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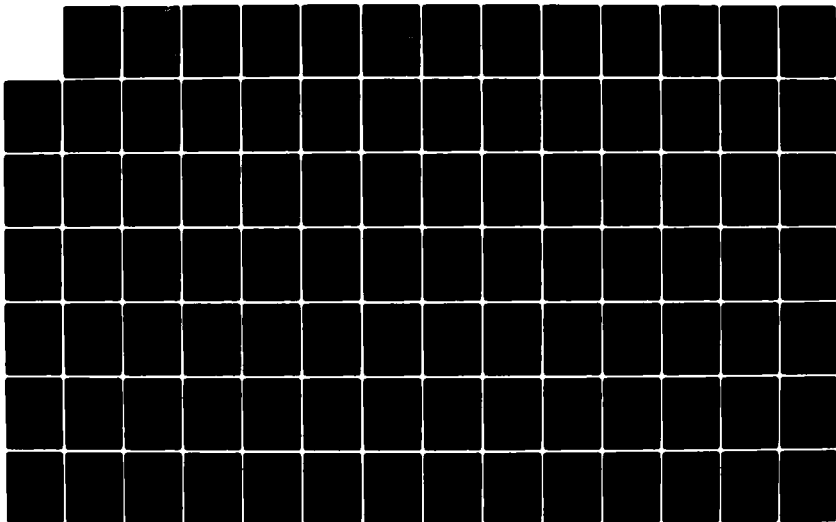
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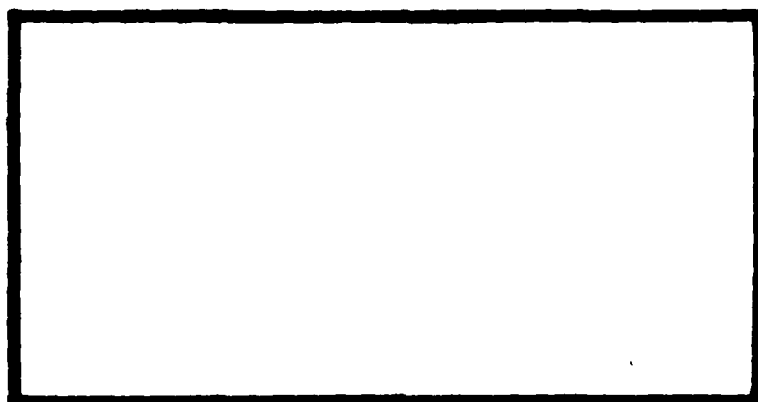


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COST ANALYSIS OF  
TURBINE ENGINE WARRANTIES

Greg T. Hellesto Captain, USAF  
Michael G. Oliverson, Captain, USAF

LSSR 85-82

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In the past, the commercial use of warranties for the purchase of turbine engines has proven cost effective. The use of warranties is now viewed by the Air Force as a viable procurement option for future Air Force turbine engine procurement. The Propulsion System Program Office (SPO) has investigated the use of warranties and recognizes the need for a system that can analyze the life cycle cost of an engine under warranty. This thesis shows the development of a decision support system in a computer model that assesses the turbine engine life cycle cost under warranty. Two versions of the warranty model were developed to provide short and long term warranty analysis and both systems were integrated into the total decision support system designed to assist SPO analysts and contract specialists to evaluate the cost effectiveness of a turbine engine warranty.

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TURBINE ENGINE WARRANTIES

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

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September 1982

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Captain Greg T. Hellesto

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Captain Michael G. Oliverson

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

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## CHAPTER I

### INTRODUCTION

In recent years, the Department of Defense (DoD) has been faced with the problem of procuring high-cost, sophisticated equipment and weapon systems within the limits of an eroding defense dollar and ever tightening budgetary constraints.

Inflation and the cost of high technology have made the difficult problem of maintaining technical and military superiority even more challenging. Efforts by DoD over the past two decades to cut costs and, at the same time, buy what is needed have precipitated the development of many new procurement concepts (13:14,15; 18:2-21; 23). One of particular importance is the concept of Life Cycle Costing (LCC) (18:4-6). This concept developed out of an awareness within DoD that the award of a contract based on the lowest price per item is not necessarily the cheapest. That is, consideration of the research and development (R&D) and production costs alone is not sufficient. Operations, maintenance and support costs that extend over the life of the item must also be included in the cost to realize the complete life cycle cost of that item (3:3; 11:12-21; 18:2-21; 24).

To motivate contractors to embrace this concept and

thereby build a more reliable product, different types of contractual incentives have been used (5:1-5; 11:18-21; 24). Most recently a great deal of interest has been directed toward the use of warranties. Under the warranty concept, an attempt is made to motivate the contractor to provide not only a better product through improved R&D, but also to provide improvements over the life of the product. As a result, the contractor is encouraged to continue to improve the reliability and maintainability after production to increase his profits (6:3; 23:1).

In the past, warranties were used in DoD primarily for the procurement of small off-the-shelf items. Their use, however, is becoming much more important in the acquisition of new complex systems. In the late 1970's, one Slay policy letter (23:1) directed DoD procurement agencies to explore the use of commercial contracting practices and implement them into the acquisition process.

Under this direction, the Deputy for Propulsion, Aeronautical Systems Division (ASD) instituted an indepth study of commercial airline engine acquisition practices. As a result of these studies, several procurement methods were targeted for further study and implementation. Paramount among these was the application of warranties to turbine engine acquisition (15; 25).

However, for ASD to effectively negotiate a warranty, the engine life cycle cost of a system under warranty must be

estimated. Establishing such an estimate should be an integral part of the negotiation process which will provide the necessary information to measure the tradeoffs between the cost and the benefits of a contract assurance. Unfortunately, an instrument capable of producing such cost estimates for turbine engines under warranty was currently not available to the turbine engine acquisition community (15; 25).

#### Problem Statement

ASD contract specialists are unable to effectively negotiate engine warranties because the information outlining anticipated warranty costs is not readily available. Current operation and support (O&S) cost data do not provide this information. As a result, the Air Force's ability to encourage contractors to improve engine reliability, maintainability and availability is seriously impaired.

#### Justification

Although the use of warranties for procurement of turbine engines within the Air Force is still in the development stage, they have been used by commercial airlines for many years. Turbine engine procurement under warranty has proven very successful in reducing operation and support costs of the major airlines (12:1-25). In order to provide the Air Force with similar cost savings, in 1978 General Alton D. Slay, Commander, Air Force Systems Command, directed that greater emphasis be placed on commercial practices, specifically the effective use of cost reducing incentives (23:1).

In 1981, Frank C. Carlucci, Deputy Secretary of Defense, re-emphasized the need to improve and update the acquisition process in DoD (10:3). His directive again identified the procurement approaches needed to incentivize contractors to attain reliability and maintainability goals and reduce maintenance, manpower and skill levels. He re-emphasized that the procurement process should include such incentives as guarantees and warranties for improving the reliability of a procurement item.

As a result of these directives, the Air Force is now in the process of developing warranties for turbine engine acquisition. However, as has already been mentioned, to effectively negotiate such warranties a competent decision support system must be developed to supply contract specialists with the specific warranty data they need during source selection negotiation. The purpose of this thesis was to develop such a decision support system.

### Objectives and Goals

#### Primary Objective

To assist the Propulsion System Program Office in the process of effectively negotiating turbine engine warranties, the researchers primary objective was to develop a decision support system that would adequately assess life cycle cost in light of warranty applications. The system had to be transparent to the decision authority and provide only required and relevant information.

### Goal One

To develop this system the researchers first determined the information necessary to assess the cost effectiveness of a warranty application. This involved identifying the elements that were needed to effectively assess cost benefits of warranties and developing a logical delivery format for the information and selection of parameters for sensitivity analysis.

### Goal Two

The researchers then selected a simulation language which was appropriate for use by ASD/YZ and then constructed a simulation model for assessing the turbine engine life cycle costs under a warranty.

### Goal Three

Once the model was verified and validated the researchers employed statistical technology to analyze simulated data and to produce the information Propulsion negotiators and support personnel need to effectively negotiate turbine engine warranties.

## CHAPTER II

### WARRANTY BACKGROUND

In both the government and commercial sectors of the American economy there is a strong and growing interest in theory, policies and procedures for assuring that products and services conform to the quality and reliability requirements of consumers. This interest was stimulated by a growing awareness of the social and economic costs to the public and to the government of inferior quality (24:16,20). Obviously, product quality and reliability are of major concern to the Department of Defense (DoD) which buys vast quantities of supplies and weapon systems.

This concern for higher quality and reliability, plus the ever increasing constraints on defense spending over the past two decades are two major factors that have influenced DoD to begin developing contract quality and reliability assurances for use in the procurement process (20:3-4). Most important among these assurances is the development and use of product warranties and guarantees (10:166). The basic assumption behind a product warranty or guarantee is that the vendor will be motivated to initially develop a quality product and then continue to improve the maintainability and reliability over its useful life. Thus, the responsibility



for the overall quality of the product remains with the contractor (3:17-19; 17:36-41; 20:25-28; 24).

Currently within DoD procurement there is an intense activity to develop and apply warranties and guarantees. The majority of the development work, however, has focused primarily on the design of contract clauses and restrictions to be included in the contract. The ability to support these clauses with data that includes the tradeoff or breakeven point between benefits gained and costs incurred is presently not a part of the decision process. The breakeven point, however, can be determined by comparing the warranty front end cost with product performance over time (3:15-18; 19:7). As Figure 2-1 illustrates, the front end cost of a warranty is the additional cost to insure improved product performance. The performance improvements include reliability improvements (4:71) that occur over the life of the product such as a reduction in manhours, parts usage rates, shipping and other related expenses. The ability to estimate and compare the life cycle cost of a product with and without a warranty provide the capability to determine the breakeven point. The breakeven estimate is the point in time when the accumulated cost curve due to improved reliability of the product under warranty and the same curve for the non-warranty option are equal (3:18; 19:9).

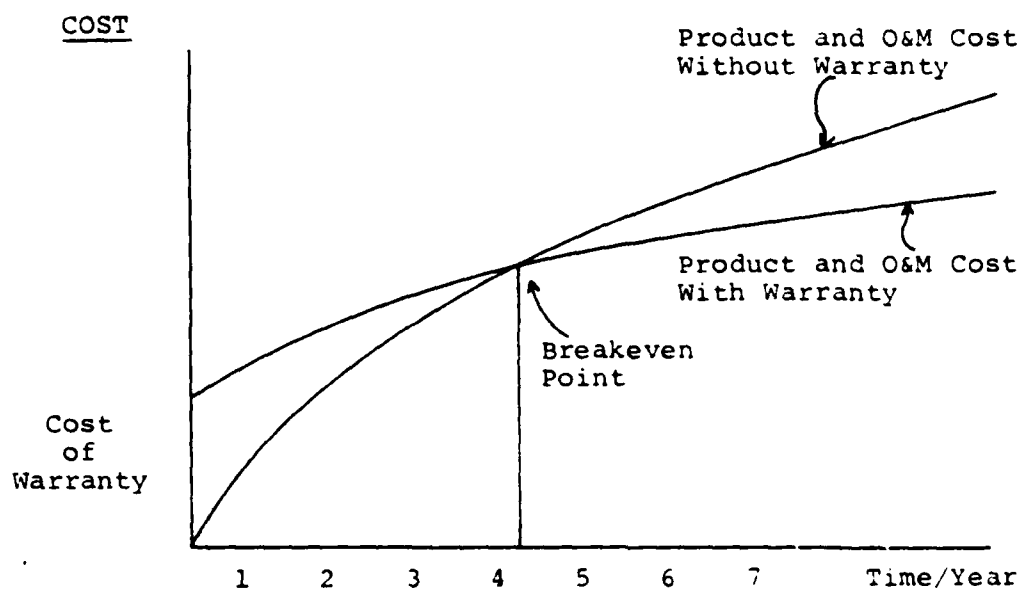


Figure 2-1 Breakeven Point

#### General Definition of Warranty

Nearly everyone has encountered warranties in some form. They range from the implied warranty received with the purchase of a toaster, to the complex reliability and performance improvement warranties used in buying equipment for the armed forces and commercial industries. To adequately discuss this subject, a uniform base of definitions is needed.

A warranty can be defined as an agreement between the purchaser and seller affording protection against "unidentifiable defects in the supplies or services provided by the seller and to limit the liability of the seller [1:9]." In effect, the warranty is actually the contractual link between

the consumer and vendor both during and after contract completion.

#### General Types of Assurances

The Uniform Commercial Code (UCC) is used by the United States Government as a guide in warranty application. Two types of warranties exist within the confines of UCC. The first is the implied warranty where the seller is providing "merchantable goods which are to be used for the purpose known to both buyer and seller [1:10]."

In the second, the expressed warranty, the parameters of performance, reliability or other measures are accurately described in some manner of documentation (1:10). It is the expressed warranty with which we concerned ourselves as this is the type currently in use and proposed for future use by the Air Force in acquisition programs.

In addition to warranties, guarantees are also used to provide similar assurances. In general usage, the terms warranty and guarantee may be considered as synonymous. However, for the purposes of this thesis, the following operational definitions were established.

#### Warranty

A warranty is intended to apply to hardware on a per unit basis. An example would be a specific engine by serial number and the parts on that engine such as fans, rotor and frames. The warranty is usually characterized by negative incentives such as a dollar penalty for less than agreed to

life lengths (2:2-26).

Because of its diversity, the expressed warranty is most commonly used warranty in DoD procurement. A wide variety of options may be incorporated within this warranty. These may range from maximum operation costs of a system over a period of time to the reliability of a specific part.

One of the first and most basic expressed warranty options used in government procurement was the Correction of Deficiency Clause. This clause was and is used as a bridge between the implied and the expressed warranty and is one of the original attempts at holding the contractor responsible for his product. This option requires the contractor to correct or repair defects discovered in items delivered to the government under that contract. The general thrust is to insure that design, workmanship and material quality are maintained at an acceptable level (3:31; 14).

As expressed warranty application techniques began to mature and expand within the government, other options were used. Three of the most commonly applied clauses or options within the expressed warranty are the standard clause, the ultimate life clause and the service clause.

The standard clause, commonly referred to as the "failure free warranty," is designed to provide protection for the consumer against defects in material, workmanship and design (20:2-26). The level of protection is expressly defined in the contract and includes the reparation require-

ments.

The life limited clause, known as the ultimate life warranty, places the burden of designing parts to last a specified lifetime on the contractor. The strength of this warranty is tied to the penalty for less than agreed life limits experienced by the parts (20:2-26).

The final option discussed here is the service clause. Just as the design and manufacture of a product requires quality assurances, so does the rework or maintenance of that product. The service warranty is simply the assurance by the maintenance or repair organization that the work done is of the expected and agreed to quality (20:2-26).

#### Guarantee

Along with the maturation of expressed warranties, guarantees also grew to be an important part of contractor assurances. However, as opposed to warranty, a guarantee applies to the aggregate population. This type of assurance applies to the shop visit rate or other levels of performance for the entire engine fleet. The guarantee may have either negative or positive incentives attached. These incentives may be a reward for better performance and a penalty for poor performance. Two of the more generally used options within a guarantee are the maximum parts cost guarantee and the reliability guarantee (2:2-26).

Within the context of the maximum parts cost guarantee, the contractor predetermines the operation and main-

tenance costs of an item and guarantees that these costs will not be exceeded. This guarantee takes into account the cost of replacing failed parts and includes positive incentives for lower per hour costs (2:2-26).

Whereas the maximum parts cost guarantee is an assurance that certain costs will not be exceeded, the reliability guarantee is an assurance of item reliability. The reliability of the item is measured by the average time or mean time between failures (MTBF). This guarantee is designed to place a requirement for an expected level of reliability, as measured by the MTBF, on the contractor.

#### Warranty and Guarantee Application

Over the past two decades DoD has developed and used warranties and guarantees for procurement. However, the use of the full range of contractual assurances has not been applied as rapidly as compared to civilian purchasers. This is particularly true for the purchase of major complex weapon systems, including aircraft turbine engines (8:4-6; 12:4,26).

#### Commercial Airline Contract Assurances

For a number of years commercial airlines have enjoyed the benefits of contractor assurances including warranties and guarantees for turbine engines. They have developed methods and organizations to both negotiate and administer the many aspects of these assurances. One major development is the concept of complete or total package procurement (TPP) (8:36).

Under this concept the airlines contract for the

engine and all supporting portions of the propulsion system such as technical data, support equipment and other assorted items as a complete package. There is one cost for the engine, and implicit in the cost is the knowledge that the engine will be provided to specification with all necessary equipment and contract assurances. The emphasis of TPP is that a single price is proposed, and included in that price are all necessary assurances and equipment. None of the items are contracted for separately (12:4,25-36).

#### Civilian vs Military Engine Procurement

DoD is not in a position to include assurances in its procurement process as extensive as those included in the TPP. Obviously, mission requirements put the government at a disadvantage when trying to apply the more inclusive type warranties (12:3-5; 16:45-67). Two major disadvantages for DoD when negotiating a turbine engine warranty include the inability of the contractor to predict engine usage parameters and the restriction placed on DoD negotiators putting them in a less competitive position (22).

#### Engine Usage (Civilian vs Military)

An estimate of turbine engine reliability in the commercial airlines is easily determined and monitored. In commercial flying rarely are normal engine operating limitations pressed or exceeded. The operating environment of the engine is steady and predictable, making it comparatively simple for the manufacturer to study the operation and main-

tenance procedures and thus specify the warranty parameters (12:4,26-28).

In contrast, Air Force contractors have difficulty in closely predicting the scale and variety of parameters of an engine when used in a fighter type aircraft. Because of the Air Force mission, this engine has a much higher probability of pressing or exceeding normal operating limitations thus making estimates of engine reliability rates difficult. This problem has made contractors skeptical and in most cases made both the military and the contractor unwilling to consider a warranty (15).

#### Procurement Methods (Civilian vs Military)

The second major advantage airlines have in buying an engine under warranty involves the procurement methods they may use. The commercial airlines enter all negotiations in the true spirit of free enterprise. They may bargain and barter with the supplier and in effect auction the price down. In its purest sense this is true competition (8:1-10; 12:5-17).

The Air Force, on the other hand, is restricted to a less than competitive position by the Defense Acquisition Regulation (DAR) (22). This document restricts the Air Force from bartering or auctioning down the price of a contract, and overall, limits the latitude the Air Force has in the entire negotiation process. These restrictions have historically made the up front cost of a warranty too expensive.

For these two reasons, warranties and similar type



assurances were not used by the Air Force for many years. However, in the late 1960's and through the 1970's, the defense dollar began to shrink. With a tightening defense budget, DoD began to look more closely at its acquisition process in order to meet its needs. The Air Force and other defense organizations began to realize that operations costs were as much or more of the total life cycle cost of the item as were the acquisition costs. Studies proliferated in the areas of cost analysis, life cycle cost and cost/benefit tradeoffs with the idea of applying contractor assurances wherever possible. One result of these studies was the recognition of the commercial success of warranty application for turbine engine procurement (25). The possibility of using contractor assurances such as warranties and guarantees began to appear to be a viable option for acquiring the high cost turbine engine technology needed to meet the needs of the Air Force.

#### Development of ASD Contract Assurances

In December 1978, General Alton D. Slay, Commander of Air Force Systems Command, directed that "more effective... cost incentives" be used in acquisition of weapon systems (23:1). This directive was interpreted, in part, to include the use of warranties for all major system and subsystem procurement (15). General Slay's policy letter initiated many acquisition concept studies by Air Force organizations that were involved with developing and buying weapon systems.

Included among these studies were those done by the Deputy for Propulsion of the Aeronautical Systems Division for turbine engine warranty application (15).

In addition to the Slay directive, emphasis for the need of contractor assurances was provided by the Carlucci initiatives in 1981. Initiative number 16 re-emphasizes the need for "contractor incentives to improve reliability and support [7:3]." This was interpreted to be high level reinforcement and administrative encouragement of the action already taken by the turbine engine acquisition organization (15). The contractor assurances under development were specifically directed at improving system reliability and reducing support costs. Both the Carlucci initiatives and the Slay policy letter have provided the direction for developing innovative and cost reducing procurement methods. The emphasis in both directives is on increasing system reliability and support with heightened contractor involvement.

Following the Slay and Carlucci directives the interest in developing contractor assurances such as warranties grew rapidly within ASD. They realized, however, that they knew very little about the subject; and, as a result, several studies were conducted. These studies included a review of contract assurances used by Delta, Eastern and United Airlines and those used by turbine engine manufacturers including General Electric, Pratt and Whitney and Rolls Royce. This initial research was a major step forward in developing a

commercial type warranty/guarantee package. It was important because it provided ASD with an indepth view of the manufacturers responsibility for the life cycle performance of his product and how this responsibility was carried forward by the use of warranties. The interest in engine warranties in the Air Force has continued to increase with the development of new methods of warranty/guarantee application and the modification of existing commercial contractor assurances (25).

#### Warranty and Guarantee Benefits

The airlines have experienced a great deal of success with turbine engine warranties. Through their use, engine reliability has increased thru providing the airlines with savings over the life of the engine. The airlines found that as the cost of a warranty increased so did the reliability of the engine and that over time this higher reliability resulted in savings (12:4,26-37).

With the success the commercial airlines have had with warranties and guarantees, the question still remains as to whether or not these types of assurances can be developed for use by ASD; and, if so, what benefits will be gained. In response to these questions, it was proposed that contract assurances similar to those used by the airlines could be developed and that a contract package, including both warranties and guarantees, would provide three general improvements to the Air Force turbine engine acquisition program (12:26-37;

15; 26).

First, it would improve the reliability of the product. Based upon the reliability improvements realized by the airlines, if similar type assurances were developed and properly negotiated, product reliability should improve at a savings to the Air Force.

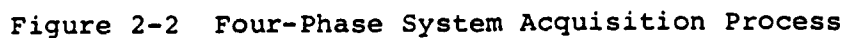
Second, a warranty would fix the cost of ownership. This means it would specifically outline the vendors responsibility for product costs during and after production and place ceilings on the different life cycle costs of the engine. These cost ceilings would apply during the early stages of procurement when the vendor is supplying training and equipment while the government is establishing self sufficiency. It would also include a ceiling on government operation costs and, most important, place a ceiling on the cost of spare parts to support the operation of the system (12:26-37; 15; 25).

Finally, warranties would reduce the cost of engine ownership. Just as good design leads to a good product, continuing design work combined with historical operating data could provide further improvement. Through design improvements overall system life and reliability would increase, and the engine shop visit rate would decrease providing more savings to the government (12:26-37; 15; 25).

Hopefully, this brief look at the general functions of a warranty or guarantee in turbine engine procurement has

## System Acquisition Cycle

### \*Negotiation Process



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that will best meet the need which is followed by the definition of the base line requirements for such a system.

The acquisition process then moves into the validation and demonstration phase. Those systems that have met the base line requirements are further studied. Within this phase, system requirements are more closely identified and defined. This narrows the field to perhaps two or three contractors whose designs meet the specifications. Prototypes may be developed to demonstrate the validity of the particular design for meeting the government's need. At the end of this phase, one design is selected for full scale development (10:574).

In the full scale engineering development phase, the selected design is developed in even more detail than in previous phases. Also, specifics for further system development and construction are worked out, and the production contracts are formalized (10:575). With the system in detail form and the contract for production finalized, the system then moves into the final phase (10:575).

Just as it states, within the production and deployment phase, the new system goes into production and is distributed to the user (10:575). Also throughout the phase, follow-on production may be contracted and engineering improvements may continue during the production and use of the product.

Contract negotiations occur during all four phases of the acquisition process (10:562). From the conceptual phase,

where many proposals may be considered, to the development and production phases of the final system, where only one proposal is considered, contracts may be negotiated and renegotiated as the system develops or as changes occur. The nature of this negotiation process is discussed in the next section.

#### The Negotiation Process

When the need for a new weapon system is identified and initial acquisition funds are allocated, the government prepares a Request for Proposal and submits this document to interested contractors. The contractors respond to the request by designing a system that meets government specifications and submit their proposal to the government. These proposals are reviewed by government contract negotiators and technical support personnel; and the source selection process begins.

The technical support team composed of engineers, logisticians, budgeteers and managers evaluate each contractor proposal. For an initial or intermediate contract, in the conceptual or validation phase, members of the team interact with contractors to clarify any differences between the contractors' proposal and government specifications. Each proposal is rated according to how well it meets the government specifications. Those that are close to the anticipated cost, and can meet the system requirements, enter the negotiation and bargaining phase of the negotiation process (25).

There are four main groups of people involved in the negotiation and bargaining process. They are: the government negotiators, the contractor negotiators, the government support team, and the contractor support team (25). The bargaining process in which these people are involved can be considered a serious complicated game of proposals and counter proposals. In the bargaining game, only the negotiators are allowed to talk to each other. These people are familiar with the rules and strategy of the game but not with the technical specifics of the product. It is the responsibility of each of the support groups to continually provide the technical information needed for effective negotiation (22:148).

Hopefully, through the bargaining process, a proposal will be made that is acceptable to both the government and the contractor. That proposal then becomes an agreement between the government and contractor. The final authority, however, for source selection decision is that person designated by law or policy to be the final decision point. This person will make, on recommendation of the proposal evaluation and agreement, a decision on the winning contract (22:149).

This summary of the negotiation process indicates the general intent of the negotiation sequence. It should be clear that for a warranty evaluation the evaluators are in fact the support group. They are the logisticians, contract buyers and program controllers who are most familiar with the process itself. However, it is the negotiator alone



who is aware of the rules and must develop the overall negotiation process.

#### Warranty Application

Having looked at the negotiation process itself, the next question is when is the warranty negotiation started during a system life cycle? The simple answer to this question is that the warranty can be applied either early or late in the acquisition process (16:4-5). A look at each, with their benefits and drawbacks is necessary.

As an example of early application, we assume that the acquisition process is at the point when the government is considering several contracts and is in a fairly good negotiating position. Most likely warranty negotiation would occur during source selection, where all the contract proposals are under consideration. With several contractors bidding against each other, the government would have the advantage of obtaining a relatively good price under acceptable conditions. The only serious drawback would be that it is early in the program and engine specifications are not well known. This makes actual price level setting more difficult.

If a warranty is negotiated during the development and production phases, it is considered a late application. The main advantage of such an application would be that the hardware would have already been developed and firm data would be available on failures and reliability. However, a strong disadvantage to such an application is that only one

contractor would be available to negotiate the contract, placing the government in a relatively poor negotiating position (15; 25).

Once the decision of time phasing has been made, the next step is to provide the information required for actual negotiation of a warranty. The entire information base can be constructed from three pieces of information. The first is the total life cycle cost without the additional costs of warranty. The second is the life cycle cost with a warranty option and the third is a comparative analysis of each, thus providing the breakeven point (15; 25). The breakeven point, as previously defined, is the point in time when the cost/benefits of the warranty and non-warranty option are equal. Therefore, by knowing the two LCC estimates and the breakeven point it is possible to determine whether a warranty will provide protection for the government or be a waste of federal funds. Simply stated, if the breakeven point occurs before the end of the systems life cycle, the application will be favorable to the government.

The data used to analyze the costs and benefits of a warranty are provided by both the government and the contractor. Contractor supplied data have been the backbone of government acquisition work for a number of years (15). The development work done by the contractor is extensive and specifically directed towards providing data in a form necessary for cost analysis. It is assumed that the data supplied in a proposal

will not be biased as the competition and contractual factors of a negotiation tend to keep the contractor within bounds to protect himself and also gain the contract.

Under the assumption that all data necessary are available from the contractor, there exists a need to assimilate that data into information to support the decision process. ASD has developed a large data base for the application of turbine engine warranties and guarantees without fully assessing LCC and breakeven points. Remedying this serious deficiency in the warranty application process was the target of this thesis. The researchers attempted to develop and implement a decision support system that assesses the warranty breakeven point and provides the information necessary to negotiate a turbine engine warranty.

## CHAPTER III

### METHODOLOGY

This chapter illustrates, in detail, the route or methodology used to accomplish the objective and goals of this research effort. It outlines a three stage process which allowed the researchers to produce a decision support system (DSS) that would assist in the evaluation of engine warranty options.

The first stage involved working with the ASD Propulsion SPO to conceptualize the O&S system and to identify the elements that define and bound the system. During the second stage an experimental design was developed, which required the creation of a simulation model of the O&S system, verification and validation of the computer model, and sensitivity analysis concerning how various model parameters effect O&S system behavior. The final stage involved the integration of the simulation model into the decision support system (DSS).

#### Conceptualization

##### Engine Operations and Support System

As previously indicated, the purpose of this research effort is to provide the Propulsion Deputate with a tool for evaluating the cost tradeoffs between warranty and non-war-

ranty options for engine procurement. To meet this objective, the researchers needed to gain a thorough understanding of the components of the O&S system as well as understand their interactions.

System Boundaries and Definition. To gain the insight and background necessary to effectively analyze and model an engine O&S system, the researchers consulted with logisticians and contracting personnel (15; 25) in ASD/YZ. Their experience and expertise with the O&S environment as well as their previous involvement with engine LCC models, provided the basic framework for an analysis of the system.

Initial studies indicated that the engine O&S system could be modeled as the interaction of two major subsystems, engine operations and engine support, as shown in Figure 3-1.

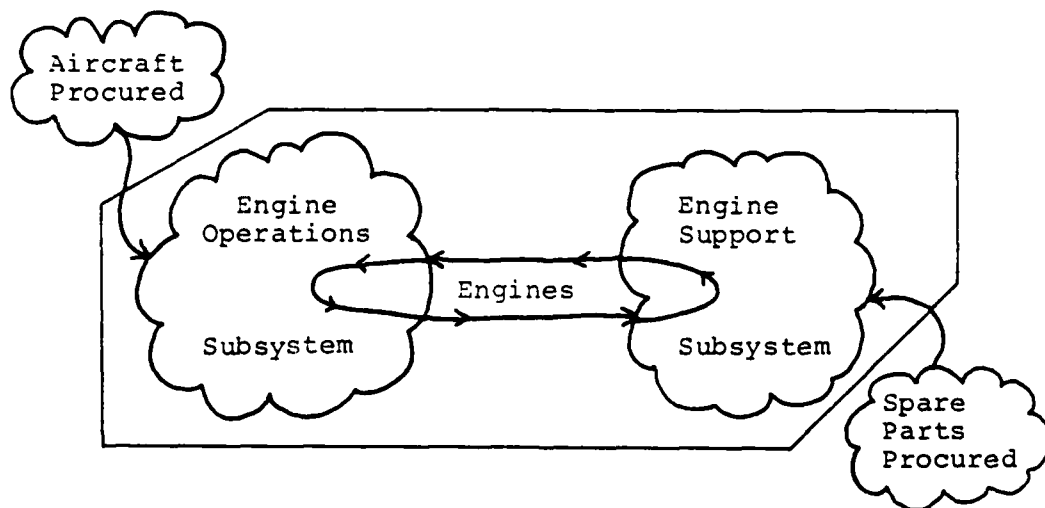


Figure 3-1 Engine O&S System

This division requires an engine be in use within the engine operations subsystem or in some state of repair within the engine support subsystem. Procurement events for such items as aircraft, engine, LRUs and SRUs are considered elements of the external environment.

Engine operations involve the day to day routine of deploying and flying aircraft. When an engine fails within the operation subsystem, it enters the support subsystem where it is repaired and returned to operation. These two subsystems are further broken down into interrelated processes which identify more specifically the system boundary and provides a flow for engine operation and support activities.

Engine Operation. The activities within the engine operation subsystem are shown in Figure 3-2.

Aircraft are procured outside the bounds of the O&S system and enter the operations subsystem following a predetermined deployment schedule. When aircraft become operational, sets of additional engine support equipment are also deployed based on the number of aircraft at each base.

As each engine first enters the inventory it is scheduled for regular inspections determined by engine operating time. An inspection may also occur because of an engine malfunction. Following each inspection the engine either remains in operation or enters the support subsystem for repair.

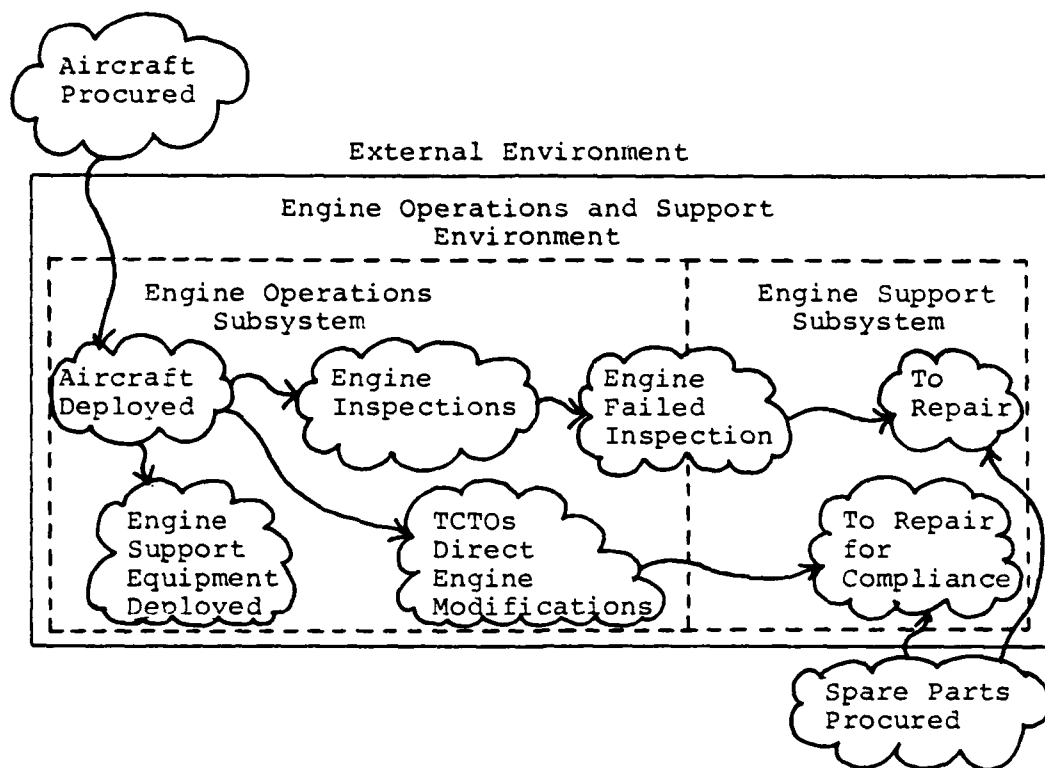


Figure 3-2 Engine Operations Subsystem

Engine improvement modifications also occur throughout the engine's life cycle. These modifications are directed by TCTOs to be completed within a certain time period. To meet the timing criteria, modifications are completed when an engine is down for repair; otherwise, the engine is removed specifically for modification. All TCTO engine modifications are accomplished in the engine support subsystem.

The engine operation subsystem discussed here identifies the routine engine activities. However, when an engine fails an inspection, or is removed for a modification,

it then enters the engine support subsystem for repair or compliance to the TCTO.

Engine Support. The maintenance activities within the support subsystem are a function of the failure probabilities of all engine components. The failure probability for each component is determined jointly by the manufacturer and the government and is used within the engine support subsystem to project engine failure and the associated maintenance activities and costs for repair. Engine repair within the support subsystem involves three distinct repair processes: the repair of line replaceable units (LRUs); the repair of shop replaceable units (SRUs); and major engine damage repair as shown in Figure 3-3.

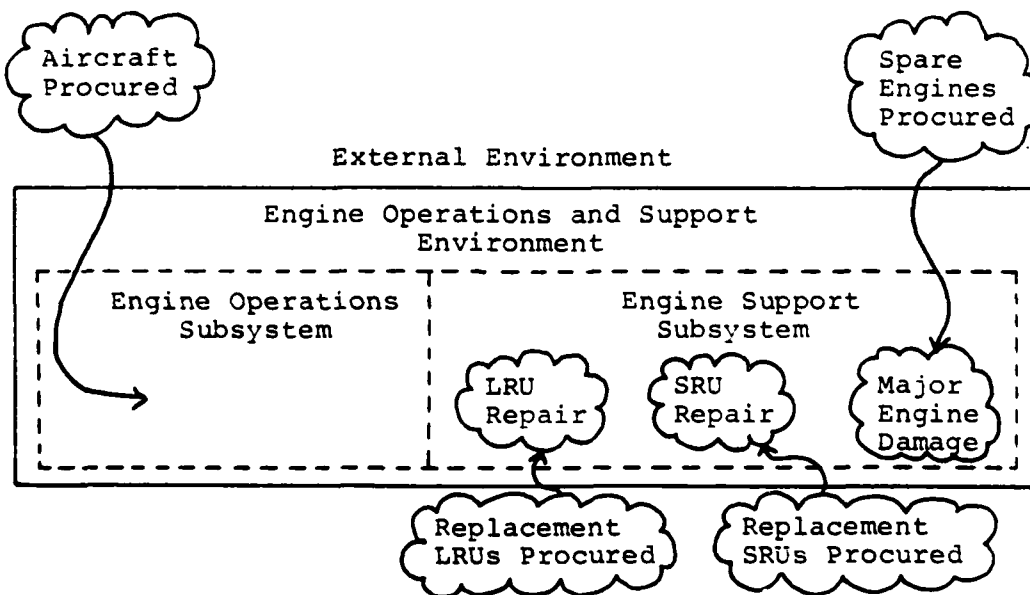


Figure 3-3 Engine Support Subsystem



Line Replaceable Units (LRUs). An LRU is described as a remove and replace item. It is an external engine component that is easily accessed by maintenance personnel and can be replaced on the flightline without removing the engine from the aircraft. Examples of LRUs on the F101 engine are shown in Table 3-1 and Figure 3-4 illustrates the maintenance flow for a failed LRU.

TABLE 3-1

LRUs (F101 Engine)

Engine Control Unit

Fuel Unit

Hydraulic Pump

Oil Pump

Anti-Icing

Alternator

Two conditions may exist when an LRU failure results in an inspection of an engine. Either the engine failure is initially determined as an LRU malfunction and the engine is repaired on the flightline, or the cause of the engine failure is unknown and the engine is removed for tear-down and repair. In the latter case, LRU failure is determined after teardown. The LRU is removed and replaced, and the repaired engine is sent to the spares engine pool. In both circumstances, the defective LRU is sent to depot for repair. If repaired, the unit is returned to the spares pool. If condemned, a replacement unit is procured from outside the O&S

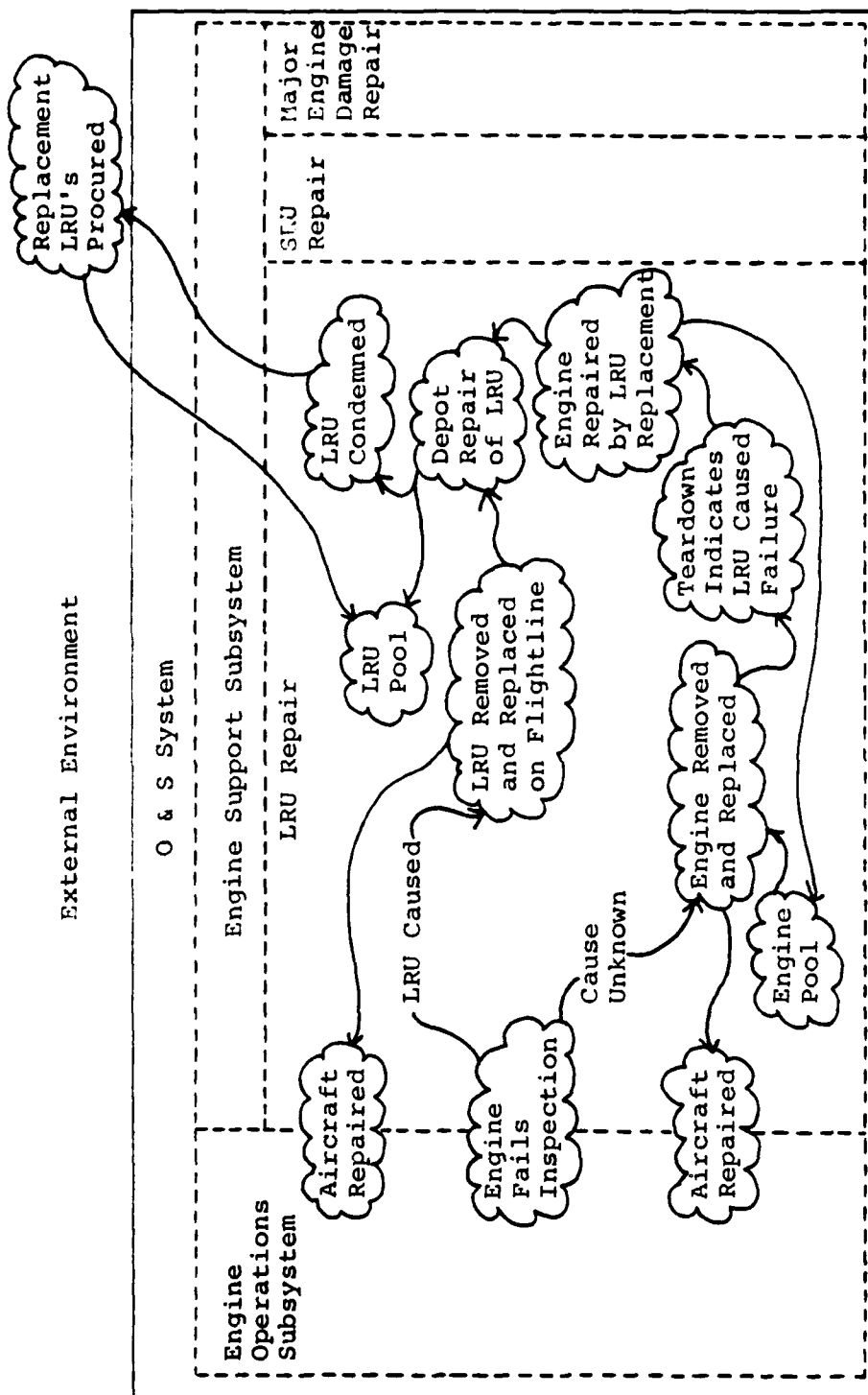


Figure 3-4 LRU Repair

system and enters the engine support subsystem through the spares pool.

Shop Replaceable Units (SRUs). In contrast to LRUs which can be removed and replaced on the flightline, SRUs are major internal engine components that require engine teardown for replacement. Table 3-2 is a listing of some of the SRUs in the F101 engine. The maintenance cycle for an SRU is shown in Figure 3-5.

TABLE 3-2

SRUs (F101 Engine)

Front Frame  
Engine Inlet Gearbox  
Accessory Gearbox  
Combustor  
Turbine Frame  
Augmenter  
Exhaust Nozzle

As illustrated, if the reason for failure is unknown the engine is removed for teardown. If it is determined that an SRU has caused the malfunction, the unit is removed and replaced and the engine is returned to the spare engine pool.

The damaged SRU is sent to the intermediate base shop or depot for repair. Whether the unit is repaired at the intermediate or depot level is determined by one or more of three basic criteria. They include, the repair time,

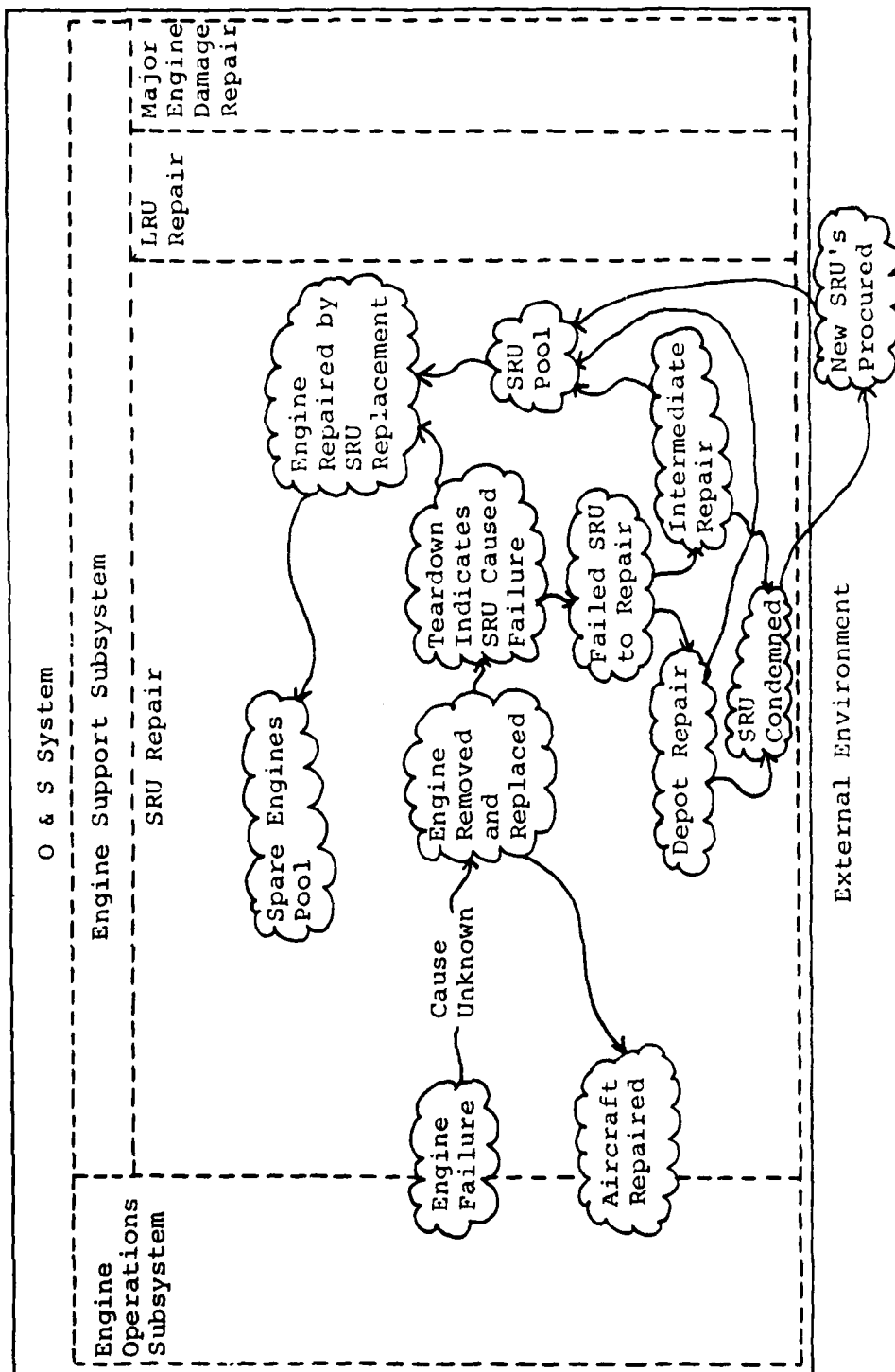


Figure 3-5 SRU Repair

the workload at each level, and the type of support equipment necessary for repair. For example, the repair of a particular SRU may require a heavy press or specialized equipment. The intermediate repair shop at the base level may not have the specialized equipment or is backed up by a heavy workload. Under these circumstances, the unit would be sent to depot for repair. Also, a depot repair would result if process manhours are too high for the intermediate shop. SRUs repaired at both levels are returned to the spares pool.

If a damaged SRU is not reparable at either level it is condemned and a new unit is procured. As with the LRUs, SRUs are also procured from outside the O&S system and enter the engine support subsystem through the SRU spares pool.

While both LRU and SRUs are removed and replaced at the base level, LRUs are repaired at the depot level and SRU repair can be made at either the intermediate base or depot level. The final area of repair is for major engine damage.

Major Engine Damage. Major damage is defined as damage not reparable by LRU or SRU replacement. Shown in Figure 3-6, when major engine damage occurs, the engine is removed and set to depot for repair. The repaired engine is then returned to the engine spares pool.

Engine replacements required to maintain the desired spares level are procured in the initial engine pur-

chase agreement. The engine spares pool is maintained by that initial procurement.

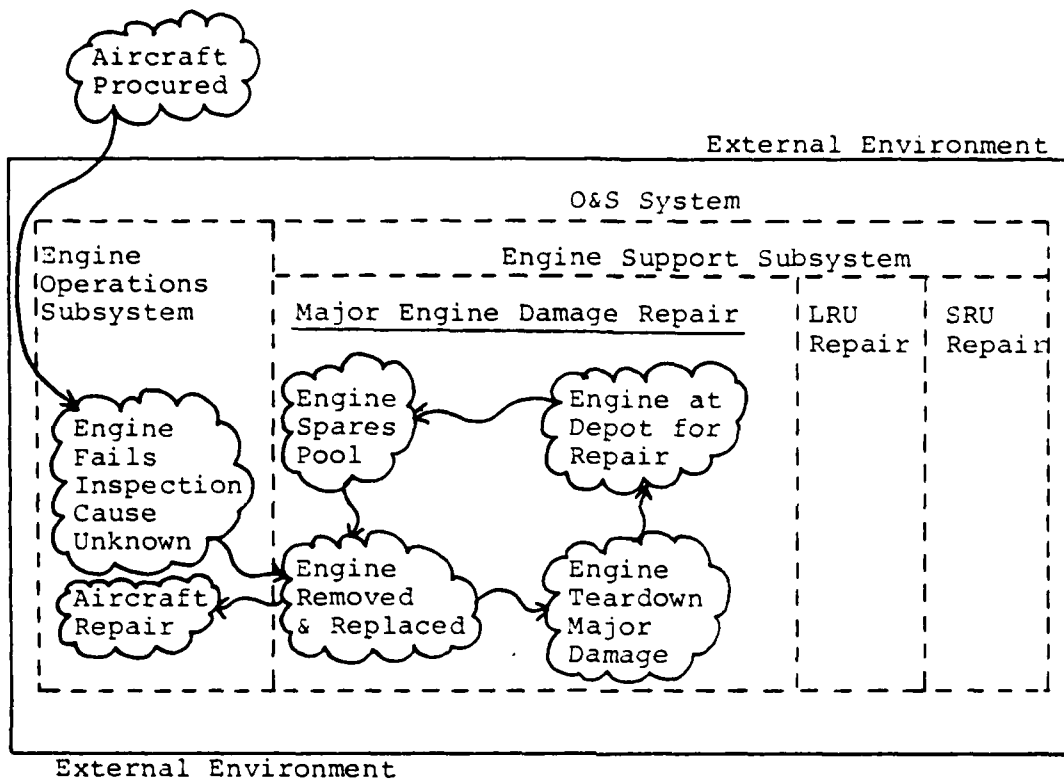


Figure 3-6 Major Engine Damage Repair

The repair of major engine damage is the final area of repair within the engine support subsystem. The discussion of the activities within this major repair area, as well as those within the LRU and SRU repair areas, has defined the boundaries and maintenance flow of the engine support subsystem. The complete O&S system including both the engine operations subsystem and the engine support subsystem is shown in Figure 3-7.

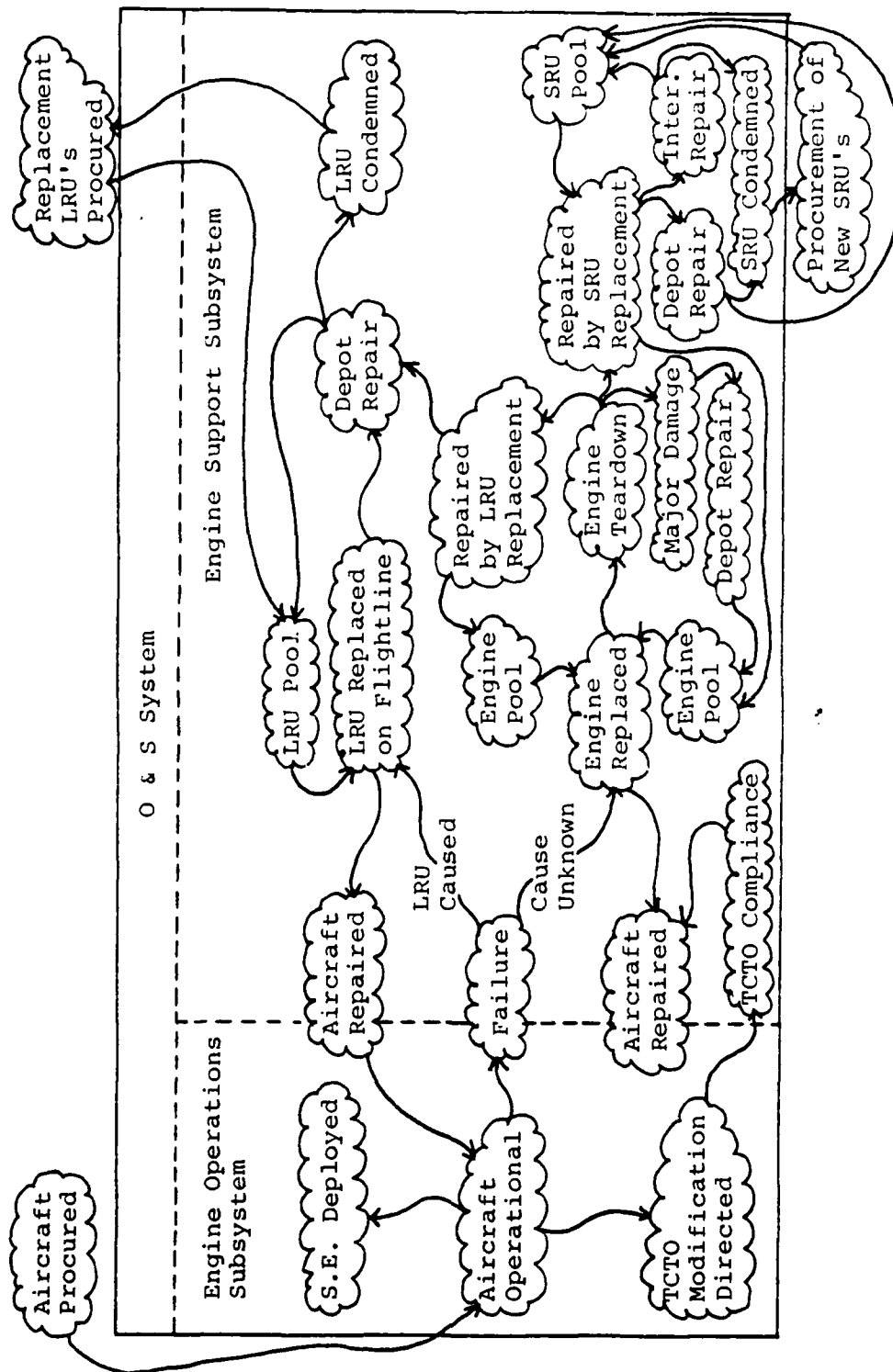


Figure 3-7 Engine Operation and Support System

System Parameters. Once the major activities were defined and the overall boundaries of the engine O&S system were established, the input parameters that would have an impact upon those activities as well as output measures of system performance had to be identified.

Input Parameters. YZ logisticians (15; 25) were consulted to help the researchers nominate the O&S system input parameters associated with the activities within the two O&S subsystems. Parameters were selected whose values are negotiable. A small number of those parameters are referred to as policy parameters because system analysts expected that they would have the greatest impact on system behavior. There were a total of five policy parameters identified by Propulsion analysts.

The parameter values for all input parameters are estimated by both the contractor and government analysts to provide as close as possible a homomorphic representation of the real world engine O&S environment. A specific level of output is derived as a result of using these values in a simulation. This output is referred to as the system measure of performance.

System Performance Measure. The most important measure of performance produced by the engine O&S model is the total cost of operations and repair accumulated over time. It is the measure used to determine if the modeled system is indeed imulating the real world. These final cost figures



are also the output data points used by YZ engine analysts and negotiators to determine the cost effectiveness of a particular warranty proposal.

In the preceding conceptual study, the system boundaries were defined and the major components and processes that constitute the daily activities of the O&S system were determined. The input parameters associated with the activities and the output or system measure of performance were also identified to complete the conceptual phase of the O&S system research process.

This research provided a conceptual view of the O&S environment and enabled the researchers to specifically identify the system components and parameters, and define the system boundaries that were to be modeled. The next phase of the research effort involved transforming this conceptualization of the O&S system into a precise mathematicological model that could be computerized and would provide the data used during the experimental design phase of the research. This design involved model validation and verification as well as the analysis of system sensitivity to various changes in policy parameter levels. The experimental design is illustrated in Figure 3-8.

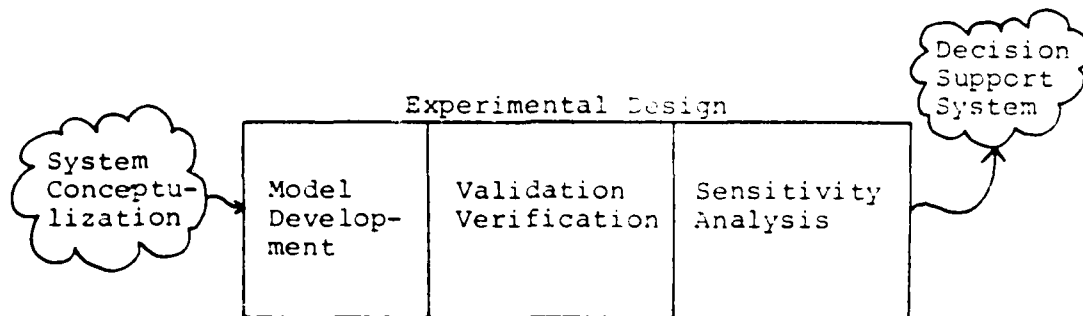


Figure 3-8 Experimental Design

### Experimental Design

The experimental design of any simulation analysis specifies the strategy for gaining information, via a simulation model, about a real world system. For the purpose of this study, the strategy for acquiring an understanding of the O&S system under warranty included a three step process.

First the O&S computer model was constructed. It was then verified and validated to develop user confidence. In the third step the model was tested for sensitivity to a change of specific parameter values which involved a screening and analysis of the five policy parameters to determine which had the greatest impact on the O&S system behavior (15).

### Model Development

Event logic is the bridge between the system conceptualization and a computer model. It ties the events together in a logical process that simulates as close as possible the real world system. This section provides the model overview

and limitations, and discusses the event logic selected to simulate the engine O&S system.

Model Overview. A brief overview of the simulation model is provided in the following section. A discrete event simulation is used to simulate engine operations and support for a peace time scenerio at five bases. This type of event simulation is most useful to engine analysts because it identifies each occurrence of an event within the system through time, thus enabling the user to track the data associated with each event. Specifically, the simulation is designed to assess and accumulate the cost for engine inspections at the base level and the cost for engine repair at the flightline, base intermediate shop and depot levels.

The basic model is also designed to provide YZ analysts with a variety of output information. The model is versatile in this respect in that it provides the user with the ability to vary the simulation period as well as determine the quantity of output data needed for warranty analysis. The internal integrity of the model does not change with different output versions but allows the analyst to choose the output information most appropriate for a warranty analysis. For the purpose of this study, two versions of model output were developed.

The first version, SHORT.3, was designed to provide a breakout of cost information for the warranty period. As the simulation tracks each engine component in the O&S system,

the accounting process accumulates and provides a monthly breakout of unit failure and repair costs. With this version analysts are able to closely follow individual unit costs and compare these costs to the anticipated contractor costs under warranty.

In the second version, WARR.3, the output of monthly data is suppressed and accumulated to provide only the year and total cost over a 20 year simulation period. YZ considers 20 years to be the normal life cycle of a system. This year end data is used to analyze the cost effectiveness of a warranty over the anticipated system life beyond the warranty period and provides the breakeven point for warranty costs.

Model Limitations. The actual repair process at each repair level is not modeled. Instead, a probability of repair and average repair times are used to represent the repair of individual parts. These figures are provided by contractor and government analysts.

The simulation also does not include the actual procurement process for the purchase of spare engines, SRUs and LRUs, or the initial procurement of aircraft and engines. When these items are needed, they are identified and procured from outside the system.

Finally, the operations process does not simulate the actual flying of aircraft to generate engine failures. Instead the number of engine failures is a function of the number of aircraft assigned and hours flown at each base. Again, these

figures are provided by government and contractor analysts.

Model Logic. Before translating the O&S system into a computer language, the model had to be designed to move through simulated time, causing events to occur in the proper order. Since the action of each activity depended upon the state and action of other activities, they had to be coordinated or synchronized through time to simulate as close as possible the real system. A listing of the general model structure and discrete events that simulate the O&S system is displayed in Figure 3-9.

The simulation executive provides three services. It first creates all variables and arrays, then reads in all parameteric values, and finally provides the initial scheduling of the system events. There are three primary events including; deployment of aircraft, TCTO's for engine modifications, and engine inspections. All other events shown are scheduled as a result of an occurrence of one of these three major events.

Aircraft Deployment. Aircraft enter the system on a predetermined monthly schedule. The specific arrival day within each month is determined by three parameters that include aircraft production quantity, maximum aircraft quantity, and the aircraft deployment schedule.

Shown in Figure 3-10, the simulation executive preschedules all aircraft for a delivery and the deployment event brings individual aircraft into the inventory. The

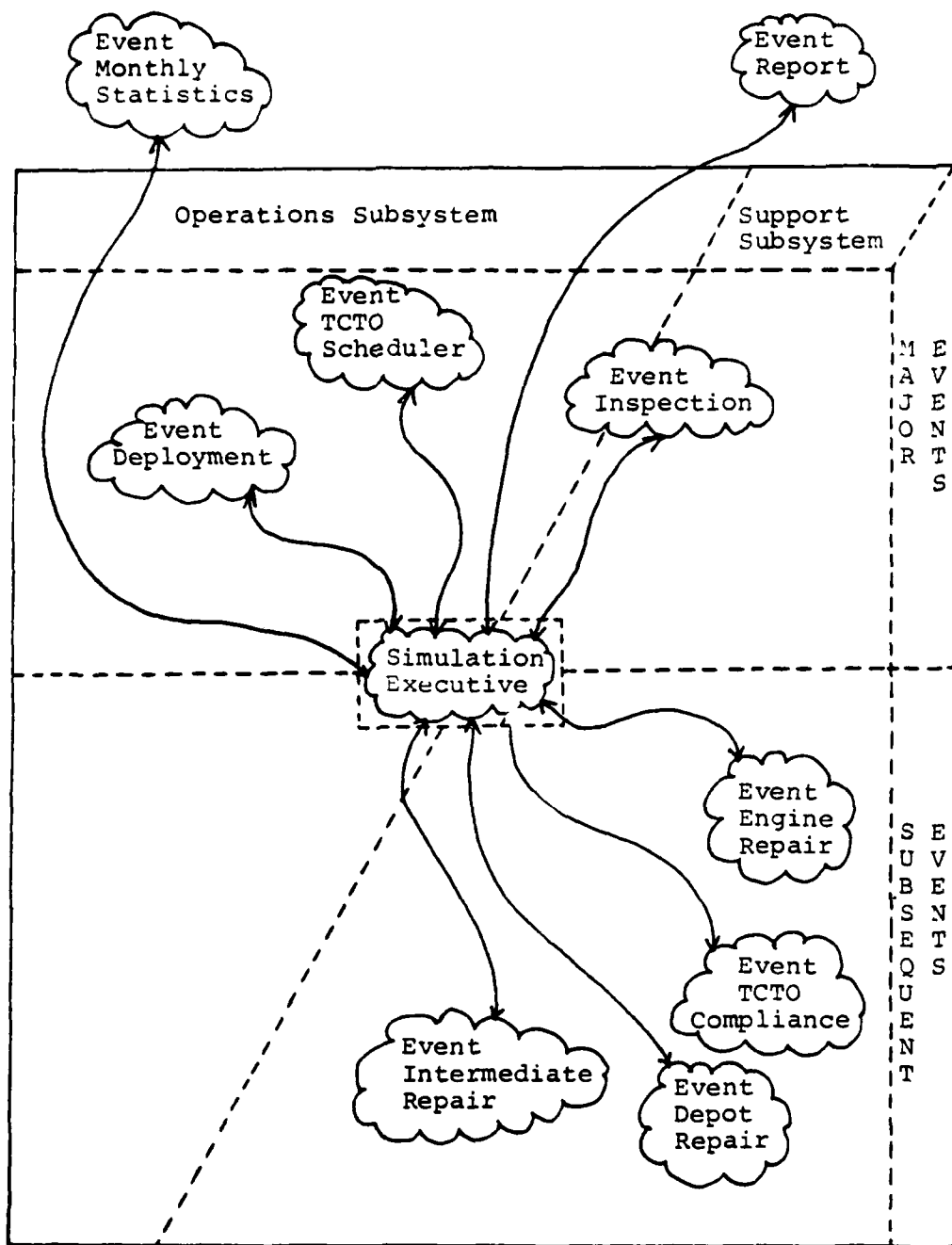


Figure 3-9 Model Logic

executive then checks the status of support equipment and, if necessary, deploys engine support equipment required at the organizational, intermediate and depot levels. The input parameter "quantity of aircraft per base" is used as a milestone for the deployment of support equipment and base activation.

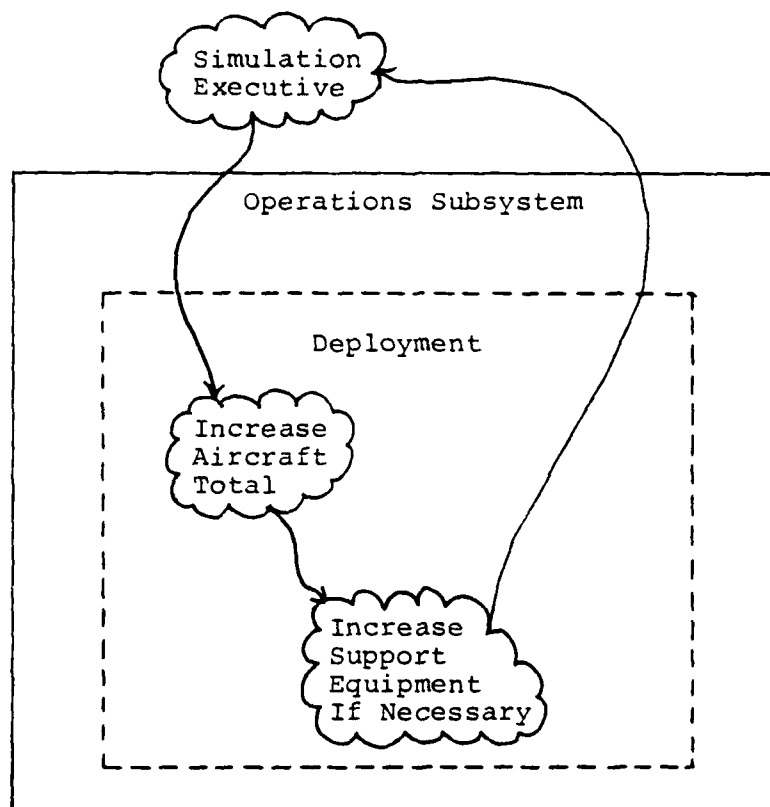


Figure 3-10 Event Deployment

When each aircraft is deployed, engine TCTO's are scheduled at some time in the future as a method of preplanned product improvement, and engine inspections are scheduled based on engine flying hours.

Engine TCTO's. The TCTO event is actually a combination of two discrete events. First, "scheduled TCTO's" are events triggered on a routine basis throughout the 20 year cycle that schedules all engines, not identified for inspections, for TCTO compliance. Second, the "TCTO compliance" event, which is the actual engine modification, is accomplished as an engine repair.

Engine Inspections. The final major event is "inspections" shown in Figure 3-11. This event controls the the largest area of the O&S system and, as indicated, directs several other subevents.

The initial inspection sequence provides accounting as it follows the total number of inspections, total organizational hours expended, and total flying hours accomplished. When an engine is identified for inspection, it is determined if the engine has failed and, if so, whether it requires removal or only LRU replacement. The engine removal probability is determined by the shop visit rate, total engines per aircraft, and the inspection frequency. If engine removal is required for repair, the initial inspection calls on the engine removal subunit. However, if only LRU replacement is required, the engine remains on the aircraft and a check of all LRUs is accomplished to determine which are to be replaced. The aircraft is then returned to service. The failed LRU or LRUs are scheduled for repair through the LRU repair event. The probability that an LRU will fail is determined by the



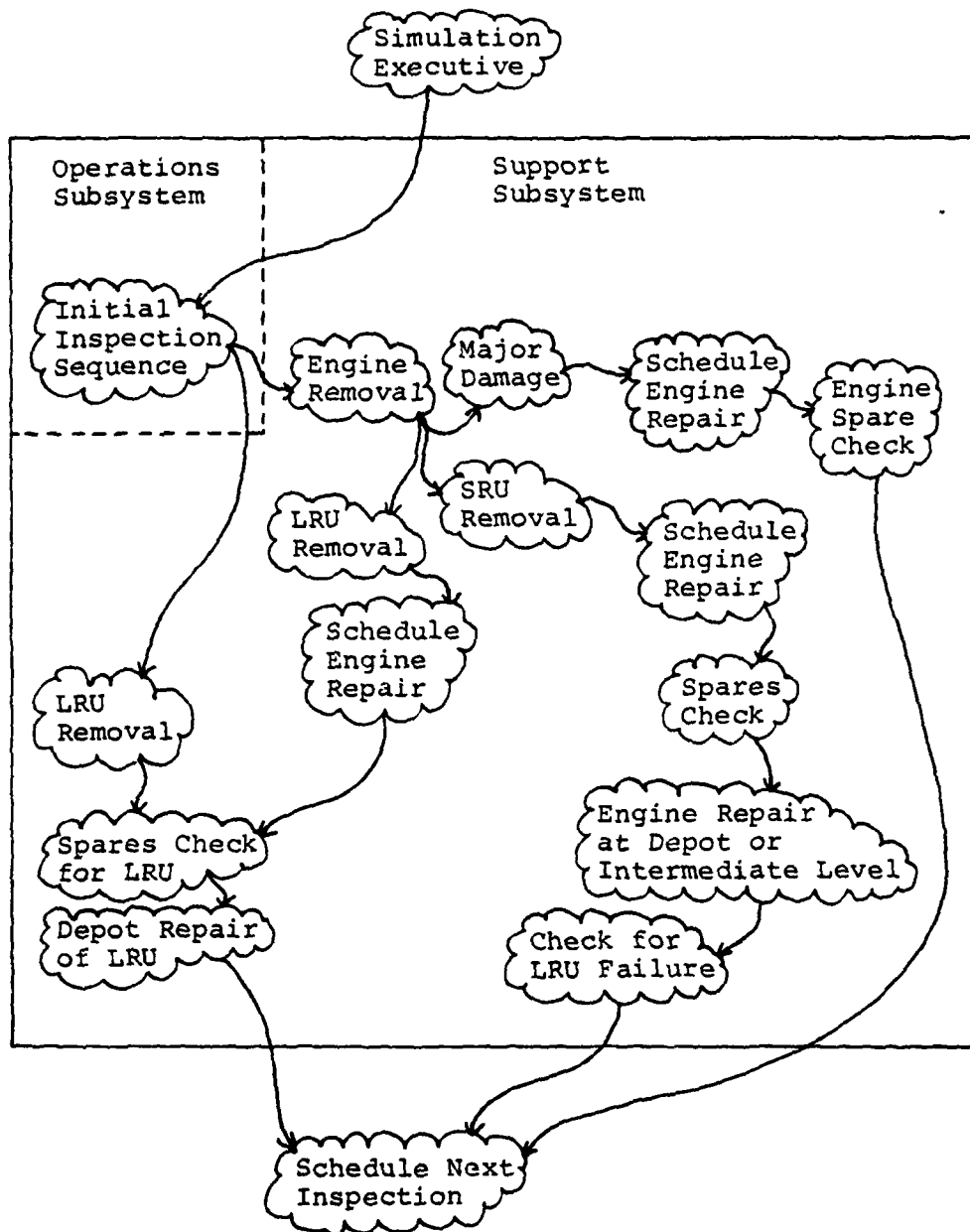


Figure 3-11 Event Inspection

LRU maintenance activities, engines per aircraft, and inspections frequency.

Engine Removal. The first subevent under inspections is engine removal. This event compiles statistics on total engine removals and organizational hours required, and determines the cause for removal. A random number generator and the failure mode distribution determine whether major engine damage, SRU failure, or LRU failure has caused the engine removal. The reason for the double check on the LRU failure is that an LRU failure may not be identified on the initial inspection and thus cause an entire engine removal. When the cause for removal is determined, the engine removal event passes control to one of the three repair subevents as appropriate, either major damage, LRU or SRU repair.

Major Engine Repair. The major damage subevent accounts for transportation time and costs to the depot, repair time and costs at the depot, and major damage removals. Engine repairs are then scheduled based on expected repair times and a spares check for engines is accomplished. "Spares check" is the subroutine which checks the level of spares for engines, LRUs and SRUs and, if necessary, procures replacements.

LRU Removal. The subevent "engine removal for LRU failure" tracks the intermediate hours required for removing the engine and schedules engine repair. It then passes action to the "check for LRU failure" subevent. This

event examines all LRUs for failure and, if a failure is encountered, the organizational, intermediate and depot repair hours are accumulated, transportation costs and times are incremented and a depot repair for each LRU is scheduled.

SRU Removal. The subevent "engine removal for SRU failure" accounts for SRU removals and the intermediate hours accrued. The engine is then scheduled for repair and the SRU repair level is determined. The SRU may be repaired at the intermediate base shop or depot level and separate subevents handle each of these possibilities. The determination as to which level, is made using random numbers and a specific probability of occurrence based on input projected maintenance action data.

Depot Repair and Intermediate Repair. The subevents for "depot" and "intermediate" repair of SRUs accomplish the same tasks. They account for the total number of repair actions and the hours required, and calculate the transportation time and cost. In addition to these actions, the SRU is scheduled for either a depot or intermediate repair event based on expected repair times. An additional check for an LRU failure is also performed since an SRU failure may mask an LRU failure.

The final step in the inspection process for each type of repair is to schedule another inspection for the aircraft and pass the process back to the simulation executive.

Intermediate and Depot Repair. The "intermediate" and "depot" repair events, Figures 3-12 and 3-13 respectively, function identically. Both determine whether LRU or SRU can be repaired. If so, they increment the particular item spares level. If the part is not reparable, then the part is condemned. The condemnation decision is based on the input condemnation factors.

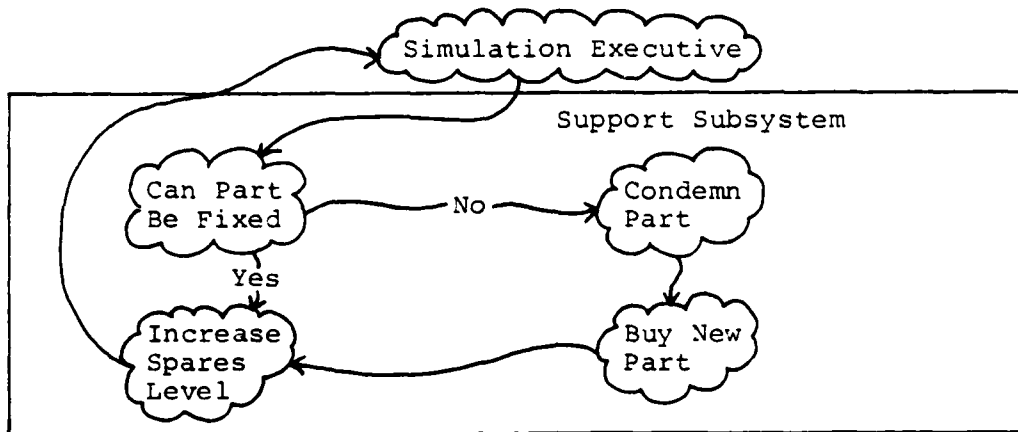


Figure 3-12 Event Intermediate Repair

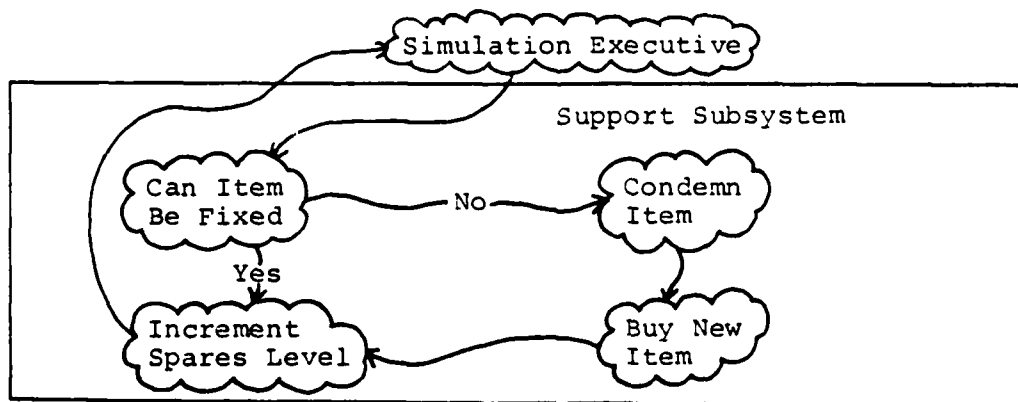


Figure 3-13 Event Depot Repair

Engine Repair. The "engine repair" event, as shown in Figure 3-14, simply increases the engine spares level by one and returns the activity to the next logical event.

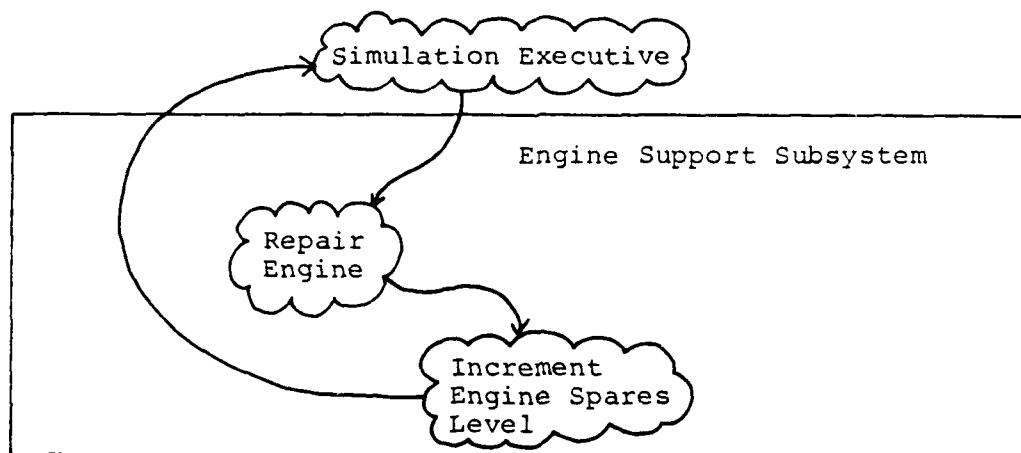


Figure 3-14 Event Engine Repair

Accounting and Reporting. The last two subevents are "accounting" and "reporting". The accounting activity shown in Figure 3-15 calculates monthly statistics necessary for determining final cost. The calculations and formulas used in this event are listed in Appendix E. The second event is the year end "reporting", Figure 3-16. This event causes the printing of the year end statistics used to analyze the cost effectiveness of the warranty.

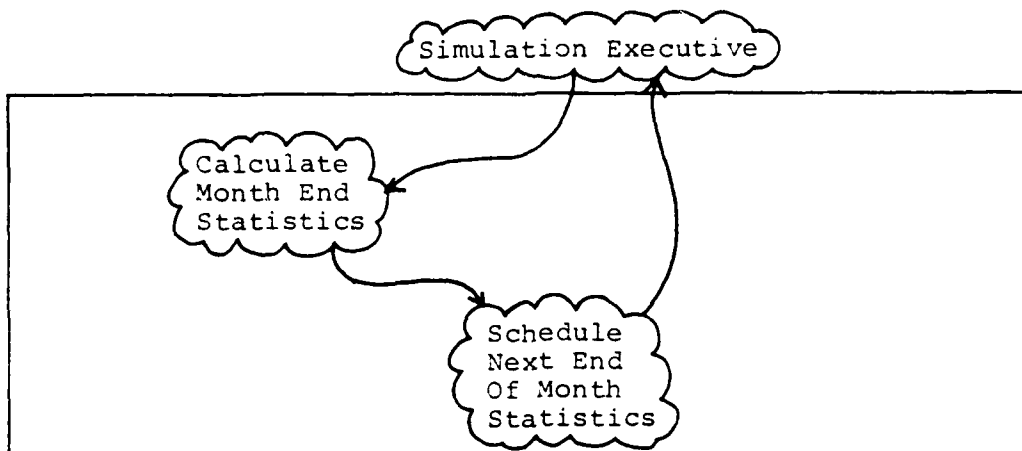


Figure 3-15 Event End of Month Statistics

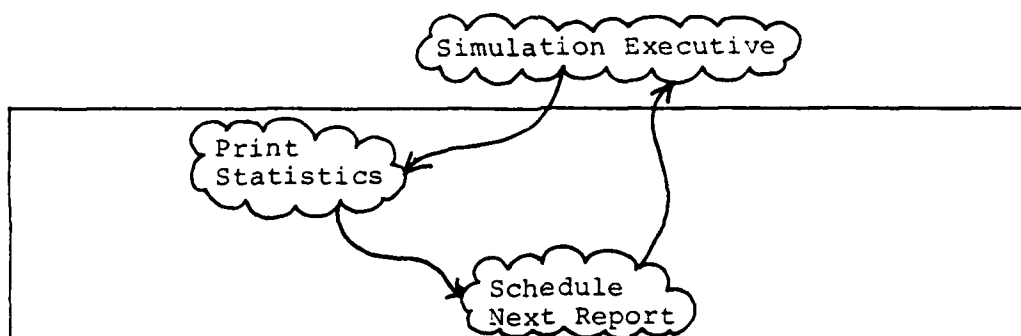


Figure 3-16 Event Report

At this point, the O&S system is sufficiently defined and structured for easy translation into a computer language. Programmers and other support personnel in YZ requested that Simgript II.5 be used as the model computer language. Additionally, they requested that the model be designed, developed and tested on the Create Computer System (15). Model coding is listed in Appendix A. Once the model was coded and debugged, the verification and validation process

was initiated.

#### Model Validation and Verification

The verification/validation phase of this simulation experiment was designed to ensure that any inferences drawn from the simulation would be correct and applicable to the real world system.

This process included first, a test of the logic of the model (model verification) and second, a comparison of model output to logical real world results (model validation) (18:208-210).

Model Verification. For model verification the model structure, parameters and environment were held constant during the simulation to check the internal consistency of the model. An attempt was made to insure that the event logic was correct and that the simulation process was indeed modeling all critical aspects of the engine operations system.

An important part of this test involved consultation with engine life cycle cost analysts at ASD (15; 18:228; 25). They checked the internal logic of the model and verified that from their experience and expertise that the model simulated the life cycle costs of engine operations and that the modeled warranty assumptions were valid.

Model Validation. Model validation involved the analysis of the model input/output transformation (18:210). For validation the model parameters were set and a variable seed used to provide the randomness associated with the engine

operations environment. The test of the model input/output transformations involved a comparison of model output to logical real world results.

For the engine warranty model, however, it was difficult to compare simulation output with the real world. Historical data for comparison was not available because of the limited use of warranties for engine procurement. To overcome this problem and provide the necessary model validation, model output was compared to the output of a previously validated model. In this case, the ASD Maintenance Concept Evaluation Model (MCEM) was used.

The MCEM has seen extensive use at ASD and is considered by the government as the primary LCC model for turbine engine cost analysis. Its structure and parameters are similar to those of the warranty model when the warranty parameters are suppressed thus providing the similarity necessary for comparison. An analytical comparison of the two model outputs, produced by controlled inputs, provides the basis for warranty model validation.

The testing procedure included a 20 year simulation period where each model simulated the engine operations from 1984 to 2004. Thirty simulation runs were made and four data points from each run including 1986, 1992, 1998 and 2004 were used for analysis. Figure 3-17 is an example of the data sets used in this analysis. The numbers under each year are the yearly accumulated operations costs in millions of dollars.



| Simulations | MCEM   |        |        |        | WARRANTY |        |        |        |
|-------------|--------|--------|--------|--------|----------|--------|--------|--------|
|             | 1986   | 1992   | 1998   | 2004   | 1986     | 1992   | 1998   | 2004   |
| 1           | 122.51 | 241.81 | 511.06 | 639.00 | 133.05   | 240.92 | 509.01 | 644.29 |
| 2           | 131.62 | 256.02 | 518.51 | 645.13 | 121.45   | 253.11 | 519.43 | 638.92 |
| 3           | 136.33 | 253.34 | 525.25 | 643.10 | 130.41   | 251.00 | 523.20 | 641.02 |
| 4           | 128.01 | 262.43 | 519.03 | 638.11 | 135.02   | 262.10 | 518.12 | 639.51 |
| *           | *      | *      | *      | *      | *        | *      | *      | *      |
| *           | *      | *      | *      | *      | *        | *      | *      | *      |
| *           | *      | *      | *      | *      | *        | *      | *      | *      |
| 30          | 125.42 | 252.50 | 520.03 | 643.34 | 123.04   | 251.92 | 520.21 | 642.43 |

Figure 3-17 MCEM and Warranty Data Sets

The four data sets from each model were tested for normality using the Lilliefors test and the population variance (5:125) for each set were tested for equality using the F test for equal population variances (two tailed). Following these tests a one-way analysis of variance (ANOVA) was performed to statistically test whether the means of the compared data sets were significantly different (5:125).

#### Sensitivity Analysis

Once the model had been constructed and sufficient confidence existed relative to its validity, the researchers then studied the sensitivity of the model output to changes in the identified policy parameters. While a number of methods could have been used for sensitivity analysis, the researchers

chose a three step process to identify the input factors that had the greatest effect on the system measure of performance.

The first step was to screen the five identified policy parameters to roughly visualize their individual impact on life cycle cost. To accomplish this, the researchers chose a  $2^5$  factorial design which identifies the parameters as factors and utilizes two levels for each to assess their effects. This method has proven useful in the early stages of other experimental work when there are many factors to be investigated.

Since an unrepeated  $2^5$  design existed, the researchers chose to use a technique suggested by Daniel (9) which relies on the following fact:

If the data are normally and independently distributed, then the  $2^k - 1$  estimates of the effects obtained from a  $2^k$  design are normally distributed. To help identify significant effects, the estimates of the effects may be plotted on normal probability paper [14:195].

The  $2^5 - 1$  or 31 effects were computed using an algorithm proposed by Yates (26) for estimating the effects computed for the years 1986, 1992, 1998, and 2004. These results were then used in a Biomedical Plotting Program to create a normality plot.

The visualization of the effects is intended to illustrate the independent parameters and parameter combinations which show the greatest effect. For the purposes of technology demonstration, the researchers chose to use only the two parameters showing the greatest effect on the system. Step 2 involved

a further study of those two parameters. This constituted a two way analysis of variance. The two factors, A and B, were evaluated at three levels each. The data collected is in line with the structure indicated in Figure 3-18.

|     |             |     |     |
|-----|-------------|-----|-----|
| A=1 | $X_{A,B,K}$ |     |     |
| A=2 |             |     |     |
| A=3 |             |     |     |
|     | B=1         | B=2 | B=3 |

Where K = 1 to 30

Figure 3-18 Two Factor, Three Level Analysis Design  
Thirty observations were collected for each cell and an SPSS ANOVA (5:470) program was used to assess the significance of the parameters and the interactions. Three hypotheses were posed for testing purposes.

Hypothesis I - The effects of the three levels of factor A are equal

Hypothesis II - The effects of the three levels of factor B are equal

Hypothesis III - The interaction effects of the two factors at all levels are equal

The third and final step was to use SPSS one way ANOVA with a Duncan's Multiple Comparison of Means Test (5:470) to identify homogenous subsets of means within the levels of a particular factor.

The sensitivity analysis above is provided as an example of the type of analysis which may accompany a simple cost analysis of warranty options. This provides a wealth of

information above and beyond the simple number output of the model. First it allows a comparison of significance of changes in levels of various parameters which may be subject to negotiating a contract. Additionally, it allows the analyst to target the controllable parameters which will be most useful in warranty negotiations.

#### Decision Support System

The purpose of the preceding model development and testing process was to provide a model and model output information that could be incorporated into a DSS which, in turn, would be used by YZL to analyze and evaluate vendor warranty proposals.

Once the basic model was verified and validated and the analysis for model sensitivity to parameter variations had identified the most important policy parameters, the model was then integrated into a decision support system that can analyze the cost effectiveness of a proposed warranty.

A negotiation process scenario was used to demonstrate how the DSS could be used in practice and is presented in Chapter IV. In this scenario both model versions are incorporated into the DSS to show their versatility. This hypothetical exercise of the DSS illustrates how this system can provide analysts with the flexibility to analyze the breakout of individual unit costs as well as to evaluate the cost effectiveness of the warranty over the life of the engine.

## CHAPTER IV

### RESULTS AND FINDINGS

This chapter discusses the results of implementing the experimental design of Chapter III to meet the objective and goals of this thesis. The primary objective was to provide the Propulsion System Program Office (SPO) with a decision support system to assess engine life cycle cost under warranty. To achieve this objective, the researchers determined the information required to adequately analyze the cost effectiveness of a warranty proposal. This involved a study of the engine O&S system, including the environmental elements that effect the system behavior, the development and testing of a simulation model of the O&S system, and testing the model's sensitivity to changes in various policy parameters. These three steps ultimately allowed the researchers to provide an exemplary demonstration of the decision support system's ability to establish life cycle cost estimates for engines under warranty.

#### System Analysis

The analysis of the engine operations and support environment was done in close cooperation with ASD LCC analysts and logisticians (15; 25). This preliminary investigation helped identify the environmental parameters that

closely describe the real world O&S system. The major engine operations and support subsystem activities and the parameters associated with those activities which resulted from this research are shown in Table 4-1. An expanded list of all system parameters and their definitions is listed in Appendix C.

TABLE 4-1

O&S System Activities and Parameters

| <u>Operations Input Parameters</u> | <u>Activity</u> |
|------------------------------------|-----------------|
| Number of Aircraft/Base            | Deployment      |
| Number of Engines/Aircraft         | Deployment      |
| Maximum Number of Aircraft         | Deployment      |
| Number of Bases                    | Deployment      |
| <u>Support Input Parameters</u>    | <u>Activity</u> |
| *Shop Visit Rate                   | Inspection      |
| *Total Engine Cost                 | Accounting      |
| % of Aircraft Deployed Overseas    | Inspection      |
| Support Equipment Cost             | Accounting      |
| Flying Hour Program                | Inspection      |
| Inspection Frequency               | Inspection      |
| Inspection Manhours                | Inspection      |
| Manhour and Material Rates         | Accounting      |
| Engine Overhaul Hours              | Inspection      |
| Transportation Times               | Inspection      |
| Total Depot Repair                 | Inspection      |
| Total Base Repair                  | Inspection      |
| Transportation Cost                | Accounting      |
| Inflation Rate                     | Accounting      |
| Discount Rate                      | Accounting      |
| First Year of Simulation           | Accounting      |
| Interval Between Reports           | Accounting      |
| Interval Between TCTO's            | Schedule TCTO   |
| Failure Mode Distribution          | Inspection      |
| *Maintenance Action Levels         | Inspection      |
| *Maintenance Manhours              | Inspection      |
| Parts Cost                         | Accounting      |
| *Condemnation Factor               | Inspection      |

Among the parameters listed in Table 4-1 are the five policy

parameters (\*) referred to earlier. They include total engine cost, reliability (maintenance action levels), maintainability (maintenance manhours), shop visit rate and condemnation factor. The analysis of these five parameters, including their individual and interactive effects on model output is addressed in the model sensitivity analysis section of this chapter.

This system study provided the background data necessary to construct the warranty simulation model.

#### Model Development

In order to fully analyze engine warranty options, Propulsion analysts felt that two versions of the simulation model would be required. As indicated in Chapter III, these two versions differ only in output, not in their internal logic.

Model Output - First Version. The first version of the model provides a monthly breakout of the factors that make-up the final O&S cost. This version is used for specific unit cost analysis for the warranty period. An example of the model output is shown in Figure 4-1. The coded model is listed in its entirety in Appendix B.

The final output of this version first provides total engine and fleet flying hours and the number of inspections performed over the simulation period. The output also includes on-wing maintenance activity which includes the number of LRUs removed and the LRU repair cost at each repair level.

Engine removal output information is also included.

-----

FILE STATUS REPORT-04 1987.75

53200.00 ENGINE FLYING HOURS  
 13300.00 FLEET FLYING HOURS  
 256 INSPECTIONS PERFORMED

ON-WING MAINTENANCE ACTIVITY  
 TO DATE 234 LRU'S HAVE BEEN REMOVED, TOTAL HRS & LABOR ARE  
 O-LEVEL=\$ 3741.60, I-LEVEL=\$ 27993.00, D-LEVEL=\$ 310045.00  
 DISTRIBUTED AMONG THE 16 IDENTIFIED LRU'S AS FOLLOWS:  
 28 6 1 123 54 2 3 22 14 7 4 2 30 4 8 16

ENGINE REMOVAL INFORMATION  
 135 ENGINES REMOVED (TOTAL EXCLUDING TOTOS)  
 15 ENGINES REMOVED - MAJOR ENGINE DAMAGE  
 15 ENGINES REMOVED - MINOR REPAIR - LRU  
 105 ENGINES REMOVED - BRU CAUSED  
 27 ENGINES REMOVED - TOTO

TO DATE 424 BRU MAINTENANCE ACTIONS HAVE TAKEN PLACE, DIVIDED AS  
 (I-LEVEL= 208, \$ 1156337.54, D-LEVEL= 219, \$ 1853299.75) AND  
 DISTRIBUTED AMONG THE 20 IDENTIFIED BRU'S AS FOLLOWS:  
 17 15 9 9 8 10 23 25 3 50 14 50 34 35 22 32 15 12 11 5

SPARE ENGINE REQUIREMENTS (FAILURES AND TOTOS) 20 \$10000000.00

SPARE BRU REQMTS (PIPELINE) \$ 12337740.00 BROKEN DOWN AS FOLLOWS:  
 4 2 3 2 2 4 7 6 2 8 4 10 2 6 7 9 5 5 2 3  
 SPARE BRU REQMTS (CONDENS) \$ 1636794.00 BROKEN DOWN AS FOLLOWS:  
 0 1 1 0 0 0 0 0 0 13 0 0 1 2 1 3 0 0 1 0  
 SPARE LRU REQMTS (PIPELINE) \$ 2455767.00 BROKEN DOWN AS FOLLOWS:  
 12 4 1 9 22 2 2 12 5 6 2 1 27 4 4 5  
 SPARE LRU REQMTS (CONDENS) \$ 230393.00 BROKEN DOWN AS FOLLOWS:  
 1 0 0 0 41 0 0 1 0 0 2 1 5 0 0 1

|                   | ORG-LEVEL     | INTER-LEVEL   | DEPOT LEVEL    |
|-------------------|---------------|---------------|----------------|
| MAINTENANCE       |               |               |                |
| HANHHOURS         | 3603          | 34529         | 44167          |
| DOLLARS           | \$ 206481.00  | \$ 1208480.00 | \$ 2635844.00  |
| SUPPORT EQUIPMENT |               |               |                |
| UNITS             | 2             | 2             | 1              |
| DOLLARS           | \$ 2100000.00 | \$ 9750000.00 | \$ 52500000.00 |

TRANSPORTATION REQUIREMENTS=\$ 35280.00

TOTAL COST=\$ 213816778.00

INFLATED COST=\$ 231637436.00

DISCOUNTED COST=\$ 213816770.00

COST/EFH = \$ 4019.11

-----

Figure 4-1 Short Version Output



This lists and catagorizes failure-caused removals as well as removals for TCTO action. A total for all engine removals is also provided.

Next, the three level maintenance manhours and costs and support equipment costs are given along with the final cost for transportation to the depot repair facility. The last output is final O&S cost which is inflated and then discounted to give a realistic cost comparison.

This output provides the Propulsion SPO with the information they need to track the individual repair costs in an easily read format for assessing cost effectiveness of a warranty which has specific coverages. For example, if the contractor has proposed a warranty for the repair and replacement of all engine LRUs for a specified period of time this model would perform as follows. It would simulate the O&S system for this period and provide YZ analysts with a monthly breakout of the LRU support costs. This allows a comparison of the expected support costs to the cost of the warranty and thus facilitates a cost effectiveness decision.

Model Output - Second Version. The second version is designed to suppress the breakout of specific unit cost and provide only year end final costs. The abbreviated output format, Figure 4-2, delivers only the yearly accumulated cost after inflating and discounting.

|      |                                   |
|------|-----------------------------------|
| FXXX | STATUS REPORT-CY 1986.00          |
|      | DISCOUNTED COST = \$ 90783643.00  |
| FXXX | STATUS REPORT-CY 1987.00          |
|      | DISCOUNTED COST = \$ 125706476.00 |
| FXXX | STATUS REPORT-CY 1988.00          |
|      | DISCOUNTED COST = \$ 255475980.00 |
| FXXX | STATUS REPORT-CY 1989.00          |
|      | DISCOUNTED COST = \$ 343905808.00 |
| FXXX | STATUS REPORT-CY 1990.00          |
|      | DISCOUNTED COST = \$ 384937704.00 |
| FXXX | STATUS REPORT-CY 1991.00          |
|      | DISCOUNTED COST = \$ 402664576.00 |
| FXXX | STATUS REPORT-CY 1992.00          |
|      | DISCOUNTED COST = \$ 420523760.00 |
| FXXX | STATUS REPORT-CY 1993.00          |
|      | DISCOUNTED COST = \$ 439961712.00 |
| FXXX | STATUS REPORT-CY 1986.00          |
|      | DISCOUNTED COST = \$ 90074101.00  |
| FXXX | STATUS REPORT-CY 1987.00          |
|      | DISCOUNTED COST = \$ 125653383.00 |
| FXXX | STATUS REPORT-CY 1988.00          |
|      | DISCOUNTED COST = \$ 236210102.00 |
| FXXX | STATUS REPORT-CY 1989.00          |
|      | DISCOUNTED COST = \$ 329571828.00 |
| FXXX | STATUS REPORT-CY 1990.00          |
|      | DISCOUNTED COST = \$ 367444912.00 |
| FXXX | STATUS REPORT-CY 1991.00          |
|      | DISCOUNTED COST = \$ 387159476.00 |
| FXXX | STATUS REPORT-CY 1992.00          |
|      | DISCOUNTED COST = \$ 403725012.00 |
| FXXX | STATUS REPORT-CY 1993.00          |
|      | DISCOUNTED COST = \$ 433623260.00 |

Figure 4-2 Long Version Output

This version looks beyond the warranty period and determines if the engine part reliability and maintainability improvements made by the contractor during the warranty period are substantial enough to warrant the front-end warranty cost. If they are, then at some point in time in the future prior to the end of the engine life cycle a breakeven point will be reached, indicating that maintainability costs to the government

are reduced because of the part reliability improvements.

This version also has the capability of multiple simulations. Up to 10 simulations can be performed in a single run. The program listing is found in Appendix A.

Once the model had been constructed and was providing engine warranty information, it was verified, validated, and tested for sensitivity to level changes in the five policy parameters.

#### Model Verification

The process of verification was defined in Chapter III as a test of model logic. A Turing test was chosen as the most feasible method of model logic assessment.

The model and four sets of model output were given to Propulsion logistics personnel for their review. They found that the model logic was in agreement with their understanding of the engine O&S system and verified the assumptions made for the warranty aspects of the model to be correct. Once verification was completed, the next step was to validate the model and its output.

#### Model Validation

Model validation is a comparison of the simulation model to output of the real world system. However, as indicated in the preceding chapter, no real world data is currently available to assess the warranty model reliability. Therefore, the Maintenance Concept Evaluation Model (MCEM) was used as a basis for model evaluation. Thirty independent simulations of

each model were made. The total accumulated costs were collected at four points throughout the 20 year simulation. Each simulation began in 1984 and data were collected at four points for analysis. These points included 1986, 1992, 1998, and 2004. The data for the MCEM model is shown in Table 4-2 and for the warranty model in Table 4-3.

The intent of this testing was to determine if any significant difference existed between the results of the two simulations. The four yearly data points were used to insure that there was no significant difference during the entire life cycle simulated. Two basic assumptions had to be substantiated before the data from these two models could be tested. First, since it was necessary to assume both samples came from normally distributed populations, a Lilliefors Test was made to detect any significant deviation from normality. The null hypothesis was:

$H_0$ : The distribution is normal for each sample,  
with the alternate being:

$H_a$ : The distribution is not normal for each sample.  
The test statistic for comparison was a Lilliefors value of .161 assuming an alpha value of .05. The decision rule is as follows:

If the Maximum Absolute Difference that is calculated is greater than the Lilliefors Table Value then the Null hypothesis is rejected and the distribution of the sample is assumed not to be normal.

The results of this testing are shown in Table 4-4 and indicate

TABLE 4-2 MCEM Output Data

| Run   | 1986   | 1992   | 1998   | 2004   |
|-------|--------|--------|--------|--------|
| 1     | 111.70 | 450.87 | 559.59 | 667.05 |
| 2     | 117.93 | 431.96 | 549.12 | 656.06 |
| 3     | 116.97 | 450.00 | 561.28 | 690.60 |
| 4     | 111.32 | 421.27 | 536.14 | 651.20 |
| 5     | 104.97 | 424.13 | 537.19 | 664.29 |
| 6     | 125.92 | 443.63 | 565.03 | 676.34 |
| 7     | 104.71 | 455.40 | 560.91 | 669.35 |
| 8     | 96.80  | 420.32 | 542.71 | 663.36 |
| 9     | 111.63 | 441.35 | 561.82 | 667.39 |
| 10    | 97.50  | 454.77 | 565.17 | 671.17 |
| 11    | 103.60 | 442.77 | 551.18 | 661.20 |
| 12    | 112.86 | 444.64 | 550.58 | 655.96 |
| 13    | 103.64 | 427.96 | 538.25 | 658.95 |
| 14    | 112.52 | 422.28 | 534.66 | 645.81 |
| 15    | 103.26 | 430.20 | 555.65 | 668.99 |
| 16    | 116.73 | 413.00 | 555.14 | 683.62 |
| 17    | 118.90 | 429.09 | 543.57 | 650.83 |
| 18    | 104.93 | 450.17 | 559.80 | 663.99 |
| 19    | 118.48 | 440.68 | 555.30 | 668.23 |
| 20    | 105.57 | 443.22 | 557.30 | 660.84 |
| 21    | 112.05 | 424.46 | 535.42 | 644.62 |
| 22    | 109.72 | 424.74 | 534.61 | 655.53 |
| 23    | 98.04  | 436.90 | 558.60 | 668.43 |
| 24    | 104.29 | 422.90 | 550.69 | 650.69 |
| 25    | 96.91  | 452.90 | 560.64 | 669.82 |
| 26    | 112.10 | 435.98 | 561.08 | 672.40 |
| 27    | 110.85 | 457.53 | 568.28 | 674.15 |
| 28    | 113.33 | 436.61 | 556.93 | 662.57 |
| 29    | 116.62 | 424.28 | 545.37 | 651.22 |
| 30    | 118.23 | 443.36 | 549.12 | 662.28 |
| Means | 109.74 | 436.58 | 551.44 | 663.56 |

TABLE 4-3 Warranty Model Output Data

| Run   | 1986   | 1992   | 1998   | 2004   |
|-------|--------|--------|--------|--------|
| 1     | 123.84 | 463.36 | 577.70 | 684.81 |
| 2     | 109.20 | 428.70 | 541.53 | 663.87 |
| 3     | 104.05 | 422.36 | 578.13 | 684.61 |
| 4     | 124.30 | 424.17 | 537.08 | 675.13 |
| 5     | 105.13 | 420.16 | 541.52 | 654.92 |
| 6     | 111.56 | 431.02 | 560.62 | 672.98 |
| 7     | 116.99 | 453.60 | 562.38 | 671.51 |
| 8     | 116.82 | 436.82 | 552.04 | 664.06 |
| 9     | 97.59  | 436.68 | 549.09 | 667.41 |
| 10    | 117.37 | 427.89 | 545.57 | 667.53 |
| 11    | 116.51 | 436.11 | 540.65 | 647.15 |
| 12    | 111.95 | 453.57 | 560.20 | 666.30 |
| 13    | 111.44 | 432.50 | 540.55 | 671.79 |
| 14    | 112.16 | 443.94 | 551.49 | 660.48 |
| 15    | 126.13 | 462.72 | 571.63 | 673.11 |
| 16    | 110.58 | 421.70 | 541.50 | 655.86 |
| 17    | 116.80 | 438.75 | 551.56 | 678.56 |
| 18    | 118.02 | 450.44 | 559.12 | 672.45 |
| 19    | 110.55 | 440.33 | 551.48 | 660.90 |
| 20    | 111.99 | 415.64 | 546.67 | 654.18 |
| 21    | 117.81 | 427.24 | 570.32 | 679.04 |
| 22    | 103.20 | 443.39 | 551.53 | 672.02 |
| 23    | 103.84 | 419.03 | 538.81 | 642.73 |
| 24    | 117.05 | 446.19 | 566.13 | 670.44 |
| 25    | 119.30 | 446.51 | 552.50 | 656.43 |
| 26    | 105.05 | 410.31 | 521.26 | 629.36 |
| 27    | 108.36 | 418.66 | 556.03 | 667.37 |
| 28    | 105.01 | 450.22 | 558.92 | 667.73 |
| 29    | 119.67 | 433.70 | 552.24 | 669.72 |
| 30    | 104.08 | 441.14 | 544.17 | 683.59 |
| Means | 112.55 | 435.90 | 552.41 | 666.20 |

that all eight distributions were in fact normally distributed.

TABLE 4-4

Normality Test (MCEM & Warranty Output)

| <u>Data Set</u> |      | <u>Mean</u><br>(Millions) | <u>Std Dev</u><br>(Millions) | <u>MAX ABS Diff</u> |
|-----------------|------|---------------------------|------------------------------|---------------------|
| MCEM            | 1986 | 109.74                    | 7.47                         | .1260               |
| MCEM            | 1992 | 436.58                    | 12.42                        | .1297               |
| MCEM            | 1998 | 552.04                    | 10.23                        | .1525               |
| MCEM            | 2004 | 663.57                    | 10.57                        | .0785               |
| WARR            | 1986 | 112.55                    | 7.09                         | .1453               |
| WARR            | 1992 | 435.90                    | 13.85                        | .0692               |
| WARR            | 1998 | 552.41                    | 12.72                        | .1306               |
| WARR            | 2004 | 666.20                    | 12.41                        | .1375               |

The second assumption that had to be made was that each population had the same variance. This involved a comparison of the variances of the two models at each of the four years. The Null hypotheses was as follows:

$$H_0: \sigma^2_{\text{warranty}} = \sigma^2_{\text{MCEM for 1986, 1992, 1998, 2004}}$$

with the alternate being:

$$H_a: \sigma^2_{\text{warranty}} \neq \sigma^2_{\text{MCEM for 1986, 1992, 1998, 2004}}$$

The test statistic for comparison was the F value:

$$F_{\alpha/2, (N_1-1), (N_2-1)} = 1.85$$

$$\begin{aligned} \text{where: } \alpha/2 &= .05 \\ N_1 &= 30 \\ N_2 &= 30 \end{aligned}$$

The decision rule for the F-Test was:

If the calculated F is greater than 1.85 then the variances are not equal

$$\text{where: } F = \frac{\text{larger } \sigma^2}{\text{smaller } \sigma^2}$$

The results of these calculations are shown in Table 4-5.

These indicate that in no case can the hypothesis that the variances are equal be rejected.

TABLE 4-5

Comparison of Variances  
(MCEM & Warranty Output)

| <u>Year</u> | <u>Model</u> | <u>Variance</u> | <u>Test Statistic<br/>Computation</u> | <u>Comparison</u> |
|-------------|--------------|-----------------|---------------------------------------|-------------------|
| 1986        | WARR.3       | 48.597          | $\frac{53.868}{48.597} = 1.108$       | 1.108 > 1.85      |
|             | MCEM.3       | 53.868          |                                       |                   |
| 1992        | WARR.3       | 185.330         | $\frac{185.330}{149.154} = 1.243$     | 1.243 > 1.85      |
|             | MCEM.3       | 149.154         |                                       |                   |
| 1998        | WARR.3       | 156.493         | $\frac{156.493}{113.256} = 1.382$     | 1.382 > 1.85      |
|             | MCEM.3       | 113.256         |                                       |                   |
| 2004        | WARR.3       | 148.810         | $\frac{148.810}{108.076} = 1.377$     | 1.377 > 1.85      |
|             | MCEM.3       | 108.076         |                                       |                   |

With the two basic assumptions supported, it was possible to analyze the means of each of the simulations. This analysis was accomplished using a Oneway ANOVA to compare the means of the two simulation populations for each year group. The hypothesis to be tested is as follows starting with the Null:



$H_0$ : The mean for each year group of the MCEM model output is equal to its respective output of the warranty model

The alternate hypothesis is:

$H_a$ : The means of the respective models are not equal

The test statistic for this analysis is a comparison of the F probability from the SPSS Oneway analysis to the chosen alpha level of .10. The decision rule is as follows:

If the F probability, or P value as it is referred to, associated with a computed value of the F Test statistic is less than the alpha value then the means are not equal.

The results of this testing are reported in Table 4-6 and indicate that the P values are greater than the alpha value in all cases. This precluded rejecting the hypothesis that there was no significant difference between the average costs of each simulation at the four data collection points.

The SPSS programs used for analysis are provided in their entirety in Appendix H.

TABLE 4-6

Oneway ANOVA  
(MCEM & Warranty Output)

| <u>Year</u> | <u>P-Value*</u> | <u>Warranty<br/>Mean<br/>(Millions)</u> | <u>Maintenance<br/>Mean<br/>(Millions)</u> |
|-------------|-----------------|---|--|
| 1986        | .1407           | 112.55                                  | 109.74                                     |
| 1992        | .8411           | 435.90                                  | 436.58                                     |
| 1998        | .9136           | 551.75                                  | 552.06                                     |
| 2004        | .3793           | 666.20                                  | 663.56                                     |

\*P-Value - The probability of obtaining a value of the F Test statistic at least as large as the reported F Value

#### Sensitivity Analysis

Testing of the model demonstrated its validity in the real world situation. Next, the researchers tested the model's sensitivity to changes in policy parameter levels to determine which parameters had the greatest effect on system behavior. This process involved first a screening of the five policy parameters to determine the two most dominant parameters and second, an extensive analysis of these two parameters. It was initially decided that two parameters would be analyzed in order to limit the total number of required simulations.

The first step in the screening process involved collecting the data of the effects of parameter change on model output for each of the five policy parameters and all their possible combinations. The treatment levels were

arranged in standard order shown in Table 4-7.

TABLE 4-7  
Policy Parameter Treatment Levels  
Standard Order

A  
B  
AB  
C  
AC  
BC  
ABC  
D  
\*  
\*  
\*  
ABCDE

With all other parameter values held at their normal level, the values of the parameter or parameter combinations shown in Table 4-7 were changed to reflect an improvement. Table 4-8 identifies each policy parameter with its corresponding factor and shows the parameter value levels that were used in the sensitivity analysis.

TABLE 4-8  
Policy Parameter Changes

| <u>Factor</u> | <u>Title</u>        | <u>Standard</u> | <u>Change</u> |
|---------------|---------------------|-----------------|---------------|
| A             | Engine Cost         | \$6.5M          | \$5.85        |
| B             | Reliability         | 0%              | +10%          |
| C             | Maintainability     | 0%              | +10%          |
| D             | Shop Visit Rate     | 2.5             | 2.25          |
| E             | Condemnation Factor | 0%              | -10%          |

Thirty simulation runs of each parameter combination were made. The average response for four of the thirty years is shown in Table 4-9.

TABLE 4-9 Yates Algorithm Inputs

| Response | 1986   | 1992   | 1998   | 2004   |
|----------|--------|--------|--------|--------|
| 1        | 127.39 | 449.13 | 566.60 | 630.52 |
| A        | 123.11 | 426.30 | 542.54 | 656.34 |
| B        | 126.97 | 447.04 | 552.66 | 655.07 |
| AB       | 122.68 | 423.38 | 526.67 | 630.56 |
| C        | 127.32 | 444.20 | 556.18 | 664.64 |
| AC       | 123.03 | 421.41 | 532.52 | 640.46 |
| BC       | 126.90 | 442.67 | 543.24 | 640.64 |
| ABC      | 122.61 | 418.81 | 519.00 | 616.14 |
| D        | 124.30 | 435.96 | 554.83 | 666.90 |
| AD       | 120.34 | 414.32 | 532.15 | 643.39 |
| BD       | 124.08 | 427.65 | 529.55 | 634.65 |
| ABD      | 120.05 | 405.81 | 507.25 | 611.77 |
| CD       | 124.23 | 431.09 | 544.49 | 651.08 |
| ACD      | 120.27 | 409.44 | 521.80 | 628.07 |
| BCD      | 124.01 | 423.24 | 520.19 | 620.30 |
| ABCD     | 119.98 | 401.40 | 497.89 | 597.42 |
| E        | 127.34 | 445.78 | 559.20 | 667.79 |
| AE       | 124.72 | 427.59 | 539.06 | 644.89 |
| BE       | 126.96 | 443.97 | 545.90 | 644.45 |
| ABE      | 122.67 | 420.31 | 521.66 | 620.04 |
| CE       | 129.06 | 445.68 | 552.09 | 652.67 |
| ACE      | 124.65 | 422.61 | 528.03 | 628.88 |
| BCE      | 125.66 | 437.37 | 532.38 | 630.12 |
| ABCE     | 122.60 | 415.94 | 512.25 | 605.61 |
| DE       | 124.30 | 432.48 | 547.30 | 655.20 |
| ADE      | 120.33 | 410.93 | 524.51 | 632.18 |
| BDE      | 124.03 | 424.83 | 523.29 | 624.42 |
| ABDE     | 120.13 | 402.99 | 500.99 | 601.54 |
| CDE      | 125.04 | 429.03 | 539.01 | 641.92 |
| ACDE     | 121.01 | 407.32 | 516.26 | 619.52 |
| BCDE     | 121.16 | 421.68 | 519.05 | 607.85 |
| ABCDE    | 119.39 | 399.51 | 495.30 | 587.25 |

The data in each year group was analyzed using the Yates Algorithm (26) which calculated an estimated effect for each parameter set shown in Table 4-10. To help isolate the two most important policy parameters the data produced by the Yates Algorithm was plotted using the BMDP package on the ASD CYBER system. The program that was used can be found in Appendix I and the normality plots for each year group are shown in Figures 4-3, 4-4, 4-5, and 4-6.

It is apparent that factors A and D are dominant over the majority of the life cycle and these two factors should be selected for further study. However, the results in general provided increased confidence in the model as the effects of each factor responded in a manner that was intuitively appealing. It was expected that engine cost (A) and shop visit rate (D) would be strong drivers over the entire system life, and that the effects of reliability (B), maintainability (C), and condemnation (E) would begin to increase as the system matured and gained flying hours.

The screening process identified the two most dominant parameters. These two parameters could then be further tested to determine if their effects were truly significant and if there was any significant interaction between them. A Two Way ANOVA was used to test the following Null hypothesis:

$H_0$ : Are the effects of factor A significant

$H_0$ : Are the effects of factor D significant

TABLE 4-10 Yates Algorithm Results

| Response | 1986  | 1992   | 1998   | 2004   |
|----------|-------|--------|--------|--------|
| I        | -     | -      | -      | -      |
| A        | -3.82 | -22.11 | -22.92 | -22.12 |
| B        | -1.04 | -6.04  | -19.42 | -26.63 |
| AB       | 0.12  | -0.43  | -0.11  | -1.24  |
| C        | -0.16 | -4.19  | -9.12  | -16.17 |
| AC       | 0.09  | -0.21  | 0.10   | 1.31   |
| BC       | -0.50 | -0.23  | 0.41   | 1.51   |
| ABC      | 0.33  | 0.42   | 0.58   | -1.03  |
| D        | -3.19 | -15.91 | -16.10 | -14.75 |
| AD       | 0.12  | 0.33   | 0.35   | -0.54  |
| BD       | 0.16  | -1.99  | -4.06  | -4.94  |
| ABD      | 0.16  | 0.29   | 0.27   | 1.64   |
| CD       | -0.15 | 0.16   | 0.76   | 1.40   |
| ACD      | 0.17  | 0.15   | -0.15  | -1.08  |
| BCD      | -0.13 | 0.40   | 0.50   | -1.64  |
| ABCD     | -0.05 | -0.44  | -0.64  | 1.36   |
| E        | -0.11 | -2.11  | -5.79  | -9.69  |
| AE       | 0.32  | 0.41   | 0.52   | -1.03  |
| BE       | -0.70 | -0.81  | -0.04  | -0.96  |
| ABE      | 0.14  | -0.14  | 0.15   | 1.31   |
| CE       | -0.08 | 0.47   | 0.55   | 1.45   |
| ACE      | 0.10  | -0.18  | -0.12  | -1.19  |
| BCE      | -0.50 | -0.45  | -0.31  | -1.72  |
| ABCE     | 0.33  | 0.45   | 0.36   | 1.47   |
| DE       | -0.35 | -0.40  | 0.36   | -0.96  |
| ADE      | -0.03 | -0.44  | -0.60  | 1.26   |
| BDE      | 0.08  | 1.05   | 1.15   | 0.84   |
| ABDE     | 0.17  | 0.10   | -0.19  | -0.98  |
| CDE      | -0.16 | 0.14   | 0.94   | -1.13  |
| ACDE     | 0.16  | 0.12   | 0.07   | 1.43   |
| BCDE     | -0.13 | 0.39   | 0.76   | 0.86   |
| ABCDE    | -0.05 | -0.47  | -0.42  | -1.14  |

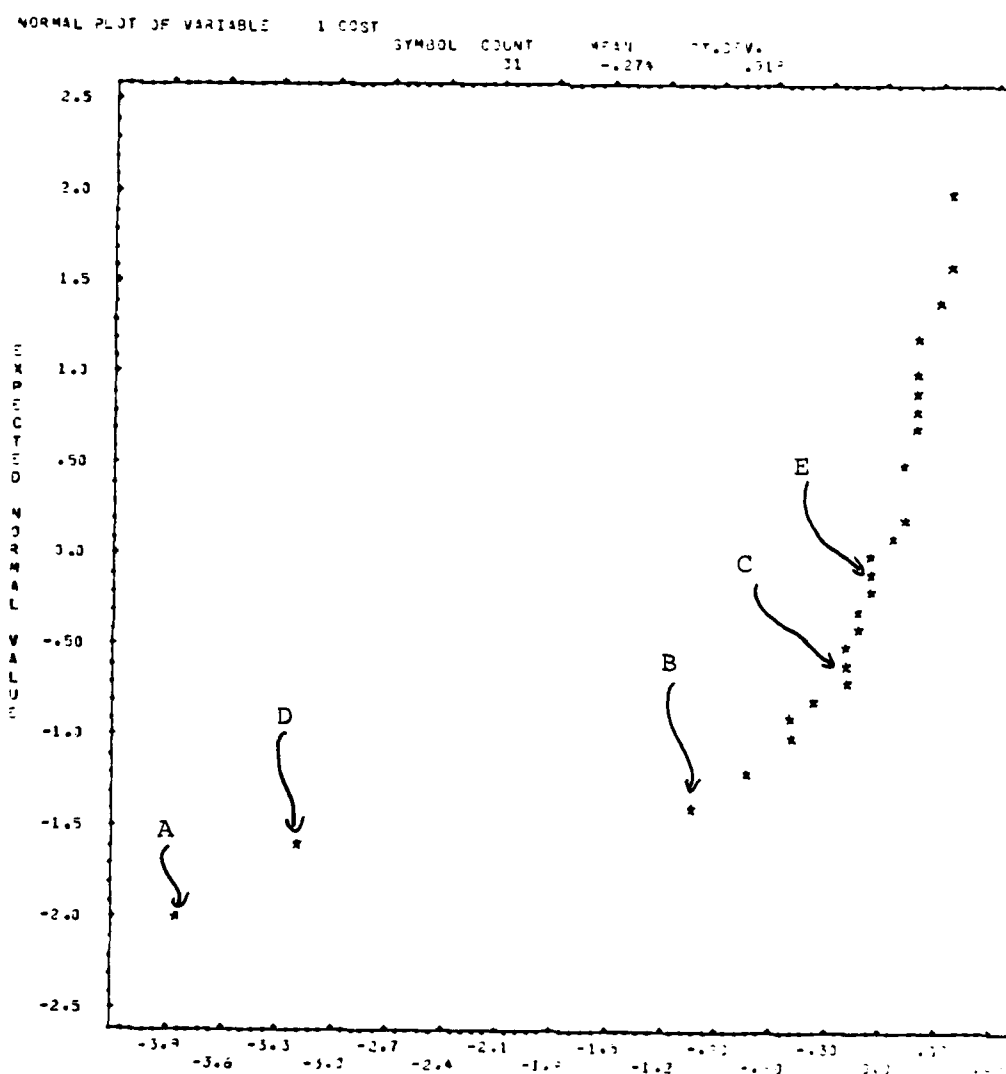


Figure 4-3 1986 Normality Plot

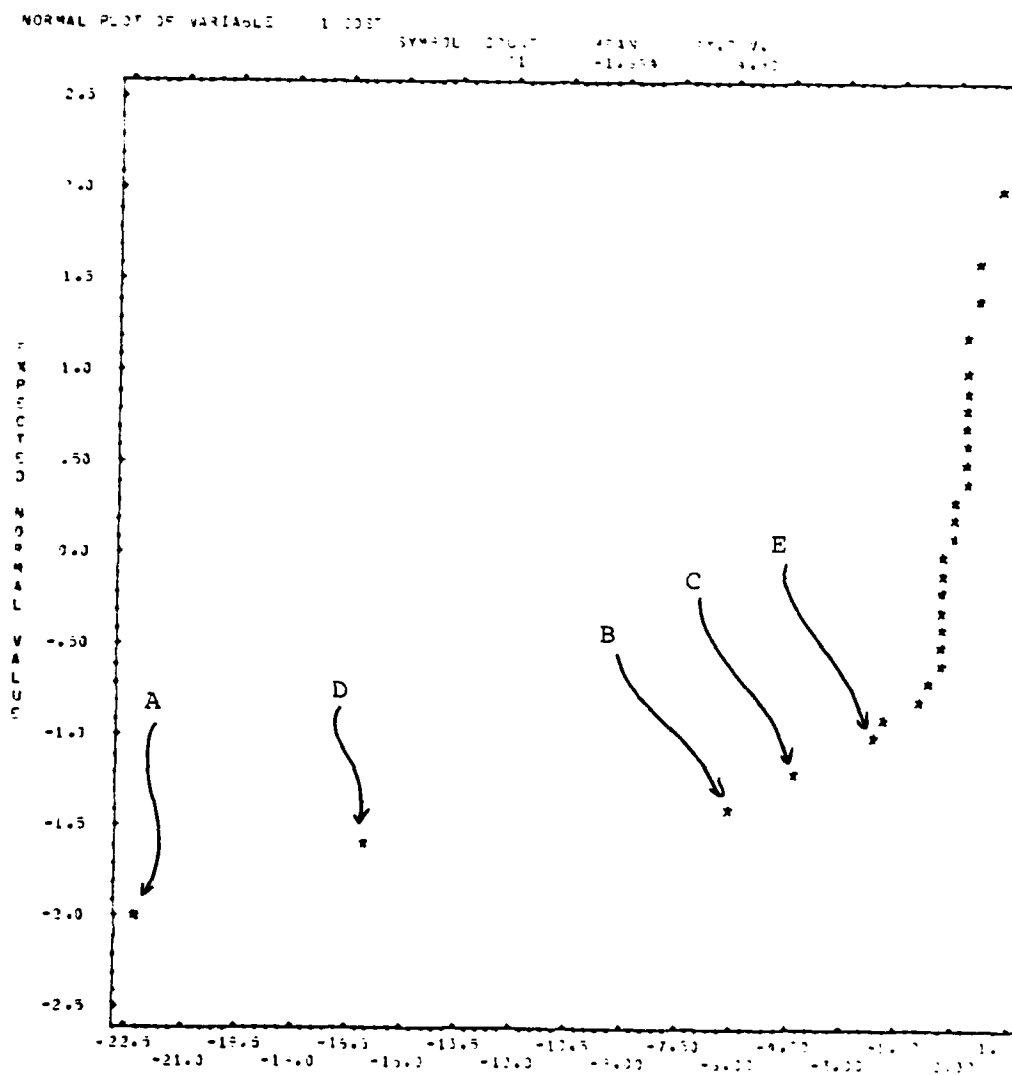


Figure 4-4 1992 Normality Plot



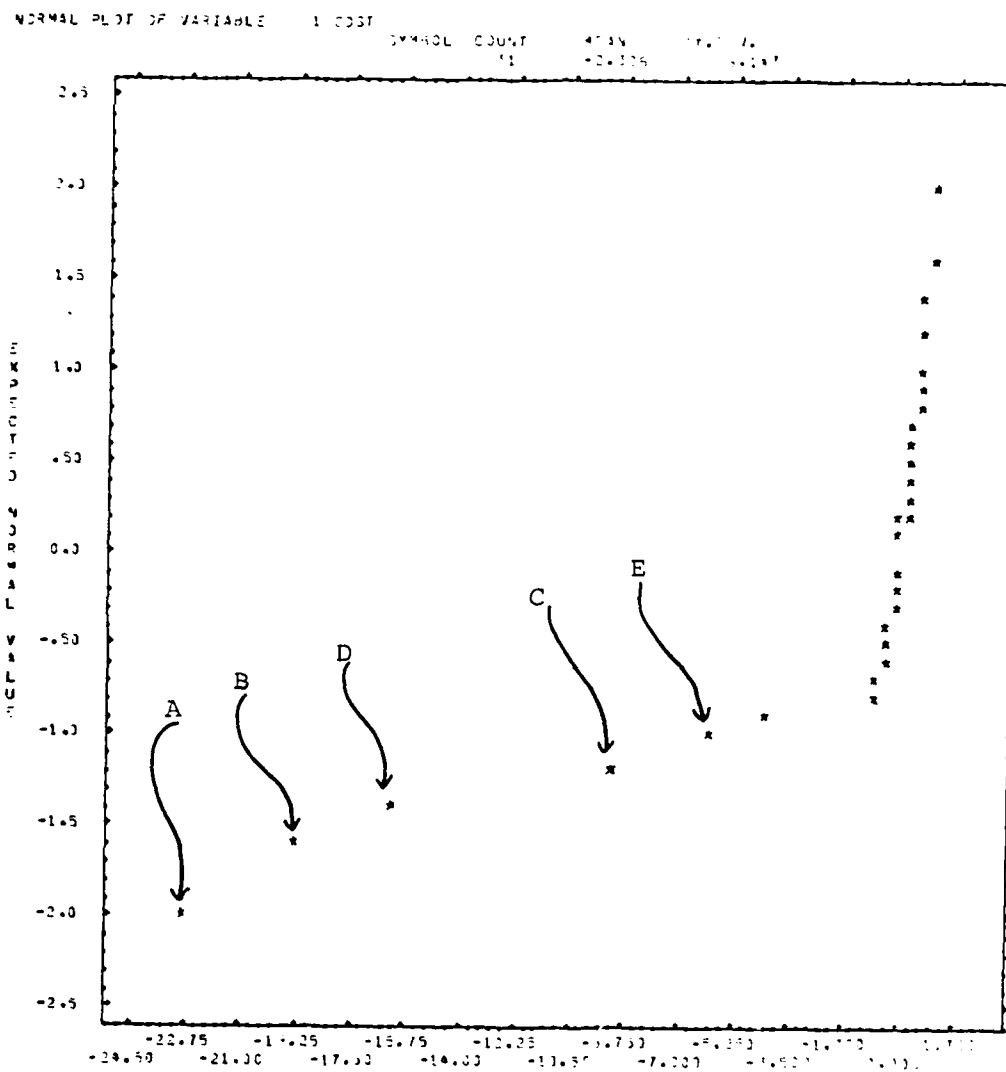
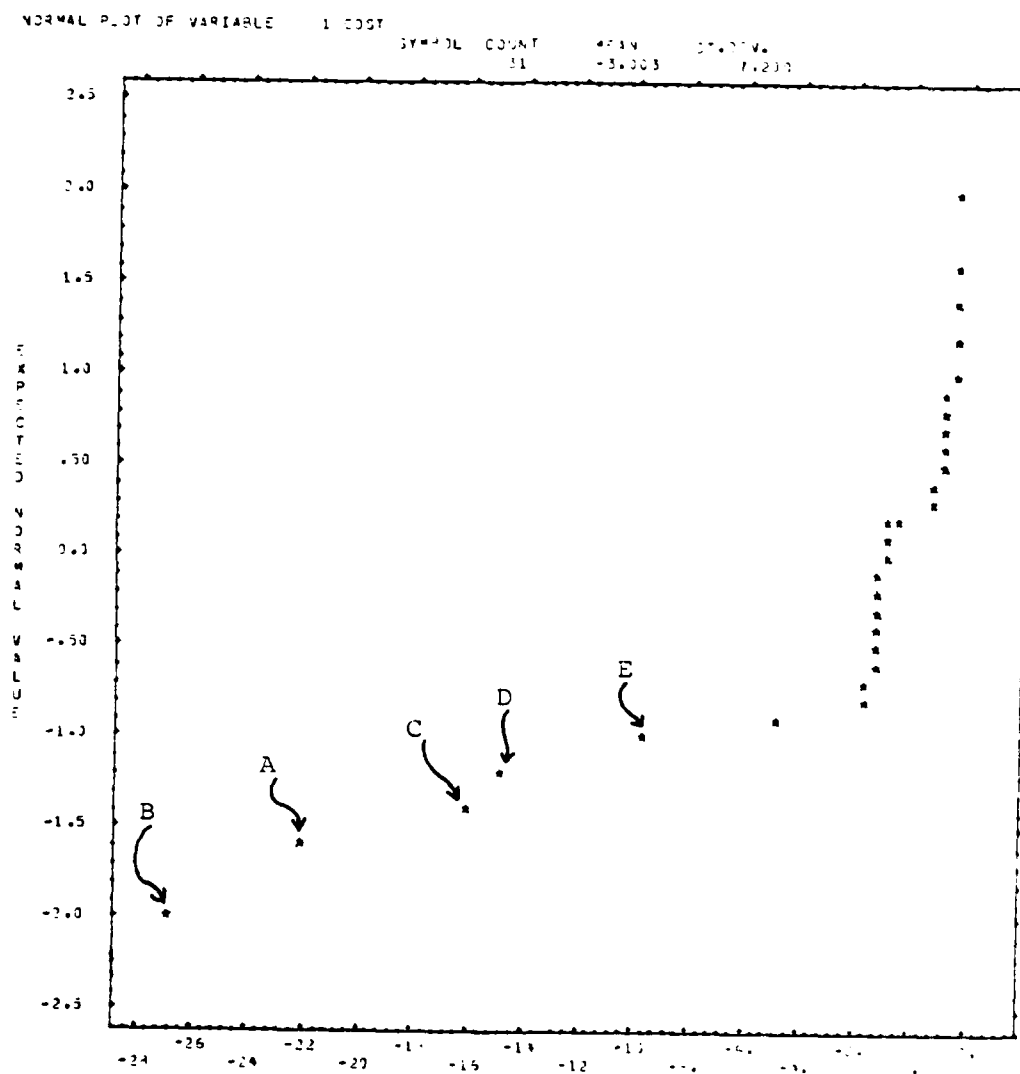


Figure 4-5 1998 Normality Plot



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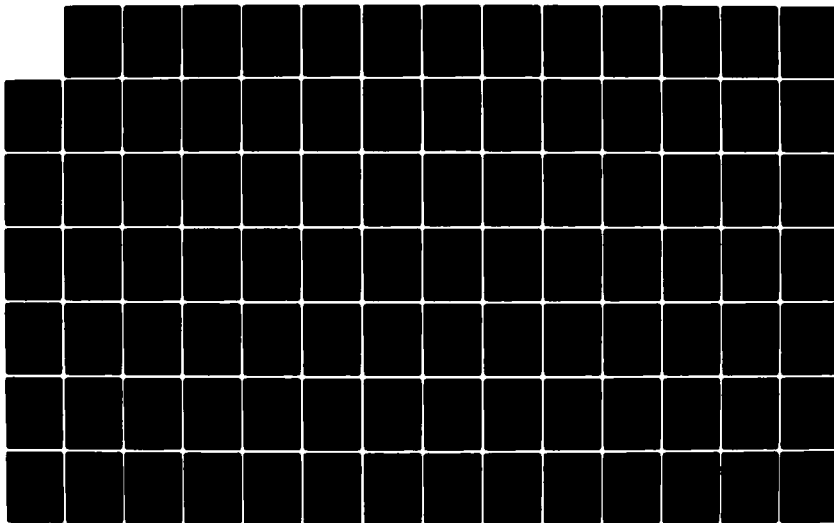
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$H_0$ : Are the interaction effects of A and B significant

In order to use this analytic method, 30 observations for each possible combination of the two factors at three levels were needed. The design for generating this data is shown in Figure 4-7 and the actual observations are listed in Table 4-11.

|   |  | Shop Visit Rate<br>D |             |             | Engine<br>Cost<br>A | K=1-30 |
|---|--|----------------------|-------------|-------------|---------------------|--------|
|   |  | i \ j                | 1           | 2           | 3                   |        |
| 1 |  |                      | $X_{1,1,K}$ | $X_{1,2,K}$ | $X_{1,3,K}$         |        |
| 2 |  |                      | $X_{2,1,K}$ | $X_{2,2,K}$ | $X_{2,3,K}$         |        |
| 3 |  |                      | $X_{3,1,K}$ | $X_{3,2,K}$ | $X_{3,3,K}$         |        |

Figure 4-7 Data Generating Design for Two Way ANOVA

Using this data a Two Way ANOVA of the three levels of engine cost was run. The Null Hypothesis was:

$H_0$ : Are the effects of factor A significant

and the decision rule was:

If  $F > F_{\alpha/2, (K-1), (N-K)}$  (where K is the total number of levels and N is the number of observations) then there is a significant difference in at least two of the three levels.

If  $\alpha/2 = .05$ ,  $K-1 = 2$ , and  $N-K = 261$  then the F Table value

$F_{.05, 2, 261} = 3.00$

The Two Way ANOVA calculated an F Value of 320.015,

TABLE 4-11 Policy Parameter Output

| Shop Visit Rate Level |        |        |                   |        |        |                   |        |        |  |
|-----------------------|--------|--------|-------------------|--------|--------|-------------------|--------|--------|--|
| 1                     |        |        | 2                 |        |        | 3                 |        |        |  |
| Engine Cost Level     |        |        | Engine Cost Level |        |        | Engine Cost Level |        |        |  |
| 1                     | 2      | 3      | 1                 | 2      | 3      | 1                 | 2      | 3      |  |
| 407.29                | 428.09 | 448.89 | 423.79            | 412.83 | 463.45 | 429.56            | 459.29 | 477.70 |  |
| 421.49                | 444.24 | 483.52 | 412.43            | 445.89 | 476.74 | 437.53            | 459.48 | 483.43 |  |
| 425.93                | 448.68 | 500.05 | 420.79            | 434.53 | 464.74 | 441.92            | 463.20 | 490.01 |  |
| 403.21                | 424.01 | 449.81 | 425.32            | 448.07 | 467.99 | 468.86            | 454.30 | 474.96 |  |
| 445.46                | 470.16 | 467.23 | 433.30            | 456.70 | 491.69 | 435.89            | 454.29 | 486.03 |  |
| 416.59                | 438.04 | 459.63 | 428.31            | 451.05 | 486.09 | 435.44            | 459.38 | 486.15 |  |
| 415.78                | 437.21 | 456.32 | 440.57            | 464.62 | 491.26 | 439.14            | 465.96 | 517.86 |  |
| 404.08                | 424.88 | 449.51 | 413.97            | 436.07 | 471.32 | 430.90            | 452.21 | 493.86 |  |
| 407.13                | 427.93 | 456.19 | 438.93            | 462.98 | 479.64 | 430.89            | 461.98 | 489.11 |  |
| 396.24                | 416.39 | 465.73 | 425.58            | 448.31 | 472.55 | 435.32            | 462.10 | 481.55 |  |
| 402.26                | 422.41 | 458.75 | 464.53            | 562.91 | 463.45 | 441.91            | 491.21 | 491.65 |  |
| 414.77                | 436.32 | 459.25 | 436.40            | 436.44 | 476.98 | 429.46            | 469.82 | 493.32 |  |
| 432.67                | 456.07 | 457.77 | 425.01            | 462.38 | 489.66 | 437.93            | 465.06 | 476.77 |  |
| 423.39                | 446.14 | 452.94 | 401.56            | 452.24 | 489.35 | 438.05            | 458.15 | 484.37 |  |
| 414.46                | 436.59 | 465.69 | 438.94            | 456.65 | 485.17 | 464.56            | 467.60 | 484.36 |  |
| 411.18                | 441.48 | 462.87 | 414.34            | 460.87 | 461.87 | 445.77            | 468.63 | 496.63 |  |
| 424.64                | 427.80 | 464.59 | 438.33            | 454.57 | 487.91 | 441.01            | 454.03 | 521.93 |  |
| 411.71                | 431.42 | 449.78 | 429.53            | 462.25 | 485.33 | 434.75            | 460.97 | 495.81 |  |
| 428.66                | 436.56 | 451.30 | 433.25            | 448.18 | 472.49 | 443.55            | 460.96 | 471.19 |  |
| 412.95                | 432.63 | 459.62 | 436.82            | 463.68 | 471.87 | 443.92            | 471.94 | 498.05 |  |
| 410.93                | 416.74 | 428.91 | 431.17            | 464.47 | 451.68 | 431.28            | 494.63 | 482.13 |  |
| 453.72                | 433.16 | 465.37 | 438.20            | 439.27 | 485.77 | 437.57            | 471.11 | 482.98 |  |
| 414.30                | 452.06 | 469.69 | 425.23            | 449.01 | 485.12 | 437.56            | 448.44 | 475.06 |  |
| 424.19                | 434.40 | 469.68 | 439.63            | 474.15 | 479.96 | 447.24            | 473.35 | 484.33 |  |
| 411.96                | 432.38 | 464.02 | 440.42            | 457.50 | 483.00 | 467.33            | 458.73 | 491.32 |  |
| 422.20                | 479.72 | 465.78 | 417.17            | 443.31 | 458.54 | 446.41            | 459.58 | 523.46 |  |
| 414.19                | 435.75 | 482.56 | 426.26            | 491.83 | 458.54 | 425.69            | 452.31 | 482.69 |  |
| 419.38                | 446.94 | 455.65 | 448.78            | 460.45 | 486.96 | 448.65            | 460.93 | 483.54 |  |
| 406.35                | 433.41 | 473.58 | 434.10            | 447.76 | 491.81 | 435.33            | 466.62 | 487.25 |  |
| 410.62                | 444.30 | 449.51 | 421.21            | 421.71 | 487.81 | 436.18            | 496.16 | 477.70 |  |

much greater than the table value of 3.00. It can be assumed then that there is a significant difference between at least two of the three levels of engine cost.

The same analysis was used to assess the significance of the different levels of shop visit rate. The Null hypothesis was:

$H_0$ : Are the effects of factor D significant

and the decision rule was:

If  $F > F_{\alpha/2, (K-1), (N-K)}$  (where K is the total number of levels and N is the number of observations) then there is a significant difference in at least two of the three levels.

If  $\alpha/2 = .05$ ,  $K-1 = 2$ , and  $N-K = 261$  then the F Table value,  $F_{.05, 2, 261} = 3.00$

For shop visit rate the ANOVA calculated an F Value of 96.243, again much higher than 3.00 indicating that there was a significant difference between at least two of the three levels.

The last assessment was an analysis of interaction between A and D.

The hypothesis for this test was:

$H_0$ : Are the interaction effects of A and D significant

with a decision rule:

If  $F > F_{\alpha/2, (K-1), (N-K)}$  (where K is the total number of levels and N is the number of observations) then there is a significant difference in at least two of the three levels.

If  $\alpha/2 = .05$ ,  $K-1 = 4$ , and  $N-K = 261$  then the F Table value

$F_{.05, 4, 261} = 2.37$

The value calculated by the Two Way ANOVA is 0.147, and is less than the table value indicating that there was no significant difference between any of the levels of interaction of the two factors. It can be assumed therefore, that the interaction effects of A and D are not significant. The computer results of the SPSS Two Way ANOVA for engine cost and shop visit rate are shown in Figure 4-8.

| ***** ANALYSIS OF VARIANCE ***** |                |     |             |         |             |
|----------------------------------|----------------|-----|-------------|---------|-------------|
| COST                             |                |     |             |         |             |
| BY ENG                           |                |     |             |         |             |
| SVR                              |                |     |             |         |             |
| SOURCE OF VARIATION              | SUM OF SQUARES | DF  | MEAN SQUARE | F       | SIGNIF OF F |
| MAIN EFFECTS                     | 127839.286     | 4   | 31959.821   | 208.129 | 0.000       |
| ENG                              | 98281.547      | 2   | 49140.773   | 320.015 | 0.000       |
| SVR                              | 29557.739      | 2   | 14778.870   | 96.243  | 0.000       |
| 2-WAY INTERACTIONS               | 90.230         | 4   | 22.558      | 0.147   | 0.964       |
| ENG SVR                          | 90.230         | 4   | 22.558      | 0.147   | 0.964       |
| EXPLAINED                        | 127929.516     | 8   | 15991.189   | 104.138 | 0.000       |
| RESIDUAL                         | 40078.608      | 261 | 153.558     |         |             |
| TOTAL                            | 168008.124     | 269 | 624.566     |         |             |
| 270 CASES WERE PROCESSED.        |                |     |             |         |             |
| 0 CASES ( 0.0 PCT) WERE MISSING. |                |     |             |         |             |

Figure 4-8 Two Way ANOVA Results

Knowing that at least two of the three levels of each factor are significantly different, the next logical step was to assess exactly how many levels of each factor are in fact different. This is done using an SPSS Oneway ANOVA with a



Duncan's Multiple Ranges a posteriori analysis of means. The Duncan's analysis operates as follows:

1. All means are ranked in ascending order.
2. Using the mean square error, the number of levels and the total number of observations, comparison factors are calculated by the SPSS program.
3. The comparison factors are used to decide if there is a significant difference between adjoining means and then between groupings.

The results for the SPSS analysis of the engine cost and SVR factors are found in Figure 4-9.

| Engine Cost Homogeneous Groups |                 |                 |
|--------------------------------|-----------------|-----------------|
| Group 1                        | Group 2         | Group 3         |
| <u>429.2356</u>                | <u>452.3244</u> | <u>475.9681</u> |
| SVR Homogeneous Groups         |                 |                 |
| Group 1                        | Group 2         | Group 3         |
| <u>439.1870</u>                | <u>453.5942</u> | <u>464.7469</u> |

Figure 4-9 SPSS Analysis of Engine Cost Factors

All homogeneous groups are indicated by underscored lines. As shown in Figure 4-9, no two groups are associated with a single underscore which indicates that, in fact, none of the levels for engine cost or SVR are homogeneous and are assumed to be significantly different.

A similar analysis was accomplished for the shop visit rate with the same results. All three levels were found to be significantly different.

The results of the sensitivity analysis section indicate that changes in the two primary policy parameters

due to either negotiation or improvement in operations and support will significantly effect the overall cost of operating the system.

SPO analysts now know which factors are most important and have a feel for what the system will do when the levels of these factors are changed. This knowledge of the primary factors and their characteristic effects on the system output allow negotiators to effectively negotiate specific factors at their optimum levels.

Once the sensitivity of the model was assessed and the analyst is aware of the most critical policy parameters, it is possible to incorporate this pertinent information into the negotiation process.

#### Decision Support System

The decision support system is designed to analyze the cost effectiveness of a warranty contract proposal. It uses both the short and long model versions to analyze engine operation and support costs for the warranty period as well as the cost effectiveness of the warranty over the entire life of the engine.

Using vendor supplied component failure probabilities and component replacement costs, SPO analysts can use the short version to compare the up front warranty cost to the anticipated support costs incurred over the warranty period.

On the other hand, the long version analyzes the long term effects of contractor improvements. That is, contractor

made improvements during the warranty period are expected to reduce system operating costs over the operational life cycle.

In Figure 4-10, both versions of the model are integrated in the complete DSS. The short version simulates engine O&S over the warranty period. The output goes directly to a file and prints monthly statistics of unit failure and repair costs.

The long version, with and without warranty input data, simulates engine O&S over a 20 year period. The year end statistics from a simulation of each input data set are filed, averaged, and compared, to provide an analysis of the cost effectiveness of the warranty.

With both model versions incorporated into the DSS, SPO analysts have the needed capability to analyze the short and long term effects of the warranty. To demonstrate this capability, a scenario of the contracting process was developed.

Short Term Warranty Analysis. In this hypothetical case, the contractor has proposed a four year contract in which he will warrant all engine SRU and LRU components against failure, and repair or replace those units at his own expense. He also guarantees that unit failure probabilities will not fall below specific values. The up front cost to the government for this four year warranty is set at \$50,000,000.

YZ analysts would use contractor supplied estimates of LRU and SRU component failure probabilities and replacement

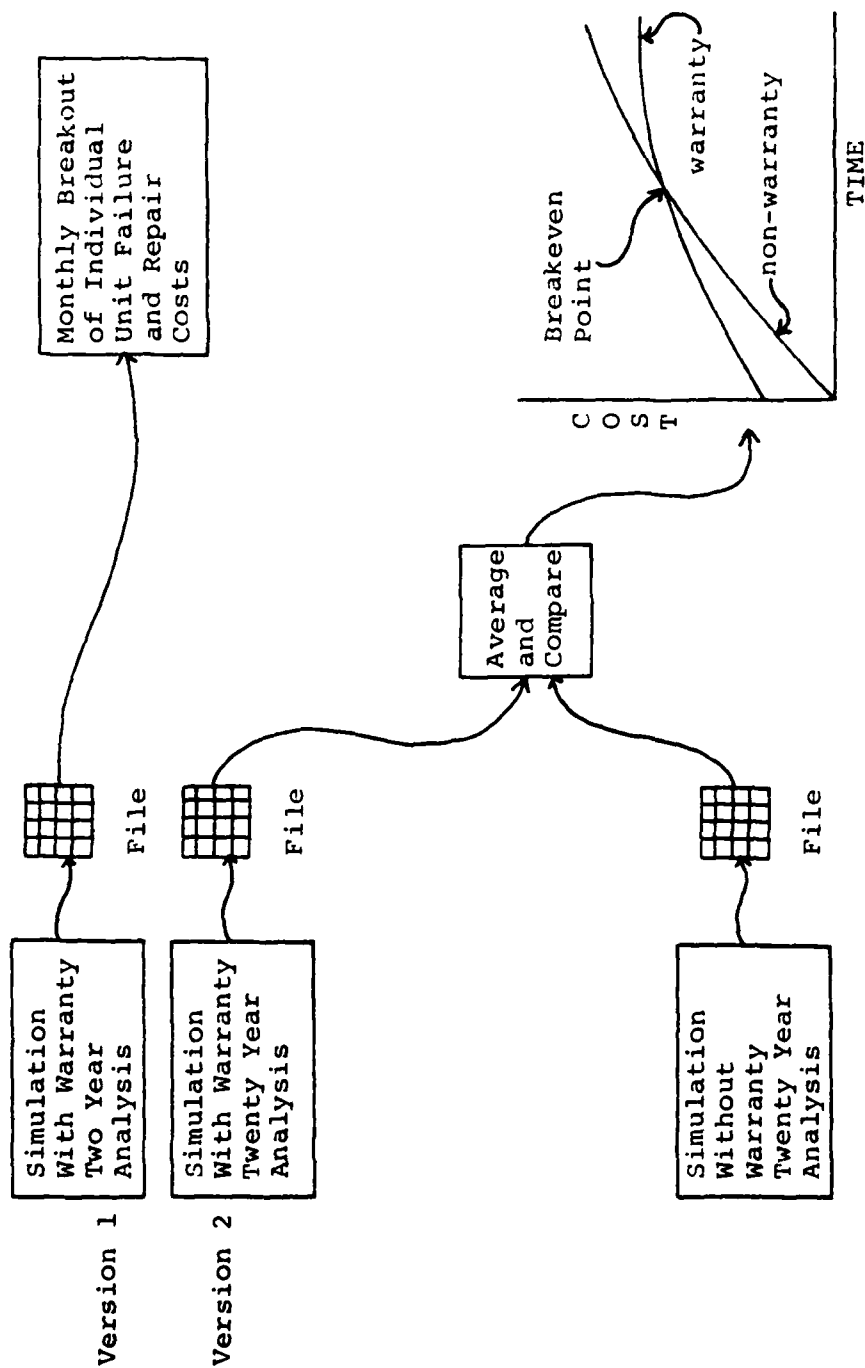


Figure 4-10 Engine Warranty DSS

costs to determine if the warranty is indeed a good investment. They would carefully analyze each LRU and SRU failure rate and replacement cost and then input these values into the short term warranty model.

The construction of the data sets used in the short term model for the four year simulation was done in accordance with the short term users manual provided in Appendix G. The data sets used in this example are shown in Figures 4-11 and 4-12.

```

75#29-SE P-02
76#FXXX 4 2.5 6500000 1.0 .0 0
77#600000 2500000 30000000 2500000
78#29 50 3.28 24 35 59 500
79#4 5 5 51 18 30 30 73
80#4000 160 50 .05 .05
81#85 91.25 2 50 9 1
82#10 .50 .10
83#46
84#0 0 1 0 0 0 0 0 0 1
85#0 1 1 1 2 2 2 2 2 3 3
87#4 4 4 4 4 4 4 4 4 4 4
88#4 4 4 4 4 4 4 0 0 0 0
89#5
90#36 28 18 18 999
91#1

```

Figure 4-11 Short Term Model Data Sets

Ten simulation runs were made and the output data was collected and summarized in Table 4-12.

The results of the four year warranty simulation for each year are graphed in Figure 4-13 and show the warranty cost to exceed the projected repair and replacement costs.

290#20  
 300#FAN-ROTOR 31.62 82.73 60.0 284.94 65.73 78.0 155953.0 .02  
 310#FAN-STATOR 232.14 86.07 70.0 58.03 54.82 102.25 123056.0 .05  
 320#FRONT-FRAME 223.6 27.0 80.0 55.89 16.4 90.6 99245.0 .02  
 330#INLET-GEARBX 82.14 32.0 10.4 82.14 25.88 16.52 7719.0 .05  
 340#FAN-FRAME 127.67 92.94 70.0 31.92 78.72 84.22 68141.0 .01  
 350#ACC-GEARBX 98.32 47.45 85.0 98.29 29.95 102.5 59949.0 .01  
 360#COMP-ROTOR 37.87 304.52 70.0 341.06 235.95 139.57 197053.0 .02  
 370#FWD-CP-STAT 171.58 281.02 50.0 171.59 211.13 119.89 164595.0 .05  
 380#AFT-CP-STAT 117.73 252.9 75.0 117.73 198.54 131.36 36281.0 .04  
 390#COMBUSTOR 90.37 64.12 87.0 809.72 55.55 96.57 48089.0 .35  
 400#COMP-CASE 65.74 187.22 60.0 262.67 174.15 73.57 54401.0 .01  
 410#HPT-ROTOR 87.78 121.3 50.0 788.64 81.54 90.76 236608.0 .01  
 420#HPT-STATOR 698.26 67.9 40.0 77.54 58.26 50.84 167904.0 .02  
 430#HPT-SHROUD 729.93 98.42 2.0 81.1 73.05 26.27 49111.0 .11  
 440#LPT-ROTOR 51.26 109.3 72.0 461.04 76.46 105.84 134517.0 .03  
 450#STG1-LPT-ST 257.52 79.35 80.0 386.4 53.53 105.82 69555.0 .07  
 460#STG2-LPT-ST 227.55 137.05 25.0 340.95 93.09 69.16 50957.0 .11  
 470#TURBINE-FRM 146.77 262.0 60.0 342.47 155.0 168.0 57378.0 .01  
 480#AUGMENTOR 232.32 125.9 70.0 25.91 83.5 113.6 180029.0 .06  
 490#EXHAUST-NOZ 105.31 192.55 40.0 11.69 114.81 117.74 271349.0 .04  
 120#16  
 130#ENGINE-CONTR 417.7 1.6 9.0 70.0 77699.0 .01  
 140#FUEL-PUMP 138.2 0.4 4.0 18.0 13491.0 .05  
 150#FAN-SPEED-SE 5.5 0.2 2.8 3.0 2573.0 .05  
 160#AFT-CONTROL 340.25 1.2 5.0 44.0 60516.0 .05  
 170#AUG-IG-PLUG 1109.88 0.3 1.5 6.5 1713.0 .90  
 180#T48-PYROM 77.41 0.5 4.0 7.5 7716.0 .05  
 190#AUG-FUEL-CTR 70.11 1.5 5.0 35.0 39980.0 .02  
 200#HYD-PUMP 245.22 0.6 4.0 30.0 37054.0 .05  
 210#LUBE-PUMP 139.47 1.0 2.0 22.0 12127.0 .05  
 220#ANTI-ICING 110.72 0.6 3.0 17.0 10593.0 .05  
 230#FAN-DIS-T2.5 67.9 0.3 2.0 11.0 6667.0 .90  
 240#FAN-INLET-T2 22.02 0.2 1.0 6.0 2354.0 .90  
 250#INLET-GUIDE 1329.79 0.0 0.5 1.0 722.0 .10  
 260#ALTERNATOR 133.62 0.6 3.0 8.0 2653.0 .05  
 270#FLAME-DET 129.58 0.2 2.0 7.0 2309.0 .04  
 280#AUG-FUEL-FU. 305.25 1.2 4.0 20.0 25387.0 .05

Figure 4-12 Short Term Model Data Sets

TABLE 4-12

## Short Version Warranty Output Data

|         | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| SRU     |       |       |       |       |       |       |       |       |       |       |
| Repair  | 13.35 | 11.90 | 12.29 | 12.70 | 12.52 | 13.69 | 11.70 | 13.43 | 12.07 | 12.36 |
| LRU     |       |       |       |       |       |       |       |       |       |       |
| Repair  | 1.01  | 0.94  | 1.16  | 1.06  | 1.10  | 1.11  | 1.06  | 1.09  | 1.16  | 1.11  |
| SRU     |       |       |       |       |       |       |       |       |       |       |
| Replace | 8.89  | 8.71  | 8.04  | 8.82  | 8.63  | 7.57  | 8.15  | 8.50  | 6.64  | 7.96  |
| LRU     |       |       |       |       |       |       |       |       |       |       |
| Replace | 0.55  | 0.69  | 0.83  | 0.74  | 0.73  | 0.63  | 0.52  | 0.64  | 0.75  | 0.81  |
| Total*  | 23.81 | 22.24 | 22.33 | 23.21 | 22.97 | 23.00 | 21.42 | 23.66 | 20.61 | 22.25 |

\*Differences in totals due to rounding.  
Costs presented in millions.

Thus over the four year warranty period, the projected replacement costs are much less than the \$50,000,000 warranty cost.

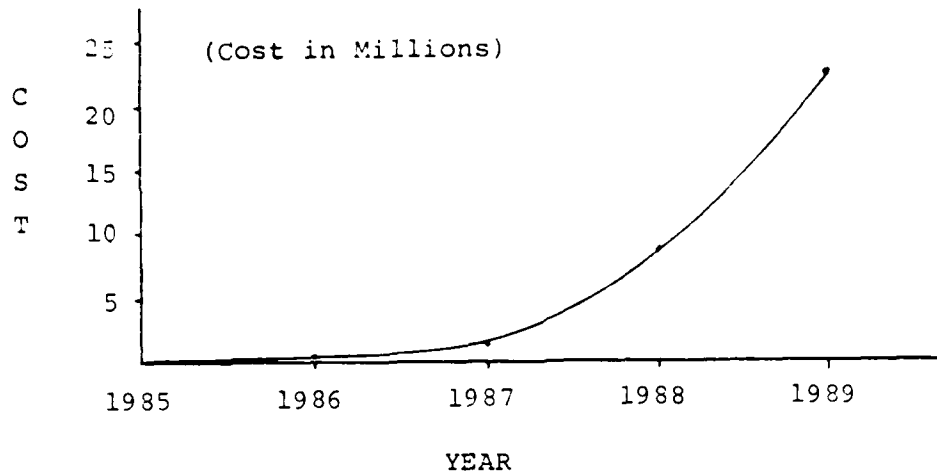


Figure 4-13 Short Term Four Year Warranty Plot

SPC analysts and negotiators now have an estimate of the short term cost of the proposal and can continue to use the model to negotiate different warranty costs or component failure rates to revise the contract proposal. However, the analysis is not complete until the entire operational life cycle of the system has been considered. It is expected that the contractor will make component reliability improvements during the warranty period to increase his profit margin. Obviously if he has warranted a particular component for a given failure rate and can reduce the failures by increasing the reliability, he replaces fewer components and realizes a better profit.



These reliability improvements, however, will continue to save repair and replacement costs beyond the end of the warranty period when the government is incurring those costs. Thus to fully analyze how cost effective a warranty is, the operational life of the engine must be analyzed. The second or long term warranty model version is used to analyze the effects of component reliability improvement over the life of the system.

Long Term Warranty Analysis. The second version of the warranty model analyzes the effect of component reliability improvement over a 20 year period. YZ analysts used data sets that were similar to those used in the short version for analysis of the extended effects of the warranty. The long term users guide, in Appendix F, was used to develop these data sets. However, to determine if the warranty is cost effective, SPO analysts must also construct non-warranty input parameter data sets whose output is used as a comparison to the warranty results. Ten simulation runs of the warranty and non-warranty parameter sets were made with the results shown in Tables 4-13 and 4-14.

The average accumulated yearly costs for both the warranty and non-warranty simulations over the twenty years are plotted in Figure 4-14.

The graph shows the breakeven point at the eleven year point of system life. By observation it appears that the engine warranty is cost effective at that point in the

TABLE 4-13 Long Version Warranty Output Data

|      | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      | 10     | Ave    |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1985 | 114.48 | 121.59 | 122.03 | 114.50 | 121.68 | 120.98 | 121.85 | 121.13 | 114.64 | 121.30 | 119.42 |
| 1986 | 146.12 | 146.19 | 154.00 | 166.17 | 146.18 | 146.72 | 145.84 | 144.87 | 160.03 | 151.82 | 150.78 |
| 1987 | 262.97 | 289.06 | 263.79 | 257.96 | 276.34 | 279.75 | 256.89 | 250.42 | 270.84 | 249.19 | 265.74 |
| 1988 | 335.13 | 349.09 | 361.97 | 361.87 | 375.20 | 254.99 | 401.34 | 357.78 | 361.06 | 352.80 | 361.12 |
| 1989 | 396.71 | 396.22 | 377.41 | 392.74 | 395.31 | 584.12 | 418.94 | 391.15 | 389.53 | 399.18 | 394.24 |
| 1990 | 411.85 | 413.56 | 398.94 | 404.67 | 424.02 | 396.71 | 434.19 | 403.86 | 405.36 | 413.64 | 410.77 |
| 1991 | 426.86 | 425.23 | 419.37 | 417.63 | 438.37 | 460.72 | 446.53 | 417.86 | 416.85 | 434.91 | 430.43 |
| 1992 | 440.50 | 446.07 | 432.96 | 432.05 | 542.04 | 472.27 | 460.76 | 439.30 | 429.89 | 445.81 | 445.17 |
| 1993 | 480.00 | 458.55 | 464.70 | 446.13 | 469.37 | 486.07 | 475.79 | 453.72 | 444.04 | 460.95 | 463.92 |
| 1994 | 493.98 | 472.65 | 477.30 | 459.73 | 483.56 | 497.48 | 478.65 | 466.81 | 458.87 | 475.27 | 476.03 |
| 1995 | 505.64 | 488.06 | 492.55 | 478.14 | 495.11 | 511.10 | 501.66 | 479.95 | 471.51 | 487.40 | 491.13 |
| 1996 | 521.10 | 501.10 | 505.36 | 492.56 | 513.73 | 527.61 | 516.26 | 495.09 | 488.04 | 499.51 | 506.04 |
| 1997 | 535.29 | 515.70 | 518.61 | 508.59 | 525.39 | 539.99 | 529.95 | 506.95 | 501.32 | 515.30 | 519.71 |
| 1998 | 548.44 | 527.65 | 531.84 | 520.67 | 540.33 | 553.39 | 543.35 | 519.40 | 514.12 | 527.63 | 532.66 |
| 1999 | 562.08 | 557.40 | 540.49 | 533.09 | 550.95 | 566.59 | 555.28 | 533.70 | 526.23 | 540.39 | 547.02 |
| 2000 | 575.19 | 568.83 | 559.43 | 545.90 | 566.83 | 581.14 | 575.15 | 544.43 | 559.54 | 554.46 | 563.09 |
| 2001 | 598.83 | 582.34 | 574.83 | 577.15 | 580.17 | 595.54 | 591.59 | 558.00 | 574.39 | 566.22 | 579.01 |
| 2002 | 602.60 | 594.68 | 588.22 | 588.70 | 591.32 | 608.58 | 602.85 | 571.31 | 587.18 | 578.32 | 591.38 |
| 2003 | 514.93 | 607.32 | 601.20 | 602.44 | 602.29 | 621.85 | 616.76 | 585.23 | 599.90 | 592.52 | 604.44 |
| 2004 | 626.12 | 620.87 | 611.61 | 615.84 | 618.43 | 636.08 | 630.56 | 596.92 | 613.69 | 607.42 | 617.75 |
| 2005 | 640.14 | 636.64 | 624.56 | 630.62 | 632.04 | 649.35 | 643.10 | 610.89 | 628.21 | 620.70 | 631.63 |

TABLE 4-14 Long Version Non-Warranty Output Data

|      | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      | 10     | Ave    |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1985 | 71.51  | 64.87  | 72.03  | 78.13  | 71.59  | 57.99  | 71.61  | 65.02  | 72.79  | 71.56  | 69.71  |
| 1986 | 117.60 | 96.59  | 102.50 | 104.18 | 110.57 | 104.33 | 96.30  | 109.33 | 116.10 | 116.51 | 107.40 |
| 1987 | 213.24 | 224.16 | 221.82 | 216.95 | 224.80 | 227.53 | 224.93 | 208.49 | 215.31 | 216.48 | 219.37 |
| 1988 | 334.77 | 316.79 | 314.45 | 313.71 | 334.52 | 310.37 | 344.13 | 341.94 | 321.51 | 284.20 | 321.64 |
| 1989 | 369.25 | 362.10 | 366.77 | 352.73 | 383.04 | 356.02 | 368.71 | 359.10 | 383.15 | 369.43 | 367.03 |
| 1990 | 391.41 | 380.42 | 386.59 | 373.57 | 402.32 | 389.62 | 387.28 | 374.84 | 403.47 | 390.47 | 387.99 |
| 1991 | 407.63 | 397.25 | 405.62 | 391.42 | 420.11 | 418.58 | 426.28 | 393.10 | 427.53 | 408.55 | 409.31 |
| 1992 | 455.89 | 414.53 | 422.89 | 428.07 | 436.70 | 431.06 | 444.62 | 416.07 | 442.98 | 428.33 | 432.11 |
| 1993 | 444.07 | 433.78 | 439.95 | 448.04 | 454.61 | 447.59 | 464.12 | 459.46 | 459.71 | 442.17 | 449.35 |
| 1994 | 465.74 | 450.79 | 460.19 | 466.08 | 475.73 | 463.63 | 481.69 | 478.97 | 477.91 | 460.13 | 468.09 |
| 1995 | 495.38 | 469.87 | 492.08 | 485.21 | 494.52 | 485.55 | 498.80 | 496.48 | 500.21 | 505.36 | 492.35 |
| 1996 | 512.88 | 488.38 | 509.91 | 506.71 | 509.84 | 502.25 | 519.04 | 515.10 | 517.60 | 523.77 | 510.55 |
| 1997 | 530.32 | 504.68 | 530.07 | 522.18 | 528.38 | 518.82 | 535.48 | 533.36 | 537.04 | 543.01 | 528.33 |
| 1998 | 545.90 | 521.73 | 547.32 | 540.50 | 547.46 | 536.68 | 554.20 | 554.07 | 556.35 | 561.78 | 546.60 |
| 1999 | 564.59 | 538.53 | 576.21 | 560.52 | 565.58 | 554.94 | 573.58 | 570.70 | 576.83 | 580.73 | 565.42 |
| 2000 | 586.67 | 553.64 | 583.04 | 576.24 | 586.09 | 573.23 | 590.63 | 588.90 | 592.53 | 597.35 | 582.83 |
| 2001 | 602.28 | 572.57 | 600.92 | 596.53 | 605.37 | 592.40 | 606.94 | 606.10 | 611.77 | 616.08 | 601.09 |
| 2002 | 619.55 | 617.40 | 617.78 | 615.17 | 620.74 | 609.84 | 623.19 | 623.22 | 630.77 | 633.05 | 621.07 |
| 2003 | 640.33 | 636.31 | 619.91 | 633.85 | 638.99 | 628.15 | 654.98 | 640.97 | 646.48 | 649.45 | 641.94 |
| 2004 | 657.09 | 655.00 | 669.05 | 651.81 | 655.82 | 644.88 | 672.61 | 664.23 | 662.67 | 672.08 | 660.52 |
| 2005 | 675.16 | 671.21 | 686.64 | 677.51 | 675.64 | 664.86 | 687.53 | 683.67 | 678.70 | 688.98 | 678.99 |

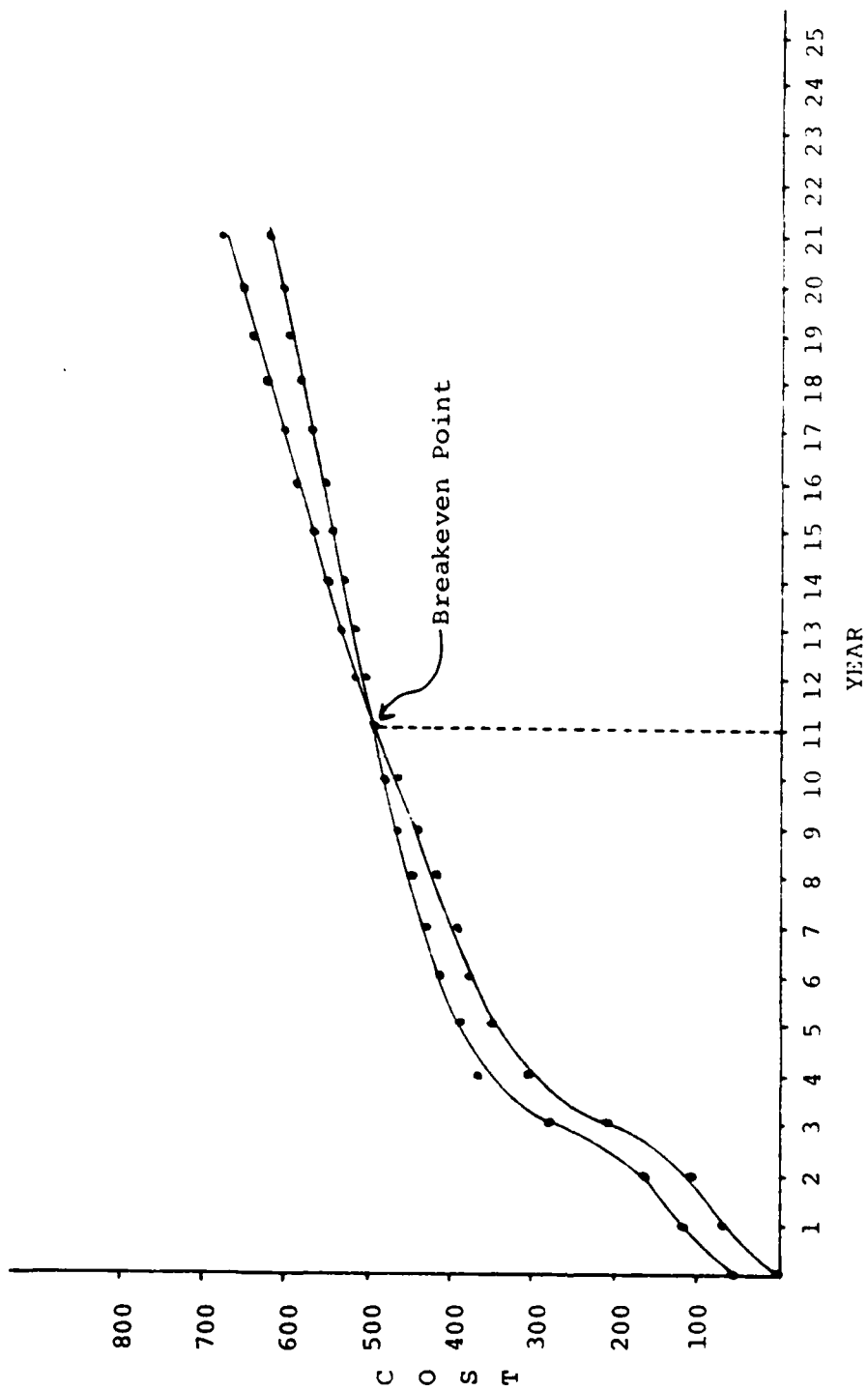


Figure 4-14 Long Term 20 Year Plot

life of the system, however, the crossover point must be further analyzed to determine the actual point in time when the difference between the warranty and non-warranty lines is in fact significant. A small sample T-Test is accomplished at different points prior to the observed breakeven point to determine when the differential of the two lines is no longer significant. For the purpose of this example, the testing began at the first data point prior to the breakeven point, that being the tenth year.

To perform this test, three assumptions need to be validated. First it is assumed that the relative frequency distribution of each sample approximates the normal. Earlier validation testing had shown that the model delivers a normal distribution and the analyst can, therefore, assume normality of the studied populations.

Second, it is assumed that the variances of each of the sampled populations are equal. To test this assumption, the variances were analyzed as follows. The Null hypothesis was:

$H_0$ : The variances are equal

and the alternate hypothesis was

$H_a$ : The variances are not equal

The test statistic for this is a comparison of the F Value which was calculated as follows:

$$F_{\alpha/2, N_1-1, N_2-1} = 3.18$$

$$\begin{aligned}\text{where } \alpha &= .10 \\ N_1 &= 10 \\ N_2 &= 10\end{aligned}$$

And the decision rule is:

If  $F > F_{\alpha/2, N_1-1, N_2-1}$  then there is significant difference between the variances.

The results are shown in Figure 4-14 and indicate that the variances are not significantly different.

$$F = \frac{\text{Large Variance}}{\text{Small Variance}} = \frac{166.7}{101.4} = 1.644$$

$$F \not> F_{\alpha/2, N_1-1, N_2-1}$$

The third and final assumption is that the samples are randomly selected. Due to the random nature of the model, the analyst can assume independence.

With the assumptions validated, the actual T-Test may be performed. First the analyst must develop the hypothesis to be tested as follows:

$$H_0: \mu_1 = \mu_2$$

$$H_a: \mu_1 \neq \mu_2$$

where  $\mu_1$  = the warranty mean

$\mu_2$  = the non-warranty mean

The next step is to develop the T-statistic for testing which is done as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_P^2 \left( \frac{1}{N_1} + \frac{1}{N_2} \right)}}$$

where  $\bar{X}_1$  = warranty mean = 476.03

$\bar{X}_2$  = non-warranty mean = 468.09

$N_1 = N_2 = 10$  samples

$$S_P^2 = \frac{(N_1 - 1)S_1^2 + (N_2 - 1)S_2^2}{N_1 + N_2 - 2} = 134.036$$

where

$S_1^2 = 166.7$  = variance of warranty

$S_2^2 = 101.4$  = variance of non-warranty

$$t = 1.53$$

and since the rejection region is

$$t > t_{\alpha/2, N_1 + N_2 - 2}$$

or

$$1.53 > 1.33$$

the test rejects the Null hypothesis and indicates that there is a significant difference.

This illustrates that the first point in time when the two costs are equal is at the breakeven point. The analyst has strong evidence that the 11 year point is truly the breakeven point and beyond that point the \$50,000,000 warrant is cost effective.

In this hypothetical case, the use of the long and

short warranty model versions has provided SPO analysts with a decision support system that can evaluate the long and short term effects of warranty. This warranty DSS is a valuable tool needed to assist in the decision making process for engine system procurement under warranty.



## CHAPTER V

### CONCLUSIONS AND RECOMMENDATIONS

#### Conclusions

The purpose of this thesis was to research and develop a competent decision support system that assesses the turbine engine life cycle cost under warranty. This DSS was requested by the Engine SPO to provide contract specialists with the specific warranty data needed to effectively analyze a warranty proposal during source selection negotiations.

The research design used to construct the decision support tool included first a conceptual study of the turbine engine operating environment. From this study, the researchers developed the engine O&S system warranty model. The model was verified and validated, and then tested for sensitivity to the change in value of five policy parameters. The sensitivity analysis of these parameters provided analysts with insight concerning parameter impact on the O&S system response. The testing proved the model to be a reliable effective tool for analyzing warranty proposals.

Two versions of the warranty model were developed to provide short and long term warranty analysis and both versions were integrated into the total warranty decision support system as a versatile tool designed to assist YZ analysts and contract

specialists evaluate the cost effectiveness of a turbine engine warranty.

#### Application

The warranty DSS can be used to evaluate warranties from two perspectives. First it examines the short term warranty period, analyzing the cost of operations and providing a breakout of unit repair and replacement costs. This allows YZ analysts to easily assess individual unit costs and compare these costs to specific contractor assurances.

Second, the DSS provides a life cycle approach to warranty analysis. In the long model version component improvements made during the warranty period are analyzed over the life of the engine system to determine their overall cost effectiveness.

These two DSS applications provide a more realistic warranty analysis by evaluating both the near and long term cost and benefits of a warranty.

#### Recommendation for Future Study

Due to time constraints, five areas of study were either abbreviated or assumed to be true in this research. They are explained below with the understanding that the knowledge gained in each area would further strengthen the already valid simulation model.

The first improvement should be the addition of further mechanization of the system. Computer coding should be designed to accomplish the analysis on the long term

version of the model. The coding should also provide a graphics capability to plot the average cost curves. This mechanization would greatly improve the speed of analysis.

Second, since the warranty model was validated using another model, it should be further assessed for validity using actual engine warranty data when that data becomes available.

Third, a study should be conducted to validate the assumption that improvements will occur due to the application of a warranty. While the model and decision support system assume an improvement occurs, they also show that without that improvement the breakeven point would never occur and the worth of the warranty would be seriously questioned. An assessment of the contractors intentions in warranty application is an area of future study which is highly recommended.

Fourth, there is the need for an analysis model for other possible maintenance concepts. The current model assumes a three level maintenance system. However, several new methods of maintenance management are being attempted and these methods should be included in separate versions of the model.

Finally, model sensitivity should be analyzed for all input parameters. Although five policy parameters were considered most important, other parameters and parametric relationships may also be significant and should be tested for their effects on model output.

APPENDICES

APPENDIX A  
PROGRAM LISTING FOR WARR.3

The simulation model contained in this appendix is written in Simscript II.5 and is designed for use on the AFLC Honeywell system. The program is stored in the Create Time Sharing System under the name of WARR.3 and uses data files stored under the names TEST100 and TEST.DAT.

```

10#45 :.8,14
20# IDENT WP0354,AFIT-LS HELLESTO WARR.3
30# LIMITS 15,40K,,10K
40# LOWLOAD
50# OPTION FORTRAN,NOMAP
60# LIBRARY SL
70# PROGRAM RLHS
80# LIMITS 15,40K,,10K
90# PRMFL H*,R.R,CACI/SIM2.5
100# FILE *1
110# FILE *2
120# FILE P1.B1S
130 PREPABLE
140 NORMALLY MODE IS INTEGER
150 EVENT NOTICES INCLUDE
160 DEPLOYMENT,
170 ENGINE REPAIR,
180 INSPECTION,
190 TCTO,
200 SCHED.TCTO,
210 END.OF.NO.STATS,
220 REPORT
230 EVERY INTER.REPAIR HAS AN PART
240 EVERY DEPOT.REPAIR HAS AN ITEM
250 DEFINE SPARE.CHECK AS A ROUTINE WITH 1 VALUE
260 DEFINE ICOUNT,ERENT,LAUCNT,SCNT1,SCNT2,MAX,LCNT,SCNT
270 AS VARIABLES
280 DEFINE YR.START,YR.REPORT,YR.TCTO,MO.QUIT,YR.BEG AS REAL VARIABLES
290 DEFINE ECNT,FHT,INO,FHP,INFED AS VARIABLES
300 DEFINE LRATE,DRG.HRS,INT.HRS,DEP.HRS,ENG.COST,EDH.HRS,TOT.COST,TIN.COST,
310 RFAC,MIL,DRATE,IRATE,DRATE,INFLAT,FIN.COST,DISC AS REAL VARIABLES
320 DEFINE SIRATE,SRATE,SI.TOT,SD.TOT,SI.PER AS REAL VARIABLES
330 DEFINE PLANES,ENGS,B.TRANS,ETCOST,STCOST,LTCOST AS VARIABLES
340 DEFINE OCOST,ICOST,DCOST,ECOST,PSPARES,OSPARES AS VARIABLES
350 DEFINE LPSPARES,LOSPARES,SE.O,SE.I,SE.D,MARK,PMU AS VARIABLES
360 DEFINE TE,TL,TS,ETITIME,ETITIME,STOTIME,SBTITIME,LDTIME AS VARIABLES
370 DEFINE SVR,ER.PROB,INAN,OVER,PER,PDAYS,UNSP,COST AS REAL VARIABLES
380 DEFINE PG,EREM,LAUREM,BRUREM AS A 1-DIMENSIONAL ARRAY
390 DEFINE EALL,EDEP,SPEC,ETCTO,LFUS,SRUS,DHRS,EBUY AS 1-DIMENSIONAL ARRAYS
400 DEFINE XEALL,XEDEF,XSPEC,XETCTO,XLRU,XSRU,XDHRS,XEBUY AS VARIABLES
410 DEFINE IS.HRS,DS.HRS,OL.HRS,IL.HRS,DL.HRS AS REAL VARIABLES
420 DEFINE LRUPROB,SRUPROB,CON,FAC AS 1-DIMENSIONAL REAL ARRAYS
430 DEFINE SCOST,LCOST,SE.COST,EFAIL AS 1-DIMENSIONAL REAL ARRAYS
440 DEFINE LRU.HRS,SRU.HRS,RESULT AS 2-DIMENSIONAL REAL ARRAYS
450 DEFINE CONDENS,LEVEL,SPARES,BASEQTY,SE.RQMT AS 1-DIMENSIONAL ARRAYS
460 DEFINE PRGM AS A ALPHA VARIABLE
470 DEFINE SEED,SED,SIM,ST AS INTEGER VARIABLE
480 END

```

```

490
500     MAIN
510     RESERVE LRUPROB,SRUPROB AS 30
520     RESERVE LRUREM,SRUREM,SCOST,LCOST AS 30
530     RESERVE PQ AS 132     RESERVE EFEM AS 6
540     RESERVE BASEQTY AS 30     RESERVE SE.RQMT,SE.COST,EFAIL AS 3
550     RESERVE LRU.HRS AS 3 BY 30
560     RESERVE SRU.HRS AS 4 BY 30
570     RESERVE RESULT AS 4 BY 30
580     RESERVE EALL,EDEF,SPEC,ETCTO,LRUS,SRUS,DHRS,EBUY AS 250
590     RESERVE LEVEL,SPARES,CON.FAC,CONDEMS AS 50
600     DEFINE NAME AS A 1-DIMENSIONAL ALPHA ARRAY     RESERVE NAME AS 2
610     DEFINE DATE AS A 1-DIMENSIONAL ALPHA ARRAY     RESERVE DATE AS 2
620     -----
630     READ DATE(1),DATE(2)
640     READ PRGM,ECNT,SVR,ENG.COST,RFAC,OVER.PER,WARR,PMW
650     LET SVR = SVR * RFAC
660     READ SE.COST(1),SE.COST(2),SE.COST(3),WARR.COST
670     READ FHP,INFREQ,INAN,ORATE,IRATE,CRATE,ED4.HRS
680     LET ER.PROB = SVR * ECNT * INFREQ / 1000
690     READ TE,TL,TS,EDTIME,ERTIME,SDTIME,SPTIME,LDTIME
700     READ ETCOST,STCOST, LTCOST, INFLAT,DISC
710     READ YR.START,YR.REPORT,YR.TCTO,NO.QUIT,SEED.SED,SIN,ST
720     LET YR.BEG = YR.START
730     READ EFAIL(1),EFAIL(2),EFAIL(3)
740     READ MAX     FOR I = 1 TO MAX READ PQ (I)
750     LET CY = YR.START     LET J = 1
760     FOR K = 1 TO ((MAX + 11) / 12) DO
770         LET JJ = J + 11
780         FOR I = J TO JJ ADD PQ (I) TO TOT
790         FOR I = J TO JJ
800             ADD TOT TO TOTAL     LET TOT = 0
810         LET CY = CY + 1     LET J = J + 12
820     LOOP
830     READ NO.OF.BASES     FOR I = 1 TO NO.OF.BASES READ BASEQTY (I)
840     READ CIRF
850     FOR I = 2 TO NO.OF.BASES LET BASEQTY(I) = BASEQTY(I) + BASEQTY(I-1)
860     LET B = 1     LET SE.RQMT (2) = 1
870     * SRU DATA * - - - - -
880     READ SCNT     FOR I = 1 TO SCNT DO
890         READ NAME(1),NAME(2),SIRATE,SRU.HRS(1,I),SRU.HRS(2,I),
900         SDRATE,SRU.HRS(3,I),SRU.HRS(4,I),SCOST(1),CON.FAC(I)
901         LET SIRATE=SIRATE*1.00
902         LET SDRATE=SDRATE*1.00
903         LET SRU.HRS(1,I)=SRU.HRS(1,I)*1.00
904         LET SRU.HRS(2,I)=SRU.HRS(2,I)*1.00
905         LET SRU.HRS(3,I)=SRU.HRS(3,I)*1.00
906         LET SRU.HRS(4,I)=SRU.HRS(4,I)*1.00
910         LET SRUPROB(I) = RFAC * (SIRATE + SDRATE) / (EFAIL(2) * SVR * 1000)
920         LET SI.TOT = SI.TOT + SIRATE     LET SD.TOT = SD.TOT + SDRATE
930     LOOP

```



```

940 LET SI.PER = SI.TOT / (SI.TOT + SD.TOT)
950 LRU DATA - - - - -
960 READ LCNT FOR I = 1 TO LCNT DO
970 READ NAME(1),NAME(2),LRATE,LRU.HRS(1,I),LRU.HRS(2,I),LRU.HRS(3,I),
980 LCOST(I),CON.FAC(I+SCNT)
981 LET LRATE=LRATE*1.00
982 LET LRU.HRS(1,I)=LRU.HRS(1,I)*1.00
983 LET LRU.HRS(2,I)=LRU.HRS(2,I)*1.00
984 LET LRU.HRS(3,I)=LRU.HRS(3,I)*1.00
990 LET LRU.POB(I) = (LRATE * ECNT * INFREQ) / 1000000
1000 LOOP
1010 - - - SCHEDULE INSPECTIONS AND DEPLOYMENTS - - - - -
1020 FOR I = 1 TO MAX DO
1030 IF PQ(I) = 0 JUMP AHEAD ELSE
1040 LET PDAYS = 30.42 / PQ(I)
1050 FOR J = 1 TO PQ(I) SCHEDULE AN INSPECTION IN
1060 (PDAYS * J) + (30.42 * (I - 1)) + ((INFREQ / FHP) * 30.42) DAYS
1070 FOR J = 1 TO PQ(I)
1080 SCHEDULE A DEPLOYMENT IN (PDAYS * J) + 30.42 * (I - 1) DAYS
1090 HERE LOOP
1100 SCHEDULE A REPORT IN YR.REPORT DAYS
1110 SCHEDULE A END.OF.MO.STATS IN 30.41 DAYS
1120 SCHEDULE A SCHED.TOTD IN 365 * YR.TOTD DAYS
1130 CALL ORIGIN.R(1,1,YR.START)
1140 START SIMULATION
1150 END
1160

```

```

1170 ROUTINE FOR INITIALIZATION
1180 LET TIME.V=0.00
1190 LET SIM=SIM+1
1200 IF SIM=31
1210     LET SEED=1
1220     LET SED=10
1230     JUMP AHEAD
1240     ELSE
1250     IF SIM=21
1260         LET SEED=1
1270         LET SED=10
1280         JUMP AHEAD
1290         ELSE
1300         IF SIM=11
1310             LET SEED=1
1320             LET SED=9
1330         ALWAYS HERE
1340         LET SEED=SEED+1
1350         LET YR.START=YR.BEG LET IMO=1 LET PLANES=0
1360         LET ENGS=0 LET B=1 LET SE.RQNT(2)=1
1370         LET ICOUNT=0 LET FHT=0 LET ORG.HRS=0
1380         LET ERQNT=0 LET EREM(1)=0 LET EREM(2)=0
1390         LET DEP.HRS=0 LET EREM(3)=0 LET EREM(4)=0
1400         LET TRANS=0 LET SCNT1=0 LET SCNT2=0
1410         LET INT.HRS=0 LET IS.HRS=0 LET OS.HRS=0
1420         LET EREM(5)=0 LET LRUCNT=0 LET DL.HRS=0
1430         LET IL.HRS=0 LET BL.HRS=0 LET LEVEL(50)=0
1440         LET EREM(6)=0 LET TOT.COST=0 LET TIN.COST=0
1450         LET FIN.COST=0 LET SPARES(50)=0
1460         FOR I=1 TO LCNT DO
1470             LET LRUREM(I)=0
1480         LOOP
1490         FOR I=1 TO SCNT DO
1500             LET BRUREM(I)=0
1510         LOOP
1520         FOR I=1 TO LCNT+SCNT DO
1530             LET LEVEL(I)=0
1540             LET SPARES(I)=0
1550             LET CONDEMS(I)=0
1560         LOOP

```

```

1570  ' - - SCHEDULE INSPECTIONS AND DEPLOYMENTS - - - - -
1580  FOR I = 1 TO MAX DO
1590  IF PQ (I) = 0 JUMP AHEAD ELSE
1600  LET PDAYS = 30.42 / PQ (I)
1610  FOR J = 1 TO PQ(I) SCHEDULE AN INSPECTION IN
1620    (PDAYS * J) + (30.42 * (I - 1)) + ((INFREQ / FHP) * 30.42) DAYS
1630  FOR J = 1 TO PQ (I)
1640    SCHEDULE A DEPLOYMENT IN (PDAYS * J) + 30.42 * (I - 1) DAYS
1650  HERE LOOP
1660  SCHEDULE A REPORT IN YR.REPORT ,DAYS
1670  SCHEDULE A END.OF.MO.STATS IN 30.41 DAYS
1680  SCHEDULE A SCHED.TC TO IN 366 * YR.TC TO DAYS
1690  IF SIMKST RETURN ELSE
1750
1760  STOP END
1770

```

```

1780  EVENT DEPLOYMENT
1790  ADD 1 TO PLANES  ADD ECNT TO ENGS
1800  IF PLANES > BASEQTY (B) ADD 1 TO SE.RQMT (2) ADD 1 TO B
1810  ALWAYS RETURN END
1820

```

```

1830     EVENT INSPECTION
1840     DEFINE SFAC AS A REAL VARIABLE      LET SFAC = 1.0
1850     ADD 1 TO ICOUNT    ADD ECNT * INFREQ TO FHT
1860     ADD IMAN TO ORG.HRS
1870     LET TO = 0    IF RANDOM.F(SEED) < OVER.PER    LET TO = 10    ALWAYS
1880     ** CHECK FOR AN ENGINE REMOVAL
1890     IF RANDOM.F(SEED) < ER.PROB GO TO 'REMOVE.ENG' ELSE GO TO 'CHECK.LRU'
1900 'REMOVE.ENG'
1910     ADD 1 TO ERCNT    ADD 55 TO ORG.HRS
1920     DEFINE X AS A REAL VARIABLE    LET X = RANDOM.F(SEED)
1930     IF X < EFAIL(1) GO TO 'MAJOR.DAMAGE'    ELSE
1940     IF X > EFAIL(1) AND X < (1 - EFAIL(3)) GO TO 'SRU.CAUSED'
1950     ELSE GO TO 'LRU.CAUSED'
1960 'MAJOR.DAMAGE'
1970     ADD 1 TO EREM(1)    ADD EOH.HRS TO DEP.HRS
1980     ADD ETCOST TO TRANS    ADD 10 TO ORG.HRS    **PACK ENGINE
1990     SCHEDULE AN ENGINE.REPAIR IN TO + TE + ETIME + TE DAYS
2000     PERFORM SPARE.CHECK(50)    GO TO 'CHECK.LRU'
2010 'LRU.CAUSED'
2020     ADD 1 TO EREM(2)    ADD 46 TO INT.HRS
2030     SCHEDULE AN ENGINE.REPAIR IN 15 DAYS
2040     PERFORM SPARE.CHECK(50)    GO TO 'CHECK.LRU'
2050 'SRU.CAUSED'
2060     ADD 1 TO EREM(3)
2070     SCHEDULE AN ENGINE.REPAIR IN ETIME DAYS
2080     PERFORM SPARE.CHECK(50)
2090     IF RANDOM.F(SEED) > SI.PER GO TO 'DEPOT.REPAIR.OF.SRU'    ELSE
2100 'IREPAIR.OF.SRU'
2110     ADD 1 TO EREM(4)    ADD LTCOST TO TRANS    ** COMPONENT
2120     FOR I = 1 TO SCNT    DO
2130         IF RANDOM.F(SEED) < SRUPROB(I)
2140             ADD 1 TO SRUREM(I)    ADD 1 TO SCNT1
2150             ADD SRU.HRS(1,I) * SFAC TO INT.HRS
2160             ADD SRU.HRS(1,I)*SFAC TO IS.HRS
2170             LET SFAC = .6
2180             ADD SRU.HRS(2,I) TO DEP.HRS
2190             ADD SRU.HRS(2,I) TO OS.HRS
2200             SCHEDULE A INTER.REPAIR(I) IN SBTIME DAYS
2210             PERFORM SPARE.CHECK(I)
2220     ALWAYS LOOP    GO TO 'CHECK.LRU'
2230 'DEPOT.REPAIR.OF.SRU'
2240     ADD 1 TO EREM(5)    ADD STCOST TO TRANS

```

```

2250   FOR I = 1 TO SCNT  DO
2260     IF RANDOM.F(SEED) < SRUPROB(I)
2270       ADD 1 TO SRUPEN (I)  ADD 1 TO SCNT2
2280       ADD SRU.HRS(3,I) * SFAC TO INT.HRS
2290       ADD SRU.HRS(3,I)*SFAC TO IS.HRS
2300       LET SFAC = .6
2310       ADD SRU.HRS(4,I) TO DEP.HRS
2320       ADD SRU.HRS(4,I) TO DS.HRS
2330       SCHEDULE A DEPOT.REPAIR(I) IN TO + TS + 10 + SDTIME + TS DAYS
2340       PERFORM SPARE.CHECK(I)
2350   ALWAYS  LOOP
2360 CHECK.LRU
2370   " CHECK FOR AN LRU FAILURE
2380   FOR I = 1 TO LCNT  DO
2390     IF RANDOM.F(SEED) < LRUPROB (I) ADD 1 TO LRUCNT
2400     ADD 1 TO LRUPEN (I)  ADD LTCOST TO TRANS
2410     ADD LRU.HRS(1,I) TO ORG.HRS
2420     ADD LRU.HRS(1,I) TO OL.HRS
2430     ADD LRU.HRS(2,I) TO INT.HRS
2440     ADD LRU.HRS(2,I) TO IL.HRS
2450     ADD LRU.HRS(3,I) TO DEP.HRS
2460     ADD LRU.HRS(3,I) TO DL.HRS
2470     LET II = I + SCNT
2480     SCHEDULE A DEPOT.REPAIR (II) IN TO + TL + LDTIME + TL DAYS
2490     PERFORM SPARE.CHECK(II)
2500   ALWAYS
2510   LOOP
2520 HERE
2530   SCHEDULE AN INSPECTION IN (INFREQ / FHP) * 30.42 DAYS
2540   RETURN END
2550

```

```

2560     EVENT INTER.REPAIR(PART)
2570     IF RANDOM.F(SEED) > (CON.FAC(PART)*1.00) ADD 1 TO LEVEL(PART)
2575     JUMP AHEAD
2580     ELSE ADD 1 TO CONDEMS (PART)
2590     HERE RETURN END
2600
2610     EVENT DEPOT.REPAIR(ITEM)
2620     IF RANDOM.F(SEED) > (CON.FAC(ITEM)*1.00) ADD 1 TO LEVEL(ITEM)
2625     JUMP AHEAD
2630     ELSE ADD 1 TO CONDEMS (ITEM)
2640     HERE RETURN END
2650
2660     EVENT ENGINE.REPAIR
2670     ADD 1 TO LEVEL(50)
2680     RETURN END
2690
2700     SUBROUTINE SPARE.CHECK(NUM)
2710     SUBTRACT 1 FROM LEVEL(NUM)
2720     IF NUM = 50 GO TO 'ENG.LOGIC' ELSE
2730     IF NUM > SCNT GO TO 'LRU.LOGIC' ELSE
2740     'SRU.LOGIC'
2750     IF LEVEL(NUM) < 0 ADD 1 TO SPARES(NUM) ADD 1 TO LEVEL (NUM)
2760     ALWAYS JUMP AHEAD
2770     'ENG.LOGIC'
2780     IF LEVEL(50) < B / 2 ADD 1 TO SPARES(NUM) ADD 1 TO LEVEL (NUM)
2790     ALWAYS JUMP AHEAD
2800     'LRU.LOGIC'
2810     IF LEVEL(NUM) < B / 2 ADD 1 TO SPARES(NUM) ADD 1 TO LEVEL (NUM)
2820     ALWAYS HERE RETURN END
2830
2840     EVENT TCTO
2850     ADD 1 TO EREM(6)
2860     SCHEDULE AN ENGINE.REPAIR IN 7 DAYS
2870     PERFORM SPARE.CHECK(50)
2880     RETURN END
2890
2900     EVENT SCHED.TCTO
2910     LET TCNUM = ENGS - (12*EALL(IMD))
2920     FOR I = 1 TO TCNUM SCHEDULE A TCTO IN (360 / TCNUM) * I DAYS
2930     SCHEDULE A SCHED.TCTO IN 365 * YR.TCTO DAYS
2940     RETURN END

```

```

2950
2960 EVENT END.OF.MO.STATS
2970 ADD 1 TO IMO
2980 IF IMO = 1
2990     LET EALL(1) = ERCNT     LET EDEP(1) = EREM(1)
3000     LET SPEC(1) = ICOUNT    LET ETCTO(1) = EREM(6)
3010     LET LRUS(1) = LRUCNT    LET SRUS(1) = SCNT1 + SCNT2
3020     LET DHRS(1) = DEP.HRS   LET EBUY(1) = SPARES(50)
3030     JUMP AHEAD ELSE
3040     LET EALL(IMO) = ERCNT - XEALL
3050     LET EDEP(IMO) = EREM(1) - XEDEP
3060     LET SPEC(IMO) = ICOUNT - XSPEC
3070     LET ETCTO(IMO) = EREM(6) - XETCTO
3080     LET LRUS(IMO) = LRUCNT - XLRU
3090     LET SRUS(IMO) = SCNT1 + SCNT2 - XSRLU
3100     LET DHRS(IMO) = DEP.HRS - XDHRS
3110     LET EBUY(IMO) = SPARES(50) - XEBUY
3120     HERE SCHEDULE A END.OF.MO.STATS IN 30.42 DAYS
3130     LET XEALL = ERCNT     LET XEDEP = EREM(1)
3140     LET XSPEC = ICOUNT    LET XETCTO = EREM(6)
3150     LET XLRU = LRUCNT    LET XSRLU = SCNT1 + SCNT2
3160     LET XDHRS = DEP.HRS   LET XEBUY = SPARES(50)
3170     LET ECOST = SPARES(50) * ENG.COST
3180     FOR I = 1 TO SCNT
3190         LET PS = PS + ((SPARES(I) - CONDEMS(I)) * SCOST(I))
3200         LET PSPARES = PS
3210         LET PS = 0
3220     FOR I = 1 TO SCNT
3230         LET CS = CS + (CONDEMS(I) * SCOST(I))
3240         LET CSPARES = CS
3250         LET CS = 0
3260     FOR I = 1 + SCNT TO SCNT + LCNT
3270         LET LPS = LPS + ((SPARES(I) - CONDEMS(I)) * LCOST(I - SCNT))
3280         LET LPSARES = LPS
3290         LET LPS = 0
3300     FOR I = 1 + SCNT TO SCNT + LCNT
3310         LET LCS = LCS + (CONDEMS(I) * LCOST(I - SCNT))
3320         LET LCSPARES = LCS
3330         LET LCS = 0
3340     LET OCOST = ORG.HRS * ORATE
3350     LET ICOST = INT.HRS * IRATE
3360     LET DCOST = DEP.HRS * DRATE
3370     LET SE.RQMT(1) = SE.RQMT(2)     LET SE.RQMT(3) = 1
3380     LET SE.O = SE.RQMT(1) * SE.COST(1) * 1.75
3390     LET SE.I = SE.RQMT(2) * SE.COST(2) * 1.75
3400     LET SE.D = SE.RQMT(3) * SE.COST(3) * 1.75
3410     LET DIF.COST = TOT.COST

```

```

3420 IF WARR = 1
3430 LET TOT.COST = (WARR.COST + ECOST + PSPARES + CSPARES +
3440 LPSPARES + LCSPARES + OCOST + DCOST + ICOST + SE.I +
3450 SE.O + SE.D + TRANS)
3460 JUMP AHEAD ELSE
3470 LET TOT.COST =
3480 (ECOST + PSPARES + CSPARES + LPSPARES + LCSPARES + OCOST + DCOST +
3490 ICOST + SE.I + SE.O + SE.D + TRANS)
3500 HERE LET INT.COST = TOT.COST - DIF.COST
3510 LET INF.COST = INT.COST*((1 + (INFLAT/12))**(IMO))
3520 LET DIF.COST = TIN.COST
3530 LET TIN.COST = TIN.COST + INF.COST
3540 LET INT.COST = TIN.COST - DIF.COST
3550 LET DIS.COST = INT.COST*(1/(1 + (DISC/12))**(IMO))
3560 LET FIN.COST = FIN.COST + DIS.COST
3570 IF IMO=24
3580 LET RESULT(1,SIM)=FIN.COST
3590 JUMP AHEAD ELSE
3600 IF IMO=96
3610 LET RESULT(2,SIM)=FIN.COST
3620 JUMP AHEAD ELSE
3630 IF IMO = 168
3640 LET RESULT(3,SIM)=FIN.COST
3650 JUMP AHEAD ELSE
3660 IF IMO=240
3670 LET RESULT(4,SIM)=FIN.COST
3680 ALWAYS HERE
3690 IF IMO < NO.QUIT RETURN ELSE
3700 PERFORM INITIALIZATION
3710 RETURN END
3720

```



```

3730      EVENT REPORT
3740      ADD YR.REPORT/365 TO YR.START
3750      IF YR.REPORT > 365
3760      WRITE PRGM,YR.START - 1 + 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
3770      JUMP AHEAD ELSE
3780      WRITE PRGM,YR.START+ 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
3790      HERE
3800      SKIP 1 LINE      WRITE FIN.COST AS B 17,"DISCOUNTED COST =$",D(13,2),/
3810      SCHEDULE A REPORT IN YR.REPORT DAYS
3820      RETURN      END
3830$      SOURCE
3840$      EXECUTE
3850$      LIMITS 15,40K,-3K,2000
3860$      FILE B*,B1R
3870$      PRMFL 6L,R,S,CACI/SIN2LIB
3880$      PRMFL 17,R,S,CACI/SIHERR
3890$      DATA 05
3900$      SELECTA TEST100
3910$      SELECTA TEST.DAT
3920$      ENDJOB

```

APPENDIX B  
PROGRAM LISTING FOR SHORT.3

The simulation model contained in this appendix is written in SImscript II.5 and is designed for use on the AFLC Honeywell system. The program is stored in the Create Time Sharing System under the name of SHORT.3 and uses data files stored under the names SHORT and TEST.DAT.

```

10HNS,J : ,8,16
20$ IDENT WPO354,AFIT-LS HELLESTO WARR.3
30$ LIMITS 15,40K,,10K
40$ LOULOAD
50$ OPTION FORTRAN,NOMAP
60$ LIBRARY SL
70$ PROGRAM RLHS
80$ LIMITS 15,40K,,10K
90$ PRMFL H*,R,R,CACI/SIM2.5
100$ FILE *1
110$ FILE *2
120$ FILE B*,BIS
130 PREAMBLE
140 NORMALLY MODE IS INTEGER
150 EVENT NOTICES INCLUDE
160 DEPLOYMENT,
170 ENGINE.REPAIR,
180 INSPECTION,
190 TCTO,
200 SCHED.TCTO,
210 END.OF.NO.STATS,
220 REPORT
230 EVERY INTER.REPAIR HAS AN PART
240 EVERY DEPOT.REPAIR HAS AN ITEM
250 DEFINE SPARE.CHECK AS A ROUTINE WITH 1 VALUE
260 DEFINE ISCONT,ERCONT,LROUT,SCONT1,SCONT2,MAX,LCONT,SCONT
270 AS VARIABLES
280 DEFINE YR.START,YR.REPORT,YR.TCTO,NO.QUIT,YR.BEG AS REAL VARIABLES
290 DEFINE LCONT,FHT,INO,FHP,INFREQ AS VARIABLES
300 DEFINE LRATE,ORG.HRS.INT.HRS,DEP.HRS,ENG.COST,EDH.HRS,TOT.COST,TIV.COST,
310 RFAC,MIL,CRATE,IRATE,DRATE,INFLAT,FIN.COST,DISC AS REAL VARIABLES
320 DEFINE SIRATE,SDRATE,SI,TOT,SI,PER,SD,TOT AS REAL VARIABLES
330 DEFINE PLANES,ENGS,B,TRANS,ETCOST,ETCOST,LTCOST AS VARIABLES
340 DEFINE OCOST,ICOST,ICOST,ECOST,PSFARES,LSFARES AS VARIABLES
350 DEFINE LPSFARES,LCSFARES,SE.D,SE.I,SE.D AS VARIABLES
360 DEFINE TE,TL,TS,EDTIME,ERTIME,SDTIME,SBTIME,LDTIME AS VARIABLES
370 DEFINE BUR,ER,PRCE,INAV,IVER,PER AS REAL VARIABLES
380 DEFINE PQ, EREM,LRUREN,SRUREN AS A 1-DIMENSIONAL ARRAY
390 DEFINE EALL,EDEF,SPEC,ETCTO,LRUS,GRUS,OHRS,EBUY AS 1-DIMENSIONAL ARRAYS
400 DEFINE XEALL,XEDEF,XSPEC,XETCTO,CLR,ESRU,XDHRS,XEBUY AS VARIABLES
410 DEFINE IS.HRS,DS.HRS,OL.HRS,IL.HRS,PL.HRS,PDOYS AS REAL VARIABLES
420 DEFINE LRUPROP,SRUPROP,CON,FAC AS 1-DIMENSIONAL REAL ARRAYS
430 DEFINE SCOST,LCOST,SE.COST,EFAIL AS 1-DIMENSIONAL REAL ARRAYS
440 DEFINE LRU.HRS, SRU.HRS AS 2-DIMENSIONAL REAL ARRAYS
450 DEFINE CONDENS,LEVEL,SPARES,BASEQTY,SE.RQNT AS 1-DIMENSIONAL ARRAYS
460 DEFINE PRGM AS A ALPHA VARIABLE
470 DEFINE SEED,SED AS INTEGER VARIABLES
480 END

```

```

490
500  MAIN
510  RESERVE LRUPROB,SRUPROB AS 30
520  RESERVE LRUREM,SRUREM,SCOST,LCOST AS 30
530  RESERVE PD AS 132  RESERVE EREM AS 6
540  RESERVE BASEQTY AS 30  RESERVE SE.RGNT,SE.COST,EFAIL AS 3
550  RESERVE LRU.HRS AS 3 BY 30
560  RESERVE SRU.HRS AS 4 BY 30
570  RESERVE EALL,EDER,SPED,ETOTO,LPRS,SRUS,CHRS,EDRY AS 250
580  RESERVE LEVEL,SPARES,CON.FAC,CONDENS AS 50
590  DEFINE NAME AS A 1-DIMENSIONAL ALPHA ARRAY  RESERVE NAME AS 2
600  DEFINE DATE AS A 1-DIMENSIONAL ALPHA ARRAY  RESERVE DATE AS 2
610  -----
620  READ DATE(1),DATE(2)  WRITE DATE(1),DATE(2) AS B 60.2 A 5.7
630  READ PRGM,ECNT,SVR,ENG.COST,RFAC,OVER.PER,WARR
640  LET SVR = SVR * RFAC
650  READ SE.COST(1),SE.COST(2),SE.COST(3),WARR.COST
660  READ FHR,INFRD,INAN,GRATE,IRATE,ORATE,CON.HRS
670  LET ER.PROD = SVR * ECNT * INFRD * 1000
680  READ TE,TL,TS,EDTIME,ERTIME,SBTIME,SBTIME,LOTIME
690  READ ETCOST,STCOST,UTCOST,INFLAT,DISC
700  READ YR.START,YR.REPORT,YR.TOTO,MO.QUIT,SEED,SED
710  LET YR.BEG = YR.START
720  READ EFAIL(1),EFAIL(2),EFAIL(3)

```

```

730 PRINT 37 LINES WITH PRGM,ECNT,ENG.COST,WARR.COST,SUR.EFAIL(1),EFAIL(2),
740 EFAIL(3),INFREQ,IMAN,FHP,EQH.HRS,SE.COST(1),SPATE,SE.COST(2),
750 IRATE,SE.COST(3),DRATE,TE,TS,TL,INFLAT,DISC,ETCOST,STCOST,LTCOST,
760 EDTIME,ERTIME,SDTIME,SBTIME,LDTIME,OVER.PER THUS
770 TURBINE ENGINE WARRANTY CONCEPT EVALUATION MODEL
780 3 LEVEL RUN FOR THE ***** PROGRAM
790
800 THE FOLLOWING PARAMETERS WERE USED IN THE EVALUATION:
810 A. THE AIRCRAFT HAS ** ENGINES AT $ *****.** PER COPY
820 WARRANTY COST = $ *****.**
830 B. SHOP VISIT RATE IS SET AT *.* / 1000 HOURS -
840 C. FAILURE MODE DISTRIBUTION:
850 -MAJOR DAMAGE = .**%
860 -SRU CAUSED = .**%
870 -LRU CAUSED = .**%
880 D. INSPECTION PARAMETERS:
890 -FREQUENCY = *** ENGINE OPERATING HOURS
900 -MANHOURS = *** REQUIRED TO COMPLETE
910 E. FLYING HOUR PROGRAM = ** HOURS / MONTH
920 F. DEPOT HOURS FOR MAJOR DAMAGE = ***
930 G. S.E. COST PER SET LABOR & MATERIAL HOURLY RATE
940 ORGANIZATIONAL $ *****.** **
950 INTERMEDIATE $ *****.** **
960 DEPOT $ *****.** **
970 H. TRANSPORTATION TIME (IN DAYS)
980 -ENGINE = *
990 -SRU = *
1000 -LRU = *
1010 I. INFLATION RATE (PROJECTED AVERAGE) = *.*
1020 DISCOUNT RATE = *.*
1030 J. TRANSPORTATION COSTS:
1040 -ENGINE = ***
1050 -SRU = ***
1060 -LRU = ***
1070 K. IN WORK TIMES:
1080 -ENGINE (DEPOT) = **
1090 -ENGINE (BASE) = **
1100 -SRU (DEPOT) = **
1110 -SRU (BASE) = **
1120 -LRU (DEPOT) = **
1130 L. PERCENTAGE OF AIRCRAFT DEPLOYED OVERSEAS *.*
1140

```

```

1150 READ MAX FOR I = 1 TO MAX READ PQ (I)
1160 SKIP 3 LINES PRINT 2 LINES WITH PRGM THUS
1170 ***** DELIVERY SCHEDULE
1180 YR J F M A M J J A S O N D
1190 LET CY = YR.START LET J = 1
1200 FOR K = 1 TO ((MAX + 11) / 12) DO
1210 WRITE CY AS I 4 LET JJ = J + 11
1220 FOR I = J TO JJ ADD PQ (I) TO TOT
1230 FOR I = J TO JJ WRITE PQ (I) AS (12) I 4
1240 WRITE TOT AS B 52, I 4, / ADD TOT TO TOTAL LET TOT = 0
1250 LET CY = CY + 1 LET J = J + 12
1260 LOOP
1270 WRITE TOTAL AS B 46, "TOTAL=", I 4, /
1280 -----
1290 READ NO.OF.BASES FOR I = 1 TO NO.OF.BASES READ BASEQTY (I)
1300 READ CIRC
1310 SKIP 1 LINE PRINT 2 LINES THUS
1320 BASE DEPLOYMENT PRIORITY SCHEDULE
1330 BASE # # OF A/C
1340 FOR I = 1 TO NO.OF.BASES - 1 WRITE I, BASEQTY(I) AS I 5, I 10, /
1350 FOR I = 2 TO NO.OF.BASES LET BASEQTY(I) = BASEQTY(I) + BASEQTY(I-1)
1360 LET B = 1 LET SE.ROMT (2) = 1
1370 --- SCHEDULE INSPECTIONS AND DEPLOYMENTS ---
1380 FOR I = 1 TO MAX DO
1390 IF PQ (I) = 0 JUMP AHEAD ELSE
1400 LET PDAYS = 30.42 / PQ (I)
1410 FOR J = 1 TO PQ(I) SCHEDULE AN INSPECTION IN
1420 (PDAYS * J) + (30.42 * (I - 1)) + ((INFREQ / FHP) * 30.42) DAYS
1430 FOR J = 1 TO PQ (I)
1440 SCHEDULE A DEPLOYMENT IN (PDAYS * J) + 30.42 * (I - 1) DAYS
1450 HERE LOOP
1460 -- SRU DATA --
1470 START NEW PAGE PRINT 4 LINES THUS
1480 SRU RELIABILITY AND MAINTAINABILITY DATA
1490 REPAIRED AT INTER REPAIRED AT DEPOT
1500 MAIN INT DEP MAIN INT DEP COST COND
1510 ACT HHR MHR ACT MHR MHR (000) FAC.
1520 READ SCNT FOR I = 1 TO SCNT DO
1530 READ NAME(1), NAME(2), SIRATE, SRU.HRS(1,1), SRU.HRS(2,1),
1540 SDRATE, SRU.HRS(3,1), SRU.HRS(4,1), SCOST(I), CON.FAC(I)
1550 WRITE I, NAME(1), NAME(2), SIRATE, SRU.HRS(1,1), SRU.HRS(2,1),
1560 SDRATE, SRU.HRS(3,1), SRU.HRS(4,1), SCOST(I)/1000., CON.FAC(I)
1570 AS I 2.8 4,2 A 6,3 D(7,1) S 4.3 D(7,1) D(6,0) D(7,2) /
1580 LET SRUPROB(I) = RFAC * (SIRATE + SDRATE) / (EFAIL(2) * SVR * 1000)
1590 LET SI.TOT = SI.TOT + SIRATE LET SD.TOT = SD.TOT + SDRATE
1600 LOOP

```

```

1610 LET SI.PER = SI.TOT / (SI.TOT + SD.TOT)
1620 // LRU DATA - - - - -
1630 START NEW PAGE PRINT 2 LINES THUS
1640 LRU RELIABILITY AND MAINTAINABILITY DATA COND.
1650 REMOVAL RATE ORG-MHRS INTER-MHRS DEP-MHRS COST FAC
1660 READ LCNT FOR I = 1 TO LCNT DO
1670 READ NAME(1),NAME(2),LRATE,LRU.HRS(1,I),LRU.HRS(2,I),LRU.HRS(3,I),
1680 LCOST(I),CON.FAC(I+SCNT)
1690 LET LRUPROB(I) = (LRATE * ECNT * INFREQ) / 1000000
1700 WRITE I,NAME(1),NAME(2),LRATE,LRU.HRS(1,I),LRU.HRS(2,I),LRU.HRS(3,I),
1710 LCOST(I),CON.FAC(I+SCNT)
1720 AS I 2,B 4,2 A 6,4 D(11,2),D(7,0),D(6,2),/
1730 LOOP
1740 SCHEDULE A REPORT IN YR.REPORT DAYS
1750 SCHEDULE A END.OF.MO.STATS IN 30.41 DAYS
1760 SCHEDULE A SCHED.TCTO IN 366 * YR.TCTO DAYS
1770 CALL ORIGIN.R(1,1,YR.START)
1780 START SIMULATION
1790 END
1800

```

```

1810 EVENT DEPLOYMENT
1820 ADD 1 TO PLANES ADD ECNT TO ENGB
1830 IF PLANES > BASEQTY (3) ADD 1 TO SE.ROMT (2) ADD 1 TO B
1840 ALWAYS RETURN END
1850

```



```

1860     EVENT INSPECTION
1870     DEFINE SFAC AS A REAL VARIABLE      LET SFAC = 1.0
1880     ADD 1 TO ICOUNT    ADD ECNT * INFREQ TO FHT
1890     ADD IMAN TO ORG.HRS
1900     LET TO = 0    IF RANDOM.F(SEED) < OVER.PER    LET TO = 10    ALWAYS
1910     ** CHECK FOR AN ENGINE REMOVAL
1920     IF RANDOM.F(SEED) < ER.PROB GO TO 'REMOVE.ENG' ELSE GO TO 'CHECK.LRU'
1930 'REMOVE.ENG'
1940     ADD 1 TO ERENT    ADD 55 TO ORG.HRS
1950     DEFINE X AS A REAL VARIABLE    LET X = RANDOM.F(SEED)
1960     IF X < EFAIL(1) GO TO 'MAJOR.DAMAGE' ELSE
1970     IF X > EFAIL(1) AND X < (1 - EFAIL(3)) GO TO 'SRU.CAUSED'
1980     ELSE GO TO 'LRU.CAUSED'
1990 'MAJOR.DAMAGE'
2000     ADD 1 TO EREN(1)    ADD EOH.HRS TO DEP.HRS
2010     ADD ETCOST TO TRANS    ADD 10 TO ORG.HRS    ** PACK ENGINE
2020     SCHEDULE AN ENGINE.REPAIR IN TO + TE + EOTIME + TE DAYS
2030     PERFORM SPARE.CHECK(50)    GO TO 'CHECK.LRU'
2040 'LRU.CAUSED'
2050     ADD 1 TO EREN(2)    ADD 46 TO INT.HRS
2060     SCHEDULE AN ENGINE.REPAIR IN 15 DAYS
2070     PERFORM SPARE.CHECK(50)    GO TO 'CHECK.LRU'
2080 'SRU.CAUSED'
2090     ADD 1 TO EREN(3)
2100     SCHEDULE AN ENGINE.REPAIR IN EBTIME DAYS
2110     PERFORM SPARE.CHECK(50)
2120     IF RANDOM.F(SEED) > SI.PER GO TO 'DEPOT.REPAIR.OF.SRU' ELSE
2130 'REPAIR.OF.SRU'
2140     ADD 1 TO EREN(4)    ADD LTCOST TO TRANS    ** COMPONENT
2150     FOR I = 1 TO SCNT    DO
2160         IF RANDOM.F(SEED) < SPURPROB(I)
2170             ADD 1 TO SRUREN(I)    ADD 1 TO SCNT1
2180             ADD SRU.HRS(1,I) * SFAC TO INT.HRS
2190             ADD SRU.HRS(1,I)*SFAC TO IS.HRS
2200             LET SFAC = .6
2210             ADD SRU.HRS(2,I) TO DEP.HRS
2220             ADD SRU.HRS(2,I) TO DS.HRS
2230             SCHEDULE A INTER.REPAIR(I) IN SBTIME DAYS
2240             PERFORM SPARE.CHECK(I)
2250     ALWAYS LOOP    GO TO 'CHECK.LRU'
2260 'DEPOT.REPAIR.OF.SRU'
2270     ADD 1 TO EREN(5)    ADD STCOST TO TRANS

```

```

2280   FOR I = 1 TO SCNT   DO
2290     IF RANDOM.F(SEED) < SRUPROB(I)
2300       ADD 1 TO SRUREM (I)      ADD 1 TO SCNT2
2310       ADD SRU.HRS(3,I) * SFAC TO INT.HRS
2320       ADD SRU.HRS(3,I)*SFAC TO IS.HRS
2330       LET SFAC = .6
2340       ADD SRU.HRS(4,I) TO DEP.HRS
2350       ADD SRU.HRS(4,I) TO OS.HRS
2360       SCHEDULE A DEPOT.REPAIR(I) IN TO + TS + IO + SDTIME + TS DAYS
2370       PERFORM SPARE.CHECK(I)
2380     ALWAYS   LOOP
2390   CHECK.LRU
2400   " CHECK FOR AN LRU FAILURE
2410   FOR I = 1 TO LCNT   DO
2420     IF RANDOM.F(SEED) < LRUPROB (I) ADD 1 TO LRUCNT
2430     ADD 1 TO LRUREM (I)      ADD LTCOST TO TRANS
2440     ADD LRU.HRS(1,I) TO ORG.HRS
2450     ADD LRU.HRS(1,I) TO OL.HRS
2460     ADD LRU.HRS(2,I) TO INT.HRS
2470     ADD LRU.HRS(2,I) TO IL.HRS
2480     ADD LRU.HRS(3,I) TO DEP.HRS
2490     ADD LRU.HRS(3,I) TO OL.HRS
2500     LET II = I + SCNT
2510     SCHEDULE A DEPOT.REPAIR (II) IN TO + TL + LDTIME + TL DAYS
2520     PERFORM SPARE.CHECK(II)
2530   ALWAYS
2540   LOOP
2550   HERE
2560   SCHEDULE AN INSPECTION IN (INFREQ / FHP) * 30.42 DAYS
2570   RETURN END

```

```

2580
2590     EVENT INTER.REPAIR(PART)
2600     IF RANDOM.F(SEED) > CON.FAC(PART) ADD 1 TO LEVEL(PART) JUMP AHEAD
2610     ELSE ADD 1 TO CONDEMS (PART)
2620     HERE RETURN END
2630
2640     EVENT DEPOT.REPAIR(ITEM)
2650     IF RANDOM.F(SEED) > CON.FAC(ITEM) ADD 1 TO LEVEL(ITEM) JUMP AHEAD
2660     ELSE ADD 1 TO CONDEMS (ITEM)
2670     HERE RETURN END
2680
2690     EVENT ENGINE.REPAIR
2700     ADD 1 TO LEVEL(50)
2710     RETURN END
2720
2730     SUBROUTINE SPARE.CHECK(NUM)
2740     SUBTRACT 1 FROM LEVEL(NUM)
2750     IF NUM = 50 GO TO 'ENG.LOGIC' ELSE
2760     IF NUM > SCNT GO TO 'LRU.LOGIC' ELSE
2770     'SRU.LOGIC'
2780     IF LEVEL(NUM) < 0 ADD 1 TO SPARES(NUM) ADD 1 TO LEVEL (NUM)
2790     ALWAYS JUMP AHEAD
2800     'ENG.LOGIC'
2810     IF LEVEL(50) < B / 2 ADD 1 TO SPARES(NUM) ADD 1 TO LEVEL(NUM)
2820     ALWAYS JUMP AHEAD
2830     'LRU.LOGIC'
2840     IF LEVEL(NUM) < B / 2 ADD 1 TO SPARES(NUM) ADD 1 TO LEVEL(NUM)
2850     ALWAYS HERE RETURN END
2860

```

```

2870     EVENT TCTO
2880     ADD 1 TO EREM(6)
2890     SCHEDULE AN ENGINE.REPAIR IN 7 DAYS
2900     PERFORM SPARE.CHECK(50)
2910     RETURN END
2920
2930     EVENT SCHED.TCTO
2940     LET TCNUM = ENGS - (12*EALL(IMO))
2950     FOR I = 1 TO TCNUM SCHEDULE A TCTO IN (360 / TCNUM) * I DAYS
2960     SCHEDULE A SCHED.TCTO IN 365 * YR.TCTO DAYS
2970     RETURN END
2980

```

```

2990  EVENT END.OF.NO.STATS
3000  ADD 1 TO IND
3010  IF IND = 1
3020      LET EALL(1) = ERCNT      LET EDEP(1) = EREM(1)
3030      LET SPEC(1) = ICOUNT     LET ETCTO(1) = EREM(6)
3040      LET LRUS(1) = LRUCNT     LET SRUS(1) = SCNT1 + SCNT2
3050      LET DHRS(1) = DEP.HRS   LET EBUY(1) = SPARES(50)
3060      JUMP AHEAD ELSE
3070      LET EALL(IND) = ERCNT - XEALL
3080      LET EDEP(IND) = EREM(1) - XEDEP
3090      LET SPEC(IND) = ICOUNT - XSPEC
3100      LET ETCTO(IND) = EREM(6) - XETCTO
3110      LET LRUS(IND) = LRUCNT - XLRU
3120      LET SRUS(IND) = SCNT1 + SCNT2 - XSRU
3130      LET DHRS(IND) = DEP.HRS - XDHRS
3140      LET EBUY(IND) = SPARES(50) - XEBUY
3150  HERE SCHEDULE A END.OF.NO.STATS IN 30.42 DAYS
3160      LET XEALL = ERCNT      LET XEDEP = EREM(1)
3170      LET XSPEC = ICOUNT     LET XETCTO = EREM(6)
3180      LET XLRU = LRUCNT      LET XSRU = SCNT1 + SCNT2
3190      LET XDHRS = DEP.HRS    LET XEBUY = SPARES(50)
3200      LET ECOST = SPARES(50) * ENG.COST
3210      FOR I = 1 TO SCNT
3220          LET PS = PS + ((SPARES(I) - CONDEMS(I)) * SCOST(I))
3230          LET PSPARES = PS
3240          LET PS = 0
3250      FOR I = 1 TO SCNT
3260          LET CS = CS + (CONDEMS(I) * SCOST(I))
3270          LET CSPARES = CS
3280          LET CS = 0
3290      FOR I = 1 + SCNT TO SCNT + LCNT
3300          LET LPS = LPS + ((SPARES(I) - CONDEMS(I)) * LCOST(I - SCNT))
3310          LET LPSPARS = LPS
3320          LET LPS = 0
3330      FOR I = 1 + SCNT TO SCNT + LCNT
3340          LET LCS = LCS + (CONDEMS(I) * LCOST(I - SCNT))
3350          LET LCSPARES = LCS
3360          LET LCS = 0
3370      LET CCOST = ORG.HRS * ORATE
3380      LET ICOST = INT.HRS * IRATE
3390      LET DCOST = DEP.HRS * DRATE
3400      LET SE.RQMT(1) = SE.RQMT(2)      LET SE.RQMT(3) = 1
3410      LET SE.D = SE.RQMT(1) * SE.COST(1) * 1.75
3420      LET SE.I = SE.RQMT(2) * SE.COST(2) * 1.75
3430      LET SE.D = SE.RQMT(3) * SE.COST(3) * 1.75
3440      LET DIF.COST = TOT.COST

```

```

3450 IF WARR = 1
3460 LET TOT.COST = (WAR.COST + ECOST + PSPARES + CSPARES +
3470 LPSPARES + LCSPARES + OCOST + DCOST + ICOST + SE.I +
3480 SE.O + SE.D + TRANS)
3490 JUMP AHEAD ELSE
3500 LET TOT.COST =
3510 (ECOST + PSPARES + CSPARES + LPSPARES + LCSPARES + OCOST + DCOST +
3520 ICOST + SE.I + SE.O + SE.D + TRANS)
3530 HERE LET INT.COST = TOT.COST - DIF.COST
3540 LET INF.COST = INT.COST*((1 + (INFLAT/12))**(IMO))
3550 LET DIF.COST = TIN.COST
3560 LET TIN.COST = TIN.COST + INF.COST
3570 LET INT.COST = TIN.COST - DIF.COST
3580 LET DIS.COST = INT.COST*(1/((1+(DISC/12))**(IMO)))
3590 LET FIN.COST = FIN.COST + DIS.COST
3600 IF IMO < MO.QUIT RETURN ELSE
3610 START NEW PAGE PRINT 1 LINE WITH FROM THUS
3620 **** PROJECTED MAINTENANCE WORKLOAD
3630 FOR I = 1 TO IMO WRITE YR.BEG + 1900 + (I/12) AS D(10,2)
3640 SKIP 1 LINE PRINT 1 LINE THUS
3650 INSPECTIONS
3660 FOR I = 1 TO IMO WRITE SPEC(I) AS I 10
3670 SKIP 1 LINE PRINT 1 LINE THUS
3680 ENGINE REMOVALS (EXCLUDING TCTOS)
3690 FOR I = 1 TO IMO WRITE EALL(I) AS I 10
3700 SKIP 1 LINE PRINT 1 LINE THUS
3710 ENGINE REMOVALS (DEPOT)
3720 FOR I = 1 TO IMO WRITE EDEP(I) AS I 10
3730 SKIP 1 LINE PRINT 1 LINE THUS
3740 ENGINE REMOVALS (TCTO)
3750 FOR I = 1 TO IMO WRITE ETCTO(I) AS I 10
3760 SKIP 1 LINE PRINT 1 LINE THUS
3770 SPARE ENGINE REQUIREMENTS
3780 FOR I = 1 TO IMO WRITE EBUY(I) AS I 10
3790 SKIP 1 LINE PRINT 1 LINE THUS
3800 MAINTENANCE ACTIONS (SRUS)
3810 FOR I = 1 TO IMO WRITE SRUS(I) AS I 10
3820 SKIP 1 LINE PRINT 1 LINE THUS
3830 LRU REMOVALS
3840 FOR I = 1 TO IMO WRITE LRUS(I) AS I 10
3850 SKIP 1 LINE PRINT 1 LINE THUS
3860 DEPOT MANHOURS
3870 FOR I = 1 TO IMO WRITE DMRS(I) AS I 10
3880 STOP END
3890

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3900  EVENT REPORT
3910  START NEW PAGE
3920  ADD YR.REPORT/365 TO YR.START
3930  IF YR.REPORT > 365
3940  WRITE PRGM,YR.START - 1 + 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
3950  JUMP AHEAD ELSE
3960  WRITE PRGM,YR.START+ 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
3970  HERE SKIP 2 LINES
3980  PRINT 3 LINES WITH FHT, FHT / ECNT,ICOUNT THUS
3990  *****,** ENGINE FLYING HOURS
4000  *****,** FLEET FLYING HOURS
4010  *** INSPECTIONS PERFORMED
4020  SKIP 1 LINE PRINT 4 LINE WITH LRUCNT,OL.HRS*DRATE,IL.HRS*IRATE,
4030  OL.HRS*DRATE,LONT THUS
4040  ON-WING MAINTENANCE ACTIVITY
4050  TO DATE ***** LRUS HAVE BEEN REMOVED. TOTAL MHRS & LABOR ARE
4060  D-LEVEL=*****,**, I-LEVEL=*****,**, D-LEVEL=*****,**
4070  DISTRIBUTED AMONG THE ** IDENTIFIED LRUS AS FOLLOWS:
4080  FOR I = 1 TO LONT WRITE LRUREM (I) AS I 5
4090  SKIP 1 LINE
4100  SKIP 1 LINE PRINT 6 LINES WITH
4110  ERENT,EREM(1),EREM(2),EREM(3),EREM(6) THUS
4120  ENGINE REMOVAL INFORMATION
4130  *** ENGINES REMOVED (TOTAL EXCLUDING TOTOS)
4140  *** ENGINES REMOVED - MAJOR ENGINE DAMAGE
4150  *** ENGINES REMOVED - MINOR REPAIR - LRU
4160  *** ENGINES REMOVED - SRU CAUSED
4170  *** ENGINES REMOVED - TOTO
4180  SKIP 1 LINE
4190  PRINT 3 LINES WITH SCNT1 + SCNT2,SCNT1,IS.HRS*IRATE,SCNT2,
4200  DS.HRS*DRATE,SCNT THUS
4210  TO DATE ***** SRU MAINTENANCE ACTIONS HAVE TAKEN PLACE, DIVIDED AS
4220  (I-LEVEL=*****,**, D-LEVEL=*****,**) AND
4230  DISTRIBUTED AMONG THE ** IDENTIFIED SRUS AS FOLLOWS:
4240  FOR I = 1 TO SCNT WRITE SRUREM (I) AS I 5
4250  SKIP 2 LINES PRINT 1 LINE WITH SPARES(50),ECOST THUS
4260  SPARE ENGINE REQUIREMENTS (FAILURES AND TOTOS) *****,**
4270  SKIP 1 LINE PRINT 1 LINE WITH PSPARES THUS
4280  SPARE SRU REQMTS (PIPELINE) *****,** BROKEN DOWN AS FOLLOWS:
4290  FOR I = 1 TO SCNT WRITE SPARES(I) - CONDEMS(I) AS I 4
4300  SKIP 1 LINE PRINT 1 LINE WITH CSPARES THUS
4310  SPARE SRU REQMTS (CONDEMS) *****,** BROKEN DOWN AS FOLLOWS:
4320  FOR I = 1 TO SCNT WRITE CONDEMS(I) AS I 4
4330  SKIP 1 LINE PRINT 1 LINE WITH LSPARES THUS
4340  SPARE LRU REQMTS (PIPELINE) *****,** BROKEN DOWN AS FOLLOWS:

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```

4350   FOR I = 1 + SCNT TO SCNT + LCNT WRITE SPARES (I) - CONDEMS(I) AS I 4
4360   SKIP 1 LINE   PRINT 1 LINE WITH LCSPARES THUS
4370 SPARE LRU REQMTS (CONDEMS) $*****.**   BROKEN DOWN AS FOLLOWS:
4380   FOR I = 1 + SCNT TO SCNT + LCNT WRITE CONDEMS (I) AS I 4
4390   SKIP 1 LINE PRINT 7 LINES WITH
4400       ORG.HRS,INT.HRS,DEP.HRS.
4410       OCOST,ICOST,DCOST,
4420       SE.RQMT(1),SE.RQMT(2),SE.RQMT(3),SE.O,SE.I,SE.D THUS
4430           ORG-LEVEL           INTER-LEVEL           DEPOT LEVEL
4440 MAINTENANCE
4450 MANHOURS           ***           ***           ***
4460 DOLLARS           $*****.**           $*****.**           $*****.**
4470 SUPPORT EQUIPMENT
4480 UNITS           ***           ***           ***
4490 DOLLARS           $*****.**           $*****.**           $*****.**
4500   SKIP 1 LINE   PRINT 1 LINE WITH TRANS THUS
4510 TRANSPORTATION REQUIREMENTS=$*****.**
4520   SKIP 1 LINE   WRITE TOT.COST AS B 17,"TOTAL COST=$",D(13,2),/
4530   SKIP 1 LINE   WRITE TIN.COST AS B 17,"INFLATED COST=$",D(13,2),/
4540   SKIP 1 LINE   WRITE FIN.COST AS B 17,"DISCOUNTED COST=$",D(13,2),/
4550   SKIP 1 LINE   WRITE FIN.COST/PH AS B 17,"COST/EPH=$",D(13,2),/
4560   SKIP 1 LINE   PRINT 1 LINE THUS
4570   -----
4580   SCHEDULE A REPORT IN YR.REPORT DAYS
4590   RETURN   END
4600$   SOURCE
4610$   EXECUTE
4620$   LIMITS 11,20K,-3K,2000
4630$   FILE 8*.B15
4640$   PRNFL SL,R,S,CACI/BIOLIB
4650$   PRNFL 17,R,S,CACI/BIOMERR
4660$   DATA 05
4670$   SELECTA SHORT
4680$   SELECTA TEST.DAT
4690$   ENDJOB

```

APPENDIX C  
INPUT DATA ELEMENT DICTIONARY



Introduction: The Data Element Dictionary defines all input parameters into both versions of the simulation model. They are presented in alphabetical order with respect to the variable name.

|            |         |  |
|------------|---------|--|
| CON.FAC(I) | Real    | The percentage of the total of all failures that are not reparable and must be replaced. |
| DATE(I)    | Alpha   | The date of the last revision of the data set.   |
| DISC       | Real    | The discount rate at which the costs are converted back to a single year dollar set.     |
| DRATE      | Real    | The rate used for cost accounting of depot work. It includes both labor and materials.   |
| EBTIME     | Integer | The total time necessary for repair of an engine on base including repair and testing.   |
| ECNT       | Integer | The total number of engines per aircraft.  |
| EDTIME     | Integer | The total time an engine is out of service due to depot repair.                          |
| EFAIL(A)   | Real    | Distribution of failures expressed as a percentage for SRU, LRU or Major Engine Failure. |
| ENG.COST   | Real    | Total cost of a spare engine.  |
| EOH.HRS    | Real    | Total hours required for a total engine overhaul.  |
| ETCOST     | Integer | Cost to transport an engine from base to depot.  |
| FHP        | Integer | Total flying hours per month that each A/C will accrue.                                  |
| IMAN       | Real    | Organizational manhours required for the inspection of an engine.                        |
| INFLAT     | Real    | The expected rate of inflation.  |
| INFREQ     | Integer | Interval in aircraft flying hours between inspections.                                   |

|               |         |  |
|---------------|---------|--|
| IRATE         | Real    | The rate used for cost accounting of intermediate work and includes labor and materials.                           |
| LCNT          | Integer | The total number of LRUs identified in the engine.   |
| LCOST(I)      | Real    | Cost of each individual LRU.   |
| LDTIME        | Integer | The total time necessary for repair of an LRU at depot level. Including repair and testing but not transportation. |
| LRATE         | Real    | The projected removal rate for each LRU.   |
| LRU.HRS (A,I) | Real    | Manhours required for the repair process for each LRU when A is the level and I is the item.                       |
| LTCOST        | Integer | Transportation cost for shipping an LRU from base to depot.  |
| MAX           | Integer | Total number of aircraft in the simulation.  |
| MO.QUIT       | Real    | The total number of months to be simulated.  |
| NAME (A)      | Alpha   | Two part names for each SRU and LRU.   |
| NO.OF.BASES   | Integer | Total number of bases to be activated.   |
| ORATE         | Real    | The rate used for cost accounting of organizational level work. It includes both labor and materials.              |
| OVER.PER      | Real    | The percentage of aircraft to be deployed overseas.  |
| PQ(I)         | Integer | The number of aircraft to be delivered each month.   |
| PRGM          | Alpha   | Title of the modeled system.   |

|              |         |  |
|--------------|---------|--|
| RFAC         | Real    | Conversion factor for analysis of probability distributions on SRU and LRU failures. |
| SBTIME       | Integer | Time necessary for repair of an SRU at base level.                                   |
| SCNT         | Integer | Total number of SRUs identified in the engine.                                       |
| SCOST(I)     | Real    | The cost of each SRU.  |
| SDRATE       | Real    | The projected removal rate for SRUs to be repaired at depot level.                   |
| SDTIME       | Integer | Time necessary for repair of an SRU at the depot.                                    |
| SECOST(A)    | Real    | Support Equipment kit costs at the three levels.                                     |
| SED          | Integer | Random number generator seed selector.   |
| SEED         | Integer | Random number generator seed selector.   |
| SIRATE       | Real    | The projected removal rate for SRUs to be repaired at the I level.                   |
| SRU.HRS(A,I) | Real    | Total hours for repair of an SRU at either intermediate or depot.                    |
| STCOST       | Integer | Cost to transport an SRU from base to depot.   |
| SVR          | Real    | The projected rate at which engines are removed and sent to the intermediate shop.   |
| TE           | Integer | Transportation time in days from base to depot for an engine.                        |
| TL           | Integer | Transportation time in days from base to depot for an LRU.                           |

|           |         |  |
|-----------|---------|--|
| TS        | Integer | Transportation time in days from base to depot for an SRU. |
| WARR      | Integer | Indicator as to warranty or non-warranty option.           |
| WARR.COST | Real    | Total cost of the warranty package.                        |
| YR.REPORT | Real    | Period between reports.                                    |
| YR.START  | Real    | Year in which the simulation starts.                       |
| YR.TCTO   | Real    | Time interval between scheduled TCTOs.                     |

APPENDIX D  
INTERNAL VARIABLE DICTIONARY

Introduction: The Internal Variable Dictionary provides a definition for the internal variables of the two versions of the simulation model. These definitions are useful in understanding the logic of the simulation strategy.

|                |         |   |
|----------------|---------|---|
| B              | Integer | Indicator of bases.   |
| CONDEMS (ITEM) | Integer | Total parts condemned at depot level for each SRU and LRU.  |
| CONDEMS (PART) | Integer | Total parts condemned at intermediate level for each SRU and LRU.   |
| CS             | Integer | Intermediate variable for calculating CSPARES.  |
| CSPARES        | Integer | Total spares of each SRU procured to replace condemned SRUs.  |
| CY             | Integer | Incremented variable based on YR.START for output with delivery schedule.                                   |
| DCOST          | Integer | Total cost for labor and material at the depot level.   |
| DEP.HRS        | Real    | Total depot hours expended to date.   |
| DHRS (IMO)     | Integer | Monthly depot hours incurred.   |
| DIF.COST       | Real    | Intermediate variable for accounting of total costs and total inflated costs to date of the previous month. |
| DIS.COST       | Real    | Total discounted costs of the current month.  |
| DL.HRS         | Real    | Total D-level hours accrued associated with SRU repair.   |
| DS.HRS         | Real    | Total depot hours accrued associated with SRU repair.   |
| EALL (IMO)     | Integer | Monthly engine removal count.   |
| EBUY (IMO)     | Integer | Monthly spare engine procurements.  |
| ECOST          | Integer | Total cost of all spare engines procured.   |



|             |         |   |
|-------------|---------|---|
| EDEP (IMO)  | Integer | Monthly major engine removals.                                    |
| ENGS        | Integer | Tabulator for total engines in the system.                        |
| ERCNT       | Integer | Counter for total engine removals to date.                        |
| EREM(1)     | Integer | Major engine damage counter.                                      |
| EREM(2)     | Integer | Total LRU caused engine removals to date.                         |
| EREM(3)     | Integer | Total SRU caused engine removals to date.                         |
| EREM(4)     | Integer | Total engine removals due to SRU failure and repaired at I-level. |
| EREM(5)     | Integer | Total engine removals due to SRU failure and repaired at D-level. |
| EREM(6)     | Integer | Total engine removals due to TCTO actions.                        |
| ER.PROB     | Real    | Probability of an engine removal.                                 |
| ETCTO (IMO) | Integer | Monthly TCTO driven removals.                                     |
| FHT         | Integer | Tabulator of total engine flying hours.                           |
| FIN.COST    | Real    | Total cost including inflation and discounting to date.           |
| I           | Integer | Counter.  |
| ICOST       | Integer | Total cost for labor and material at the intermediate level.      |
| ICOUNT      | Integer | Tabulator of total number of inspections having occurred.         |
| II          | Integer | Counter.  |
| IL.HRS      | Real    | Total I-level hours accrued associated with LRU repair.           |

|             |         |  |
|-------------|---------|--|
| IMO         | Integer | Month indicator.   |
| INF.COST    | Real    | Total inflated costs of the current month.                   |
| INT.COST    | Real    | Total inflated cost to date of the previous month.           |
| INT.HRS     | Real    | Total intermediate hours expended to date.                   |
| IS.HRS      | Real    | Total intermediate hours accrued associated with SRU repair. |
| J           | Integer | Counter.   |
| JJ          | Integer | Counter.   |
| K           | Integer | Counter.   |
| LCS         | Integer | Intermediate variable used to calculate LCSPARES.            |
| LCSPARES    | Integer | Total spares of each LRU procured to replace condemned LRUs. |
| LEVEL(50)   | Integer | Total spare engines available.                               |
| LEVEL(ITEM) | Integer | Total spare parts available for each SRU and LRU.            |
| LEVEL(PART) | Integer | Level to date of each spares pool of LRUs and SRUs.          |
| LPS         | Integer | Intermediate variable for calculating LPSPARES.              |
| LPSPARES    | Integer | Total spares of each LRU procured to fill the pipeline.      |
| LRUPROB(I)  | Real    | Probability for failure of a specified LRU.                  |
| LRUREM(I)   | Integer | Total LRU removals by each type.                             |
| LRUS(IMO)   | Integer | Monthly LRU removal count.                                   |

|         |         |  |
|---------|---------|--|
| NUM     | Integer | Incremented identifier for SRUs and LRUs.                      |
| OCOST   | Integer | Total cost for labor and material at the organizational level. |
| OL.HRS  | Real    | Total O-level hours accrued associated with LRU repair.        |
| ORG.HRS | Real    | Tabulator for total number of organizational hours utilized.   |
| PDAYS   | Real    | Time in between delivery of aircraft during a specified month. |
| PLANES  | Integer | Tabulator for total aircraft in the system.                    |
| PS      | Integer | Intermediate variable for calculating PSPARES.                 |
| PSPARES | Integer | Total spares of each SRU procured to fill the pipeline.        |
| SCNT1   | Integer | Total SRUs failed and repaired at I-level.                     |
| SCNT2   | Integer | Total SRUs failed and repaired at D-level.                     |
| SD.TOT  | Real    | Total maintenance actions for SRUs at D-level.                 |
| SE.D    | Integer | Total cost for SE at the depot level.                          |
| SED     | Integer | Incremented argument for randomizing the number generator.     |
| SEED    | Integer | Incremented argument for randomizing the number generator.     |
| SE.I    | Integer | Total cost for SE at the intermediate level.                   |

|             |         |  |
|-------------|---------|--|
| SE.O        | Integer | Total cost for SE at the organizational level.   |
| SE.RQMT(1)  | Integer | Total SE sets required for the O-level.  |
| SE.RQMT(2)  | Integer | Total SE sets required for the I-level.  |
| SE.RQMT(3)  | Integer | Total SE sets required for the D-level.  |
| SFAC        | Real    | Factor for reduction in labor hours due to multiple failures in one removal.                 |
| SI.PER      | Real    | Probability of depot repair of an SRU.   |
| SI.TOT      | Real    | Total maintenance actions for SRUs at I-level.   |
| SPARES(NUM) | Integer | Total spare engines procured.  |
| SPEC(IMO)   | Integer | Monthly inspections.   |
| SRUPROB(I)  | Real    | Probability for failure of a specified SRU.  |
| SRUREM(I)   | Integer | Total removals of each SRU.  |
| TCNUM       | Integer | Accounts for engines having complied with TCTO actions and not requiring further scheduling. |
| TIN.COST    | Real    | Total inflated cost to date.   |
| TO          | Integer | Factor for addition of extra repair time if engine is overseas.                              |
| TOT         | Integer | Total number of engines delivered in one year.   |
| TOTAL       | Integer | Total number of engines delivered.   |
| TOT.COST    | Real    | Basic total cost to date.  |

|        |         |   |
|--------|---------|---|
| TRANS  | Integer | Total transportation costs incurred to date.  |
| X      | Integer | Random variable for determination of engine failure mode.                                 |
| XDHRS  | Integer | Total report hours incurred (to previous month).  |
| XEALL  | Integer | Total engine removals (to previous month).  |
| XEBUY  | Integer | Total spare engines procured (to previous month).   |
| XEDEP  | Integer | Total major engine removals (to previous month).  |
| XETCTO | Integer | Total TCTO driven engine removals (to previous month).                                    |
| XLRUS  | Integer | Total LRU removals (to previous month).   |
| XSPEC  | Integer | Total inspections (to previous month).  |
| XSRUS  | Integer | Total SRU removals (to previous month).   |
| YR.BEG | Real    | A static variable allowing the incremented variable YR.START to be used at a later point. |

APPENDIX E  
MODEL LOGIC

The purpose of this appendix is to provide an indepth view of the model logic to provide an understanding of the actual process used to simulate the Engine O&S System. This analysis is accomplished by a reverse flow process. The analysis starts with the monthly statistics event and defines the derivation of the final cost. Each Discrete Event is then discussed.

### Event Monthly Statistics

#### Final Discounted Cost

This is the measure of system performance and is the major piece of data collected. It is calculated from the total inflated O&S costs using the following formula:

$$\text{Discounted Cost for Month IMO} = \text{Inflated Cost for Month IMO} \left( \frac{1}{1 + \left( \frac{\text{Discount Rate}}{12} \right) \text{IMO}} \right)$$

The discounting is done on a monthly basis and is accomplished in order to provide a true representation of costs in similar year dollars. As stated before, the discounted costs are derived from inflated cost as shown in the following paragraph.

#### Inflated Cost

This cost is an adjusted O&S aggregate cost after inflation growth. The inflation calculation is performed as follows:

$$\text{Inflated Cost for Month IMO} = \text{Monthly Aggregate O\&S Cost} \left( 1 + (\text{Inflation Rate}/12) \text{IMO} \right)$$

### Monthly Aggregate O&S Cost

This is the total of all monitored costs and involves the summation of a number of variable values. Each variable will be discussed and traced back to their respective origins.

The first variable, WARR.COST, is the cost of the warranty. Not only is this value an input to the aggregate cost, it is a direct input as a system parameter. Therefore, this value is supplied directly from input without any transformation.

Second is the total cost for spare engines (ECOST) which is computed by a multiplication of the total engines required for spare assets by the actual cost of the engines. The latter is an input value while the former is accumulated as follows. During the spare check routine, the level of engines is queried. If it is below a level equal to  $1/2$  the total number of bases, another engine is procured. Engines are decremented from the spares level at the beginning of the spare check routine as a result of engine removals in the inspection event. An engine removal can occur due to major damage, LRU failure or SRU failure. The decision factor is the input parameter "failure mode distribution" which defines the percentage of all removals attributed to each of the three possibilities. The use of a simple random number generator allows the use of these probabilities in randomizing the decision. The overall engine removal decision is controlled by another random number generator compared to an engine



removal probability. This probability is calculated from the product of three input parameters; shop visit rate, total number of engines on the aircraft, and the inspection frequency divided by 1000:

$$ER.PROB = (SVR*ECNT*INFREQ)/1000$$

Having derived the total engine cost, the third cost factor is the cost of pipeline SRU and LRU spares.

#### SRU/LRU Spares Cost (Pipeline)

The pipeline is defined as the total number of units necessary to allow normal operations taking into account repair times, transportation times and failure rates. These costs for the total number of SRU or LRU spares necessary to fill the pipeline is calculated by the product of the total number required, times their individual costs. The individual unit costs are stored in an array and each month the total cost is calculated for each SRU or LRU. This total cost calculation is accomplished by taking the total units procured and subtracting the total number of units condemned. This gives a true figure of SRUs or LRUs required solely for the pipeline. Total SRU/LRU procurements are driven by the spare check subroutine which causes the purchase of a specified unit if the total in the spares pool falls to zero for SRUs, or less than 1/2 of the total number of bases for LRUs. Spares pool usage is, in turn, controlled by item removals in the inspection event. The probability of an SRU or LRU failure is generated using the following equations for SRUs and LRUs:

$$SRU.PROB = \left( \begin{array}{cc} \text{Expected} & \text{Expected} \\ \text{Maintenance} & + \text{Maintenance} \\ \text{Actions} & \text{Actions} \\ \text{at Inter-} & \text{at Depot} \\ \text{mediate} & \end{array} \right) / \left( \begin{array}{cc} \text{SRU} & \\ \text{Failure} & \text{Shop} \\ \text{Rate} & * \text{Visit} * 1000 \\ \text{Proba-} & \text{Rate} \\ \text{bility} & \end{array} \right)$$

$$LRU.PROB = \left( \begin{array}{ccc} \text{Maintenance} & * & \text{Total \#} & * & \text{Inspection} \\ \text{Actions} & & \text{of Engines} & & \text{Frequency} \end{array} \right) / 1,000,000$$

All of the required data is provided as values to input parameters. The use of a random number generator output to compare to the probability on each SRU or LRU simulates the failure in a real life situation.

#### SRU/LRU Spares (Condemnation)

The total cost for condemned spare SRUs or LRUs is calculated in the same manner as the pipeline spares with the addition of one factor; that of condemnation. It can be seen in Figure E-1 that during the repair event the decision to condemn is accomplished using a random number which is compared to the appropriate input condemnation factor. The total number of condemned units is tallied and the costs are accumulated by the simple multiplication of the total condemned units times their procurement cost. The latter is an input value.

#### Organizational, Intermediate and Depot Costs

The next three factors in the aggregate cost include the manhour and material costs for the three maintenance levels. Organizational, Intermediate and Depot hours are accrued throughout the system. They are each accumulated in their

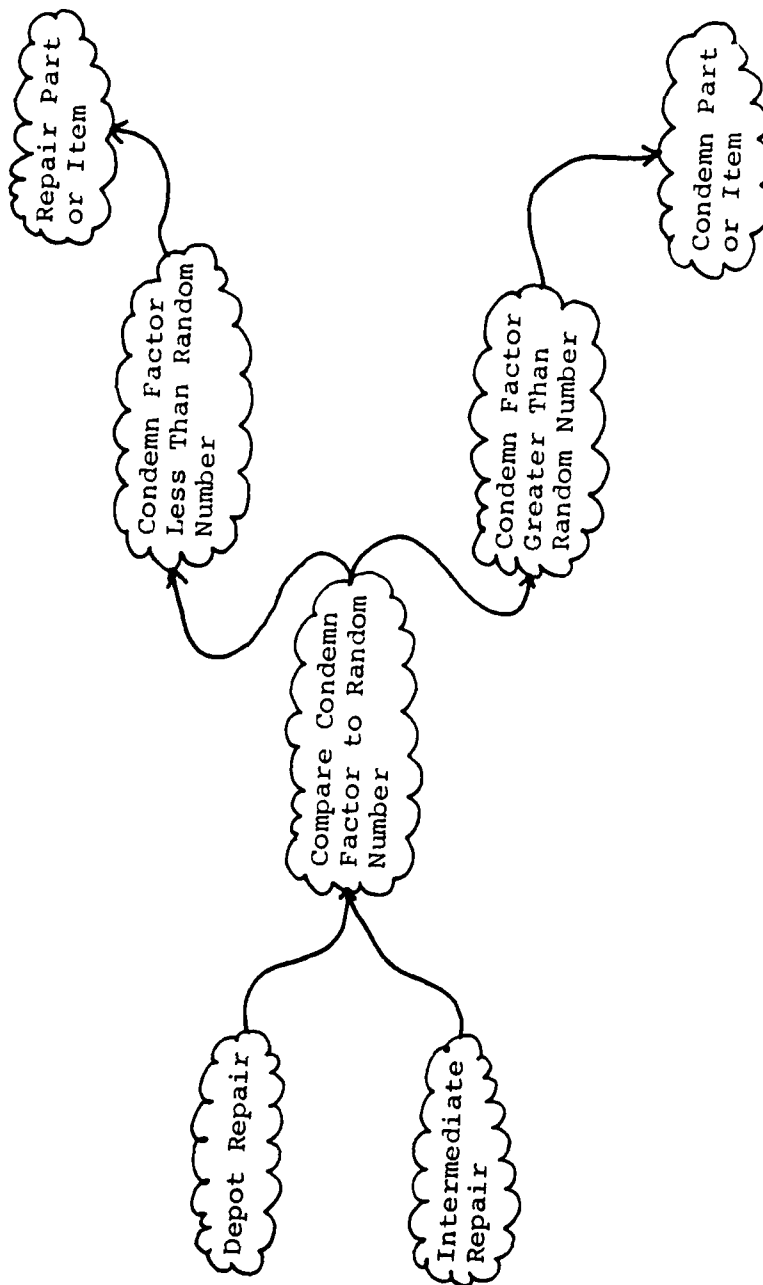


Figure E-1 Condemnation Process

respective counters and costs are calculated monthly by multiplying the total hours by the input manhour and material hourly costs. The accumulation process for the next three aggregate factors are roughly similar.

#### Support Equipment Costs - O-I-D Levels

The cost for support equipment sets is defined as the total number of sets required at each level times their individual procurement costs. The latter value is input to the system as a parameter value. Total S.E. kit requirements are determined in the deployment event where the system procures organizational and intermediate sets for each base and one depot set for the entire system. Therefore, the input total number of bases drives the support equipment set buy.

#### Transportation Costs

The last aggregate cost is for the cost of transporting the SRUs, LRUs and engines between base and depot. This cost is directly accumulated throughout the system when a unit of any type is transported. The cost for transporting each type is provided as a value for an input parameter.

To this point the accrual of total costs and, in some manner, how they tie back to the rest of the system has been discussed. However, it should be of interest to the reader how each of the specific events function. Therefore, we will now analyze each event at the micro level and explain the logic involved.

### Event Deployment

In this event, the intent is to bring those aircraft into operational services which were scheduled for deployment in the main portion of the program. The total number of planes is increased as is the total number of engines. The total number of planes is compared to the total required for the current base and, if necessary, a new base is initialized with support equipment kits.

### Event Inspection

Within this event the inspection, fault isolation, and repair scheduling functions are portrayed. We start with the bookkeeping functions such as incrementing the total number of inspections completed, the total number of flying hours and charging the inspection manhours to the organizational hour counter. A check is then made to determine if the aircraft is overseas. If the randomly generated number is less than the input variable overseas percentage (OVER.PER) then the time for transport overseas (TO) is set to 10 as opposed to 0 for the CONUS.

The next check is for an engine removal as a result of the inspection. As stated before, the engine removal probability is calculated as follows:

$$\left( (\text{Shop Visit Rate}) * \frac{\text{\# of Engines}}{\text{per A/C}} * \frac{\text{Inspection}}{\text{Frequency}} \right) / 1000$$

If the random number drawn is smaller than the engine removal probability, the engine is removed and action is transferred

to the Check LRU subunit which will be discussed later.

#### Remove Engine

This is the decision point for cause of failure. Using the Failure Mode Distribution input values and a randomly generated number the failure type is determined. Action is then transferred to either Major Damage, SRU Caused, or LRU Caused after the engine removal count is increased by one.

#### Major Damage

In this section we simulate the activities which result after a catastrophic failure of an engine. First the bookkeeping where major damage failures are incremented by one, the input parameter Engine Overhaul Hours is added to Depot manhours and the Organizational hours are incremented by 10 for engine packing purposes. Additionally, the cost of transporting the engine is summed to the total transportation costs. An engine repair is then scheduled for completion in a matter of days as defined by first the Engine Transport Time input parameter  $\times 2$  + Overseas Transport Time, if necessary, and Engine Depot Time which is input as a system parameter value. A spare check is then performed and finally the activity is transferred to Check LRU for LRU failure checks.

#### LRU Caused

This simulates the maintenance activity if an engine is removed and the failure is subsequently found to be due to

LRU malfunction. An accounting is made of the type of removal and 46 hours are added to intermediate hours for the removal and replacement of the LRU(s). An engine repair is scheduled for completion in 15 days and a spare check of engines is performed. Once these are completed, action is transferred to Check LRU.

#### SRU Caused

This indicates an engine removal was due to an SRU failure. The type of failure is increased by one and an engine repair is scheduled for completion in engine Base Repair Time days, a value which is input in the first data set. A spares check for engine is then accomplished. The next step is to determine whether the SRU will be repaired at depot or intermediate level. This is done by use of a random number comparison to a value calculated as follows:

SI.TOT = Total of all SRU intermediate maintenance actions

SD.TOT = Total of all SRU depot maintenance actions

SI.PER = The value against which the comparison is made

$$\text{Where SI.PER} = \frac{\text{SI.TOT}}{(\text{SI.TOT} + \text{SD.TOT})}$$

Thus the percentage of intermediate actions is the decision factor. If the random number is less than the SI.PER value, the repair is to be done at the intermediate level and action is transferred to IREPAIR of SRU otherwise action is transferred to Depot Repair of SRU. Regardless of which subunit

action is transferred, the logic is the same.

#### Repair or Depot Repair

In both of these possibilities, the type of failure is incremented and transportation costs are assessed. At this point, each SRU is checked for failure by use of a random number compared to each SRU's failure probability. Manhours associated with each failure are accounted for and a repair is scheduled. The repair time for each is dictated by either the parameter value SRU Base Repair Time for intermediate repair or the following equation for depot repair:

$$\begin{array}{ccccccc} \text{Transport} & & \text{SRU Trans-} & & \text{SRU} & & \text{SRU Trans-} \\ \text{Time} & + & \text{port Time} & + & \text{Depot} & + & \text{port Time} \\ \text{Overseas} & & \text{to Depot} & & \text{Time} & & \text{from Depot} \end{array}$$

Each of the above values are input as system parameters. In either case, a spare check is accomplished and activity is then transferred to Check LRU.

#### Check LRU

In this activity each LRU is checked for a failure. This is done by comparison of a random number to the individual LRU failure probabilities. Each LRU failure probability is determined by the following equation:

$$\text{LRU.PROB} = \left( \frac{\text{Projected Maintenance Actions} \times \text{Total Engines per A/C} \times \text{Inspection Frequency}}{1000} \right)$$

If the random number is less than LRU.PROB, the LRU is considered failed and the appropriate repair hours are assigned. A depot repair for each LRU is scheduled in accordance with the following formula:



|                               |   |                                |   |                             |   |                                |
|-------------------------------|---|--------------------------------|---|-----------------------------|---|--------------------------------|
| Overseas<br>Transport<br>Time | + | LRU Depot<br>Transport<br>Time | + | LRU Depot<br>Repair<br>Time | + | LRU Depot<br>Transport<br>Time |
|-------------------------------|---|--------------------------------|---|-----------------------------|---|--------------------------------|

Each of these are values input into the system parameters.

The final step in the inspection event is to schedule another inspection.

#### Event Intermediate Repair and Event Depot Repair

In these events a random number is generated and compared to an input condemnation factor. If the random number is less than the condemnation factor the part is condemned, accounted for and passess out of the system. Otherwise it is repaired and is returned to the spares pool by incrementing the appropriate level value by one.

#### Event Engine Repair

In this event the level (50) or engine spares pool is incremented by one and the action is completed.

#### Event TCTO

In this type of maintenance action the type of engine removal is accounted for and an engine repair is scheduled in seven days. A spare check is then performed to assess the spares pool level for engines. The last event to be considered is the scheduling of TCTOs.

#### Event Schedule TCTO

In this activity all the TCTO compliances for a particular TCTO are scheduled. Each engine that will not be removed during the coming year will be scheduled for a compliance point. This is done by forecasting the total engine

removals for the next 12 months and requiring all engines, save those to be removed to be complied with by separate engine removals. The last step is to schedule the next scheduling of a TCTO in  $[(365) * (\text{Years between TCTOs})]$  days.

While some of the points made in this appendix may seem redundant with Chapter 3, it is the intent of this section to bring a more indepth look at the model logic for the interested reader.

APPENDIX F

USER'S MANUAL  
LONG TERM WARRANTY  
ANALYSIS VERSION  
(WARR.3)

Purpose: To evaluate warranty packages over the life cycle of the engine system.

Alternate Uses: O&S Cost Studies  
Project Base/Depot Workloads  
Determine Parts Requirements  
Sensitivity Analysis

Description: The WARR.3 model is a Monte Carlo type simulation model. It is written in Simscript II.5 and designed for usage on the Create computer system.

Files: Input Data Files - TEST100  
- TEST.DAT  
Source Program - WARR.3

This manual is designed to be used with the User's Manual for the SHORT.3 version. The intent of this version is to compare the expected improvement resulting from a warranty application to the expected results without those assurances. The following procedures will assist in accomplishing the desired analysis.

Step 1 - As in the SHORT.3 procedure, create the two data files using the same instructions with 2 exceptions.

- a) Change the name of the "SHORT" file to "TEST100".
- b) Add the variables "SIM" and "ST" to the end of the seventh line of data.

(i.e. MO.QUIT, SEED, SED, SIM, ST)

The added variables are used to initialize the simulation number and stopping point. The normal setting for 10 simulation runs is SIM = 1 and ST = 11. However, up to 30 total runs can be made by adjusting the SIM and ST levels up. However, due to time constraints on the Create system making

more than 10 runs at one time is not recommended.

Step 2 - With the data files constructed it is possible to run the simulation. The simulation should be made first with the warranty option including the expected improvements and warranty costs. The data sets can then be reset to show the non-warranty conditions and the simulation is performed again.

Due to the size of these two projects they will require overnight running. In the morning results can be collected at the central site. Since there is no automation of data handling beyond this point, the yearly accumulated totals for all 10 runs of each option should be averaged and the average lines plotted. This plot of accumulated cost versus time will provide the breakeven point. Further testing can be done using an SPSS F test to determine when the two lines are no longer significantly different. However, this technology has not been built in and is left to the analyst.

APPENDIX G  
USER'S MANUAL  
SHORT TERM WARRANTY  
ANALYSIS VERSION  
(SHORT.3)

Purpose: To evaluate warranty packages effective for short periods of time.

Alternate Usage: Operation and Support Cost Studies  
Project Base/Depot Workloads  
Determine Parts Requirements  
Sensitivity Analysis

Description: The SHORT.3 model is a Monte Carlo type simulation model. It is written in Simscript II.5 and designed for usage on the Create computer system.

Files: Input Data Files - SHORT  
- TEST.DAT  
Source Program - SHORT.3

This manual is intended to illustrate the commands necessary to perform the computer operations to execute the SHORT.3 simulation program. Words underlined indicate a response by the operator and CR indicates a carriage return.

To Start

Log on the Create Computer System

STATION ID - XY CR (Terminal Identifier)

USER ID - 82X111 CR

PASSWORD - LL11 CR

PROBLEM NO. - WPOOOO CR

SYSTEM?

The user is now ready to build the 2 data files necessary for input to the SHORT.3 model. The first data file will contain engine parameters, cost data, pipeline assumptions, delivery schedule and basing concept. The second data file will contain SRU and LRU reliability and maintainability data. The following data file examples will assist the user in

constructing his or her own. The entries indicate the input variable.

#### Building SHORT Data File

SYSTEM? Editor CR

OLD OR NEW? New CR

ENTER

\*75#DATE(1) DATE(2) CR

\*76#PRGM ECNT SVR ENG.COST RFAC OVER.PER WARR CR

\*77#SE.COST(1) SE.COST(2) SE.COST(3) WARR.COST CR

\*78#FHP INFREQ IMAN ORATE IRATE DRATE EOH.HRS CR

\*79#TE TL TS EDTIME EBTIME SDTIME SBTIME LDTIME CR

\*80#ETCOST STCOST LTCOST INFLAT DISC CR

\*81#YR.START YR.REPORT YR.TCTO MO.QUIT SEED SED CR

\*82#EFAIL(1) EFAIL(2) EFAIL(3) CR

\*83#MAX CR

\*84#PQ(1) PQ(2) ... PQ(MAX) CR

\*85#NO.OF.BASES CR

\*86#BASEQTY(1) ... BASEQTY(NO.OF.BASES) CR

\*87#CIRF CR

CR

- SAVE SHORT CR

DATA FILE SHORT SAVED

- DONE CR

SYSTEM? Editor CR

OLD or NEW? New CR

ENTER

\*300#SCNT CR

\*310#NAME(1) NAME(2) SIRATE SRU.HRS(1,1) SRU.HRS(2,1)

SPRATE SRU.HRS(3,1) SRU.HRS(4,1) SCOST(1) CON.FAC(1)

CR

\*320#... CR ALL SRU DATA IDENTICAL

...

\*450#LCNT CR

\*460#NAME(1) NAME(2) LRATE LRU.HRS(1,1) LRU.HRS(2,1)

LRU.HRS(3,1) LCOST(1) CON.FAC (1+SCNT) CR

\*470#... CR ALL LRU DATA IDENTICAL

...

\*550# CR

- SAVE TEST.DAT CR

DATA FILE TEST.DAT SAVED

- DONE CR

SYSTEM?

At this point, the user is ready to run the SHORT.3 simulation model. To do this follow the procedure below.



SYSTEM? CARD CR  
OLD or NEW? OLD SHORT.3 CR  
\*READY  
\*RUN CR  
\*SNUMB E002T

E002T is the system identifier for the run. This allows the user to check the status of the run. Status checks are accomplished as follows:

\*JSTS E002T CR  
\*E002T EXECUTING

25 minutes to 1 hour later

\*JSTS E002T CR  
\*E002T OUTPUT WAITING ID=XY  
Normal Termination

Output can now be obtained as follows:

\*LINE LENGTH 132 CR  
\*JOUT E002T CR  
FUNCTION? Activity 2 CR  
FUNCTION? EPRINT 06 CR

.  
.  
.

Model Output

\*END OF 06  
FUNCTION?

Before exiting the JOUT system, the user should release the job by the following actions.

FUNCTION? Release CR  
SYSTEM? Bye CR

APPENDIX H  
SPSS ANALYSIS PROGRAMS

The Statistical Package for the Social Sciences (SPSS) is a canned set of analytic processes used for routine data analysis.

This appendix contains all SPSS programs used in the analysis of data in this research effort. The programs shown here are written for use on the AFIT Harris system.

```

1 8SPSS*SPSS8
2 RUN NAME      ONEWAY ANOVA FOR VALIDATION
3 PRINT BACK    CONTROL
4 VARIABLE LIST  GROUPS,OUTPUT
5 INPUT FORMAT  FREEFIELD
6 N OF CASES    UNKNOWN
7 ONEWAY        OUTPUT BY GROUPS(1,2)
8 STATISTICS    ALL
9 READ INPUT DATA

```

```

1 8SPSS*SPSS8
2 RUN NAME      LILLIEFORS TEST FOR NORMALITY
3 PRINT BACK    CONTROL
4 VARIABLE LIST  OUTPUT
5 INPUT FORMAT  FREEFIELD
6 N OF CASES    UNKNOWN
7 NPAR TESTS    K-S(NORMAL)=OUTPUT
8 STATISTICS    ALL
9 READ INPUT DATA

```

```

1 8SPSS*SPSS8
2 RUN NAME      TWO WAY ANALYSIS OF VARIANCE
3 PRINT BACK    CONTROL
4 VARIABLE LIST  ENG,SVR,COST
5 INPUT FORMAT  FREEFIELD
6 N OF CASES    UNKNOWN
7 ANOVA         COST BY ENG(1,3) SVR(1,3)
8 STATISTICS    ALL
9 READ INPUT DATA

```

```

1 8SPSS*SPSS8
2 RUN NAME      ONEWAY ANOVA FOR ENGINE COST
3 PRINT BACK    CONTROL
4 VARIABLE LIST  ENG,SVR,COST
5 INPUT FORMAT  FREEFIELD
6 N OF CASES    UNKNOWN
7 *SELECT IF    (SVR EQ 2)
8 ONEWAY        COST BY ENG(1,3)
9               RANGES = DUNCAN(.10)
10 STATISTICS    ALL
11 READ INPUT DATA

```

```

1 8SPSS*SPSS8
2 RUN NAME      ONE WAY ANOVA FOR SHOP VISIT RATE
3 PRINT BACK    CONTROL
4 VARIABLE LIST  ENG,SVR,COST
5 INPUT FORMAT  FREEFIELD
6 N OF CASES    UNKNOWN
7 SELECT IF     (ENG EQ 2)
8 ONEWAY        COST BY SVR(1,3)
9               RANGES = DUNCAN(.10)
10 STATISTICS    ALL
11 READ INPUT DATA

```

APPENDIX I  
BMDP ANALYSIS PROGRAM

The Biomedical Data Package is a canned set of analytic processes used for biomedically oriented data analysis.

This appendix contains the BMDP program used to generate the normality plots presented in the text. The program shown was altered only slightly by changing the year input and the data sets in order to plot the four sets of data. This program is designed for use on the ASD CYBER System with interface through the AFIT Harris System.

JOB GHT SYST BCDDMP PRI=15 OUT=0

\*RJE 100 GHT \*

GHT,CM100000. T790704,HELLESTO

ATTACH,BMDP5D,ID=BMDP,SN=ASDAD.

BMDP5D.

/\*EOR

/PROBLEM TITLE IS '2004'.

/INPUT VARIABLE IS 1.

FORMAT IS '(F6.2)'.

/VARIABLE NAMES IS COST.

/PLOT TYPES ARE NORM.

/END



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INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYSTEMS  
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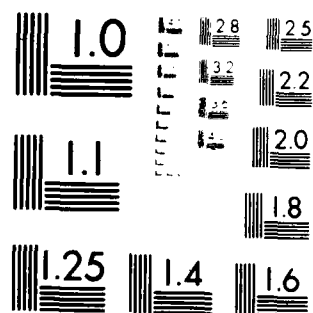
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