATION OF USAF TACTICAL MISSILE AVAILABILITY USING SYSTEM SIMULATION

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Jay A. Hall, BA
Captain, USAF

Marie E. Niehaus, BA
GS-12

September 1982

This thesis, written by

Captain Jay A. Hall

and

Marie E. Niehaus

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 29 September 1982

COMMITTEE CHAIRMAN

ACKNOWLEDGEMENTS

We would like to thank Mr. Roy Wood for his help and advice in this thesis effort. In addition, we would like to express our appreciation to Jackie McHale for her typing expertise. Last, but not least, we would like to thank Robin for putting up with so much grief (and the beers for lunch).

TABLE OF CONTENTS

Chapter | Page

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Background

Although the United States may not be facing an immediate crisis, General David C. Jones, USAF, Chairman of the Joint Chiefs of Staff (30:1) cautioned Congress in January, 1980 that:

> Under the best circumstances, the 1980's will be a period of widespread international turmoil and instability. . . . The world is in many ways more different and more threatening than a year ago and all signs point to even greater risks as the days pass.

In this light, it is imperative that the United States and its allies obtain the optimum effectiveness from each weapon system. U. S. survival depends on the maintenance of a credible military and economic posture. In addition, it depends on the allies' ability to marshall defense resources in a timely manner to meet any military threat. In this era of shrinking budgets and conservative military funding, the Department of Defense (DOD) must pursue higher levels of weapon system effectiveness (1:70-74).

The Air Force concept of system effectiveness (SE) is the product of three factors: availability, dependability, and capability. The following diagram depicts the

Air Force system effectiveness concept (6:Fig 1-2):

SYSTEM EFFECTIVENESS

AVAILABILITY	DEPENDABILITY	CAPABILITY
Measure of system condition at start of mission	Measure of system condition during performance of mission	Measure of results of mission
- Reliability	- Flexibility	- Lethality
- Maintainability	- Survivability	- Destruction

Source: Adapted from Blanchard and Lowry, Maintainability, p. 3 (McGraw-Hill Book Company, 1969).

Availability

Although the Air Force, Navy, and Army concepts of SE differ, there is agreement as to availability factors. All three services agree that availability, which is the probability that a system will be ready for use, is a function of reliability and maintainability (8:1-14; 34:2). Because availability ultimately impacts dependability and capability later in the system mission, availability, reliability, and maintainability will be the focus for the remainder of this thesis.

Reliability

Reliability is generally defined as the probability of successful performance under specified conditions of time and use (8:1-14; 18:5-3; 34:3). DOD Military Standard 721B (MIL-STD-721B), Definition of Effectiveness Terms for Reliability, Maintainability, Human Factors and Safety, defines reliability as the probability that an item will perform its intended function for a specified interval under stated conditions (31:7).

Reliability, as it relates to weapon systems, is one of the most important characteristics by which the tactical suitability of a product is judged. As tactical roles become more sophisticated and keep pace with the changing threat, weapons systems must become more complex to satisfy increased performance requirements (20:1). When the system configuration becomes more complex, reliability becomes more problematic (29:126). Not only does it become more difficult to define and achieve a specified design reliability, it also becomes more difficult to control and demonstrate after production. Because a predictable upper limit of reliability exists for every system concept or design approach, total elimination of these difficulties is impossible (8:1-1).

Defense managers and design contractors have recognized the reliability problem for a long time. They have attempted to improve reliability in the weapon acquisition process for the past thirty years (1:10-66). In 1952, the Advisory Group on Reliability of Electronic

Equipment formed and made many recommendations for reliability improvement. One recommendation resulted in the establishment of a military standard for designing and conducting reliability tests (MIL-STD-781) (20:1).

The DOD recognizes that exercising deliberate and positive reliability engineering methods throughout the evolutionary life cycle of the weapon system can increase the upper limit of reliability. Reliability is controllable from the early planning stages through design, development, production, and the inevitable product improvement phases. To insure a high probability of program success, management should constantly monitor and guide reliability throughout the system life cycle (8:1-1; 14:126; 32:1-3).

Maintainability

Maintainability is a term used to define a characteristic of design and installation. It is expressed as the probability that an item will be retained in or restored to a specific condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources (32:5). Another common definition expresses maintainability in terms of ease and economy of maintenance, safety, and accuracy in the performance of maintenance actions (6:1; 10:1-10).

The objective of maintainability is to design and develop systems which can be maintained in the least time, at the least cost, and with minimum expenditure of support resources without adversely affecting the item performance or safety characteristics (6:1).

The increasing complexity, size, and quantity of items comprising a system requires increased maintainability emphasis during the engineering phase (6:1; 8:1-1). Maintainability goals pressure designers to provide equipment the USAF can procure, operate, maintain, and support for less expenditure of critical resources (6:3; 12:16-22).

One point should be made clear. Maintainability differs greatly from maintenance. Maintainability is a design parameter and involves initial acquisition cost; whereas, maintenance is a consequence of design and involves continuous costs and efforts. Maintenance costs often range from ten to one hundred times the procurement cost (34:7).

Determination of Availability

Determination of weapon system availability in the United States Air Force is a continuing problem. In particular, estimating tactical missile availability is very difficult due to the various operational environments, reliability estimates and maintenance concepts employed.

As new missile systems enter the USAF inventory, availability estimates drive maintenance resource requirements, manpower levels, logistic support requirements and eventually the number of missiles required to meet the mission requirement.

A computer simulation model of the air-to-ground AGM-65 Maverick missile maintenance and operational environment provides a starting point for determining tactical air-launched missile availability and the factors which impact on availability. Based on Mean Time Between Failure (MTBF) and maintenance data from the field, the simulation model will estimate missile availability and allow sensitivity analysis to be conducted on maintenance resource requirements, manpower and logistic support requirements.

Problem Statement

There is a need for a missile specific computer simulation model based on existing maintainability, reliability, support equipment and manpower data which allows USAF managers to realistically estimate missile availability.

Literature Review

Availability of a weapon system can be influenced by efficient management and logistics planning and better design and development of the system. This thesis will not consider specific engineering design techniques since the concern here is with support of a system once it has been designed. Consequently, engineering studies on procedures for designing reliability and maintainability into the system will be excluded. However, the general concept that improved design for reliability or maintainability can increase availability will be considered.

Review of Existing Availability Models - Analytical Methods

A mathematical model of a system consists of a set of equations whose solution explains or predicts changes in the state of the system. The use of mathematical models is a result of analytical efforts to abstract and describe the real world. It is abstraction that makes mathematical models general, subject to manipulation and precise in terms of information gained in their use (23:11-12).

There are two reasons for mathematical models' popularity. First, there is in the discipline of mathematics, an inherent rigor that forces the decision-maker to identify the important elements of the problem and the relationships that exist among these elements. Second, mathematics is a powerful technique for manipulating data and coming to conclusions based on a set of assumptions (22:5).

Formal mathematical analysis may be the most desirable and powerful approach to problem solving when the necessary data is available. However, this method which consists of writing equations which completely describe the problem under study, is frequently too complicated to utilize and in some cases the mathematics have not been developed which will permit all the desired factors to be considered simultaneously. The mathematical model is also a problem in communication. It is often hard to convince people what the formula says is really the best thing to do. Additionally, lack of precise information, insufficient evidence concerning cause and effect and uncertainty limit the usefulness of mathematical tools in dealing with management problems (27:39).

General analytical methods for computing system availability are essentially the same, but use different wording particularly for the maintenance or down time portion of the formula and the denominators of the formulas. Igor Bazovsky's Reliability Theory and Practice includes a chapter which covers system availability. Bazovsky defines system availability as (4:173):

$$A = \frac{M}{M + T^1 M}$$

where:

A = availability

M = mean time between failures

T^1M = average maintenance time for every system operating time (includes preventative and corrective maintenance)

A thesis entitled "Reliability and Maintainability Analysis: A Conceptual Design Model" defines system availability as the fraction of total time a system is operating or capable of doing so. The formula is (11:4):

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MDT}}$$

where:

MTBF = mean time between failure

MDT = mean down time, the mean time during which the item is not in condition to perform its intended function

The advanced medium-range air-to-air missile (AMRAAM) system availability is being calculated using the following formula (17:B-29):

$$\text{Availability} = \frac{\text{possessed hours} - \text{MD hours}}{\text{possessed hours}}$$

where:

possessed hours = total accumulated clock hours the missile is on hand, regardless of operational status, possessed time begins on arrival, accumulating twenty-four hours per day thereafter until the item is expended or removed from the program.

MD hours = mission downtime status exists when a missile is in a condition in which it cannot perform its entire operational mission, MD hours are the total hours in this status.

For example, if possessed hours were forty-eight and the mission downtime were six hours, the availability for the AMRAAM missile system would be:

$$\text{Availability} = \frac{48 - 6}{48}$$
$$= .875$$

A method used to compute the AIM-9L Sidewinder missile availability included the formula (16:B-22):

$$A_o = \frac{M_s \times D}{M_s + (ACC \times MDT)}$$

where:

A_o = operational availability

M_s = missile mean flying hours before failure (MFHBF) in flight hours based on guidance and control section (GCS) data

D = fraction of AIM-9L missiles delivered that pass incoming inspection

ACC = missile captive carry flight hours per month

MDT = missile down time which included ordering/shipping/ repair time (taken from the AIM-9J Recoverable Consumption Requirements/File Maintenance AFLC Form 712)

For example, if M_s was 265.2 flight hours, D was 17 missiles inspected and 17 missiles passed or $^{17}/_{17}$ = 1.0, ACC was 43.3 missile captive carry hours per month, and MDT was 14 days for ordering and shipping plus 62 days for repair cycle which included 22 days actual repair time for a total of 76 days or 2.53 months, the operational availability of the AIM-9L missile would be:

$$A_o = \frac{265.2 \times 1.0}{265.2 + (43.3 \times 2.53)}$$
$$= .707$$

The operational availability (A_o) is dependent on reliability, logistics time and captive carry rate. As an example of how these variables can change the availability, consider the effect on operational availability where spare missile sections are stocked at base level rather than at the depot. The MDT can now be defined as the verification of a bad missile at the missile maintenance activity test bench, removal and replacement (R & R) of the failed section, and re-test of the new missile unit. For this situation, MDT = 2 hours or .0028 months, therefore:

$$A_o = \frac{265.2 \times 1.0}{265.2 + (43.3 \times .0028)}$$
$$= .999$$

There are several drawbacks with this analytical approach. First, the MDT was treated as a constant (2.53 months or .0028 months). In actuality, the mean down time will approximate a normally or lognormally distributed random variable. Second, this analytical model only used the reliability of the Guidance and Control Section (GCS) as determined in the Phase I test program. The model ignored the reliability of the warhead, target detector, rocket motor, etc., which, if included, would lower the calculated availability. Although the AIM-9L availability formula goes into more detail than other formulas reviewed above, it is still an over-simplification of "real world" missile availability.

The Logistics Management Institute developed a deterministic model to identify the relationships among system and subsystem reliability and availability design requirements and life cycle costs. The purpose of the model was to determine the optimum value of Mean Time Between Failures (MTBF) for a number of subsystem or major components of a system, such that the total life cycle costs of the system as affected by MTBF will be at a minimum. Three areas of cost included in the model are: (1) cost of system down-time; (2) cost of achieving reliability; and (3) cost of maintenance (which includes the cost of spares) (9:3-4,26). One of the major shortfalls of this model is that the amount of risk associated with the reliability of alternatives was not considered. In the systems development environment, information regarding costs and results of the reliability and maintainability alternatives is likely to be imperfect. With the use of a computer simulation model, different values for reliability and maintainability can be included without difficulty and sensitivity analysis can be performed to see how sensitive the model is to certain parameters.

After review of the more prominent availability models several deficiencies come to light:

1. Many analytical models employ simplification as a means of stripping away unimportant details at the risk of assuming simpler relationships. For instance, most analytical models assume linear relationships between two variables, even though we suspect that the true relationship may be curvelinear.

2. Many models assume that over the time interval being studied, the characteristics or output values of the system or components remain constant. For example, most electrical engineers work with models of circuits based on constant values of resistors, diodes and capacitators, when in reality the characteristics of these components may vary as a function of temperature, humidity, and age.

After analysis of the deficiencies with an analytical approach to weapon system availability, the authors feel that a computerized system simulation approach to the availability problem exists. If properly done, the systems simulation process of problem analysis, abstraction of essential qualities and synthesis of the key elements of a problem, will result in a model that approximates the behavior of the real system under study (28:10-18).

Review of Existing Availability Models - Simulation Models

Management today is becoming increasingly difficult as the systems of our society become more complex. The complexity is due to the interrelations among the various elements of the organization and the physical system with which it interacts. Changing one aspect of a system may produce changes or create a need for changes in other parts of a system. Since the arrival of electronic computers, one of the most useful and important tools for analyzing the design and operation of complex processes or systems is simulation (21:1). Simulation provides the most flexible and realistic representation for complex problems of any quantitative procedure (28:256).

Shannon defines simulation as "the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system or of evaluating various strategies for the operation of the system." The functions of a model are prediction and comparison or to provide a logical way to forecast the outcomes of alternative actions; and possibly make a preference among the alternatives. Models help organize and sort out hazy concepts and inconsistencies. The construction of a model network of a complex system forces modelers to think through what steps are necessary and in what sequence to represent a realistic situation. The model shows the needed interrelationships, accomplishments, timing, required resources, etc. Ambiguities and inconsistencies become evident when building a model and, therefore, a more organized and valid approach is taken in the problem-solving process (21:2-6).

The Aircraft Reliability and Maintainability Simulation (ARMS) model was developed to analyze the capabilities and requirements of Army aircraft. This model is capable of simulating a complex scenario and provides numerous output data concerning the aircraft's capability to perform in a given environment. ARMS enables management to observe the impact of a proposed action prior to implementation. The systems level impact of changes in reliability and maintainability parameters at the component level, the optimum mix of maintenance resources and the effectiveness of alternate maintenance concepts can be determined with ARMS (13:2). The ARMS model has three major groups of logic: (1) control logic; (2) aircraft mission logic; and (3) aircraft maintenance logic. Each logic group is further divided into numerous routines and subroutines. Detailed features of this model permit correspondingly detailed support issues to be examined.

However, the need for detailed data limits the usefulness of the ARMS model for logistics planning early in the development cycle. Long running times, large memory requirements and computer costs limit the amount of experimentation and replication that can be performed.

Recognizing the need for greater flexibility and increased realism, recent Air Force sponsored availability estimating techniques incorporate the use of computer simulation. The Air Force Test and Evaluation Center (AFTEC) attempted to modify the existing Logistics Composite Model (LCOM) to estimate tactical missile availability. The major deficiency with this modified LCOM simulation stems from the fact that LCOM was initially intended to assess base level support activities on aircraft flight operations. In addition, LCOM is a very complex model and its analysis of missile availability is very time consuming and expensive.

In an effort to avoid the problems with LCOM, AFTEC initiated development of a less complex but more specific simulation model designed to address AGM-65 missile system availability. The new model, based on the Simulation Language for Alternative Modeling (SLAM), provides a very detailed description of the AGM-65 operating and maintenance environment. Unfortunately, the SLAM model has been less than successful in its intended purpose. The major problems with the SLAM model are its lack of documentation, its massive data requirement and the fact that existing maintenance and reliability data collection systems do not allow for direct input into the SLAM model (5).

Significance of the Problem

Evaluating logistics performance (including weapon system availability) with models currently available has caused problems because the data required by the models is not readily available (14:67). Limitations of models have been identified by GAO investigators and the Joint AFSC/AFLC Commander's Working Group on Life Cycle Cost. These groups concluded that: (1) the models are not adequate or are too complex; (2) the input data required is difficult to obtain and there is a shortage of trained personnel to do the analysis; (3) the models are not sensitive to relationships between design and performance; and (4) there is little incentive for management to trade off technical performance to improve system supportability because it is difficult to quantify the benefits of such investments and tradeoffs (9:90; 19:34).

In light of the deficiencies of the models reviewed above, this thesis effort will employ the Queuing-Graphical Evaluation Review Technique (Q-GERT). The graphical model associated with Q-GERT is a means of representing the system under study. The network establishes a means by which the analyst can define and organize relationships among system components, parameters of the system, and decision points and rules within the system. When the network is complete, the analyst may study it and determine flaws in the design or the system or errors in logic even before the network is run on the computer. Experience has shown that networks are an excellent means of explaining systems and system parameters to those not well versed in the methods of Operations Research or Systems Analysis (26:1-5). Both network modeling and computer simulation will be incorporated in this thesis. The detailed procedures for building the Q-GERT simulation language network model will be described in Chapter II of this thesis.

Research Objectives

The intent of this thesis is to describe a Q-GERT model development and analysis procedures applicable to USAF tactical missile availability. Specific objectives include:

1. Identification and definition of the AGM-65 maintenance and operational environment.

2. Definition of system parameters from existing maintenance data collection systems and translation of those parameters into a Q-GERT network.

3. Identification of the most significant forces

affecting the availability of the AGM-65 missile system.

4. Provide integration of missile system reliability/maintainability data needed to measure missile availability.

5. Provide an improved conceptualization of missile availability for other researchers to use to define availability.

Research Questions

The research done in this thesis will address the following questions:

1. What are the relationships between reliability and maintainability with other elements in the AGM-65 missile system which affect the total availability of the system?

2. Can a conceptualization of the inter-relationships between the availability of a missile system and the other elements of the system be developed and used as the basis for a Q-GERT computer simulation model?

3. Can the developed model function as a management tool, whereby, managers can evaluate the effect that proposed changes in reliability/maintainability parameters have on availability?

Description of the USAF AGM-65A/B Maverick Missile

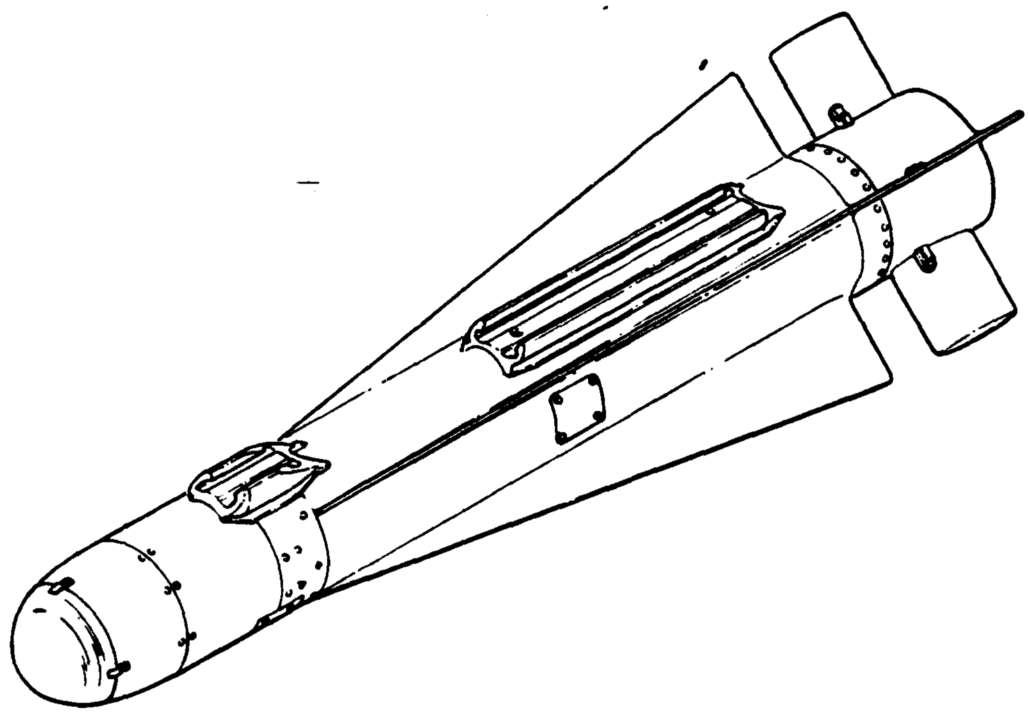


FIGURE 1-1: USAF Model AGM-65A/B Maverick Missile

The AGM-65A/B Maverick missile, Figure 1-1, is a television-guided, rocket-propelled, air-to-ground missile for use against field fortifications, surface-to-air missile (SAM) sites, and armored vehicles (3:1-1). The AGM-65A is identical to the AGM-65B in physical and aerodynamic characteristics but differs in that the AGM-65B provides for image magnification and provides different electrically generated cockpit scope symbology. The missile is capable of launch-and-leave operation through automatic missile guidance provided by an electro-optical homing device.

Table 1-1 lists major missile characteristics, major components and general functional descriptions. The forward section of the AGM-65, shown in Figure 1-2, contains the guidance unit. The guidance unit is a hermetically sealed unit consisting of the electro-optical seeker, guidance electronics, autopilot electronics, and autopilot sensors.

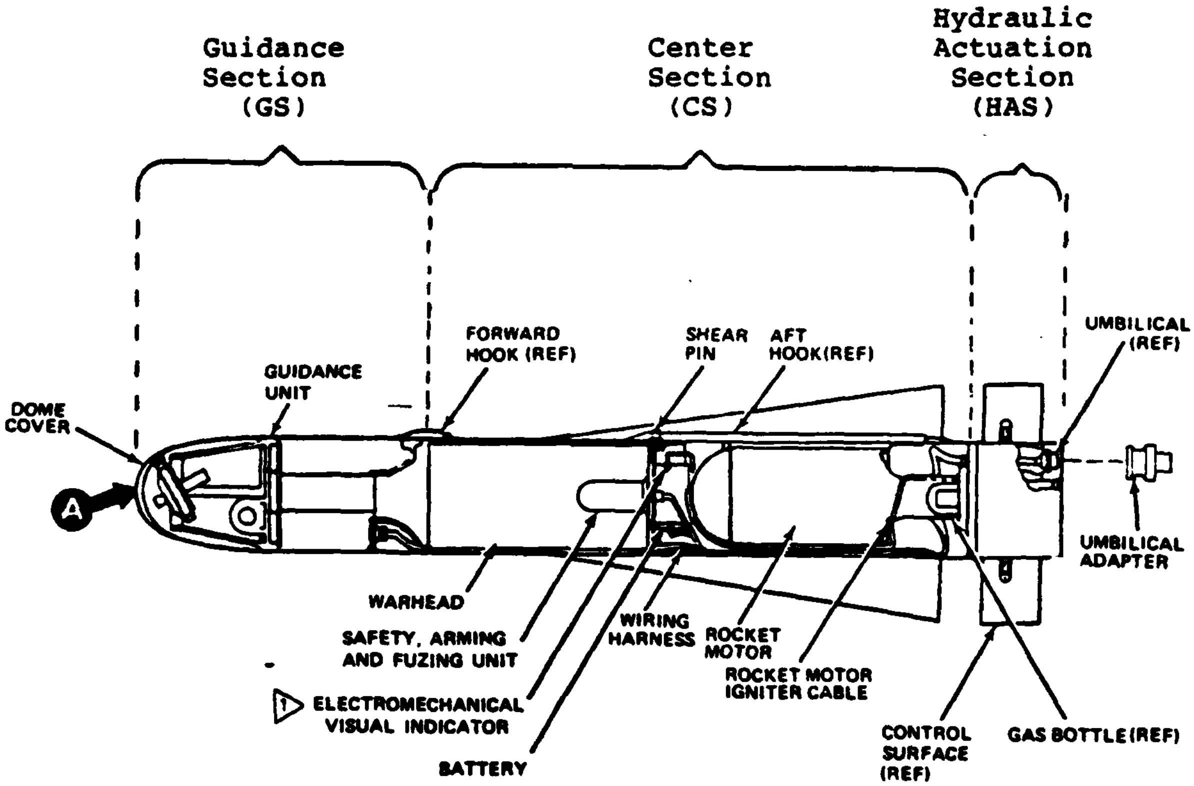


FIGURE 1-2: AGM-65A/B Major Sections

TABLE 1-1

AGM-65A/B MISSILE CHARACTERISTICS

Size and Weight	
Length	97.7 inches
Diameter	12 inches
Stabilizer span	28.5 inches
Weight (prelaunch)	461 ±15 pounds
Weight (guidance unit)	88.30 ±1.25 pounds
Propulsion	
Type	Solid Propellant dual thrust (boost sustain) rocket motor
Guidance System	
Type	Homing, proportional navigation
Guidance head	Television-guided
Electrical power source	Aircraft power while captive; thermal battery during launch and in free-flight
Control System	
Control surfaces	Four; one pitch-roll pair, one yaw-roll pair
Servopositioners	Four hydraulic
Hydraulic power source	Compressed-gas-driven-free-piston hydraulic pump
Weapons Control System	Aircraft weapons control system of carrying aircraft

The center section consists of the missile main structure and wing assembly which contains the warhead, the safety, arming and fusing (SAF) unit, the battery and rocket motor. The hydraulic actuation system (HAS) is attached to the main structure and wing assembly and converts electrical guidance unit commands into hydraulic power to deflect missile control surfaces to steer and stabilize the missile during launch and free flight.

CHAPTER II

METHODOLOGY

Overview

Chapter II provides an introduction to the Q-GERT simulation language and its application to the AGM-65 Maverick missile availability model. Chapter II explains the various underlying assumptions used in the model prior to operationally defining the model. The definition of the model breaks the Q-GERT network into four distinct phases and a clock mechanism used to control simulation activities. A phase-by-phase discussion of the network aids conceptualization and understanding. The chapter concludes with a description of several model parameters and explanation of the values assigned.

Model Language

To model this system, the Q-GERT (Graphical Evaluation and Review Technique for modeling Queues) simulation language was used. The modeling philosophy of Q-GERT consists of four steps: (1) the system is broken down into its significant elements; (2) the elements are described and analyzed; (3) the elements are integrated into a model network; and (4) model evaluation provides an assessment of system performance (26:viii). Therefore, Q-GERT provides a means of conceptualizing systems as well as simulating them.

The Q-GERT modeling procedure consists of two parts. First, the network diagram is developed, which includes items flowing through the network (transactions), activity or processing times and decision points and queues (nodes). Next the graphical representation is converted into Q-GERT instruction codes which correspond to node types and activities/services. The Q-GERT Analysis Program does the actual simulation and prints out the results and statistics (26:4).

The two basic symbols in Q-GERT are nodes and branches. Nodes are used to separate activities and represent milestones. There are generally three sections to a node symbol. The left section determines queue capacity information and conditions for releasing a transaction from a node. The center section determines how a transaction is treated when it is released (allowing transactions to flow through the remaining network). For example, transactions that accumulate in a queue will be released from the node either on a first-in, first-out basis (F) or on a last-in, first-out basis (L). Attribute assignment is also indicated in the center portion of the node. Attribute values give a transaction an identity and can be used to distinguish between types of transactions and between transactions of the same type. The network processes transactions differently based on attribute values of transactions. The shape of the right side of the node specifies the type of node (regular or queue), the branching type (deterministic, probabilistic, or conditional), and the node number. Table 2-1 (see pages 27-32) explains the Q-GERT symbols used in the network flowchart of missile availability.

Transactions pass through nodes and are routed along activity branches designated by arrows drawn between nodes. An activity represents either a time delay or a service process. Service activities can only follow queue nodes and are constrained by the number of work stations (servers) available to perform the service activity. Additionally, service activity occurs only when a work station or server is free. Time delays and service times are enclosed in parentheses along the activity branches. The time value can be either a constant value or a sample from a probability distribution. Also, information on the server identification number, the number of parallel servers, the probability of taking a branch and/or cond.tions for taking a branch of the network may be included.

TABLE 2-1

Q-GERT MODEL SYMBOLOGY

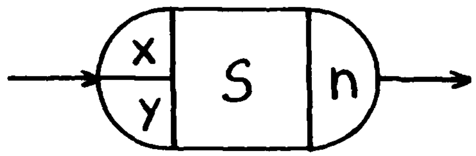
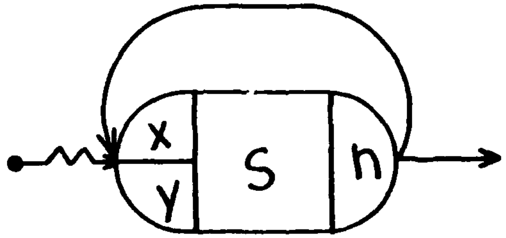
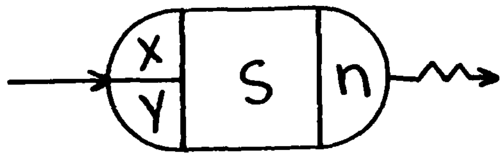
Node Type	Q-GERT Symbol	Parts Description
Regular		x = number of transactions to initially release the node y = number of subsequent transactions to release the node s = statistics collection (I) or mark time (M) n = node number
Source		The jagged arrow at the beginning of a node indicates the starting point of the system.
Sink		The jagged arrow at the end of a node indicates the departure of a tr/nsaction from the system.

TABLE 2-1 (continued)

Q-GERT MODEL SYMBOLOGY

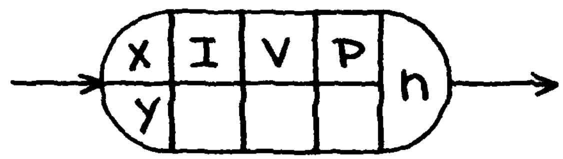
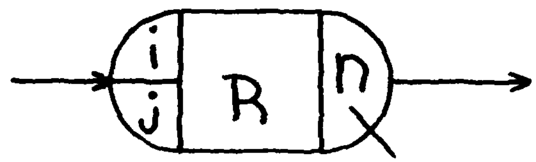
Node Type	Q-GERT Symbol	Parts Description
Attribute Assignment		I = the attribute number V = source from which the value for the attribute is taken CO = a constant value NO = a normal distribution EX = a exponential distribution LO = a lognormal distribution IN = incremental function P = the parameter set number
Queue		i = the initial number in the queue j = the maximum capacity of the queue R = ranking procedures in the queue L = last-in, first-out F = first-in, last-out The hash mark in the right section indicates the node is a queue node. Queue nodes can have probabilistic branching and attribute assignments

TABLE 2-1 (continued)

Q-GERT MODEL SYMBOLOGY

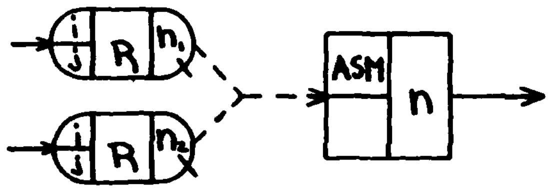
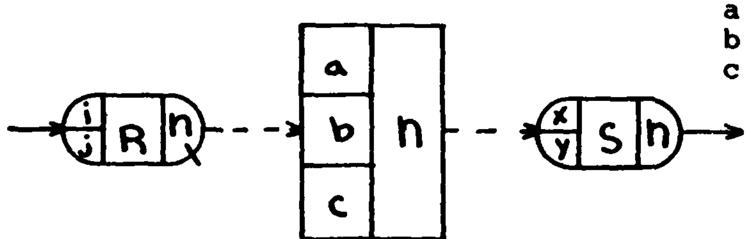
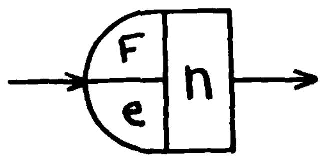
Node Type	Q-GERT Symbol	Parts Description
Assembly		ASM indicates that a transaction is taken from each input queue before continuing through the network
Allocate		a = queue selection rule b = resource type number c = number of units to be allocated to each transaction passing through the node
Free		F = resource type number e = number of units to free

TABLE 2-1 (continued)

Q-GERT MODEL SYMBOLOGY

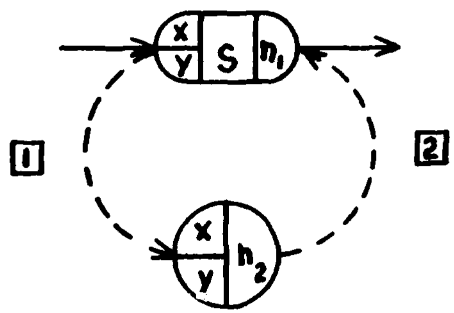
Node Type	Q-GERT Symbol	Parts Description
Nodal Modification		When activity 1 along the dashed line is completed, node n_1 will be replaced by node n_2 When activity 2 along the right dashed line is completed, node n_2 will be replaced by n_1

TABLE 2-1 (continued)

Q-GERT MODEL SYMBOLOGY

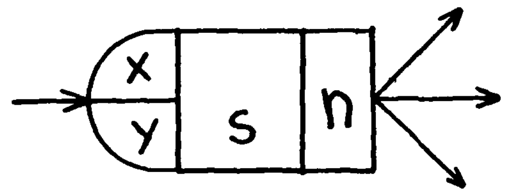
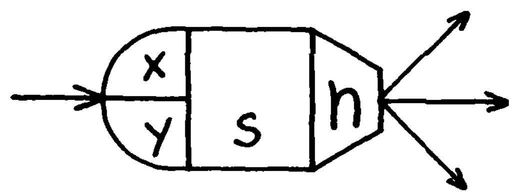
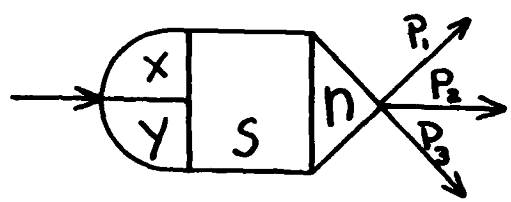
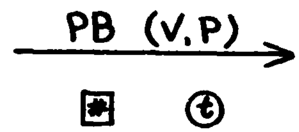
Node Type	Q-GERT Symbol	Parts Description
Conditional Take-All		The squared-off right section indicates that any activities meeting the conditions on the branches could be initiated
Conditional Take-First		The right section indicates that the *first* activity meeting the condition of the branch will be initiated (therefore, the branches are in the order in which the evaluations are to be made)
Probabilistic		The pointed right section indicates the probability that a transaction will follow a given branch. The probabilities emanating from a node must add to one

TABLE 2-1 (continued)

Q-GERT MODEL SYMBOLOGY

Node Type	Q-GERT Symbol	Parts Description
Solid Line Activity		PB = the probability of taking a branch V = the distribution or function type P = the parameter set number where the parameters for a particular distribution are contained # = the activity number t = the number of parallel servers or work stations
Non-Solid Line		Portrays a direct transfer of a transaction from one node to another node -- does not represent an activity

Several concepts included in the network flowchart of missile availability require further explanation than given in the symbol table (Table 2-1). First is the concept of allocating resources to transactions. A resource is "an entity which is required by a transaction before the transaction can proceed through the network" (26:355). Until a resource type is available for allocation to a transaction, the flow of the transaction through the network is halted. Additionally, once a resource is allocated to a transaction, it cannot be re-allocated until the resource is freed or no longer being used. In the missile availability network, resource allocation limits the number of missiles that are available for flight to twenty-four. The only time a resource is freed is when the missile (transaction) goes to a maintenance queue.

Next, the concept of nodal modification needs elaboration. Nodal modification involves the replacement of one node by another node once an activity is complete. This allows the modeler to set or reset switches as activities are completed. For example, in the missile availability network, the nodal modification indicates that flying activity takes place eight hours a day, with sixteen hours off.

Model Assumptions

Shannon, in his book on systems simulation, defines a model as a representation of an object, system, or idea in some form other than that of the entity itself (28:4). Depending on the complexity of the system to be modeled, the model may be an exact replica or it may be an abstraction of the system's more prominent properties. A model of the AGM-65 Maverick missile system is extremely complex and requires significant abstraction and simplification. The modeling effort seeks to analyze the missile availability problem, abstract its important features, select and modify basic assumptions, and then enrich and elaborate the model until a useful approximation of the real AGM-65 missile system results. Assumptions and important features of the AGM-65 availability model include the following:

1. For modeling purposes, maintenance personnel and support equipment, to include test equipment, vehicles, and munitions handling equipment (MHE) will be assumed to be available when needed. For example, in the guidance section (GS) maintenance portion of the model, missile maintenance technicians and associated equipment will be available to remove and replace all failed GS transactions. Numbers of personnel and equipment can be arbitrarily set by the modeler.

2. Upon arrival, all missiles will receive an initial receiving inspection. Missiles rejected for any reason will be returned to the shipper and exit the simulation.

3. All missiles passing the receiving inspection will enter the storage environment and remain there until a requirement exists in the flight activity. A last-in, first-out (LIFO) inventory system ensures the first missiles into storage will remain in a protective environment as long as possible.

4. The flying activity will be assumed to be limited to twenty-four aircraft. The aircraft and associated aircrews will be assumed to be available when required.

5. Recognizing that many tactical aircraft are capable of carrying a number of air-to-ground missiles in various configurations, the simulation will limit one missile to one aircraft.

6. All flying activities are captive carry sorties, i.e., none of the missiles are launched or inadvertently released and all return to base. (See Chapter V, Conclusions and Recommendations, for suggested launch embellishments).

7. Although the model allows for missile section failures in flight, the failures do not effect aircraft

performance and both aircraft and missile return to base for post-flight inspection.

8. Once a missile has been identified as having a failed section, it will be routed to the appropriate maintenance activity. Reflecting the complexity of today's missile components and current Air Force two-level missile maintenance philosophy, the field maintenance activity will be limited to section removal and replacement (R & R). Field R & R activities are complemented by a depot repair activity which has the necessary test equipment and expertise to repair the item.

9. The maintenance activities will continue as long as there are missiles to be processed. In this manner, the maintenance activities attempt to keep pace with the flying activity.

10. The AGM-65 availability model will use hours for the simulation time units. This feature allows additional flexibility and clarity.

11. Missiles are considered available unless the missile is in an inspection, maintenance, or transport activity. Missiles in storage are considered available. Only when the breakout inspection identifies a bad missile coming out of storage will the missile be considered unavailable.

Model Definition

The AGM-65 operations system modeled consists of several distinct phases. The first portion of the system is the missile generation phase. This phase simulates the arrival of a given number of AGM-65 Maverick missiles to a Tactical Fighter Wing. While in this phase, the missiles receive a randomly selected mean time between failure (MTBF) for each of the three major missile sections. In addition, each missile undergoes a receiving inspection which rejects damaged or defective missiles. Missiles that pass the receiving inspection proceed to the storage phase.

The storage phase consists of the storage environment where minor deterioration of the missile stockpile occurs. Subsequent removal from storage (more commonly called "breakout" from storage) and the accompanying breakout inspection identify defective missiles. After the breakout inspection, missiles that fail enter the appropriate maintenance activity depending on which section fails. Missiles that pass the breakout inspection flow into an "available" missile queue. The available missile queue can be considered the beginning of the third phase.

The phase following storage pairs one missile to one fighter aircraft which flies a complete mission and returns to base. This type of mission is commonly called a captive carry mission or sortie. Each captive carry sortie concludes with a post-flight inspection which determines whether any of the three missile sections failed. If no failures are observed, the missile is still operational and eligible to be returned to the available missile queue. If the post-flight inspection identifies a failed section, the failed missile leaves the captive carry phase and enters the maintenance phase.

The maintenance phase begins when the failed missile arrives at the appropriate maintenance activity. Each missile section has its distinct maintenance activity due to manpower and test equipment requirements. The maintenance phase is limited to removal and replacement of failed missile sections. Repair activities are performed by the depot at Ogden Air Logistic Center. Failed sections flow through the system to depot, while missiles processed through the remove and replace activities return to the storage queue with a last-in, first-out (LIFO) inventory rule for future operations. This rule keeps the bulk of the missile stockpile in an unused or "deep storage" condition. Depot repaired sections return to the system as serviceable assets to be used in the remove and replace activities.

Finally, the total system must include a method to control the amount of captive carry flying activity each day and a method to control the number of flying days per week. The control method used incorporates a clock mechanism to stop and start flying activities.

An in-depth discussion of each phase follows.

Missile Generation Phase

Source node 1, in Figure 2-1, generates the requested number of AGM-65 missiles.[1] Each missile generated can be thought of as a transaction flowing through the Q-GERT network. Each missile transaction possesses attributes which represent some characteristic of the missile. In this case, attribute 1 assigned at source node 1 acts as a counter, incrementing by one as each missile transaction is generated. The number of missiles generated is at the discretion of the analyst. For simulation purposes, one-hundred missiles will be generated.

The conditional take-all branching from the output side of source node 1 causes the transaction to traverse both paths emanating from the node. As shown, the upper path from node 1 back to node 1 has the condition A1.LE.99, which allows transactions with a value of attribute 1 of 99 or less to traverse the path. All transactions possessing

---

[1]Node and activity numbers may not flow sequentially due to refinements and modifications to the model. This does not affect network logic.

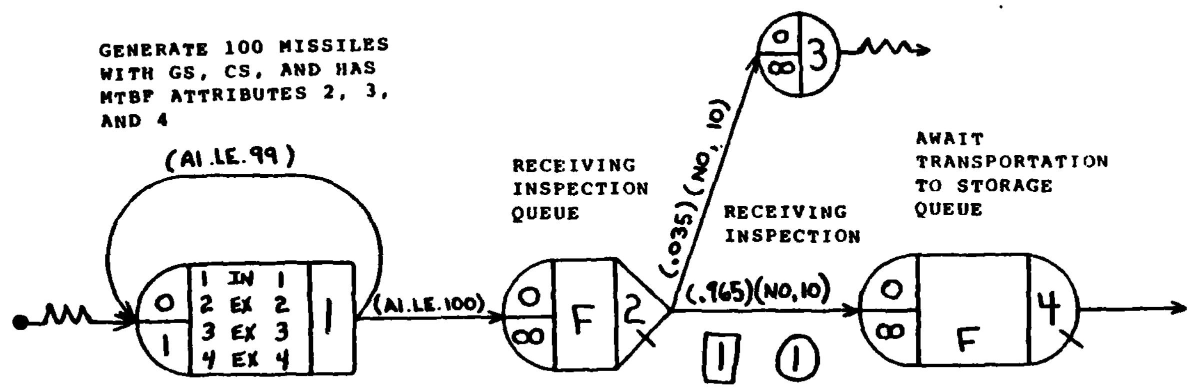


FIGURE 2-1: Missile Generation Phase

an attribute 1 value of one-hundred or less will pass over the conditional branch A1.LE.100 simulating the arrival of one-hundred AGM-65 missiles.

Each missile generated by source node 1 also receives attributes 2, 3, and 4 representing randomly selected, exponentially distributed MTBFs for each of the three respective missile sections: guidance section (GS), center section (CS), and hydraulic actuation section (HAS). Values assigned to attributes 2, 3, and 4 are found in Table 2-3 on page 57.

Upon arrival, the missiles enter queue node 2 and wait for a server in the receiving inspection (activity 1). The probabilistic branching on the output side of node 2 represents the probabilistic outcome of the receiving inspection activity. The failure values of the receiving inspection for each missile section are found in Table 2-2 under receiving inspection data. The failure value used in the network is the cumulative value of all the sections. The upper branch routes damaged, defective, or otherwise rejected missiles to sink node 3 where they exit the system. The remaining missile transactions flow through the system to queue node 4 to await transportation to storage.

TABLE 2-2

AGM-65 INSPECTION DATA

Missile Serial Number Block 00001 - 15000	Receiving Inspection	Breakout from Storage Inspection 6 Months	Breakout from Storage Inspection 36 Months
	Fails / Checks	Fails / Checks	Fails / Checks
Guidance Section (GS)	424 / 12132	149 / 2496	128 / 2527
Probability	.0349	.0597	.0506
Center Section (CS)	136 / 12132	19 / 2496	5 / 2527
Probability	.0112	.0076	.0020
Hydraulic Actuation Section (GS)	113 / 12132	46 / 2496	65 / 2527
Probability	.0093	.0184	.0257

Data summarized from AGM-65 Missile Test Description, Air-to-Ground Launched Missile (G300B) Automated Data Processing System, 8 Feb 82.

Storage Phase

After passing the receiving inspection, transactions enter queue node 4 to await the transportation to storage activity represented by activity 2 and in queue node 5 (Figure 2-2). Queue node 5 performs several functions, one of which sets attribute 5 to zero. Attribute 5 will be used later to identify missile failures during future breakout inspections. In addition, queue node 5 allows the analyst to specify a last-in, first-out (LIFO) inventory policy to ensure the last missile in from a repair activity will be used first. A LIFO inventory system keeps the majority of the inventory in an unused condition, while accumulating captive carry time on the fewest missiles possible. Activity 3 probabilistically assigns the transactions emerging from queue node 5 to regular nodes 6, 7, 8, and 9 where attribute 5 is updated to reflect a particular type of storage-induced deterioration of the missile. An attribute 5 value of 1.0, for example, indicates a guidance section (GS) failure, a value of 2.0 indicates a CS failure, 3.0 indicates a HAS failure, and a 4.0 represents a missile that has not experienced any storage-related failures. Attribute 5 and the probabilistic branching values to assign storage-induced failures are found in Table 2-2 under the six-month breakout inspection data. Queue node 10 acts as an accumulator and

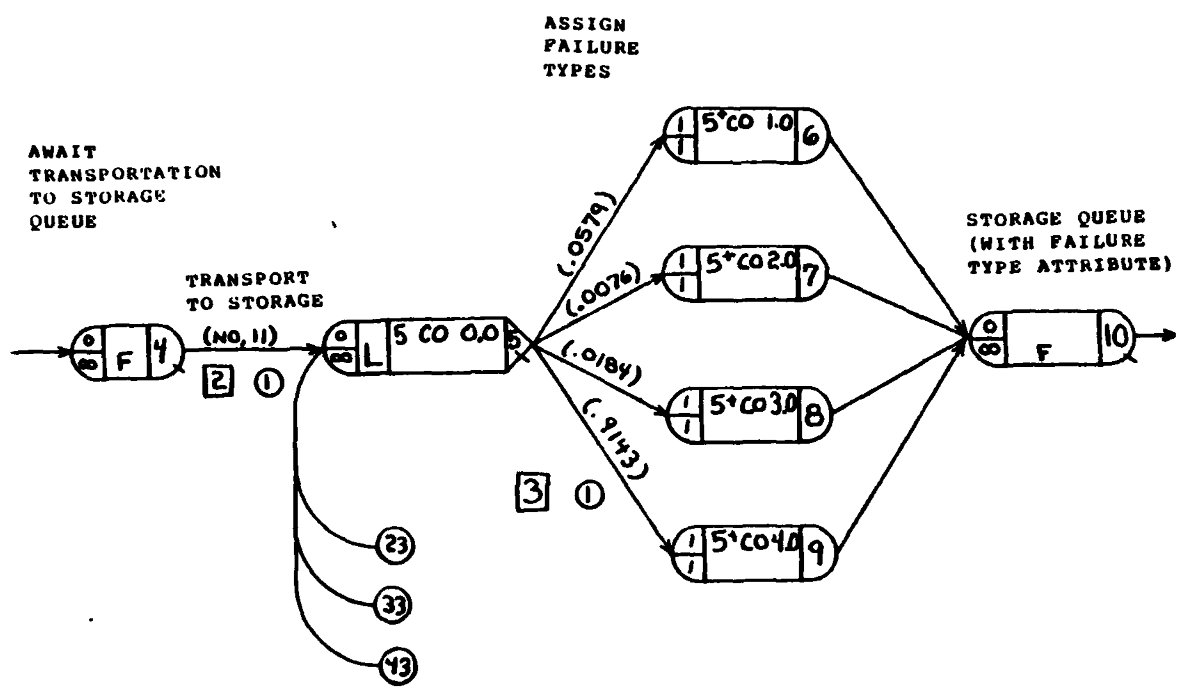


FIGURE 2-2: Storage Phase

stores the missile transactions and associated failure identifying attributes until the missiles are removed from storage.

Allocate node 12 (Figure 2-3) provides the mechanism which limits the number of missiles out of the protective storage environment. Allocate node 12 takes a missile transaction waiting at queue node 10 and allocates one unit of resource 1 to the transaction prior to passage to queue node 13. In this case, resource 1 represents the capacity of the captive carry flying activity. Since most Tactical Fighter Wings consist of several fighter squadrons of twenty-four aircraft, the capacity of the flying activity will be limited to twenty-four. Stipulating that the aircraft fly with only one missile on board, the capacity of the flying activity is twenty-four missiles. Consequently, 1 unit of resource 1 represents one "space" out of the possible twenty-four in the flying activity.

As the missile transaction, with its respective attributes and its associated unit of resource traverse activity 5 and realize regular node 14, the type of storage induced failure can be determined and the missile routed to the appropriate activity. For example, Figure 2-3 illustrates how a missile that failed a breakout inspection gets to the appropriate maintenance activity. Remember that missile transaction number 1 exits regular node 1 with

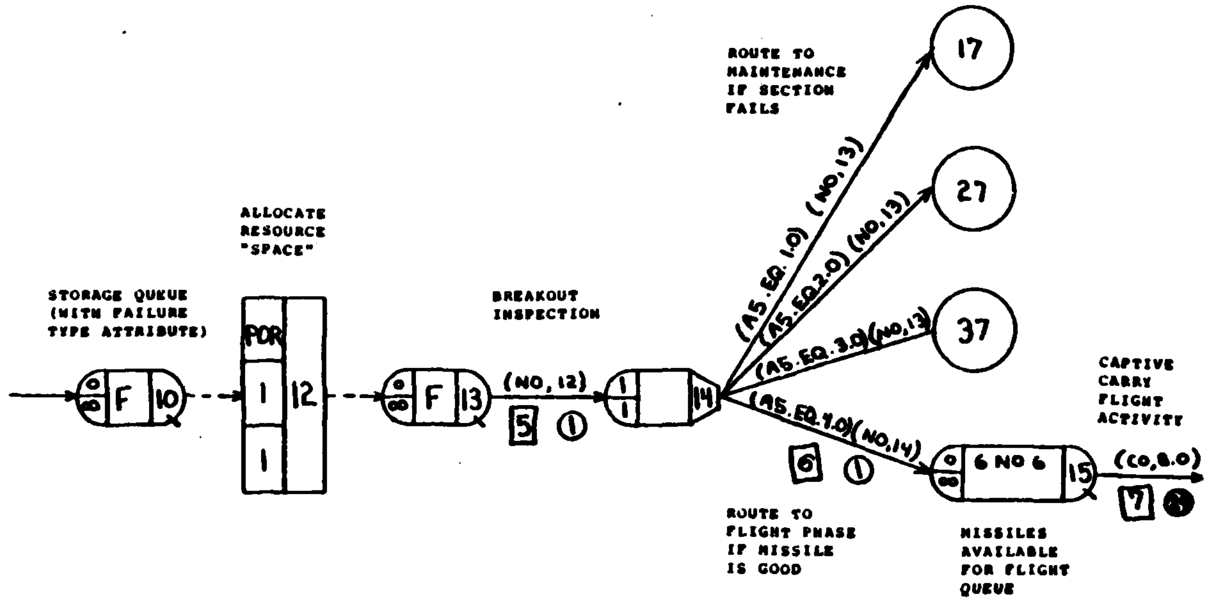


FIGURE 2-3: Breakout from Storage

three MTBF attributes represented by attributes 2, 3, and 4. The missile transaction also has a storage induced failure attribute (attribute 5 assigned at regular node 6) and an associated unit of resource 1 (assigned by allocate node 12). For illustration, assume attribute 5 is equal to 2.0 and as the transaction passes through regular node 14, encounters the conditional take-first branching, and satisfies the condition A5.EQ.2.0. This condition represents a center section failure and routes the failed missile to queue node 27 where the missile enters the appropriate CS maintenance activity. As the missile enters the CS maintenance activity, the unit of resource 1 is "freed" at free node 28 (Figure 2-4) and flows back to allocate node 12 where it will be allocated to another missile transaction.

If the missile transaction emerging from regular node 14 meets condition A5.EQ.4.0 on the lower branch, the transaction does not have a storage induced failure, flows to the available missile queue and keeps the unit of resource 1. In this manner, twenty-four missiles collect in the available missile queue (queue node 15). Those missiles failing the breakout inspection flow to the appropriate maintenance activity, and the maximum possible number of missiles remain in an unused condition in storage.

Captive Carry Flight Phase

As missile transactions arrive at queue node 15, the captive carry flight phase begins. Missiles arrive at queue node 15 (Figure 2-4) with three exponentially distributed MTBF attributes. In addition, queue node 15 assigns attribute number 6 which represents a captive carry flight duration time. Missile transactions queuing at this node wait until one of the twenty-four aircraft acting as servers becomes free.

Activity 7 determines the length of time the missile stays associated with the aircraft. The analyst controls the sortie rate for the captive carry missile by manipulating the activity duration. In this case, the missile will be limited to one sortie per eight-hour flying day.

Realization of regular node 16, with conditional take-first branching, signifies the completion of a sortie. Node 16 accounts for the captive carry flight duration and decrements the three exponentially distributed MTBF attribute values by the appropriate flight duration time (attribute 6 assigned at queue node 15). In this fashion, the MTBFs tend toward zero as the missile accumulates captive carry flight hours. The conditional take-first branching checks the values of the three MTBF attributes. The conditional branching represents the post-flight

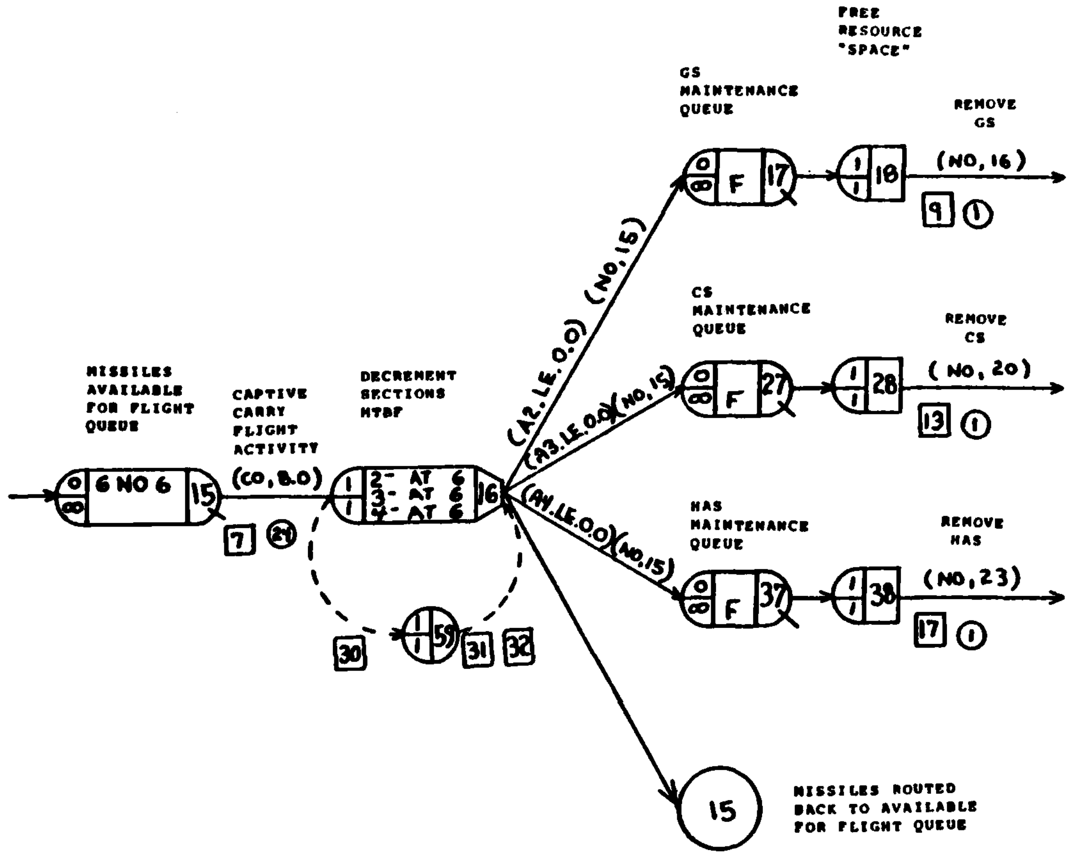


FIGURE 2-4: Captive Carry Flight Activity

missile inspection and as a MTBF attribute meets the condition of being less than or equal to zero, a failure occurs and the missile transaction and resource unit traverse the path to a maintenance activity. Routing to the maintenance activity frees the unit of resource 1 and signals for another missile to be broken out of storage.

In the case where none of the missile sections satisfy one of the A_j.LE.0.0 conditions, the missile has not experienced a failure. The missile is operationally ready and returns to queue node 15 (the available missile queue), keeps the unit of resource 1, and flies another captive carry mission. This cycle repeats until a MTBF attribute reaches zero, satisfies an A_j.LE.0.0 condition, and a failure occurs.

Once a failure occurs, the times associated with the upper three branches emanating from regular node 16 represent the time consumed during the transportation to the appropriate missile maintenance activity.

Maintenance Phase

Missile transactions routed by the post-flight inspection enter the maintenance phase at queue nodes 17, 27, and 37 (Figure 2-5). Since the three parallel maintenance activities are structured almost identically, the guidance section (GS) maintenance activity will be discussed in-depth with the center section (CS) and

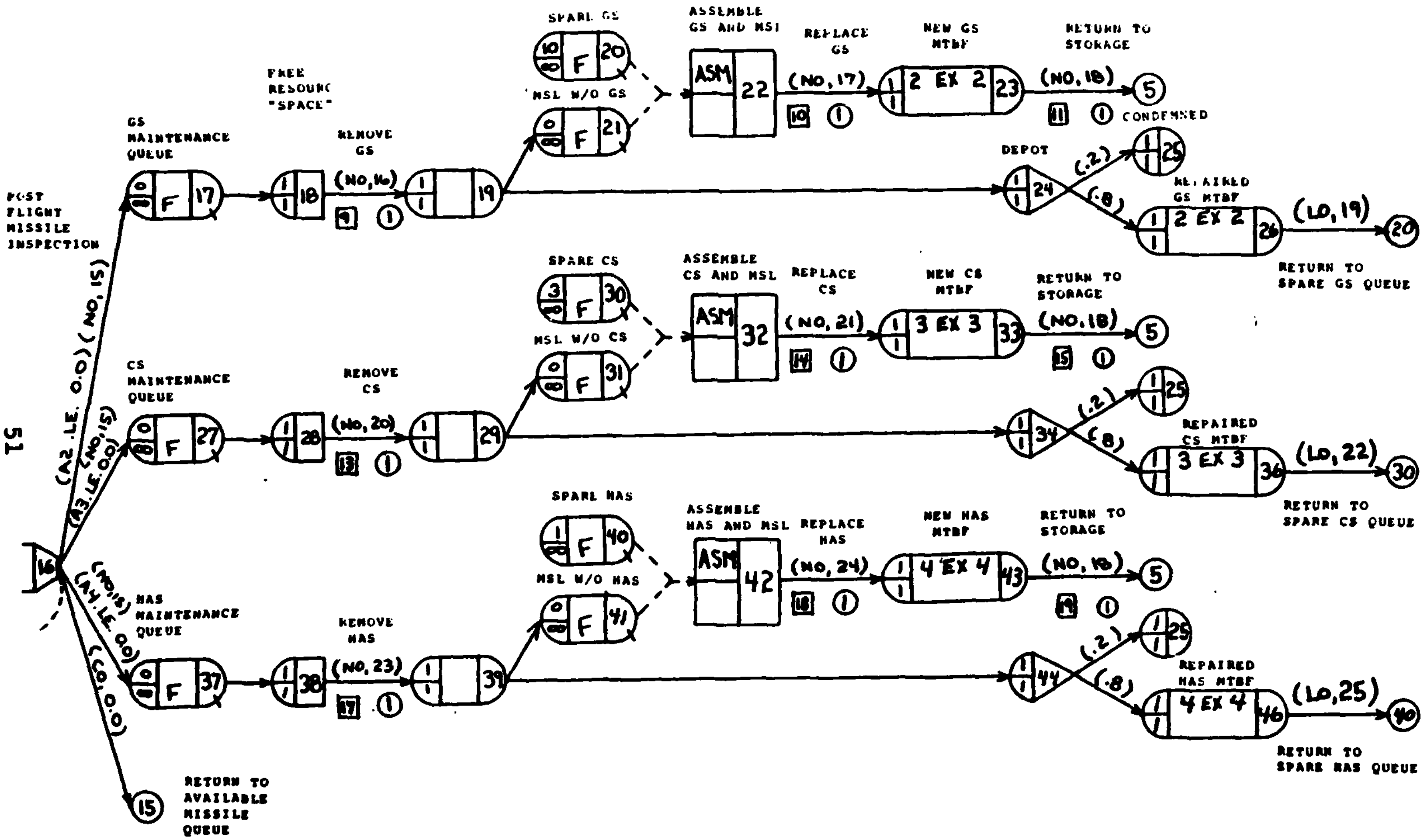


FIGURE 2-5: Maintenance Phase

hydraulic actuation section (HAS) comments limited to points of significant difference.

Queue node 17 accepts all missile transactions and associated resource units and holds them until a server in the GS removal activity becomes available. As the server removes the failed GS, transactions emerge from free node 18. As transactions emerge from free node 18, the unit of resource 1 is freed from the missile transaction, leaving only the missile transaction to flow through the maintenance activity. The unit of resource 1 returns to allocate node 12, creating a "vacant" space in the available missile queue and allows a missile to be broken out of storage.

Once the failed GS is removed, the missile passes through node 19 without the GS to queue node 21. A missile without a GS waits at queue node 21 until it can be assembled with a spare GS waiting in queue node 20. The assembly operation provided by select node 22 requires one transaction from both preceding queues and routes them to regular node 23. This activity represents the replacement operation where a new or repaired GS can be installed on a missile without a GS. The resulting missile transaction passes through node 23, acquires a new exponentially distributed GS MTBF attribute (while preserving the other two sections' MTBFs) and returns to the storage environment via activity 11. Once in the storage environment, the repaired missile will have a priority for breakout over unused missiles, as mentioned earlier.

Removing the GS from a missile during the maintenance activity creates a transaction representing only the failed missile section. The failed section flows through the network to a depot repair activity from regular node 19 to regular node 24. The probabilistic branching at node 24 illustrates the repair activity at a depot. Those GS transactions that cannot be repaired are condemned and exit the network at sink node 25. Reparable GS transactions are repaired, and acquire a new exponentially distributed MTBF during passage through regular node 26, and return to queue node 20 to await a replacement activity.

As stated above, the differences between the GS maintenance activity and the CS and HAS maintenance activities deserve comment. Removal times for the three sections vary, as well as the replacement times. Finally, the section MTBF attribute assignments correspond to the respective section at nodes 23, 33, 43, 26, 36, and 46.

Clock Mechanism

As stated in the system definition, a clock mechanism controls the amount of captive carry flying activity each day and controls the number of flying days per week.

The network depicted in Figure 2-6 controls periods of flying activity. Source node 56 generates a single transaction with the value of attribute 1 set to zero. When node 57 is realized, the attribute value increases by one and activity 30 begins. While activity 30 is in progress, node 16 of Figure 2-4 is in the network and flying occurs. Upon completion of activity 30, a nodal modification occurs and replaces node 16 with node 59 which routes all transactions back to queue node 15 and all flying activities indicated by realization of node 16 stops.

The transaction, upon completion of activity 30, enters node 58 with conditional take-first branching. The transaction traverses the top path (activity 31) if attribute 1 is less than or equal to 4. In this fashion, five days of flying eight hours and not flying sixteen hours occurs. When attribute 1 achieves a value of 5, the transaction traverses the lower branch (activity 32) from node 58 and flying operations halt for fifty-six hours representing a weekend. Upon completion of activity 31 or 32, nodal modification replaces node 59 with node 16 and flying activities resume. Completion of activity 32 causes realization of node 60 which resets the value of attribute

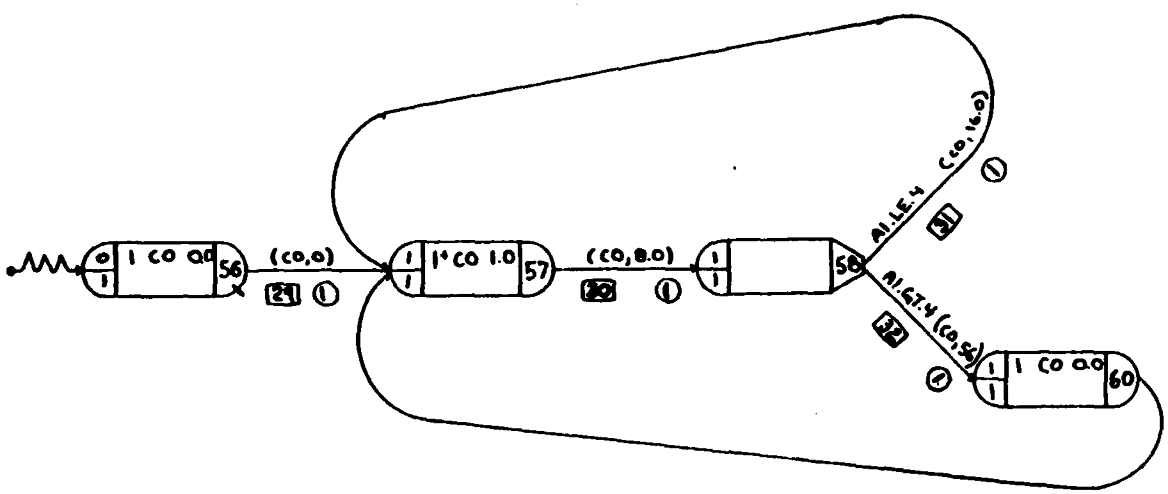


FIGURE 2-6: Network Clock Mechanism

1 to zero so that upon realization of node 60, a new week of flying activities begin.

Complete System Network

The four phases previously discussed can be combined to form a complete network as shown in Figure 2-7 on pages 58-60. Input cards to run the Q-GERT simulation are found in Appendix A.

Parameter Description

The Q-GERT simulation parameters are found in Table 2-3. Model parameters for mean time between failures (MTBF) were derived from the data contained in AGM-65A Missile Test Description, Air-to-Ground Launched Missile (G300B) Automated Data Processing System as of February 8, 1982. The MTBF for each missile section was determined from analysis of missile serial numbers 00001 through 02000 (2). Since experience has shown that failure rates of complex equipment follow a poisson curve and MTBF follows the exponential curve, we assumed the G300B computed MTBFs were exponentially distributed (7:15-16).

Transportation times and remove and replace times were based on estimates from the field and assumed to be normally distributed. Flight duration was arbitrarily set and does not necessarily represent what would occur during an exercise at base level.

TABLE 2-3

SIMULATION PARAMETERS
(in hours)

Parameters	Distribution Type	Mean	Standard Deviation
MTBF:	exponential		
guidance section		24.93	-
center section		99.75	-
hydraulic section		399.00	-
Transport time:	normal		
maintenance to storage		0.50	.056
storage to flightline		1.00	.083
flightline to maintenance		1.50	.167
Inspect time:			
receive		0.25	.028
breakout		0.50	.056
Flight duration:	normal	1.00	.250
Repair time:	lognormal		
guidance section:			
remove		0.50	.056
replace		1.00	.167
depot		-1056-	-40-
center section:			
remove		0.75	.056
replace		1.00	.167
depot		-1056-	-40-
hydraulic section:			
remove		0.50	.056
replace		1.00	.167
depot		-1056-	-40-

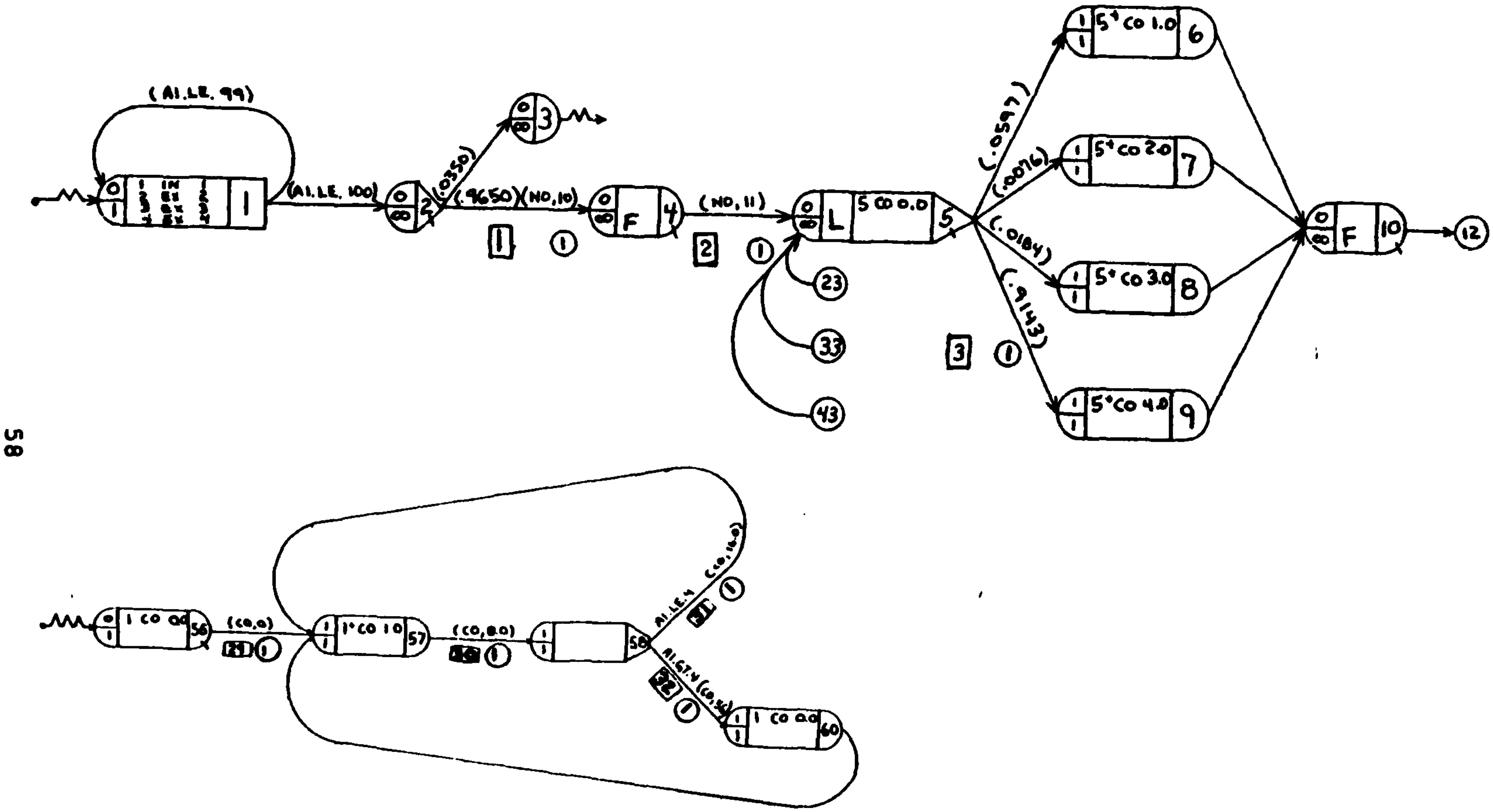


FIGURE 2-7: Complete Network

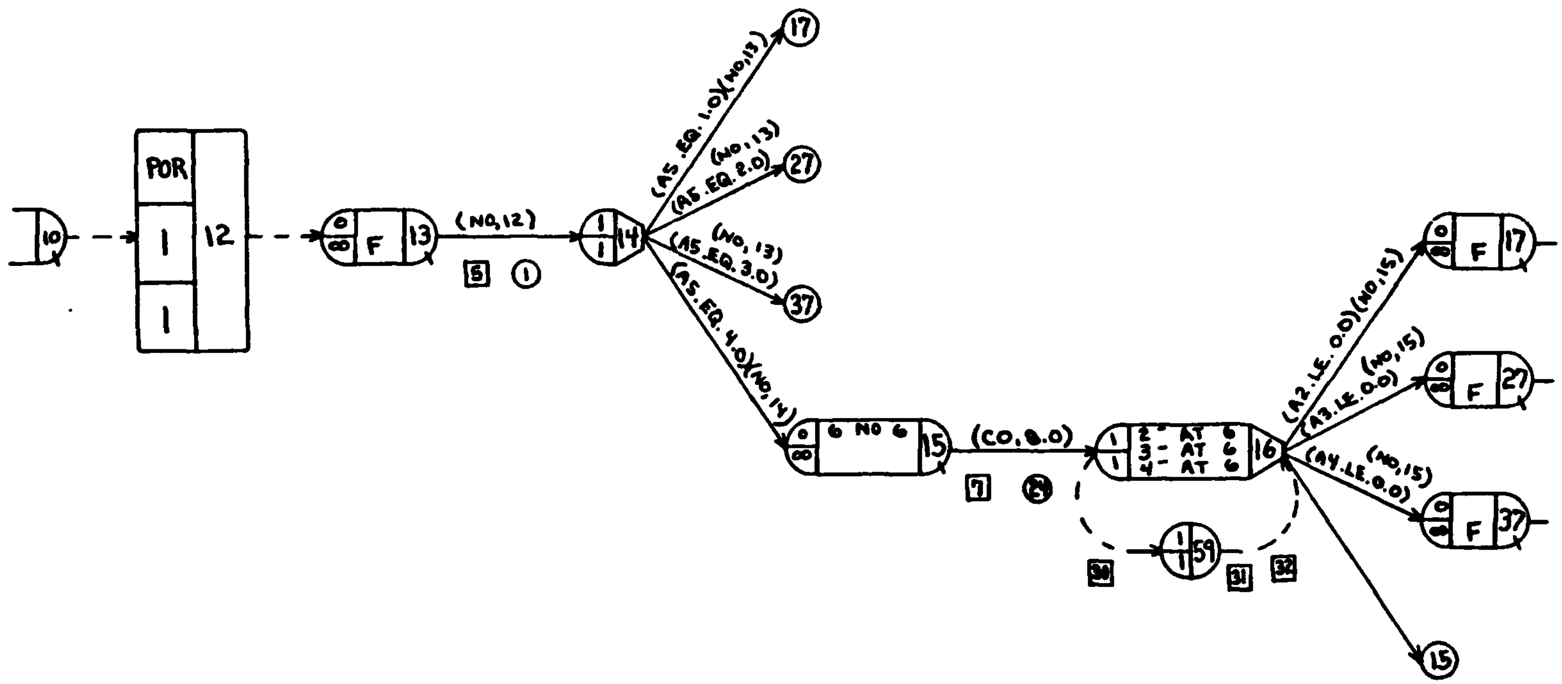


FIGURE 2-7: Complete Network (continued)

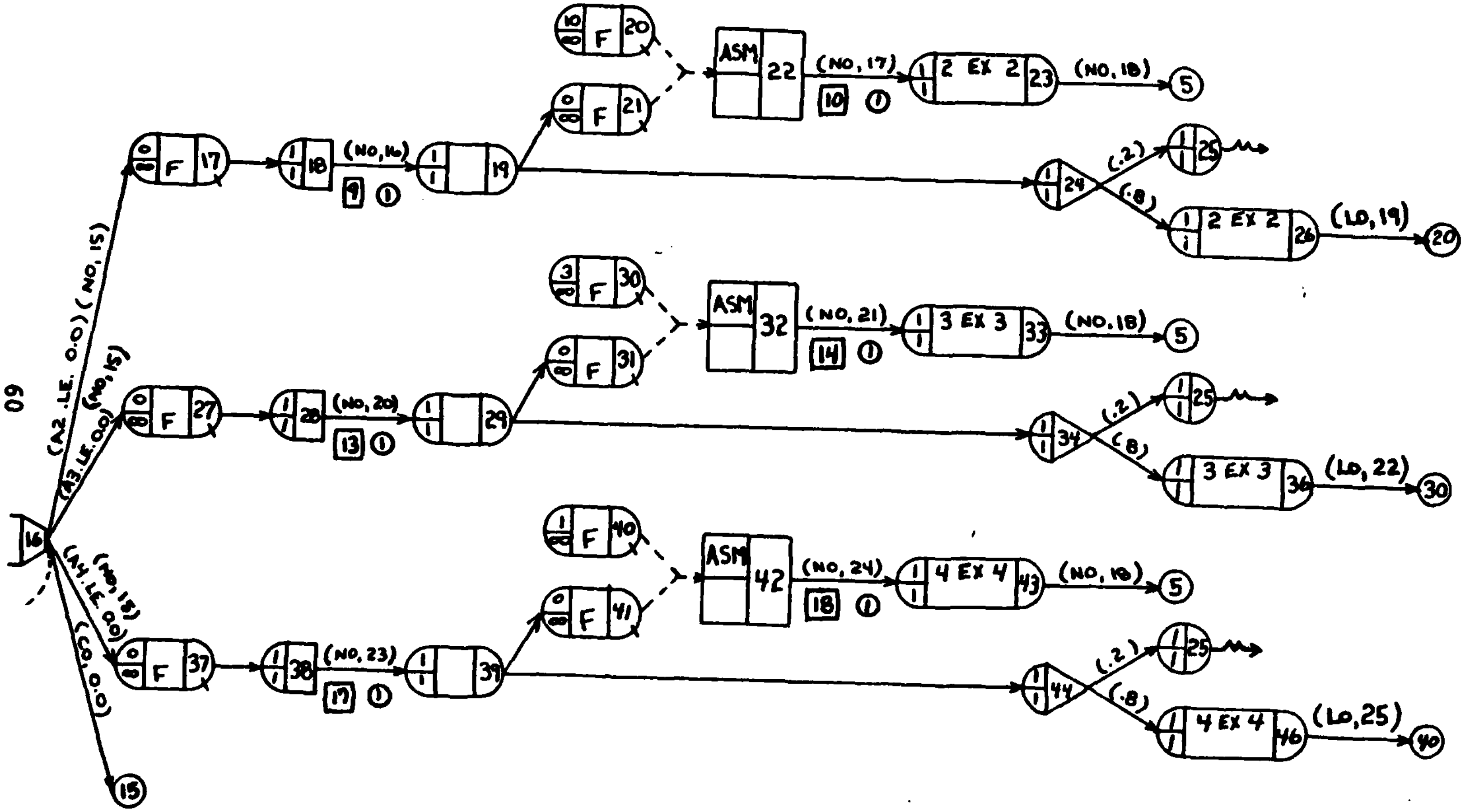


FIGURE 2-7: Complete Network (continued)

Depot repair times were also based on estimates from the field. The Air Force has determined that expected task times associated with repair actions are lognormally distributed and stated that there is overwhelming evidence that the lognormal distribution is the best descriptor for corrective maintenance repair times (15). Therefore, the lognormal distribution was used for depot maintenance repair.

This model was designed to provide flexibility to the modeler and dependent on the particular scenario at the base, the parameter values described above could be changed to represent the specific situation being modeled.

Model Output

The Q-GERT analysis program output consists of a statistical recap of all nodes and activities. Average numbers, current numbers, and average waiting times are given for queues; resource and server utilization information is given for all activities along with information concerning any ongoing activities at the end of the simulation.

Determining AGM-65 missile availability using the Q-GERT simulation relies on the availability definition provided by MIL-STD-721 as being the measure of the degree to which an item is in an operable and committable state at the start of the mission, when the mission is called for at an unknown point in time (31:2). AGM-65 missile availability (expressed as a percentage) [illegible] be determined by summing the number of missiles currently in the storage queue (queue node 10) and the number of missiles involved in the flight activity, and then dividing by the initial number of missiles at the start of the Q-GERT simulation.

$$\text{Availability} = \frac{\left[\begin{array}{c}\text{number in}\\ \text{queue node 10}\end{array}\right] + \left[\begin{array}{c}\text{number in}\\ \text{flying activity}\end{array}\right]}{\text{Initial number at start of simulation}}$$

Missiles in storage (queue 10) and the flying activity (activity 7) are considered available until determined otherwise. Missiles anywhere else in the simulation network are considered unavailable, either due to exit from the system (missiles rejected upon receipt) or involvement in a maintenance or transportation activity.

CHAPTER III

EXPERIMENTAL DESIGN

Overview

Chapter III identifies some of the many factors that can impact the availability of a missile system. From the many, two significant factors are selected to construct the experimental design used to assess the impact of varying factor levels on missile availability. Once the experimental design has been constructed, the results are discussed in greater detail in Chapter IV.

Experimental Approach

The simulation model of a missile availability system has many factors which can be independently varied. Table 3-1 lists the factors included in the network described in Chapter II. However, since most systems work according to the Pareto principle, only two factors were used in the experimental design. The Pareto principle states that a system generally has a few significant factors and many insignificant ones in terms of performance and effectiveness (28:153). Furthermore, a three-level factorial design experiment with all the factors included would require 3^{20}, or 3,486,800,000 computer runs.

TABLE 3-1

LIST OF VARIABLE FACTORS

1. Missile Arrival Rate
2. Service Time - Receiving Inspection
3. Service Time - Transporting to Storage
4. Service Time - Breakout Inspection
5. Service Time - Transporting to Maintenance
6. Service Time - Transporting to the Flightline
7. Server Numbers - Receiving Inspection
8. Server Numbers - Transport to Storage
9. Server Numbers - Breakout Inspection
10. Server Numbers - Transport to Maintenance
11. Server Numbers - Transport to Flightline
12. Server Numbers - Aircraft Available for Flight
13. Service Time - Flight Duration
14. Service Time - Post Flight Inspection and Transport to Maintenance
15. Service Time - Section Removal
16. Service Time - Service Time
17. Server Number - Post Flight Inspection and Transport to Maintenance
18. Server Number - Section Removal
19. Server Number - Section Replacement
20. Service Time - Depot Pipeline Time

The two factors selected for the experiment were: (1) mean time between failure, and (2) the spares level at the base for each section of the missile. Normally, the mean time to repair equipment would be included as a major factor affecting availability. In this model, all repair is done at the depot and repair times are not controllable at the base level. Removal and replacement of missile sections accomplished at base level involve times so small in relation to the total simulation time, and would have only a minor impact on the resulting availability percentage. Therefore, repair times and remove and replace times were excluded as factors in the experimental design.

Three levels of the factors were used in order to conduct sensitivity analysis. By varying the factors both up and down from the mean levels from the G300B data system and data obtained from the field on spares levels at the base, simulation results indicate the sensitivity of the model to changes in the parameters of the factors.

The factorial design of two factors at three levels is shown in Table 3-2. This experimental design is one where all levels of factor A are combined with all levels of factor B. Shannon states that an experiment on one factor is seldom considered adequately replicated unless the experiment had eight samples at each level (28:163-164). Naylor, Wetz, and Wonnacott say that sample

TABLE 3-2

FACTORIAL DESIGN OF TWO FACTORS, THREE LEVELS

	A_1	A_2	A_3
B_1	xxx	xxx	xxx
B_2	xxx	xxx	xxx
B_3	xxx	xxx	xxx

A is the factor for MTBF
B is the spares level factor
X is the number of replications

size can be increased in two ways: (1) the total length of the simulation run can be increased, or (2) runs of a given length may be replicated by using different sets of pseudo-random numbers (25:705). The length of the simulation run for this experimental design was kept at 480.0 hours in order to model a flying exercise in an operational scenario. Therefore, the second method stated above was used to increase the sample size.

The design shown in Table 3-2 indicates there are nine measurements for each level rather than eight referenced by Shannon. This requires three iterations of each level of the two factors with a particular random seed number for each iteration. The total sample size is, therefore, 27.

The parameters selected for each level of each factor are illustrated in Table 3-3. With reference to the Q-GERT network, Figure 2-7, the MTBF for each section is initially assigned at node 1, when the missiles are first arriving from the manufacturer. At nodes 23, 33, and 43, a new MTBF is given to missile sections that are replaced. New MTBFs are also given at nodes 26, 36, and 46 after a section has been repaired. The initial number of spares for each section of the missile is shown in nodes 20, 30, and 40 in the upper left hand portion of the node.

TABLE 3-3

SIMULATION EXPERIMENTAL PARAMETERS

Factor	Level	Value*		
		GS	CS	HAS
A (MTBF)	1	22.437	89.775	359.1
	2	24.930	99.750	399.0
	3	27.423	109.725	438.9
B (spares)	1	7	2	0
	2	10	3	1
	3	13	4	2

* The value for factor A is a mean value for an exponential distribution whereas the value for factor B is a constant

Data Analysis

The results of each level of each factor on the availability are tabulated at Table 4-1. The data obtained from the simulation runs were analyzed graphically by plotting the results of availability against the different levels of both factors. The data results, as well as the graphical analysis are described in Chapter IV, Experimental Results.

CHAPTER IV

EXPERIMENTAL RESULTS

Overview

Chapter IV discusses the initial Q-GERT computer simulation run, sensitivity analysis and the results of the experimental design and validation and verification of the AGM-65 availability model.

The AGM-65 availability model, developed through a process of embellishment and compounding of simple relationships to form complex ones, is a representation of the complex AGM-65 operational environment. The model can be used to evaluate current reliability, maintainability, and logistic support factors and their effect on missile availability as well as to predict missile availability given hypothetical or projected parameter values. As with most computer simulation models, the AGM-65 availability model can be very scenario-specific depending on modeler specification of input parameters. This chapter describes the simulation results using the scenario and parameters contained in Chapter II and the experimental design contained in Chapter III.

Initial Simulation Run

The initial simulation run was used for two purposes. First, the initial run helped ascertain if the model actually performed in the intended way. This is covered in more detail later in this chapter in the section on model validation. Second, the results from the first simulation run were used as the basis for comparison with other simulation runs which incorporate different levels of MTBF and spares. The Q-GERT Analysis Program statistical output of the initial run is included in Appendix B.

Sensitivity Analysis

As stated in Chapter III, Experimental Design, two factors were examined and were varied both up and down from the mean levels to conduct sensitivity analysis. In addition, each combination of the various levels of the factors was replicated three times. The results of these computer runs are shown in Table 4-1.

Availability is computed from the numbers contained in Table 4-1 by adding the number of missiles in storage plus the number of missiles involved in the flying activity and dividing by 100 (or the number of missiles arriving to the base). Since three replications of each situation were made, availability for each replication was added together and divided by three to arrive at an average. For example, when both MTBF and spares are at level one, the resulting

TABLE 4-1

SIMULATION RESULTS

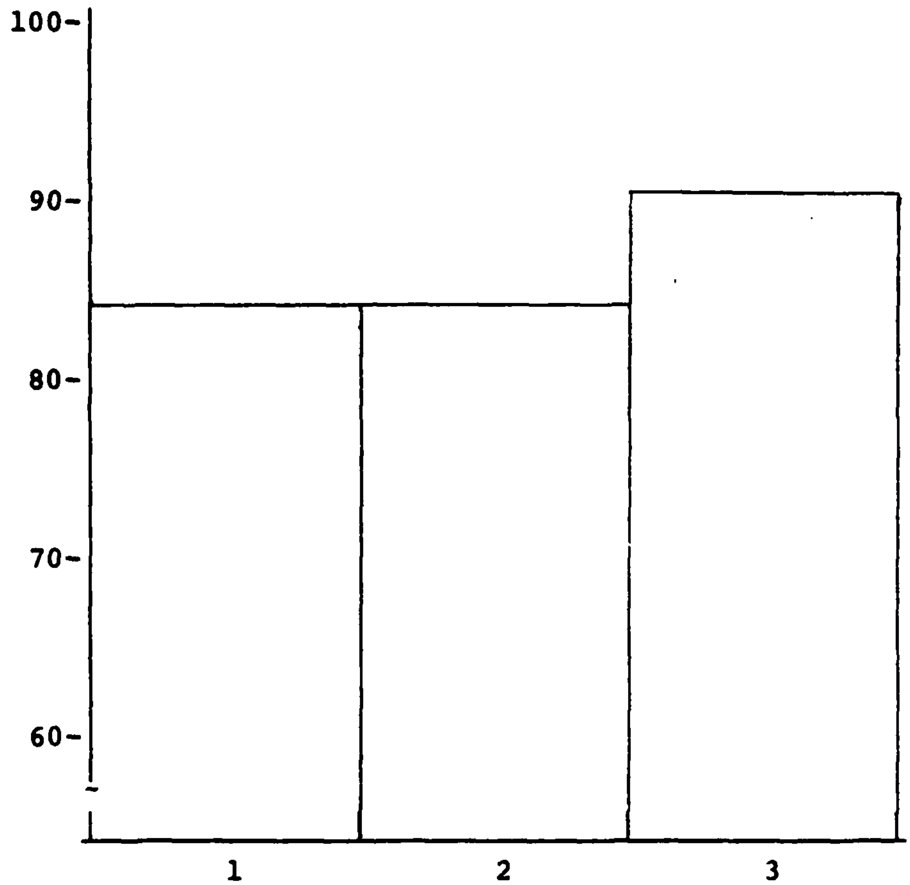
Level of Spares	Level of MTBF	Repli-cation #	Rejec-ted on Receipt	# Stored	# Flying	# in Maint.	# Con-demned
1	1	1	2	57	24	17	9
		2	1	61	24	18	5
		3	3	64	24	15	3
1	2	1	2	61	24	17	5
		2	1	62	24	15	6
		3	1	57	24	25	2
1	3	1	2	62	24	18	3
		2	1	60	24	18	5
		3	1	55	24	21	5
2	2	1	2	60	24	19	9
		2	5	59	24	21	5
		3	2	63	24	19	3
2	1	2	2	63	24	19	6
		2	2	70	24	13	4
		4	4	62	24	19	5
2	3	1	2	64	24	19	5
		2	4	67	24	15	3
		3	3	65	24	15	7
3	1	1	2	63	24	27	3
		2	3	69	24	18	5
		3	2	69	24	17	7
3	2	1	2	65	24	22	6
		2	2	72	24	10	8
		3	1	75	24	13	3
3	3	1	2	68	24	23	2
		2	4	71	24	13	3
		3	1	71	24	19	2

availability is 84.667 percent, or:

$$\frac{57 + 24}{100} + \frac{61 + 24}{100} + \frac{64 + 24}{100} = \frac{2.54}{3} = .84667$$

A visual representation of the results are shown in Figures 4-1, 4-2, and 4-3. These histograms plot the percentage of availability (the average of three replications) versus constant values for MTBF and a variable spares level. For example, in Figure 4-1, the availability percentage is displayed for the three spares levels when the MTBFs for the three missile sections are held constant at the low level. Figure 4-2 shows the resulting availability for each level of spares when the MTBFs for the sections are at a constant mean level and Figure 4-3 is the same, except the MTBF level is the higher values.

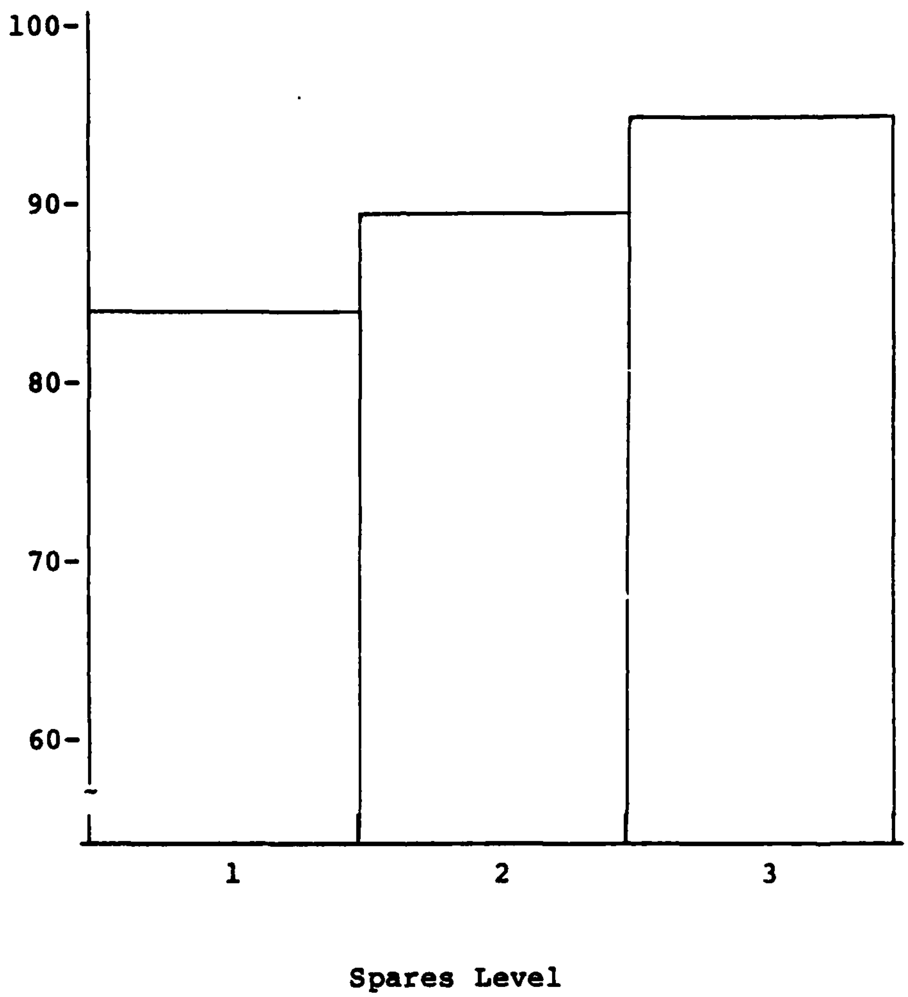
It is evident from the graphs that as the spares level increases, the availability percentage also increases, particularly when the MTBF values are at the middle and high levels. However, varying the MTBF up and down by 10 percent indicated inconsistent results (Figure 4-4). When the spares are set at level one, the availability percentage decreases as MTBF increases. Level two of the spares results in increasing availability as MTBF increases. Finally, when level three of the spares is examined, the availability first increases and then



Spares Level

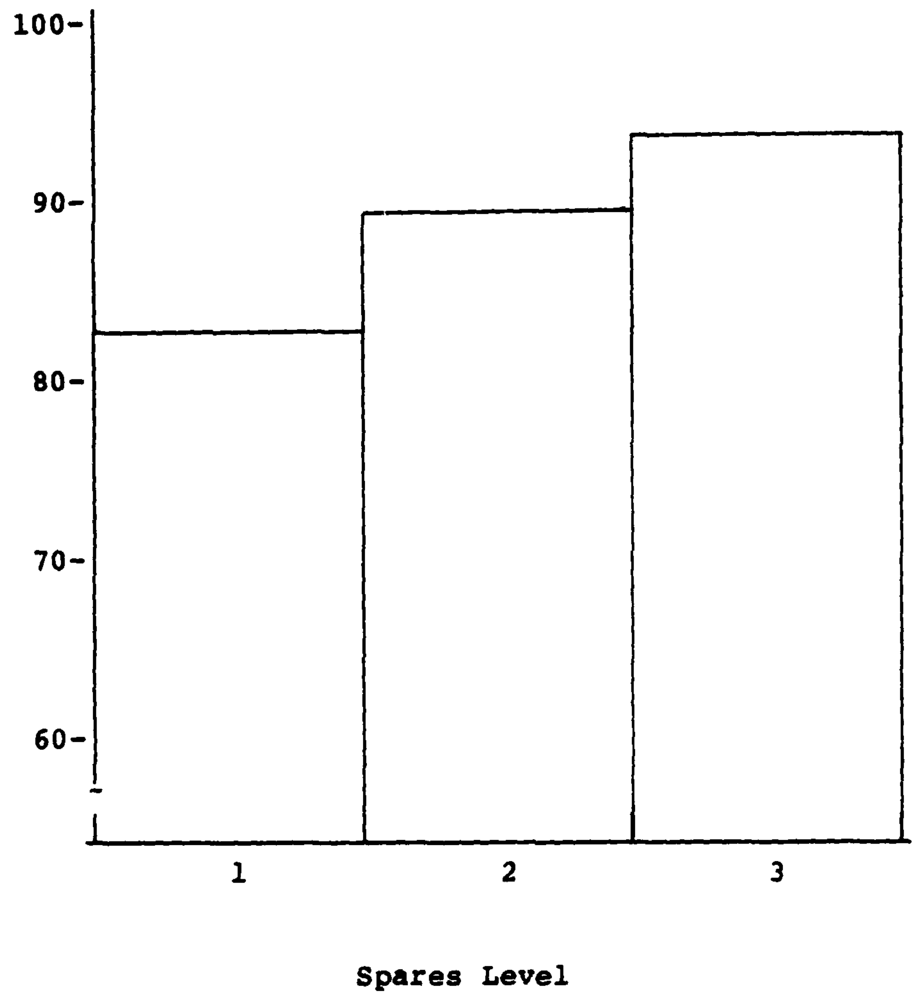
	Spares Level Values			MTBF Values
GS	7	10	13	22.437
CS	2	3	4	89.775
HAS	0	1	2	359.100

FIGURE 4-1: Availability Versus Spares Level (Low MTBF)



	Spares Level Values			MTBF Values
GS	7	10	13	24.93
CS	2	3	4	99.75
HAS	0	1	2	399.00

FIGURE 4-2: Availability Versus Spares Level (Mean MTBF)



	Spares Level Values			MTBF Values
GS	7	10	13	27.423
CS	2	3	4	109.725
HAS	0	1	2	438.900

FIGURE 4-3: Availability Versus Spares Level (High MTBF)

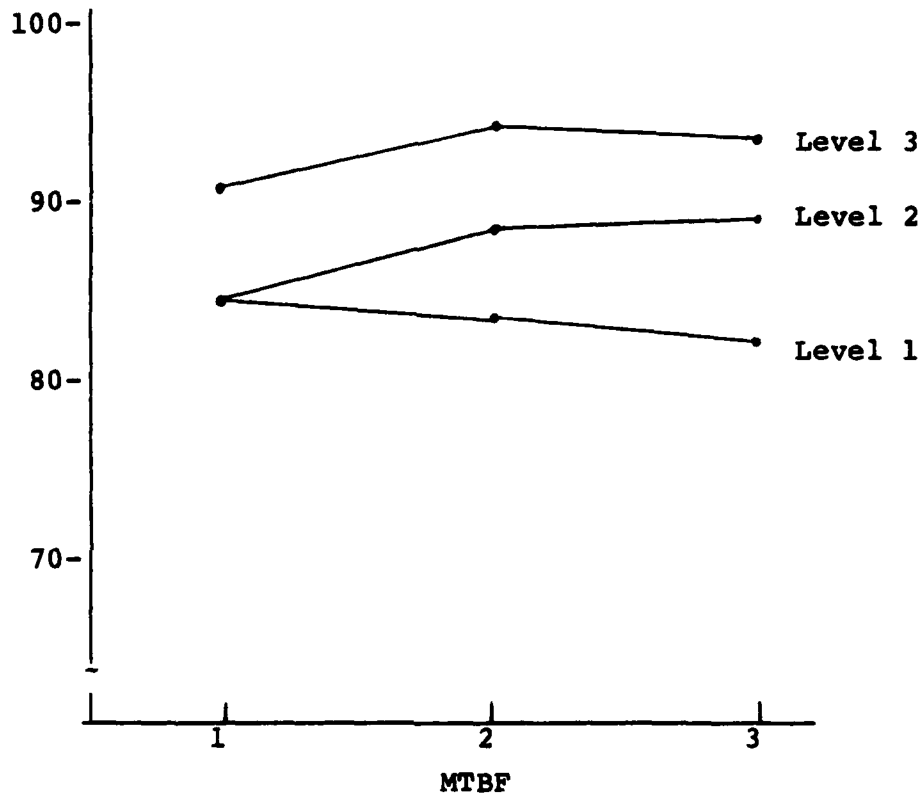


FIGURE 4-4: Availability Versus MTBF

decreases as MTBF increases. This is due, in part, to the random number generation and analyzing only three replications. Also, since the guidance section fails most often, it is the driving factor in the computation of availability. The guidance section MTBF goes from 22.437 hours to 27.423 hours and results only in slight changes in availability percentages. MTBF would have a larger impact if more missiles were flown instead of being in storage. In addition, if the MTBF for the guidance section was varied by 50 percent or more, a greater impact would be visible.

Validation and Verification

This section describes the efforts made to establish model credibility through verification and validation. Naylor and Finger feel that verifying and validating computer simulation models remains the most elusive of all the unresolved methodological problems associated with computer simulation techniques (24:92). Verification and validation involve the determination that the model performs as planned or that values are computed as they should be and the transactions occur as they should. The process of establishing that the model behaves as the real system behaves when given a set of assumptions and parameters is also a part of verification and validation (24:92).

Most approaches to verification and validation include formulating postulates and hypotheses describing the system of interest (model construction), subjecting the postulates to examination to ensure the model flow is logical and comparing the input-output transformations to the real world (33:249). Chapter II gave an in-depth description of the model construction which involves the first step of verification and validation. The output of the initial simulation run referenced earlier in this chapter was scrutinized to ensure the reasonableness of the results. In addition, the Q-GERT Analysis Program has a "trace" option that prints out the flow of all transactions from node to node and along the proper sequence of service activities (see Appendix B). Thus, the Q-GERT output satisfies the second step of the verification/validation procedure. The third and last step in the verification approach has not been accomplished, but should be undertaken in the future. This would involve testing the model's ability to predict the behavior of the AGM-65 system. Two alternatives are available to test the model's prediction capabilities--historical verification and verification by forecasting. Historical verification is concerned with retrospective predictions and was not completed because the information prepared concerning availability was aggregated data and did not represent the level of detail contained in the simulation model, making comparisons futile. Furthermore, each base operates under different constraints and scenarios and the simulation model would have to be varied to reflect these changes. Verification by forecasting deals with prospective predictions. This could be undertaken in the future if, as stated above, the model was changed to account for any variations from the original model.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

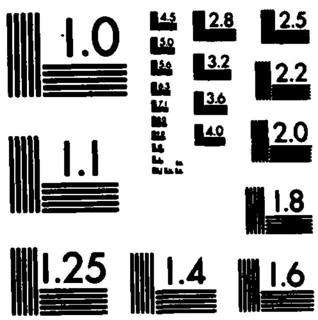
Difficulties exist in the assessment of tactical missile availability in the USAF. Air Force Test and Evaluation Center (AFTEC) analysts require a method to analyze questions concerning missile availability and missile logistics support requirements. To be successful, the method must consider the relationships between support resource, reliability, and maintainability factors. Management decisions concerning reliability and maintainability relative to missile availability must be readily evaluated. In addition, the results must be timely and easy to communicate to others not familiar with missile operations.

The primary objective of this thesis effort is to develop a model that will provide AFTEC analysts a management tool that can be used to assess USAF tactical missile availability. Chapter II has shown that after identifying and defining the significant factors in the AGM-65 maintenance and operational environment, a Q-GERT simulation model can integrate missile reliability and maintainability data needed to measure missile availability. Using data gathered from the G300B Air-to-Ground Launched Missile Automated Data Processing System, HQ AFTEC/LG, HQ TAC/LGW and ASD/TAM to form reliability and maintainability parameters, the Q-GERT model provides a concise vehicle that can be used to describe the relationship between reliability (MTBF) and maintainability (base level R & R and depot repair). Networks, such as the one developed in Chapter II, provide graphic representation of the AGM-65 operational environment and provide USAF managers a clearer picture of the overall AGM-65 availability concept.

Simulation of the AGM-65 system through the use of the Q-GERT model in Chapter IV demonstrated the ease in which the network can be used to analyze various changes in reliability and maintainability parameters. The model can be used to assess the availability of existing missile systems by inserting the appropriate section MTBF values into the model. In similar fashion, the model can be used to predict the availability of missiles still in the research and development stages by inserting engineering estimates of the section MTBFs. For example, suppose the AGM-65 were to receive an improved guidance section which had an estimated MTBF of two-hundred hours and it was necessary to measure the resulting impact on availability. By simply changing input card 1230 (see Appendix A) from

AD-A124 118 A DETERMINATION OF USAF TACTICAL MISSILE AVAILABILITY USING SYSTEM SIMULATION(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST..
UNCLASSIFIED J A HALL ET AL. SEP 82 AFIT-LSSR-59-82 F/G 15/5 NL

END
DATE
FILMED
83
DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

PAR,2,24.93 to PAR,2,200.0, the AGM-65 availability model will generate the new availability estimate using a GS MTBF of 200.0 hours.

The AGM-65 availability model can be used to analyze the impact of fluctuating spare part inventories at the base level or to assess reductions in the maintenance and repair cycle times. With the modification of one or two input cards, the model will allow managers to evaluate the effect of proposed changes in logistics support on tactical missile availability.

Recommendations

AFTEC and AFIT efforts to use system simulation should continue. Efforts should focus on extension of the AGM-65 model to include manpower and test equipment as constraining resources such as shown in Figure 5-1. An additional embellishment should include the provision for missile launch or inadvertent release similar to that shown in Figure 5-2.

The concepts behind the AGM-65 availability model can be used to model a number of USAF tactical missiles such as the AGM-88 (HARM), AIM-9L (SIDEWINDER) and many other types of weapon systems in the USAF inventory. The model could simulate any system that consists of several subsystems or sections which arrives at a base, experiences storage or age-induced degradation, undergoes some manner

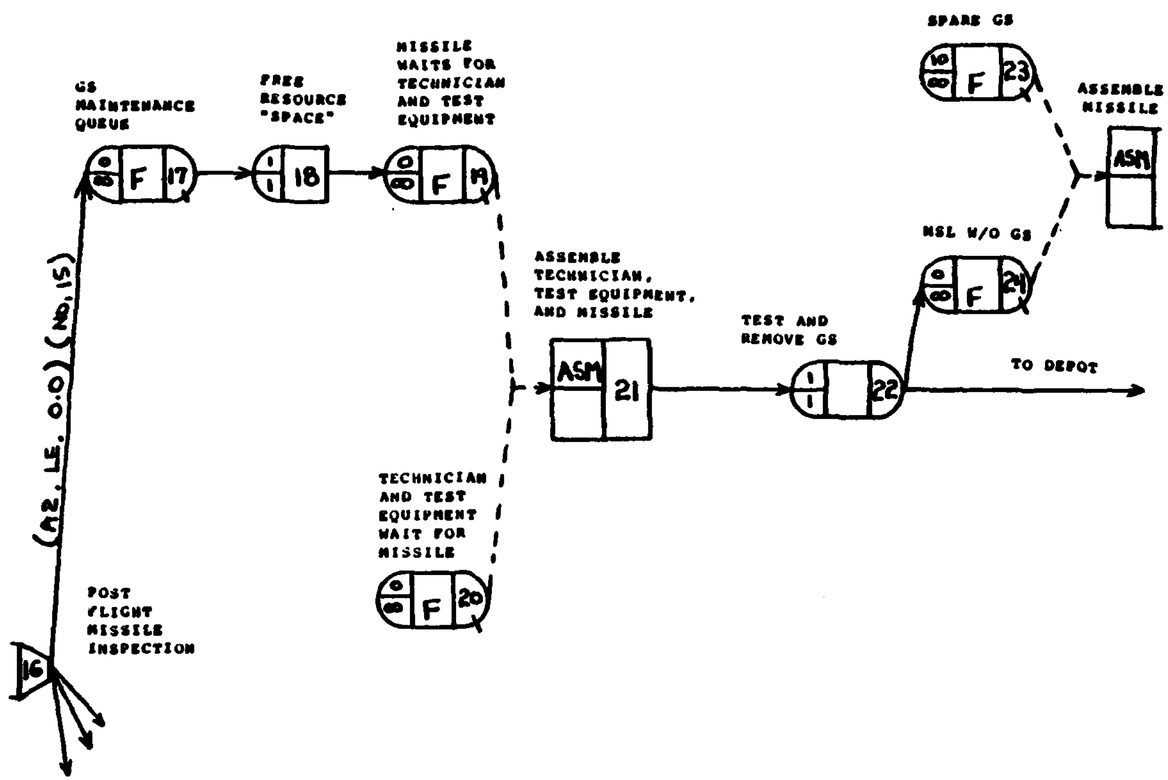


FIGURE 5-1: Manpower and Test Equipment Constraint

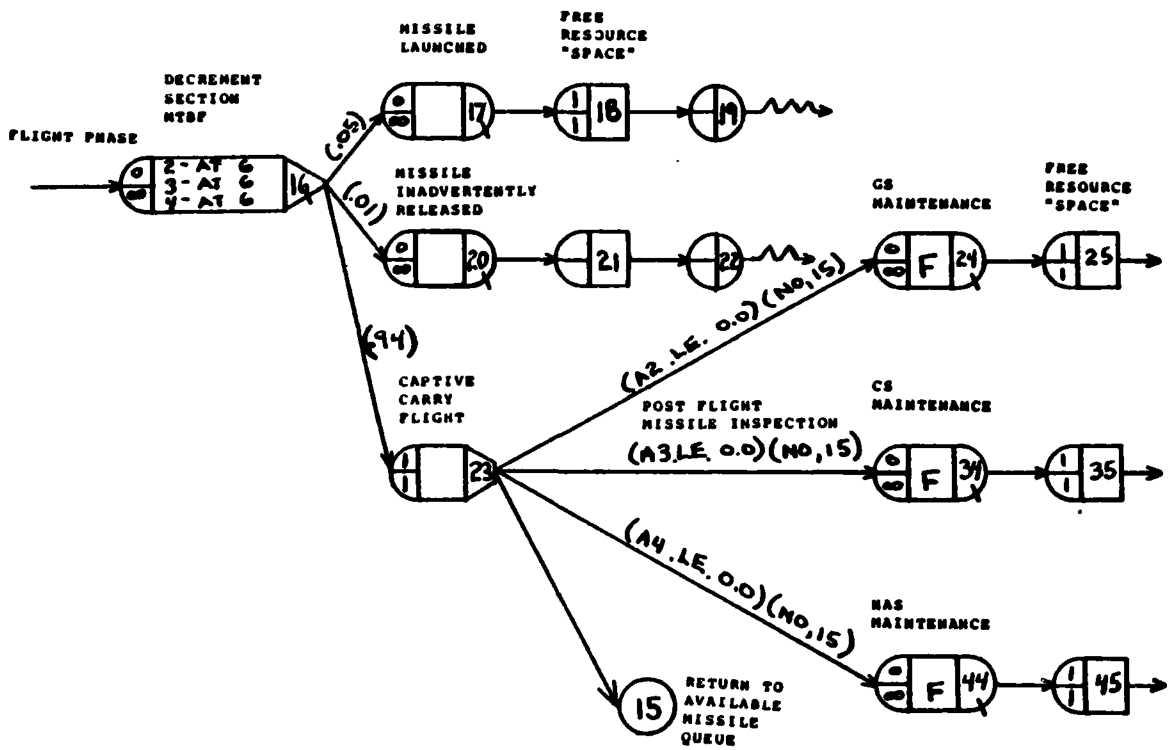


FIGURE 5-2: Launch and Inadvertent Release Scenario

of use or operation, or fails as a result of its operation and requires maintenance and repair. Modification to the existing model would be minor with the major changes limited to constructing maintenance activities to handle the appropriate number of sections. For instance, a system with five major sections would require two more MTBF attributes and two more maintenance activities than the existing AGM-65 availability model.

Based on the results of the Q-GERT simulation, it may be concluded that the AGM-65 availability model will satisfy AFTEC's need for a tactical missile availability model.

APPENDIX A

Q-GERT CODE LISTING OF AVAILABILITY NETWORK MODEL

Q-GERT Code Listing

General Project Information

```
100=JAH,CN125000.T820420,JAYHALL,CMM
110=ATTACH,PROCFIL,QGERTPROC,ID=AFIT.
120=BEGIN,QGERT.
130=*EOR
140=GEN,J/M,THESIS,7,23,1982,0,2,999,400.0,3,E,,4,(20)E4*
```

Nodes

```
150=SOU,1,0,1,A*
160=QUE,2/INSPQ,,,P*
170=SIN,3,1,1*
180=QUE,4/WAITSTOR*
190=QUE,5/STOREQ,,,P,L*
200=REC,6,1,1*
210=REC,7,1,1*
220=REC,8,1,1*
230=REC,9,1,1*
240=QUE,10/STORATTR,(10)12*
250=ALL,12,,1,1,10/13*
260=QUE,13*
270=REC,14,1,1,F*
280=QUE,15/AVAILMSL*
290=REC,16,1,1,F*
300=QUE,17/CCSMAINT*
310=FRE,18*
320=REC,19,1,1*
330=QUE,20/SPARECCS,10,(10)22*
340=QUE,21/MMOCCS,(10)22*
350=SEL,22,ASM,(7)20,21*
360=REC,23,1,1*
370=REC,24,1,1,P*
380=SIN,25,1,1*
390=REC,26,1,1*
400=QUE,27/CSMAINT*
410=FRE,28*
420=REC,29,1,1*
430=QUE,30/SPARECS,3,(10)32*
440=QUE,31/MMOCS,(10)32*
450=SEL,32,ASM,(7)30,31*
460=REC,33,1,1*
470=REC,34,1,1,P*
480=REC,36,1,1*
490=QUE,37/HASMAINT*
500=FRE,38*
510=REC,39,1,1*
520=QUE,40/SPAREHAS,1,(10)42*
530=QUE,41/MMOHAS,(10)42*
540=SEL,42,ASM,(7)40,41*
550=REC,43,1,1*
560=REC,44,1,1,P*
570=REC,46,1,1*
580=VAS,1,1,IN,1,2,EX,2,3,EX,3,4,EX,4*
590=VAS,5,5,CO,0.0*
```

Q-GERT Code Listing

Value Assignment

```
600=VAS,6,5+,CO,1.0*
610=VAS,7,5+,CO,2.0*
620=VAS,8,5+,CO,3.0*
630=VAS,9,5+,CO,4.0*
640=VAS,15,6,NO,6*
650=VAS,16,2-,AT,6,3-,AT,6,4-,AT,6*
660=VAS,23,2,EX,2*
670=VAS,33,3,EX,3*
680=VAS,43,4,EX,4*
690=VAS,26,2,EX,2*
700=VAS,36,3,EX,3*
710=VAS,46,4,EX,4*
```

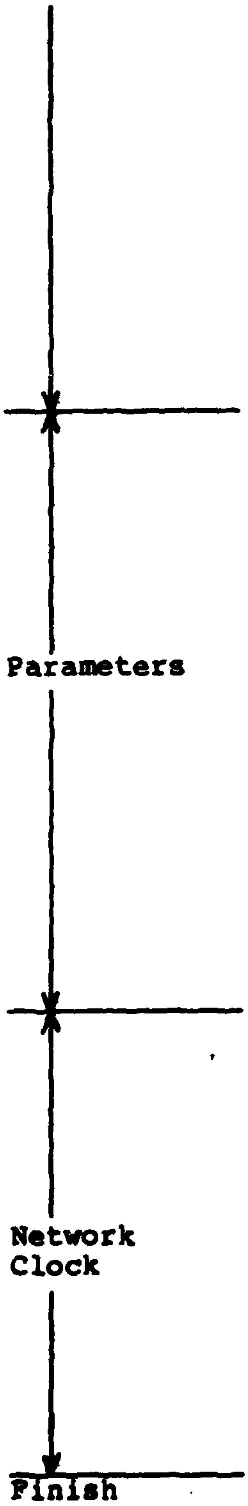
Resources

```
720=RES,1/MSLCAP,24,12*
```

Activities

```
730=ACT,1,1,(9)A1.LE.99*
740=ACT,1,2,(9)A1.LE.100*
750=ACT,2,3,NO,10,1/RECINSP,1,.0350*
760=ACT,2,4,NO,10,1/RECINSP,1,.9650*
770=ACT,4,5,NO,11,2/TRANSSTO*
780=ACT,5,6,,,3/ASSIGN,1,.0597*
790=ACT,5,7,,,3/ASSIGN,1,.0076*
800=ACT,5,8,,,3/ASSIGN,1,.0184*
810=ACT,5,9,,,3/ASSIGN,1,.9143*
820=ACT,6,10*
830=ACT,7,10*
840=ACT,8,10*
850=ACT,9,10*
860=ACT,13,14,NO,12,5/BRKOUT*
870=ACT,14,17,NO,13,6/STOFAIL,(9)A5.EQ.1.0*
880=ACT,14,27,NO,13,6/STOFAIL,(9)A5.EQ.2.0*
890=ACT,14,37,NO,13,6/STOFAIL,(9)A5.EQ.3.0*
900=ACT,14,15,NO,14,6/STOFAIL,(9)A5.EQ.4.0*
910=ACT,15,16,CO,8.0,7/FLTOPS,24*
920=ACT,16,17,NO,15,8/FLTFAIL,(9)A2.LE.0.0*
930=ACT,16,27,NO,15,8/FLTFAIL,(9)A3.LE.0.0*
940=ACT,16,37,NO,15,8/FLTFAIL,(9)A4.LE.0.0*
950=ACT,16,15,CO,0.0,8/FLTFAIL*
960=ACT,17,18*
970=ACT,18,19,NO,16,9/REMCCS*
980=ACT,19,21*
990=ACT,22,23,NO,17,10/REPCCS*
1000=ACT,23,5,NO,18,11/RESTORE*
1010=ACT,19,24*
1020=ACT,24,25,,,12/BEPINSP,,.2*
1030=ACT,24,26,NO,19,12/BEPINSP,,.8*
1040=ACT,26,28*
1050=ACT,27,28*
1060=ACT,28,29,NO,20,13/REMCS*
1070=ACT,29,31*
1080=ACT,32,33,NO,21,14/REPCS*
1090=ACT,33,5,NO,18,15/RESTORE*
```

Q-GERT Code Listing




```
11ØØ=ACT,29,34*
111Ø=ACT,34,25,,,16/DEPINSP,,.2*
112Ø=ACT,34,36,NO,22,16/DEPINSP,,.8*
113Ø=ACT,36,38*
114Ø=ACT,37,38*
115Ø=ACT,38,39,NO,23,17/REMHAS*
116Ø=ACT,39,41*
117Ø=ACT,42,43,NO,24,18/REPHAS*
118Ø=ACT,43,5,NO,18,19/RESTORE*
119Ø=ACT,39,44*
12ØØ=ACT,44,25,,,2Ø/DEPINSP,,.2*
121Ø=ACT,44,46,NO,25,2Ø/DEPINSP,,.8*
122Ø=ACT,46,4Ø*
123Ø=PAR,2,24.93*
124Ø=PAR,3,99.75*
125Ø=PAR,4,399.Ø*
126Ø=PAR,6,1.Ø,Ø.Ø,,.25*
127Ø=PAR,1Ø,.25,Ø.Ø,,.Ø2Ø*
128Ø=PAR,11,.5,Ø.Ø,,.Ø56*
129Ø=PAR,12,.5,Ø.Ø,,.Ø56*
13ØØ=PAR,13,.5,Ø.Ø,,.Ø56*
131Ø=PAR,14,1.Ø,Ø.Ø,,.Ø83*
132Ø=PAR,15,1.5,Ø.Ø,,.167*
133Ø=PAR,16,.5,Ø.Ø,,.Ø56*
134Ø=PAR,17,1.Ø,Ø.Ø,,.167*
135Ø=PAR,18,.5,Ø.Ø,,.Ø56*
136Ø=PAR,19,1Ø56,Ø.Ø,,4Ø*
137Ø=PAR,2Ø,.75,Ø.Ø,,.Ø56*
138Ø=PAR,21,1.Ø,Ø.Ø,,.167*
139Ø=PAR,22,1Ø56,Ø.Ø,,4Ø*
14ØØ=PAR,23,.5,Ø.Ø,,.Ø56*
141Ø=PAR,24,1.Ø,Ø.Ø,,.167*
142Ø=PAR,25,1Ø56,Ø.Ø,,4Ø*
143Ø=SOU,56,Ø,1*
144Ø=REG,57,1,1*
145Ø=VAS,57,1+,CO,1*
146Ø=REG,58,1,1,F*
147Ø=REG,59,1,1*
148Ø=REG,6Ø,1,1*
149Ø=VAS,6Ø,1,CO,Ø.Ø*
15ØØ=ACT,56,57*
151Ø=ACT,57,58,CO,8,3Ø/DAYSHIFT*
152Ø=ACT,58,57,CO,16,31/MAINT,,,A1.LE.4*
153Ø=ACT,58,6Ø,CO,56,32/WKEND,,,A1.GT.4*
154Ø=ACT,6Ø,57*
155Ø=ACT,59,15*
156Ø=MOD,3Ø,16,59*
157Ø=MOD,31,59,16*
158Ø=MOD,32,59,16*
159Ø=FIN*
16ØØ=*EOR
```

APPENDIX B

INITIAL Q-GERT ANALYSIS PROGRAM OUTPUT

Q-GERT Output

NODE	TRANSACTION PASSAGES
1	100
2	100
3	4
4	96
5	110
6	9
7	1
8	1
9	99
10	40
12	40
13	40
14	40
15	1419
16	336
17	19
18	19
19	19
20	10
21	10
22	10
23	10
24	19
25	5
27	4
28	4
29	4
30	3
31	3
32	3
33	3
34	4
37	1
38	1
39	1
40	1
41	1
42	1
43	1
44	1
56	1
57	16
58	15
59	1059
60	3

Q-GERT Output

RESULTS FOR RUN 3

ELAPSED TIME FOR RUN = 480.0000

	NUMBER IN Q-NODE					** WAITING TIME ** IN QUEUE
NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
2	INGPQ	2.5767	0.	99.	0	12.3683
4	WAITSTOR	2.3212	0.	46.	0	11.6059
5	STOREQ	0.0000	0.	0.	0	0.0000
10	STORATTR	64.5473	0.	72.	62	201.6610
13		.0215	0.	3.	0	.2153
15	AVAILMSL	0.0000	0.	0.	0	0.0000
17	CCSMAINT	0.0000	0.	0.	0	0.0000
20	SPARECCS	1.4073	0.	10.	0	71.3896
21	MWOCCS	2.1040	0.	9.	9	53.2045
27	CSMAINT	0.0000	0.	0.	0	0.0000
30	SPARECS	.3955	0.	3.	0	63.2794
31	MWOCS	.6555	0.	1.	1	70.4587
37	HASMAINT	0.0000	0.	0.	0	0.0000
40	SPAREHAS	.0219	0.	1.	0	10.5051
41	MWOHAS	0.0000	0.	0.	0	0.0000

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	MSLCAP	24	23.652	24	0	.340	24

Q-GERT Output

NODE	TRANSACTION PASSAGES
1	100
2	100
3	2
4	98
5	111
6	7
7	1
8	2
9	101
10	41
12	41
13	41
14	41
15	1422
16	336
17	14
18	14
19	14
20	10
21	10
22	10
23	10
24	14
25	4
27	2
28	2
29	2
30	2
31	2
32	2
33	2
34	2
37	1
38	1
39	1
40	1
41	1
42	1
43	1
44	1
56	1
57	16
58	15
59	1062
60	3

Q-GERT Output

RESULTS FOR RUN 2

ELAPSED TIME FOR RUN = 400.0000

	NUMBER IN Q-NODE					** WAITING TIME ** IN QUEUE
NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
2	INSPQ	2.5596	0.	99.	0	12.2861
4	WAITSTOR	2.4609	0.	49.	0	12.0532
5	STOREQ	0.0000	0.	0.	0	0.0000
10	STORATTR	67.6124	0.	74.	70	292.3770
13		.0203	0.	3.	0	.2382
15	AVAILMSL	0.0000	0.	0.	0	0.0000
17	CCSMAINT	0.0000	0.	0.	0	0.0000
20	SPARECCS	2.1009	0.	10.	0	100.8427
21	MWOCCS	1.5069	0.	4.	4	51.6654
27	CSMAINT	0.0000	0.	0.	0	0.0000
30	SPARECS	1.9012	1.	3.	1	304.1849
31	MWOCS	0.0000	0.	0.	0	0.0000
37	HASMAINT	0.0000	0.	0.	0	0.0000
40	SPAREHAS	.0749	0.	1.	0	419.9622
41	MWOHAS	0.0000	0.	0.	0	0.0000

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	MSLCAP	24	23.649	24	0	.351	24

Q-GERT Output

NODE	TRANSACTION PASSAGES
1	100
2	100
3	2
4	98
5	112
6	4
8	4
9	104
10	49
12	49
13	49
14	49
15	1416
16	336
17	14
18	14
19	14
20	10
21	10
22	10
23	10
24	14
25	6
27	7
28	7
29	7
30	3
31	3
32	3
33	3
34	7
37	4
38	4
39	4
40	1
41	1
42	1
43	1
44	4
56	1
57	16
58	15
59	1056
60	3

Q-GERT Output

RESULTS FOR RUN 1

ELAPSED TIME FOR RUN = 400.0000

NUMBER IN Q-NODE — ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
2	INSPQ	2.5682	0.	99.	0	12.3272
4	WAITSTOR	2.3717	0.	40.	0	11.6166
5	STOREQ	0.0000	0.	0.	0	0.0000
10	STORATTR	65.3192	0.	73.	63	279.9394
13		.0300	0.	3.	0	.3721
15	AVAILMSL	0.0000	0.	0.	0	0.0000
17	CCSMAINT	0.0000	0.	0.	0	0.0000
20	SPARECCS	2.0116	0.	10.	0	134.9505
21	MWOCCS	1.0392	0.	4.	4	35.6295
27	CSMAINT	0.0000	0.	0.	0	0.0000
30	SPARECS	.4070	0.	3.	0	70.0458
31	MWOCS	1.0142	0.	4.	4	69.5420
37	HASMAINT	0.0000	0.	0.	0	0.0000
40	SPAREHAS	.0232	0.	1.	0	11.1392
41	MWOHAS	1.0477	0.	3.	3	221.7254

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	MSLCAP	24	23.671	24	0	.329	24

SELECTED BIBLIOGRAPHY

REFERENCES CITED

1. Acker, David D. "The Maturing of the DOD Acquisition Process," Defense Systems Management Review, Summer 1980, pp. 7-77.

2. Airborne/AGE Work Unit Code Manual USAF Model AGM-65A/B. Technical Order 21M-AGM65A-06. Change 8: 23 July 1980. Published under authority of the Secretary of the Air Force.

3. Assembly, Service, and Maintenance USAF Model AGM-65A/B Missile. Technical Order 21M-AGM65A-2-1. Change 9: 1 March 1980. Published under authority of the Secretary of the Air Force.

4. Bazovsky, Igor. Reliability Theory and Practice, Englewood Cliffs NJ: Prentice Hall, Inc., 1962.

5. Beyers, Major Mel. AFTEC/LG, HQ AFTEC, Kirtland AFB NM, Telephone interview. 20 May 1982.

6. Blanchard, Benjamin S., Jr., and E. Edward Lowry. Maintainability; Principles and Practices. New York: McGraw-Hill Book Company, 1969.

7. Budne, Thomas A. "Basic Philosophies in Reliability," Industrial Quality Control, September 1961.

8. Bureau of Naval Weapons. Handbook: Reliability Engineering. NAVWEPS 00-65-502. Washington: Government Printing Office, 1 June 1964.

9. Coleman, Herbert J. "Weapons Maintainability Guidance Sought by GAO," Aviation Week and Space Technology, 16 February 1981, pp. 90-91.

10. Coppola, Anthony and Alan N. Sukert. "Reliability and Maintainability Mangement Manual." Unpublished Report, Rome Air Development Center, Griffiss AFB NY, July 1979.

11. Czajkowski, Major Anthony F. "Reliability and Maintainability Analysis: A Conceptual Design Model." Unpublished Report, SLTR 3-72, AFIT/SL, Wright Patterson AFB OH, March 1972. AD 73120.

12. Duddy, John H., Joseph J. Addison, and Stuart O. Parsons. "Maintainability, Engineering, and Logistic Engineering: Cooperation or Conflict," Logistic Spectrum, Spring 1979, pp. 16-22.

13. Friese, William C., John Florence, and Richard Engelhardt. "Development Program for an Aircraft Reliability and Maintainability Simulation (ARMS) Model." Unpublished research report No. TR 75-264, U.S. Army Air Mobility and Development Laboratory, Fort Eustis VA, July 1975.

14. Geisler, M. A. and B. L. Murrie. "Assessment of Aircraft Logistics Planning Models," Omega, Vol 9, 1981, pp. 59-69.

15. Gunkel, Richard A. "Study of Air Force Maintenance Task Times." Unpublished report, Headquarters Tactical Air Command, Langley Air Force Base VA, 1974.

16. Headquarters AFTEC, "AIM-9L Phase I, FOT&E Final Report," Air Force Test and Evaluation Center, Kirtland AFB NM, 1981.

17. Headquarters AFTEC, "AMRAAM FOT&E Draft Test Plan - Annex B," Air Force Test and Evaluation Center, Kirtland AFB NM, 20 April 1981.

18. Ireson, William Grant. Reliability Handbook. New York: McGraw-Hill Book Company, 1966.

19. Jones, William S. "Is Reliability the Key to Reduced Support Costs?" Defense Management Journal, May 1978, pp. 30-35.

20. Logistics Management Institute. Criteria for Evaluating Weapon System Reliability, Availability and Costs. LMI Task 73-11, Defense Documentation Center, Alexandria VA, March 1974. AD 777456.

21. Lowell, James R. "An Analysis of Air Force Avionics Test Station Utilization Using Q-GERT Modeling and Simulation." Unpublished report, Thesis No. 79-265T, AFIT Student at Arizona State University, December 1979. AD 019478.

22. McLaughlin, Frank S. and Robert C. Pickhardt. Quantitative Techniques for Management Decisions. Boston: Houghton Mifflin Co., 1979.

23. McMillian, Claude, PhD, and Richard Gonzalez. Systems Analysis - A Computer Approach to Decision Models. Homewood IL: Richard S. Irwin, Inc., 1968.

24. Naylor, Thomas H. and J. M. Finger. "Verification of Computer Simulation Models," Management Science, Vol 14/No 2, October 1967, pp. B-92-101.

25. Naylor, Thomas H., Kenneth Wertz, and Thomas Wonnacott. "Methods for Analyzing Data From Computer Simulation Experiments," Communications of the AGM, Vol 10/No 11, November 1967, pp. 703-710.

26. Pritsker, A. Alan B. Modeling and Analysis Using Q-GERT Networks, New York: John Wiley and Sons, Inc., 1979.

27. Riciardi, Franc M., Clifford J. Craft, Donald G. Malcolm, Richard Billman, Charles Clark, Joel M. Kibbee, and Richard H. Rawdon. Top Management Decision Simulation - The AMA Approach. New York: American Management Association, Inc., 1957.

28. Shannon, Robert E. Systems Simulation - The Art and Science. Englewood Cliffs NJ: Prentice-Hall Inc., 1975.

29. Swett, Colonel Ben H., USAF. "Reliability and Maintainability in the Acquisition Process - DOD Directive 5000.X," Defense Systems Management Review, Winter 1977, pp. 126-147.

30. U. S. Congress. House of Representatives. United States Military Posture. Statement of General David C. Jones, USAF, 96th Congress, 2nd Session, January 1980. Washington: Government Printing Office, 1980.

31. U. S. Department of Defense. Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety. MIL-STD-721B. Washington: Government Printing Office, 1980.

32. ________ Reliability and Maintainability in the Acquisition Process. DOD Directive 5000.40. Washington: Government Printing Office, 1980.

33. Van Horn, R. L. "Validation of Simulation Results," Management Science, Vol 17, 1971, pp. 247-257.

34. Zwiacher, Lieutenant Colonel John, USAF, and Major Thomas Hill, USAF. "Reliability and Maintainability." Readings for the Reliability Course 435, December 1973, pp. 1-12.

DATE
ILMED
–8