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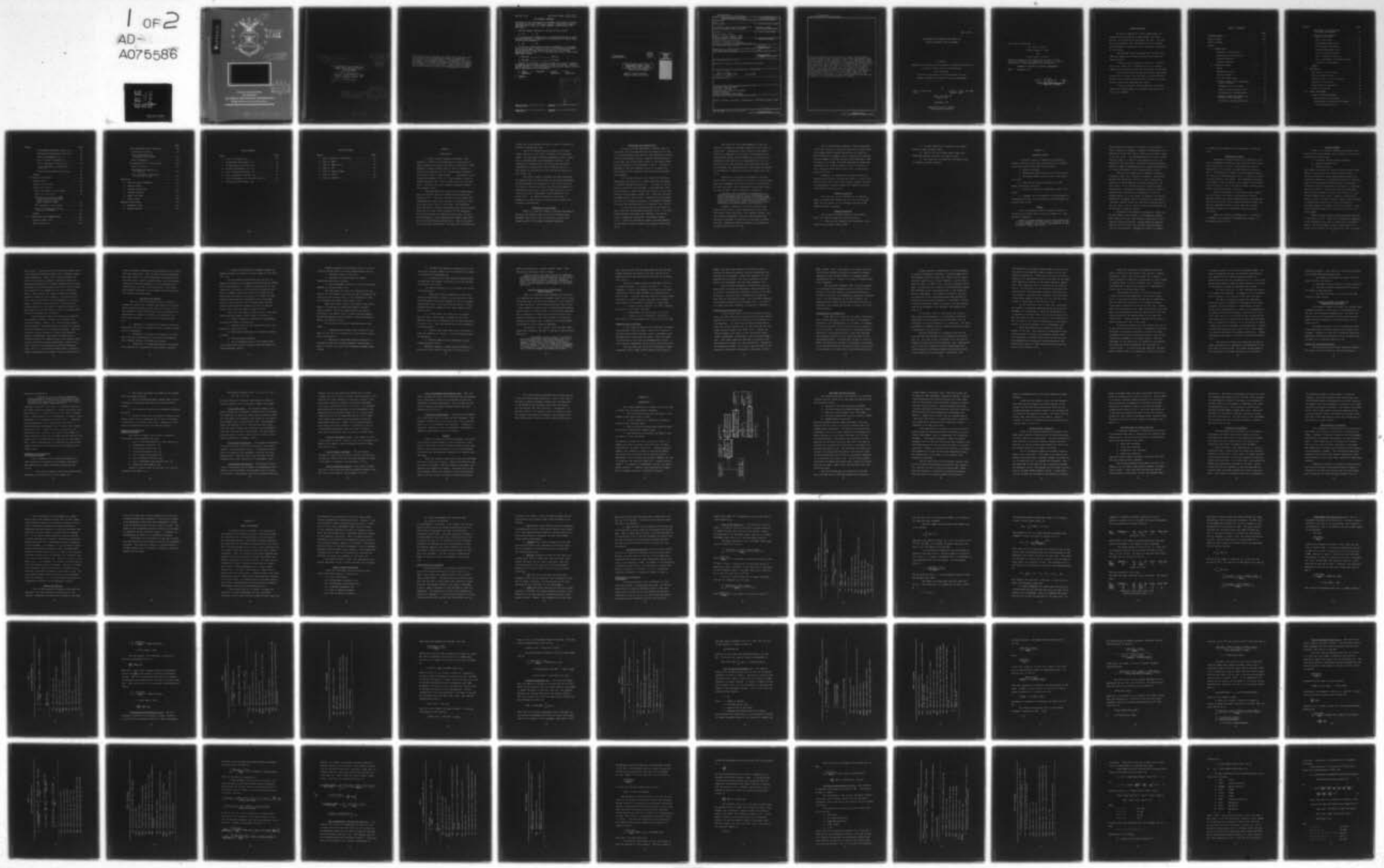

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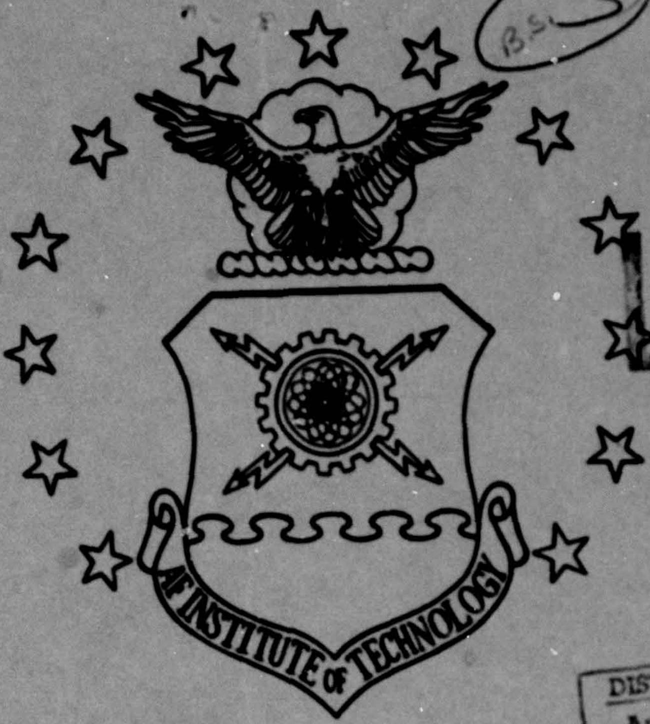

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AN OPERATING AND SUPPORT COST MODEL FOR AVIONICS AUTOMATIC TEST EQUIPMENT.

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One of the fastest growing elements of weapon system support equipment which relates directly to Operating and Support (O&S) costs is Automatic Test Equipment (ATE). The importance of ATE has expanded to such a degree that it requires additional management attention. The importance is exemplified by the $600 million projected development and acquisition costs of ATE for the F-16. This amount of cost qualifies the F-16 ATE for major program status. This thesis documents the development of a model to estimate and measure O&S costs for avionics ATE. The model will be an important addition to the tools used in ATE Life Cycle Costing (LCC) techniques. It is envisioned primarily as an evaluation tool to be used in ATE source selection, but may also be useful in various design trade-off studies.

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AN OPERATING AND SUPPORT COST MODEL FOR AVIONICS AUTOMATIC TEST EQUIPMENT

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

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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

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CHAPTER I

INTRODUCTION

In today's complex defense environment, great emphasis is placed on the development and acquisition of weapon systems that provide the most for each dollar. When speaking of weapon systems there is often a tendency to overlook the importance of "all the equipment required on the ground to make a weapon system . . . operational in its intended environment [1:A2-1]." This equipment, known as Support Equipment (SE), runs the gamut from low cost hand tools to multimillion dollar computer operated automatic test stations (23:1).

"The development and acquisition of Support Equipment are integral parts of a defense system acquisition program [23:1]." The cost of SE for Air Force weapon systems presently ranges from 5 percent to 15 percent of the total acquisition costs of the system. The importance of SE has grown so rapidly over recent years that the aggregate cost of all SE in the inventory in 1975 approached $4.5 billion and has increased each year since. SE has a great influence on total Operating and Support (O&S) costs of the Air Force defense system (23:1). Due to inflation and technological advancement, the O&S costs of maintaining current Air Force systems has grown to nearly 60 percent of potential expenditures (26).

One of the fastest growing elements of SE which relates directly to O&S costs is Automatic Test Equipment (ATE). The importance of ATE has expanded to such a degree that it requires additional management attention. The importance is exemplified by the $600 million projected development and acquisition costs of ATE for the F-16. This amount of cost qualifies the F-16 ATE for major program status (25).

The role of support equipment has been recognized and numerous policies and regulations have been established for SE development and acquisition. Even with this guidance several problems have been identified with respect to evaluating alternatives in new SE acquisition and in controlling the cost of equipment already deployed in the field (23:1). One specific problem is that there is presently no proven method of estimating O&S costs of SE available to SE managers.

Statement of the Problem

There is a need for a model to estimate and measure Operating and Support costs for avionics Automatic Test Equipment that will be used in Life Cycle Costing techniques applied to ATE Support Equipment programs.

Background and Justification

The policy of the Department of Defense (DOD) in compliance with the Armed Services Procurement Act of 1947 is to procure supplies and services from responsible sources at fair and reasonable prices. Supplies and services procured under this policy should result in the lowest overall cost of ownership to the government (1:A5-1). One way to determine a fair and reasonable price is to employ Life Cycle Costing (LCC) techniques when acquiring new systems and equipment.

LCC "covers the entire cost spectrum from design, development and acquisition, through operating and support to ultimate equipment salvage [26]." LCC began in the Air Force in 1968 with the procurement of nonrepairable items and progressed in stages through applications to major subsystems to major weapon systems (26). Today LCC continues to expand within the Air Force. Depending on the intended use, LCC is "a costing discipline, a procurement technique, an acquisition consideration and a trade-off tool [14:39]."

In its use as a costing discipline, LCC deals primarily with O&S cost-estimating methods (14:39). O&S costs, those generally associated with ownership, include the costs of operation, maintenance, and general support (17:1). Since 1975 the DOD has placed increased emphasis on O&S costs in order to reduce total weapon system costs (6:ii).

One reason for this added emphasis is that O&S costs of a system will probably exceed the initial cost of acquisition. Additionally, O&S costing has been determined to be important in the areas of Force/Support Program Balance, Weapon Systems Comparisons, Historical Cost Perspective, and Design to Cost Implementation (31:2-4). While O&S costs have generally been associated with complete systems, the same benefits of these types of analysis can be applied to acquisition below the system level such as SE.

According to the Logistics Management Institute, the Air Force is procuring SE at the rate of $1 billion per year and investments in SE are projected to increase (25). As noted previously, ATE is becoming a significant factor in total SE costs. ATE is defined to include all

> Electronic devices capable of automatically or semi-automatically generating and independently furnishing programmed stimuli, measuring selected parameters of an electronic, mechanical, electro-mechanical, or electro-optical item being tested, and making a comparison to accept or reject the measured values in accordance with predetermined limits [1:A2-2].

Recently, acquisition of SE has received high-level attention due to large expenditures in this area. The General Accounting Office, the Inspector General, and the Logistics Management Institute have documented SE acquisition problems in the areas of high cost, untimely delivery, inadequate trade-off analysis, and unrealized standardization potential (25).

One of the earliest attempts to improve management of ATE O&S costs was in June 1971 when the Air Force Logistics Command (AFLC) directed San Antonio Air Logistics Center (SA-ALC) to prepare a plan to identify and quantify the cost elements involved with Air Force ownership of ATE. As stated in its scope, the model developed by SA-ALC only documents costs of ATE procured by the Air Force and is not a predictive model which lends itself to sensitivity analysis (1:5A-1).

Presently, the Aeronautical Systems Division SE System Project Office indicated that there is a need for an O&S cost model which could "help program managers forecast SE requirements, estimate budgets and schedules, and perform trade-off analysis [25]."

Research Objective

The objective of this research was to develop a model to estimate and measure O&S costs for avionics ATE which could be useful in LCC techniques applied to ATE Support Equipment programs.

Research Questions

The following research questions were posed to guide the research toward the stated objective:

1. What are the variables that contribute to the operating and support costs of ATE?

2. To what categoties of operating and support costs do these variables apply?

3. What is the relationship among these variables that defines operating and support costs?

4. How sensitive are operating and support costs to changes in these variables?

CHAPTER II

LITERATURE REVIEW

A literature review of appropriate regulations, manuals, directives, and other publications was conducted to evaluate and/or define the following areas:

1. Models in general.
2. Mathematical models being used in the Air Force.
3. Accounting models and their use in the Logistics field.
4. AFLC O&S and Logistics Support Cost (LSC) models, techniques, and uses.
5. Logistic Support Cost Commitments (LSCC) techniques.
6. Elements to be considered in the development of a mathematical model for the estimation and measurement of the O&S costs of ATE.

Models

One of the aspects of man's reasoning faculty is the ability to predict what is going to happen; i.e., the ability to forecast.

> Rational conduct depends not only upon knowing what is really happening and being able to interpret it, but on having present in our minds a representation of what is going to happen next [5:100].

This prognosis may often be inaccurate, but is continuously corrected by feedback. A mental representation or an abstraction of the real world is what can be called a model of the real world. This representation may be more or less accurate, that is, a more or less predictive aid in the behavior of the real world. "Because they are predictive, models are open to experimentation as a means of evaluating the likely performance of the thing modelled [5:100]."

The process of modeling is a process of mapping a conceptual model into a scientific language. During this process some conceptual richness is lost, because this conceptual richness depends on nuance, association, and mood, and it is not transferable into scientific terms. Nevertheless, a conceptual homomorphic scientific model is obtained that is precise and unambiguous (5:112-113). Because reality is in many cases too complex to be exactly reproduced, or because certain variables are irrelevant to a specific problem, models are simplified abstractions of the real world; that is, various degrees of abstraction can be obtained in modeling (28:20).

According to the degree of abstraction, models can be scale models, analog models, or mathematical models. Scale models, with the least degree of abstraction, are a physical replica of reality. Analog models are physical models that do not look like the real thing but behave like the thing modeled. Mathematical models use symbols to represent the complexity of relationships in some systems.

Mathematical Models

Mathematical models typically are presented in the form of mathematical equations that establish the relationships between the variables. These models are easy to manipulate for the purpose of experimentation and prognosis. The dependent variables of the mathematical models tell how well a system performs, that is, reflect the level of effectiveness of the system. The independent variables of the model can be divided into two classes: controllable from the point of view of the decision maker (decision variables), and uncontrollable (28:20-23).

From the standpoint of the decision maker, models can be divided into normative and descriptive models. Normative models are usually optimum models that prescribe the course of action, while descriptive models reflect the system's performance under various input sets of data; descriptive models do not guarantee optimal solutions (27:30-39).

Models can further be deterministic, if certainty is assumed; and stochastic or probabilistic models, if uncertainty exists (27:75).

Logistics Models

There is an interface between the logistics area and Air Force system design; this interface involves three broad decision situations:

1. Conceptual design/concept evaluation.
2. Detailed system design.
3. Support planning.

When models are applied to solve Air Force logistics managerial situations they are called Logistics Models. During the conceptual design phase logistics models can handle the comparison of "different concepts for achieving some set of performance characteristics or operational objectives, and for establishing envelopes for system characteristics [24:6]." During the detailed system design phase logistics models can handle the selection of a particular hardware design from a number of alternatives. Finally, during the support planning phase logistics models can handle the estimation of the kind and amount of resources required to support a particular design. A particular logistics model could very well be used for all three phases.

There are many logistics models developed and used in the logistics field. They can be categorized, depending on the methodology they use, as analytical or simulation models. Analytical models "yield a single answer or a unique set of answers for any given set of values of input data [24:10]." The solution that this type of model gives is the desired consequence sought, and it requires a minimum of computation. Most of the logistics models fall within the analytical category. Simulation models are appropriately employed for systems characterized by large data bases or sizable solution sets (24:10); that is, when the situation is too complex for the use of analytical models. When dealing with complex situations, however, simulation models do not necessarily give optimal solutions; what they furnish is an approximation to the best answer. Even with a good selection of input data the optimal solution is not assured. Simulation models are more expensive than the analytical ones, and present difficulties in debugging and validation.

The analytical models can further be categorized into probability models, network or flow models, and accounting models. Models, like the reliability models, that are based on the probability of occurrence of events, are called probabilistic or probability models. When the situation involves movement of things, like materials, spares, or reparables, flow models are best suited. Accounting models are commonly used in the logistics field because resources are usually expressed in terms of dollars. They are "a structured way of adding component costs [24:12]." The accounting models used in logistics compute the operating and support costs at relatively low levels of hardware breakdown--Line Replaceable Units (LRUs)--and total these costs. They include initial and replenishment spare costs, on- and off-equipment maintenance costs, inventory costs, support equipment costs, cost of personnel training and training equipment, cost of management and technical data, and cost of new facilities. As we shall see, the model developed in this research effort falls into this class of logistics model.

Life Cycle Cost Models

The life cycle cost models include a variety of mathematical models that "address some aspect of life cycle costing during the weapon system acquisition cycle [8:1]." They translate system characteristics and performance into requirements for support resources, and ultimately into dollar cost estimates. Life cycle cost models are used for:

1. Computation of Operating and Support cost estimates which are taken as decision criteria by DSARC or other levels of management.
2. Computation of Operating and Support cost targets which are incorporated into contractual commitments, and to measure success in meeting such targets.
3. Computation of comparable Operating and Support Cost estimates for consideration during source selection.

4. Trading off alternative equipment designs and support concepts on the basis of their impact on life cycle cost (8:1).

The link between system design and the cost to operate and support the equipment resulting from that design can be established by: (1) making a good estimate of the operational and support costs during the acquisition process; (2) keeping records of the costs of operating and maintaining the system in the field; (3) finding out what operating and structural characteristics of the system drive the costs for O&S; and (4) feeding back what DOD learns to the industrial community so they can improve design from an O&S cost impact viewpoint (31:4).

Life cycle cost models do have utility in the Integrated Logistics Support (ILS) context, as tools to:

1. Study the impacts of operational requirements on design and support alternatives.

2. Identify areas of high support costs as a consequence of design decisions.

3. Make useful comparisons of alternative support postures.

4. Develop budget estimates.

5. Act as evaluation tools in the source selection process and to define incentive goals and other contract guarantees (24:30).

Comparing operating and support costs of a new system with the O&S costs of current systems permits one to:

1. Determine trends in O&S costs.

2. Determine shifting demands for support resources among similar systems.

3. Focus management attention on critical resource demands of the new system (31:3).

The most important reason for evaluating O&S cost impacts of a new system is the need for DOD to implement the Life Cycle Cost concept, that is, the integration of O&S cost targeting and weapon system design (31:4).

There are several types of LCC models: Cost Factor Models, Cost Estimating Relationship Models, Economic Analysis Models, Logistics Support Models, Reliability Improvement Cost Models, Level of Repair Analysis Models, Maintenance Manpower Planning Models, Inventory Management Models, and Warranty Models.

The following are desired characteristics of LCC models:

1. Completeness--LCC models must include all elements of life cycle cost appropriate to the decision issue under consideration.

2. Sensitivity--LCC models must be sensitive to the specific design or program parameters under study in order to resolve life cycle cost differences between alternatives.

3. Validity--LCC models are abstractions of the real world and some judgment will be required with respect to how valid cost estimates are.

4. Availability of input data--LCC models should use data that are readily available at low cost and have a high level of accuracy.

LCC models developed up to now present the following deficiencies:

1. There are certain parameters not taken into account by such models. Models are not sensitive to certain performance and design parameters, such as accuracy, speed, range, and, as one author has pointed out, "Early tradeoff decisions frequently have large impacts on O&S costs [8:24]."

2. In many cases, LCC models are too complex. They may have a large number of parameters which may obscure a small set of parameters that are more relevant to life cycle cost. Also, the definitions of the parameters are often unclear.

3. In many cases input data are not available on time, are expensive to collect, or lack the desired level of confidence.

4. Some LCC models are not sensitive to wear-induced failures (8:8-9).

Generally speaking, a model must be oriented to a relatively narrow range of application in order to be useful for analysis of a specific design issue. Input data must be relatively easy to obtain.

> General purpose LCC models tend to be inadequate for specific applications because they (a) lack resolution with respect to specific decision issues, (b) do not reflect characteristics of peculiar equipment types, (c) require data in formats that are too extensive or are not compatible with formats of available data [8:4].

Logistics Support Cost Commitments (LSCC) Technique

LSCC is a relatively new technique that contractually embodies the concept of aggregate target cost for measuring O&S costs, and provides incentives to the contractor to lower O&S costs. This technique has been used in only a small number of contracts and its effectiveness requires more evaluation. However, LSCC is an innovative technique that if applied on a selective and controlled basis will broaden the Design to Cost (DTC) concept to include the operating and support cost in addition to the development and production costs already encompassed.

The Design to Cost concept, which has been implemented with success by the DOD, is defined in DOD Directive 5000.28 as

> . . . a management concept wherein rigorous cost goals are established during development and the control of systems costs (acquisition, operating, and support) to these goals is achieved by practical tradeoffs between operational capability, performance, cost, and schedule. Cost, as a key design parameter, is addressed on a continuing basis and as an inherent part of the development and production process.

Also, DOD Directive 5000.28 establishes the need for measurable operating and support cost goals "which can be monitored during test and evaluation as well as in operation [13:3]."

One way to measure operating and support costs is in terms of dollars. In order to do this, ". . . it is necessary to convert the measures of reliability and maintainability, such as MTBF and MTTR into expressions of cost [13:24]." The LSCC technique takes into account these cost goals in terms of dollars, and uses the following three elements to determine achievement of these goals:

1. A target logistic support cost (TLSC), defined according to a LSC model framework.
2. A measurement and verification of the LSC.
3. A remedy or price adjustment, according to the results of the measurement and verification of the LSC.

Framework for an LSC Model

In the Logistics Support Cost Commitment Technique the government logistics support costs, as a function of contrator-controllable equipment logistic parameters, are represented by a simplified cost model. This cost model is structured in line with the recommendations of the Joint Logistic Commanders' Design to Cost Guide (30:23-24).

The cost model has two kinds of parameters: those parameters, such as MTBF and Not Reparable This Station

(NRTS), over which the contractor has certain control through his engineering design, and other parameters that describe the environment in which the equipment is to be operated and maintained. The latter parameters are supplied by the government with the model framework (9:2).

The cost model framework is developed by the program office or acquisition management staff personnel and is given to the interested contractors as part of the LSCC provisions. This cost model framework will become the basis for the negotiated contract, and for formal communication between contractor and government (9:3). An outline of a basic LSC model framework is presented in Appendix A.

Target Logistics Support Cost

A cost target within the LSCC has several benefits. First, the LSCC contractual technique provides great design flexibility to the contractor permitting LSC reduction to the government. The contractor has many alternatives to lower the logistic support cost as long as he can meet the target logistic support cost (TLSC) (9:3). Second, the logistic support cost impact of the interactions among logistic parameters is reflected in the cost model framework. This impact cannot be detected if reliability and maintainability targets are set individually. Looking at the mathematical model, it is easy to see how costs can be changed by increasing or decreasing a parameter, such as

MTBF or NRTS. Third, cost impact is in terms of dollars, facilitating "effective analysis of trade-offs between acquisition cost and LSCC impacts of equipment design expenditures [9:3]." Fourth, it is easy to perform sensitivity analysis.

The cost model framework (CMF) could be expanded to incorporate other parameters and all possible interactions, but "as the accuracy and comprehensiveness of the CMF is enhanced, its mathematical complexity increases [9:5]." As the complexity of the CMF increases, the responsibilities under the LSCC become more difficult to determine; risk becomes much harder to assess, and incentives decrease.

Implementation Considerations

Since LSCC is an important and complex legal document, several managerial decisions require considerable attention in the implementation of the LSCC. For example, it is very important for the verification environment to be fully defined. Failure definition, parameter estimate definition, and responsibilities of both the government and contractor must be clearly stated and must include considerable detail. The LSCC must include all kinds of detail and definitions relevant to determining the method to be followed during the verification stage, and any kind of adjustment in the TLSC prior to the verification test.

Another important consideration is the development of contract adjustment procedures. From the comparison of the measured logistics support cost (MLSC) and the target logistics support cost, contract remedies or price adjustments are made. If MLSC < TLSC, positive adjustment can be used. An award fee as a function of the difference between MLSC and TLSC, up to a specified value, is one method of positive adjustment. An increment of the price per unit as a function of the difference between MLSC and TLSC is another way of positive adjustment. If the MLSC > TLSC by a certain percentage, usually 10 percent, the LSC performance of the equipment is not adequate, and remedies are used (9:7).

If the MLSC = TLSC or they differ only within a small specified percentage, it is regarded as sufficient compliance of the LSC target by the contractor, and the contractor is given the benefit, e.g., award fee. All price adjustments or remedies must be conducted according to what is specified in the LSCC (9:7).

Another consideration is related to the kind of risk that the LSCC exposes both the contractor and government to. Cost risk is part of business risk, and has two elements--statistical risk and technical risk. Statistical risk is the risk of making incorrect award/remedy decisions because of differences between the MLSC and the LSC of the underlying true population. Statistical risk considerations are necessary because MLSC is only an estimate of the true measured logistics support cost of the underlying population. Technical risk is the risk due to variability of the possible values of the MLSC of the underlying population relative to the target logistics support cost. This technical risk is a function of the state of the art, the efficiency of the manufacturing process, the compliance with the development schedule, and other technical factors. Statistical and technical risks both have a significant impact on the LSCC as a tool for the transmission of incentives to the contractor (9:9).

If the statistical risk is very high, incentives are reduced, and needless expenditures may be incurred if equipment is rejected when it meets the requirements, or if equipment is accepted when it should be rejected (9:9). When the technical risk is very high or the variability of the true MLSC of the underlying population is very large, the use of the LSCC technique is not recommended (9:9).

Other considerations are related to the legal aspects of the LSCC. The contractor's responsibility for various factors of LSC has to be balanced against sufficient authority to control those factors of the LSC; and the government has to guarantee the maintenance of the prenegotiated levels of those factors over which the contractor has no control (9:9).

Since both contractor and government are interested in having low statistical risks, one way to reduce statistical risks is by using the LSCC for a group of items: developing a TLSC for the aggregate of items instead of separate TLSCs for each individual item. Statistical risk reduction is due to the existence of independence of variability of test data among items.

Two problems may arise in trying to lower statistical risk with the aggregation over several items. First, if the prime contractor passes down to subcontractors the same LSCC provision on an item-by-item basis, sucontractor's statistical risk may be very high. Second, during the verification test, some items may have very high MLSC, but the aggregate target may be met due to the "offsetting effect of low measured LSCs for the remaining items [9:15]." These high MLSC items may be the cause of weapon systems down time in the field.

Of prime consideration is the research that has to be done when structuring the LSCC. The purpose of the LSCC technique is to maximize contractor incentive to reduce government LSCs while maintaining statistical risk to contractor and government at acceptable levels. Thus the assessment of the values that will establish the relationship among the control parameters has to be made in a rigorous manner. If these values are realistic, the Cost Model Framework (CMF) will adequately represent the costs of logistic support for the actual equipment demand. If control parameters are well set and their relationships well defined, it will "permit extensive studies of trade-offs among the four parameters [9:17]." It also will permit enough time to study the LSCC statistical risk prior to negotiation of terms and conditions of the LSCC.

The LSCC technique is a well conceived and innovative contracting technique. It appears to be an effective way to transmit to the contractor DOD life cycle goals.

The CMF is a simplified model that represents government LSCs as a function of contractor-controllable equipment logistic parameters. Nevertheless, the LSCC needs certain prerequisites in order to be recommended as an adequate contractual technique: statistical and technical risks have to be low enough so that contractors are attracted to work on a project and so that LSCC effectiveness in transmitting incentive to the contractor to design a reduced LSC item of equipment can be maintained. However, the LSCC techniques have been used in only a small number of contracts and need a more complete evaluation. "Future applications should be on a selective and controlled basis [9:17]."

The Logistics Support Cost model was the type of model developed for the estimation and measurement of the O&S costs for avionics ATE. This model concept permits the utilization of the LSCC technique for contractual commitment purposes. The reasons for selecting this model and the LSCC technique approach were:

1. LSC models are designed to support the technique of life cycle costing.

2. LSC models are very useful in source selection.

3. The LSCC technique transmits DOD life cycle cost goals to the contractor.

4. The LSCC technique is in line with the DOD "Design to Cost" concept.

Logistics Support Cost Model for Automatic Test Equipment

The logistics support cost model for automatic test equipment developed in this study is a representation of the real world expressed mathematically. The model can serve as an aid in the decision-making process and help reduce the risks associated with uncertainties of the future (19:77).

The model consists of a set of mathematical equations representing different operation and support cost elements. Summation of this set of equations yields the approximate operating and support cost for automatic test equipment over a specified period of time.

Reliability and Maintainability

The two primary factors which determine operating and support cost are reliability and maintainability.

According to AFLCP 800-3,

> . . . reliability is the principal performance factor influencing design and life cycle support costs. It predominates as a lead factor in determining other factors such as availability, maintenance load factors, and spares and support requirements [2:7].

Increased reliability could result in decreased operating and support costs but probably at a higher acquisition cost. Maintainability is a quantification of the ease of maintenance. "Maintainability is a consideration of design, while maintenance is a consequence of design [2:11]." Designing ease of maintenance into a product may also result in reduced operation and support costs, but again may increase acquisition costs. These two factors (reliability and maintainability) illustrate the necessity for a model in which acquisition costs can be weighed against operating and support costs in determining the "best buy" for the government. Thus it was important to understand the relationship between reliability and maintainability and operation and support costs.

Assumptions and Limitations for Model Development

Basic assumptions and limitations necessary for model simplicity in developing the automatic test equipment operating and support cost model were as follows (10:4):

1. Each base of operation using the automatic test equipment was considered to be fully operational.

2. The spares requirement was based on the highest level of program activity.

3. Only one Technology Repair Center (TRC) location and several intermediate base repair locations were considered.

4. Only recurring training for maintenance personnel was used.

5. Certain factors that contribute to operation and support costs were not considered due to lack of estimates or difficulty in evaluating such costs. Examples of these factors are modification costs and software changes.

Factors of the Logistics Support Cost Model

The logistics support cost factors considered in the automatic test equipment model are:

1. Cost of Test Replaceable Unit (TRU) Spares (C_1)
2. On-Equipment Maintenance (C_2)
3. Off-Equipment Maintenance (C_3)
4. Inventory Management Cost (C_4)
5. Cost of Support Equipment (C_5)
6. Cost of Personnel Training (C_6)
7. Cost of Management and Technical Data (C_7)
8. Calibration Requirements (C_8)

Logistics support costs are the sum of all factors included in the model; e.g.,

$$\text{ATE Logistics Support Cost} = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8$$

The cost factors are discussed individually in order to gain more insight into the logistics support cost model.

Cost of TRU Spares. The logistics support cost model provides for a systematic determination of the types and quantities of spares and repair parts required to maintain and support the automatic test system and its associated hardware for a fixed period of time. The equipment spares are necessary to fill the field and depot repair pipelines and to replace the items which are condemned at base level over the life of the system. The base repair pipeline spares include a safety stock to protect against random fluctuations in demand (10:3-1).

On-Equipment Maintenance. On-equipment maintenance includes servicing, preventive maintenance, time change removals, and unscheduled removals. On-equipment maintenance for automatic test equipment is done at the intermediate level. This cost factor also includes the time expended during fault-isolation to a subassembly level.

Off-Equipment Maintenance. Off-equipment maintenance is associated with the repair of subassemblies after removal from the automatic test equipment when a failure has occurred. Off-equipment costs are estimated using the average value of labor where the average cost to repair includes the cost of labor (salaries, fringe benefits, overhead and lost time) employed in the repair process (7:44). Erroneously removing a properly functioning subassembly will also be included as part of this cost. Off-equipment maintenance can be accomplished at the intermediate level where one facility provides support to one or more using organizations or at the Technology Repair Centers (TRCs) which possess more sophisticated equipment and greater maintenance capability. Repair at two different maintenance levels can cause confusion in determining cost of off-equipment maintenance since the costs to repair at base level are different than the costs at the TRC level.

Inventory Management Costs. This element of cost is considered as the new inventory life cycle management cost based on the number of spares estimated under the spares cost factor (7:33).

Cost of Support Equipment. This cost factor includes the quantities and costs to acquire and maintain new peculiar items of TRC and base shop equipment utilized in the repair of automatic test equipment (10:3-7).

Cost of Personnel Training. This factor includes the cost to train base and depot maintenance personnel over the life of the automatic test equipment (10:3-10).

Cost of Management and Technical Data. This cost factor includes the labor costs associated with the preparation of maintenance forms due to equipment failures and scheduled or periodic maintenance. Also included are the costs to acquire and update technical orders and other technical data (10:3-11).

Calibration Requirements. Calibration requirements are a cost factor that is unique for test equipment. This element includes the cost of calibration of all items that require it on the automatic test equipment. Calibration intervals, calibration time, and equipment turnaround are important items affecting this cost factor.

Summary

There is a definite need for management tools which can aid the Air Force manager in decision making in this time of tight money and ever-increasing weapon system costs. The life cycle costing technique is one of the management tools which has been employed successfully in reducing system costs.

There are different models which have been developed and used in life cycle costing. Some of the models are the life cycle cost models, logistics support cost models, and operation and support cost models. Unavailability of support equipment models has resulted in poor cost reduction results and has invoked criticism of systems acquisition.

Life cycle costing techniques have not been applied to all Air Force systems acquisition. Such is the case in the area of support equipment acquisitions and especially in the automatic test equipment arena where increasing cost has focused high level attention. Consequently, it was the intent of this research effort to develop a logistics support cost model for automatic test equipment that could prove useful in ATE life cycle costing applications.

CHAPTER III

METHODOLOGY

This chapter describes the methods which were used to answer the following research questions:

1. What are the variables that contribute to the operating and support costs of ATE?
2. To what categories of operating and support costs do these variables apply?
3. What is the relationship among these variables that defines operating and support costs?
4. How sensitive are operating and support costs to changes in these variables?

The research followed the steps outlined in Figure 1 to address the areas of variable identification, variable relationships, and model sensitivity. Research question number 1 was answered by comparing existing O&S models with actual data collected from the depot and field. Examination of the variables and personal judgment was used to categorize the variables identified to answer question number 2. An adaption of dimensional analysis was used to answer question 3. Question 4 was addressed by a mathematical computer analysis of the model variables.

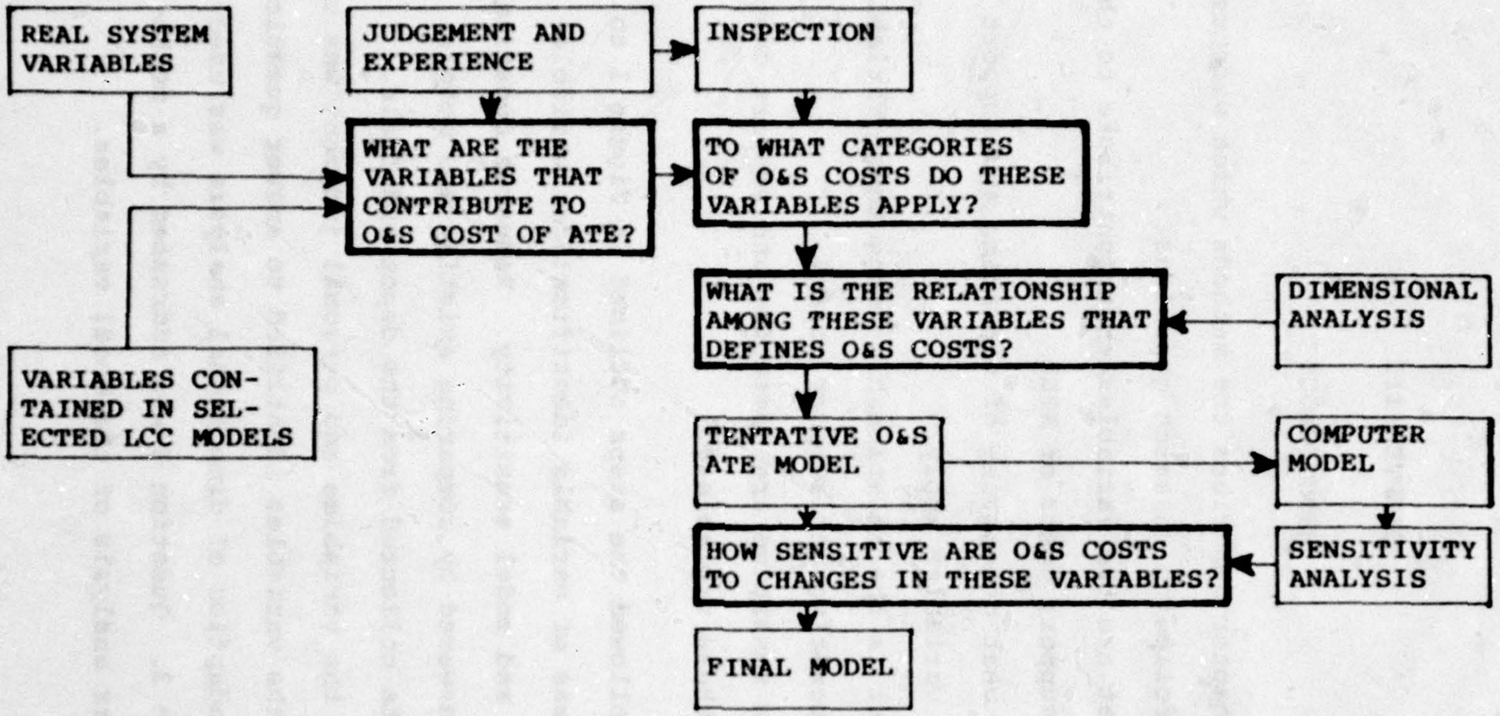

Fig. 1. Steps Included in Methodology

Data Base and Data Validity

The primary data used in the selection of the model variables and for validation of the model was obtained from the following sources:

1. San Antonio Air Logistics Center (SA-ALC)
2. Air Force Logistics Command Headquarters (AFLC)
3. Newark Air Force Station, Ohio (AFLC/AGMC)
4. Air Force Acquisition Logistics Division (AFALD)
5. DCASPRO Bendix Corporation

Spares requirement data and depot maintenance data were obtained from San Antonio Air Logistics Center (ALC) and DCASPRO Bendix Corporation. San Antonio is the prime ALC responsible for all Air Force Automatic Test Equipment and Bendix Corporation is the prime contractor for F-15 ATE. The system manager, item manager, and contractor for ATE supplied the necessary historical data which were used to determine the variables that contribute to the majority of operating and support cost. The contractor and depot maintenance actions performed provided an indication of those variables responsible for driving the maintenance component of the operating and support cost. Typical data gathered from SA-ALC and Bendix were spares cost, number of failures, mean time to repair, depot costs, ATE operating time, and contractor costs.

The field maintenance data available at HQ AFLC were retrieved from the USAF Maintenance Data Collection

System commonly called 66-1 data. The data sources were the D056 and D041 management information systems. Typical field maintenance data reported by Work Unit Codes (WUC) were the maintenance action performed, manhours to repair, and when failure occurred. These maintenance data were initially recorded by the maintenance technician effecting ATE LRU repair and were documented in accordance with AFM 66-1. Repair at the field level was charged against a particular WUC which is a hierarchical parts identification system which identifies every reparable or major component in the ATE (29:11-002).

Data pertaining to calibration intervals and calibration times for ATE were obtained from Newark Air Force Station (AFLC/AGMC), which is responsible for calibration equipment. The manhours expended to remove or replace equipment that was sent for calibration were charged to the field maintenance activity and were included in the field level data. However, the actual time required to calibrate each component at either the Precision Measurement Equipment Laboratories at the depot or the contractor was gathered by AFLC/AGMC.

The data pertaining to the different Logistic Support Cost models were obtained from the Air Force Acquisition Logistics Division at Wright-Patterson AFB. These data were necessary in studying the variables presently being utilized by the existing models and providing a basis for standardization of variable symbols and nomenclature.

Since the only sources of data for the research were from Air Force agencies and data systems, it was assumed that the data were accurate and valid for the intended purposes of variable selection and validation of the operation and support cost model. All data, once collected, were classified as either nominal, ordinal, interval, or ratio in accordance with the guidelines outlined by Emory (15:113-117).

Existing Model Variables

Three of the existing operating and support cost models were studied to determine the variables being used and their symbols and nomenclature. This was necessary to take advantage of existing computer programs that were modified in order to perform the mathematical analysis of the proposed operation and support cost model.

One of the models studied was the AFLC Logistics Support Cost (LSC) model. This model is an applied cost analysis technique which is general purpose in content and is not appropriate for all systems and categories. The LSC model must be tailored for use on particular systems and equipment (10:4). The program for this model is available on the AFLC CREATE computer system. Another model that was studied was developed by the Operations Analysis

Office at HQ AFLC under the name Project ABLE (Acquisition Based on Consideration of Logistics Effects). Project ABLE is an effort "directed towards creating tools which measure the logistics consequences of Reliability and Maintainability and applying them so as to make new weapon systems better--sooner [21:1]." An actual application of an operating and support cost model to the F-4E aircraft program was also studied to determine actual variables used. The model is the A-X ten-year operating and support cost model (7:1).

Variables Used in Actual Cost Data

A study was undertaken to determine what variables are presently being used in computing actual operation and support costs. The following groupings of variables were among those considered in the study:

1. Depot cost variables
2. Field cost variables
3. Calibration cost variables
4. Spare cost variables

These cost areas commonly represent the actual O&S costs that are currently being recorded.

The variables making up the depot cost were, for example, cost to repair, depot pipeline spares, and depot time to repair. These data were obtained from the ATE system manager at SA-ALC/MMI division and DCASPRO Bendix

Corporation. The field cost variables consisted of on and off equipment maintenance done on the ATE. This included such maintenance actions as: time spent on adjustments of the ATE, removal or replacement of components, and actual troubleshooting time. The calibration cost data were obtained from AFLC/AGMC at Newark AFS, Ohio. These data pertained to: calibration intervals, calibration times, and cost of calibration. The last area of cost considered was the amount and cost of spares necessary to support a particular piece of ATE.

Selection of Variables

The determination of variables for the operating and support cost model was made by comparing the variables presently being used on other operating and support cost models and the variables which are actually contributing to O&S costs of Automatic Test Equipment.

The first step in the comparison was to list all variables found in existing O&S cost models and variables observed in actual data. Once listed, an attempt was made to match each variable, one for one, between the existing models and actual data. If a direct match was possible the variable was tentatively included in the model. When a direct match was not possible, as was the case when the existing model contained variables not found in existing data or vice versa, an evaluation based on the strength of the variable was made to judge whether it should be included. Only those variables which collectively contributed approximately 80 percent to the actual operating and support cost were considered for inclusion in the ATE operating and support cost model. This decision was based on the value volume concept originally observed by the Italian economist, Pareto, who based his findings on the fact that a few items usually account for the majority of the value of a system (28:159).

Relationships of Variables

The categories of variables for the proposed model were found to be similar to those found in existing O&S models. Examples of variable categories are off-equipment maintenance, on-equipment maintenance, and spares requirements. A more complete list of categories is found on page 26 in the list of factors considered in the model. The categories of variables was determined through examination and personal judgment. The relationships among the variables were determined by personal experience, dimensional analysis, and in some cases, adaption of dimensional analysis.

Dimensional analysis is a method of specifying the form of the functional relationship between a number of variables if and when we know that just one relationship must necessarily tie these variables together (12:4-5).

For the purpose of the development of a mathematical model that predicts the O&S costs for ATE, dimensional analysis technique was applied in finding the functional relationships between the selected variables. Dimensional analysis enabled us to find the variables that must enter the relationship in certain definite combinatins. In our model, where dimensional analysis was used variables selected were grouped in categories representing partial O&S costs; then, dimensional analysis was applied to this category. For example, if C_3 is a category representing off-equipment maintenance cost, the dimensional analysis technique would allow us to find C_3 as a function of several variables such as manhours (X_1), operating time (X_2), and cost per manhour (X_3). Thus, $C_3 = f(X_1, X_2, ... X_n)$, where $X_1, X_2, ..., X_n$ represent the selected variables that go into the functional group or category. Further, the dimensional analysis technique would help to determine the X_i that best dimensionally combine to yield the C_3 value. The relationship between these variables was also determined with this technique; i.e., the relationship that maps the independent variables into the dependent variable.

Sensitivity Analysis

Once the ATE operation and support cost model was developed, the final task was to insure that all the important independent variables were included in the model while at the same time, insuring simplicity of the model. A computer program was developed to calculate the changes in the dependent variable when each independent variable value was changed through an entire range of values. The ranges of the independent variable values were established by inspection and by consulting experts. A computer run was performed for each of the independent variables.

The purpose of this sensitivity test was to determine the relative driving effect of each of the independent variables. This analysis allowed us to decide whether a variable should stay in the model or whether it should be dropped from the model.

CHAPTER IV

MODEL DEVELOPMENT

As stated earlier in Chapter I, the objective of this research was to develop a model to estimate and measure O&S costs for avionics ATE which could be useful in LCC techniques applied to ATE support equipment programs. More specifically, the model was developed with the intent that it be used primarily as an aid in source selection and as a means of defining incentive goals and other contract guarantees. Thus, the accounting type model appeared most appropriate for these purposes and model development was aimed at producing this class of model. The model was not intended as a means of predicting operating and support costs based on design parameters (e.g., range, weight, thrust, etc.), nor was it envisioned as a means of estimating total life cycle costs. Estimating total life cycle costs would require a model which incorporated all elements of life cycle cost. As stated earlier, this model development effort considered only high cost drivers and omitted ATE software costs due to data unavailability.

Data availability is, of course, a primary consideration in model development and use. The model described in this thesis contains variables whose values can be determined by the analysis of data available through various government and contractor sources. However, in the early stages of weapon system acquisition--prior to selection of a full scale development (FSD) contractor--many of the estimates required to be made of variables in the model can only be made with a reasonable degree of accuracy by the competing contractors. Thus, the model should be provided to the contractors and employed by them initially to set target logistics support costs (TLSCs). The government would then use the model subsequent to FSD to determine measured logistics support costs (MLSCs). This comparative characteristic of model use eliminates the necessity for the model to contain all elements of life cycle cost.

With these thoughts in mind, the remainder of this chapter describes the way in which the model was developed.

Steps in Model Development

A model was developed using the following categories (previously defined in Chapter II):

C_1 = cost of TRU spares
C_2 = on-equipment maintenance cost
C_3 = off-equipment maintenance cost
C_4 = inventory management cost
C_5 = cost of support equipment
C_6 = cost of personnel training

C_7 = cost of management and technical data

C_8 = cost of calibration

For development of this model it was assumed that the contractor would be given the weapon system First Line Unit (FLU) testing requirements and that no TRU would be repaired at field level. The steps that were followed in the development of the model were: identification of the variables, grouping of the variables into the different categories and determining their relationships to obtain the category equation, and finally combining all of the categories to obtain the overall O&S cost model for automatic test equipment. The AFLC Logistics Support Cost Model was used as a guide in development of this model (10).

Identification of Variables

The identification of variables consisted of listing all the variables obtained from actual data, i.e., depot, field, PMEL, and comparing them to the variables used in other models. Variables that were found in actual data and were used in other models were selected as candidates for the proposed operation and support cost model. A matrix, shown in Appendix B, was developed to show this comparison. The explanation of each of the variables is presented in Appendix C. A direct match between all of the variables from actual data and from other models was not possible in all cases. A list of these variables and the justification for including them in ATE O&S models is as follows:

1. POH--monthly peak operating hours are important in determining the cost of TRU spares during a surge condition. Peak operating hours depend on the efficiency with which the contractor's equipment can meet surge weapon system testing requirements.

2. TARGAVAL--the target availability of the ATE would be furnished by the government and would be necessary to determine the appropriate number of spare TRUs that would minimize cost.

3. BCA/DCA--although the data for the total cost of additional items of common base (BCA) and depot (DCA) support equipment was not readily available, such data could be required of the contractor on new procurements. Depending on the type of ATE, this cost could be rather substantial.

4. DPA--the cost of the depot peculiar shop equipment could also be substantial and, although the data was not readily available, it could be part of the data furnished by the contractor on a new procurement.

5. DCOND--the actual data for the fraction of TRUs returned to the depot for repair expected to result in condemnation at the depot was not available from any of the present sources. However, the condemnation rate for some

TRUs could be very high and would have a great effect on the cost of TRU spares. The data for this variable therefore has to be obtained.

6. RIP--the data for the fraction of failures that can be repaired in place could not be obtained from actual data. This variable should be kept in the ATE O&S model as it contributes to the on and off equipment maintenance and can have an impact on the maintenance concept employed. The data could be required from the contractor on a new procurement.

7. Calibration Variables--the cost of ATE calibration was not found to be included in any available model. However, available data at both the field and AGMC level indicated that calibration costs represented a major cost input in the operation of ATE. An example of the importance of calibration was found in the dedication of unique calibration to support of F-15 ATE. A list of calibration variables considered is contained in Table 8, page 76.

Relationship of Variables by Category

In the development of the relationship of variables by category, two techniques were used. One was the modification of existing equations found in other cost models and the other was by using dimensional analysis. Equations C_1, C_2, C_3, C_4, C_5, C_6, and C_7 were derived by modifying existing equations from the AFLC Logistics

Support Cost Model (10). Dimensional analysis was used to derive equation C_8.

Cost of TRU Spares (C_1). This equation, shown in Table 1, is used to calculate the cost of spares required to support the ATE over the life of the system. Spares are required to fill the depot repair pipeline, to replace condemned items, and to fill the base supply pipeline.

The spares necessary to fill the depot repair pipeline are computed as follows:

$$\sum_{i=1}^{n} \frac{(POH)(QPA_i)(1-RIP_i)(1-DCOND_i)(DRCT)}{MTBF_i} UC_i$$

where $\frac{(POH)(QPA_i)}{MTBF_i}$ is the number of monthly failures for the i^{th} TRU, $(1-RIP_i)$ is the fraction of TRUs that cannot be repaired in place, $(1-DCOND_i)$ is the fraction of items which are not condemned, DRCT is the depot repair cycle time and UC_i is the unit cost for the i^{th} TRU.

The cost of spares necessary to replace the TRUs that will be condemned is as follows:

$$\sum_{i=1}^{n} \frac{(TOH)(QPA_i)(1-RIP_i)(DCOND_i)}{MTBF_i} UC_i$$

where $\frac{(TOH)(QPA_i)}{MTBF_i}$ is the number of failures for the i^{th}

TABLE 1

COST OF TRU SPARES (C_1)

$$C_1 = M \sum_{i=1}^{N} STK_i (UC_i) + \sum_{i=1}^{N} \frac{(POH)(QPA_i)(1-RIP_i)(1-DCOND_i)(DRCT)}{MTBF_i} UC_i$$

$$+ \sum_{i=1}^{N} \frac{(TOH)(QPA_i)(1-RIP_i)(DCOND_i)}{MTBF_i} UC_i$$

STK - Number of spares of the i^{th} TRU required for each base plus safety stock

M - Number of bases

UC_i - Unit cost

POH - Peak operating hours per month

QPA_i - Quantity of like TRUs per system

RIP_i - Fraction of failures that can be repaired in place

$MTBF_i$ - Mean time between failures

$DCOND_i$ - TRUs condemned at the depot

DRCT - Depot repair cycle time

TOH - Total operating hours

TRU over the life of the system and $DCOND_i$ is the fraction of items that are condemned.

The base supply pipeline spares requirement cost is as follows:

$$M \sum_{i=1}^{N} (STK_i)\ UC_i$$

where M is the number of bases, UC_i is the unit cost for the i^{th} TRU, and STK_i is the number of spares required at the base to fill the demand of failed TRUs.

It is generally assumed that the mean demand for spares at the base follows a poisson probability distribution (10:3-2). In order to determine STK it is necessary to first determine the lead time demand. The mean demand rate is:

$$\lambda_i = \frac{(POH)(QPA_i)(1-RIP_i)}{(M)(MTBF_i)}$$

and the pipeline time, t_i, is the weighted average of order and shipping time (OST).

The demand for spares over the lead time would be $\lambda_i t_i$. The probability of X demand during time t, would be

$$P = (X|\lambda_i t_i)$$

The expected number of backorders (XBO_i) for increasing values of stock levels (STK_i) is:

$$XBO_i = \sum_{i=1}^{n} (X-STK_i)\ P\ (X|\lambda_i t_i)$$

The probability AV_i of a spare TRU being available when demanded is then calculated as follows (10:3-2):

$$AV_i = \left[1 - \frac{XBO_i}{(QPA_i)(UEBASE)}\right]^{QPA_i}$$

This value of AV_i is calculated for different values of STK_i and an index is generated which gives the difference of the different stock levels divided by its unit cost. This shows the increase in availability as a result of the increase in stock levels as a function of cost. The probability AV of any spare for the system being available when demanded would be

$$AV = \prod_{i=1}^{n} AV_i = AV_1 \cdot AV_2 \cdot AV_3 \ldots AV_{n-1} \cdot AV_n$$

This assumes that each TRU is necessary to keep the automatic test equipment operational.

A target (TARGAVAL) for system spare availability is established and the calculated AV has to be equal to or greater than the TARGAVAL. When AV $\geq$ TARGAVAL the spares availability criteria has been met at the least cost. An example to illustrate the above concept will follow. Assuming a system with only one TRU, the spare requirements data as computed by the model would be:

WUC	DMDMEAN(λ_i)	XBO	AV	STK	DPIPE	TOTAL COND
FAAAO	.67	.18	.9129	1	21	7

System AV = .913

where DPIPE is the number of spares required for the depot pipeline and TCOND is the number of units condemned.

The target system availability was .9. Note that the system availability is the same as the TRU AV since there is only one TRU. The model was examined again using two TRUs with the following results:

WUC	DMDMEAN(λ_i)	XBO	AV	STK	DPIPE	TOTAL COND
FAAAO	.67	.18	.9129	1	21	7
FAABO	.02	.02	.9904	0	1	1

System AV = .904

Note that system AV = $AV_1 \times AV_2$.

The model was again exercised using three TRUs. The results were:

WUC	DMDMEAN(λ_i)	XBO	AV	STK	DPIPE	TOTAL COND
FAAAO	.67	.04	.9821	2	21	7
FAABO	.02	.02	.9904	0	1	1
FAACO	.44	.01	.9944	2	13	10

System AV = $AV_1 \times AV_2 \times AV_3$ = .967

Target Availability was = .9

Note that in order to meet the target availability, FAAAO availability and STK level were increased. The STK level of TRU FAAAO was increased to 2 and this resulted in its availability AV increasing to .9821. The reason the STK for FAAAO was increased rather than FAABO or FAACO was that it was more economical to increase the availability of this component in order to meet the target availability criteria. Having established the required STKs for N number of TRUs to meet the system availability requirement the cost can be found by

$$M \sum_{i=1}^{N} STK_i \; UC_i$$

where M is the number of bases and UC_i is the unit cost for the i^{th} TRU. The cost for all TRU spares would then be

$$M \sum_{i=1}^{N} STK_i (UC_i)$$

$$+ \sum_{i=1}^{N} \frac{(POH)(QPA_i)(1-RIP_i)(1-DCOND_i)(DRCT)}{MTBF_i} UC_i$$

$$+ \sum_{i=1}^{N} \frac{(TOH)(QPA_i)(1-RIP_i)(DCOND_i)}{MTBF_i} UC_i$$

On-Equipment Maintenance Costs (C_2). The on-equipment maintenance cost equation C_2, as shown in Table 2, pertains to the cost of all maintenance, both corrective and preventive, that is performed on the ATE without removal of any equipment.

The term,

$$\frac{(TOH)(QPA_i)}{MTBF_i}$$

refers to the number of failures of like items over the life of the ATE (TOH). The manhours expended per failure at base level consist of preparation and access manhours (PAMH), manhours to repair a failure in place (RIP)(IMH), and manhours to remove and replace a TRU sent to the depot for repair (1-RIP)(RMH); RIP being the fraction of TRUs which can be repaired in place. Therefore, the corrective maintenance costs for one TRU using a base labor rate of BLR is:

$$= \frac{(TOH)(QPA_i)}{MTBF_i} [PAMH_i + RIP_i (IMH_i)$$

$$+ (1-RIP_i)(RMH_i)] (BLR)$$

The corrective maintenance costs for (n) number of TRUs is

TABLE 2

ON-EQUIPMENT MAINTENANCE (C_2)

$$C_2 = \sum_{i=1}^{N} \frac{(TOH)(QPA_i)}{MTBF_i} \left[PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i) \right] BLR$$

$$+ \frac{TOH}{SMI} (SMH)(BLR)$$

TOH - Total system operating hours

QPA_i - Quantity of like TRUs within the system

$MTBF_i$ - Mean time between failure

$PAMH_i$ - Average manhours expended for preparation and access

IMH_i - Average manhours expended to perform corrective maintenance in place

RIP_i - Fraction of TRU failures which can be repaired in place

BLR - Base labor rate

SMI - Scheduled maintenance interval

SMH - Average manhours to perform scheduled maintenance

$$= \sum_{i=1}^{n} \frac{(TOH)(QPA_i)}{MTBF_i} [PAMH_i + RIP_i(IMH_i) + (1-RIP_i)(RMH_i)] (BLR)$$

The next element to be addressed is the cost of preventive maintenance which is,

$$\frac{TOH}{SMI} (SMH)(BLR)$$

where SMI is the interval between preventive maintenance actions, and $\frac{TOH}{SMI}$ is the number of preventive maintenance actions. SMH is the average manhours required to perform the preventive maintenance action, and BLR is the base labor rate. The total cost for all on-equipment maintenance would then be

$$= \sum_{i=1}^{n} \frac{(TOH)(QPA_i)}{MTBF_i} [PAMH_i + RIP_i(IMH_i) + (1-RIP_i)(RMH_i)] (BLR) + \frac{TOH}{SMI} (SMH)(BLR)$$

Off-Equipment Maintenance Costs (C_3). The off-equipment maintenance cost equation is shown in Table 3. C_3 includes the maintenance manhours to repair components

TABLE 3

OFF-EQUIPMENT MAINTENANCE (C_3)

$$C_3 = \sum_{i=1}^{N} \frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i} \Bigg\{ \Big[(DBCMH_i)(DLR) + (1-DCOND_i)\Big((DMH_i)(DLR+DMR) + (DMC_i)(UC_i)\Big)\Big] + 2\Big[(PSC)(1-OS) + (PSO)(OS)\Big] (1.35W_i) \Bigg\}$$

TOH - Total operating hours

QPA_i - Quantities of like TRUs in a system

RIP_i - Fraction of TRU failures which can be repaired in place

$MTBF_i$ - Mean time between failure

$DBCMH_i$ - Average time to bench check a failed TRU at the depot

DLR - Depot labor rate

$DCOND_i$ - TRUs condemned at the depot

DMH_i - Average manhours expended for corrective maintenance at the depot

DMC_i - Average supply and repair costs for lower level assemblies of a particular TRU

TABLE 3--Continued

DMR - Depot consumable material consumption rate

UC_i - TRU unit cost

PSC - Average packing and shipping costs to CONUS locations

PSO - Average packing and shipping costs to overseas locations

OS - Fraction of total force deployed to overseas locations

W_i - TRU weight in pounds

which have been removed from the ATE. The term

$$\frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i}$$

refers to the failed items returned to the depot for repair. The cost to benchcheck each failed TRU is (DBCMH)(DLR) and the cost to repair the TRU that has not been condemned is

$$(1-DCOND_i)[(DMH_i)(DLR+DMR)+(DMC_i)(UC_i)]$$

where $(1-DCOND_i)$ is the fraction of TRUs not condemned at the depot, DMH is the manhours to repair the TRU, (DLR+DMR) is the cost per manhour to repair the TRU including the cost of the base consumable material consumption rate (DMR), expressed in dollars per hour, and $(DMC_i)(UC_i)$ is the cost of stockage and repair of TRU subassemblies. The TRU transportation cost from the bases to the depot is divided into overseas (PSO) and CONUS (PSC) rates. The combined transportation rate is

$$(PSC)(1-OS) + (PSO)(OC),$$

where OS is the fraction of bases overseas. The one-way transportation cost would be

$$[(PSC)(1-OS) + (PSO)(OS)]\ (1.35W_i)$$

where 1.35 W_i is the package weight of each TRU. The total two-way transportation cost would be

$$2[(PSC)(1-OS) + (PSO)(OS)](1.35\ W_i)$$

The off-equipment maintenance cost for n TRUs would then be

$$= \sum_{i=1}^{n} \frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i} \Big\{ [(DBCMH_i)(DLR) + (1-DCOND_i)\Big((DMH_i)(DLR+DMR) + (DMC_i)(UC_i)\Big)] + 2[(PSC)(1-OS) + (PSO)(OS)](1.35\ W_i) \Big\}$$

Inventory Management (C_4). The inventory management cost equation includes all factors that can be attributed to new inventory life cycle costs based on the number of spares estimated to have been required. The computer equation and variable definitions are shown in Table 4. The cost to enter the N TRUs and items within the TRU into the government inventory is

$$[IMC + (PIUP)(RMC)] \sum_{i=1}^{N} (PP_i + 1)$$

where IMC is the initial management cost, (PIUP)(RMC) is the recurring management cost over the life of the system, and PP is the number of new consumable items within a TRU.

TABLE 4

INVENTORY MANAGEMENT COST (C_4)

$$C_4 = [IMC+(PIUP)(RMC)] \sum_{i=1}^{N} (PP_i+1) + (PIUP)(M)(SA)(N)$$

PP_i - Number of new "P" coded consumable items in a TRU

PIUP - Life of the system in years

RMC - Recurring management cost to maintain a line item of supply in the wholesale inventory system

IMC - Initial management cost to introduce a new line item of supply into the Air Force inventory

SA - Annual inventory management cost per line item

N - Number of different TRUs within the ATE

M - Number of bases

The base supply management cost for n TRUs over the life of the system at M number of bases is

$$(PIUP)(M)(SA)(N)$$

where SA is the annual base supply management cost per TRU. The total cost then for inventory management is

$$[IMC+(PIUP)(RMC)] \sum_{i=1}^{N} (PP_i+1) + (PIUP)(M)(SA)(N)$$

<u>Cost of Support Equipment (C_5)</u>. The complete equation and variable definitions for the cost of support equipment are shown in Table 5. Equation C_5 contains those variables which pertain to the cost of new peculiar items necessary to support the ATE. In order to compute the support equipment cost it is first necessary to determine the number of test equipment required. This is done using the queueing theory equation

$$n = \frac{\lambda}{\rho\mu}$$

where n = number of servers

λ = workload arrival rate

μ = service rate of one server

ρ = combined utilization rate of one server

For this particular application, n is the number of pieces of support equipment which will be required to support the

TABLE 5

COST OF SUPPORT EQUIPMENT (C_5)

$$C_5 = \sum_{i=1}^{N} \frac{(POH)(QPA_i)(1-RIP_i)\left[DBCMH_i + (1-DCOND_i)(DMH_i)\right]}{MTBF_i} \cdot$$

$$\sum_{j=1}^{K} \frac{\left[(1+PIUP)(COD_j)(CAD_j)\right]}{(DUR_j)(DAA)(1-DOWN_j)}$$

$$+ \left[1+0.1(PIUP)\right]\left[DCA+DPA+M(BCA)\right]$$

POH - Peak operating hours per month

QPA_i - Quantity of like TRUs

RIP_i - Fraction of maintenance actions that can be repaired in place

$MTBF_i$ - Mean time between failure

$DBCMH_i$ - Depot bench check manhours

$DCOND_i$ - Fraction of TRUs condemned at the depot

DMH_i - Average depot manhours expended in repair of TRU

TABLE 5--Continued

PIUP - Operating life of system in years

COD_j - Annual fraction of support equipment cost attributed to maintenance of the support equipment

CAD_j - Depot support equipment unit cost

DUR_j - Combined equipment utilization rate at the depot

DAA - Manhours available per man at the depot

$DOWN_j$ - Fraction of time the support equipment is down for maintenance

DCA - Total cost of additional items of common depot support equipment

DPA - Total cost of additional items of peculiar depot support equipment

BCA - Cost of additional items of common base shop support equipment per base

M - Number of bases where ATE is located

K - Number of line items of peculiar shop support equipment used in repair of the TRU the depot workload. The depot workload arrival rate, λ, will be

$$\frac{(\mathrm{POH})(\mathrm{QPA}_i)(1-\mathrm{RIP}_i)}{\mathrm{MTBF}_i}$$

where

$$\frac{(\mathrm{POH})(\mathrm{QPA}_i)}{\mathrm{MTBF}_i}$$

is the total number of failures and $(1-\mathrm{RIP}_i)$ is the fraction of failures which cannot be repaired-in-place. The service rate, μ, will be

$$\frac{(\mathrm{DAA})(1-\mathrm{DOWN}_j)}{(\mathrm{DBCMH}_i) + (1-\mathrm{DCOND}_i)(\mathrm{DMH}_i)]}$$

where DAA represents the manhours available per man at the depot, $(1-\mathrm{DOWN}_j)$ is the fraction of time the j^{th} item of support equipment will be operational and

$$[\mathrm{DBCMH}_i + (1-\mathrm{DCOND}_i)(\mathrm{DMH}_i)]$$

represents the manhours to benchcheck and repair the i^{th} TRU.

The combined utilization rate ρ of the support equipment is defined as DUR_j. Since

$$n = \frac{\lambda}{\rho\mu}$$

and substituting the support equipment variables, the following equation is obtained.

$$n = \frac{\dfrac{(POH)(QPA_i)(1-RIP_i)}{MTBF_i}}{(DUR_j)\left[\dfrac{(DAA)(1-DOWN_j)}{DBCMH_i + (1-DCOND_i)DMH_i)}\right]}$$

Simplifying, the number of pieces of support equipment required becomes

$$n = \frac{(POH)(QPA_i)(1-RIP)_i[DBCMH_i+(1-DCOND_i)(DMH_i)]}{(DUR_j)(DAA)(MTBF_i)(1-DOWN_j)}$$

The cost of each item of support equipment will be designated CAD_j and the cost to maintain the support equipment over the life of the ATE will be defined as

$$(PIUP)(COD_j)(CAD_j),$$

where COD_j is the annual cost to maintain the support equipment (SE) expressed as a fraction of the unit cost (CAD_j). Therefore, the cost to procure and maintain the j^{th} item of SE will be

$$(CAD_j)+(PIUP)(COD_j)(CAD_j)$$

or $$[1+(PIUP)(COD)_j)](CAD_j)$$

The cost of the j^{th} item of SE for the i^{th} TRU would then be

$$\frac{(POH)(QPA_i)(1-RIP_i)[DBCMH_i+(1-DCOND_i)(DMH_i)]}{(DUR_j)(DAA)(MTBF_i)(1-DOWN_j)} \cdot$$

$$[1 + (PIUP)(COD_j)](CAD_j)$$

Included in the SE cost is the cost of additional items of common depot support equipment (DCA), cost of additional items of peculiar depot support equipment (DPA), cost of additional items of common base shop support equipment per base (BCA), and the cost to maintain the equipment over the life of the ATE (PIUP). It is assumed that the annual cost to maintain the equipment is 10 percent of this combined cost; therefore, the cost of the additional equipment is,

$$[DCA+DPA+M(BCA)] + 0.1\ (PIUP)[DCA+DPA+M(BCA)]$$

where M is the number of bases.

If there are N number of TRUs and K number of pieces of support equipment required per each TRU, then the total cost of SE is

$$\sum_{i=1}^{N} \frac{(POH)(QPA_i)(1-RIP_i)[DBCMH_i+(1-DCOND_i)(DMH_i)]}{MTBF_i} \cdot$$

$$\sum_{j=1}^{k} \frac{[(1+PIUP)(COD_j)(CAD_j)]}{(DUR_j)(DAA)(1-DOWN_j)} +$$

$$[1+0.1(PIUP)][DCA+DPA+M(BCA)]$$

Cost of Personnel Training (C_6). The cost of personnel training as shown in Table 6, includes those factors which represent the total cost of training base and depot personnel over the life of the ATE.

The first step in determining the cost of training is to find the total number of personnel that would be required to support the system over its operating life. The total base corrective maintenance manhours expended over the life of the ATE is the number of failures over the life of the system

$$\frac{(\mathrm{TOH})(\mathrm{QPA}_i)}{\mathrm{MTBF}_i}$$

multiplied by the repair-in-place manhours:

$$[(\mathrm{PAMH}_i)+(\mathrm{RIP}_i)(\mathrm{IMH}_i) + (1-\mathrm{RIP}_i)(\mathrm{RMH}_i)]$$

as defined in development of equation C_2, page 53. The preventive maintenance manhours would simply be:

$$\frac{\mathrm{TOH}}{\mathrm{SMI}}\ (\mathrm{SMH})$$

Therefore, for N number of TRUs, the total base maintenance manhours are

$$\sum_{i=1}^{n} \frac{(\mathrm{TOH})(\mathrm{QPA}_i)}{\mathrm{MTBF}_i}[(\mathrm{PAMH}_i)+(\mathrm{RIP}_i)(\mathrm{IMH}_i)+(1-\mathrm{RIP})(\mathrm{RMH}_i)]$$

$$+\ \frac{\mathrm{TOH}}{\mathrm{SMI}}\ (\mathrm{SMH})$$

TABLE 6

COST OF PERSONNEL TRAINING (C_6)

$$C_6 = \frac{[1 + (PIUP-1)(TRB)]}{(PIUP)(PMB)} (TCB) \left[\sum_{i=1}^{N} \frac{(TOH)(QPA_i)}{MTBF_i} \left\{ PAMH_i + RIP_i(IMH_i) + (1-RIP_i)(RMH_i) \right\} + \frac{TOH}{SMI} (SMH) \right] + \frac{[1 + (PIUP - 1)(TRD)]\ TCD}{(PIUP)(PMD)} \cdot$$

$$\sum_{i=1}^{N} \frac{(TOH)(QPA_i)(1-RIP_i)\ [DBCMH_i + (1-DCOND_i)DMH_i]}{MTBF_i} + TE$$

PIUP - Operating life in years of the system

TRB - Annual turnover rate for base personnel

TRD - Annual turnover rate for depot personnel

TCB - Cost of training per man at base level

TCD - Cost of training per man at depot level

PMB - Direct productive manhours per man per years at base

PMD - Direct productive manhours per man per year at depot

TABLE 6--Continued

TOH - Total operating hours over the life of the system

QPA_i - Quantity of like TRUs

$MTBF_i$ - Mean time between failure

$PAMH_i$ - Average preparation and access time expended

RIP_i - Fraction of TRUs that can be repaired in place

IMH_i - Average manhours expended for corrective action in place

RMH_i - Average manhours expended for isolating, removing, and replacing a failed TRU

SMI - Scheduled maintenance interval

SMH - Average manhours expended per preventive maintenance action

$DBCMH_i$ - Average manhours expended in depot bench check

$DCOND_i$ - Fraction of TRUs condemned at the depot

DMH_i - Average manhours expended to correct failed TRU at the depot

TE - Cost of training equipment

Similarly, the total depot maintenance manhours expended over the life of the ATE are

$$\sum_{i=1}^{n} \frac{(\mathrm{TOH})(\mathrm{QPA}_i)(1-\mathrm{RIP}_i)}{\mathrm{MTBF}_i} [(\mathrm{DBCMH}_i)+(1-\mathrm{DCOND}_i)(\mathrm{DMH}_i)]$$

(Refer to derivation of equation C_3.)

If PMB represents the base direct productive manhours per man per year, PMD the depot direct productive manhours per man per year and PIUP the operating life of the system, then the number of personnel required annually to maintain the ATE is

$$\sum_{i=1}^{n} \frac{(\mathrm{TOH})(\mathrm{QPA}_i)[(\mathrm{PAMH}_i)+(\mathrm{RIP}_i)(\mathrm{IMH}_i)+(1-\mathrm{RIP}_i)(\mathrm{RMH}_i)] + \frac{\mathrm{TOH}}{\mathrm{SMI}}(\mathrm{SMH})}{(\mathrm{MTBF}_i)(\mathrm{PIUP})(\mathrm{PMB})}$$

$$+ \sum_{i=1}^{n} \frac{(\mathrm{TOH})(\mathrm{QPA}_i)(1-\mathrm{RIP}_i)[(\mathrm{DBCMH}_i)+(1-\mathrm{DCOND}_i)(\mathrm{DMH}_i)]}{(\mathrm{MTBF}_i)(\mathrm{PIUP})(\mathrm{PMD})}$$

If TCB is the cost to train personnel at the base, TCD is the cost to train personnel at the depot, and TE is the cost of training equipment, then the total personnel training cost (assuming no personnel turnover) is:

$$\frac{\mathrm{TCB}}{(\mathrm{PIUP})(\mathrm{PMB})} \left[\sum_{i=1}^{n} \frac{(\mathrm{TOH})(\mathrm{QPA}_i)}{\mathrm{MTBF}_i} [(\mathrm{PAMH}_i)+(\mathrm{RIP}_i)(\mathrm{IMH}_i)+(1-\mathrm{RIP}_i)(\mathrm{RMH}_i)] + \frac{\mathrm{TOH}}{\mathrm{SMI}}(\mathrm{SMH}) \right]$$

$$+ \frac{\mathrm{TCD}}{(\mathrm{PIUP})(\mathrm{PMD})} \left[\sum_{i=1}^{n} \frac{(\mathrm{TOH})(\mathrm{QPA}_i)(1-\mathrm{RIP}_i)}{\mathrm{MTBF}_i} [(\mathrm{DBCMH}_i+(1-\mathrm{DCOND}_i)(\mathrm{DMH}_i)] \right] + \mathrm{TE}$$

However, as a result of personnel turnover, additional training costs will be incurred. If the annual turnover rate at the base is TRB and at the depot is TRD, then the turnover over the life of the system (not including the first year) is: (PIUP-1)(TRB) and (PIUP-1)(TRD), respectively. Thus the final expression for C_6 is:

$$\frac{[1+(PIUP-1)(TRB)]}{(PIUP)(PMB)}\,TCB\left[\sum_{i=1}^{n}\frac{(TOH)(QPA_i)[(PAMH_i)+(RIP)_i(IMH_i) +(1-RIP_i)(RMH_i)]}{MTBF_i}+\frac{TOH}{SMI}(SMH)\right]$$

$$+\frac{[1+(PIUP-1)(TRD)]}{(PIUP)(PMD)}(TCD)\left[\sum_{i=1}^{n}\frac{(TOH)(QPA_i)(1-RIP_i)[DBCMH_i+(1-DCOND_i)(DMH_i)]}{MTBF_i}\right]+TE$$

<u>Cost of Management and Technical Data (C_7)</u>. The equation for the cost of management and technical data includes the labor costs associated with the preparation of maintenance forms and the costs of acquiring and maintaining necessary technical data. The complete equation and variable definitions are shown in Table 7. Every corrective maintenance action, whether on-equipment or

TABLE 7

COST OF MANAGEMENT AND TECHNICAL DATA (C_7)

$$C_7 = \sum_{i=1}^{N} \frac{(TOH)(QPA_i)}{MTBF_i} [MRO + (1 - RIP_i)(SR + TR + MRF)]\ BLR$$

$$+ \frac{TOH}{SMI} [MRO + 0.1\ (SR + TR)]\ BLR + TD(JJ + H)$$

TOH - Total operating hours of the system

QPA_i - Quantity of like items per system

$MTBF_i$ - Mean time between failure

MRO - Average manhours per failure to complete on-equipment maintenance records

MRF - Average manhours per failure to complete off-equipment maintenance records

RIP_i - Fraction of failures that can be repaired in place

BLR - Base labor rate

SR - Average manhours per failure to complete supply transaction records

TR - Average manhours per failure to complete transportation forms

TD - Average cost per original page of technical documentation

TABLE 7--Continued

JJ - Number of pages of organizational level technical orders to maintain the system

SMI - Scheduled maintenance interval

H - Number of pages of depot level technical orders required to maintain the system off-equipment, requires completion of maintenance records. In the case of off-equipment failure, supply transaction records and transportation forms have to be completed. If total number of failures over the life of the ATE is

$$\frac{(TOH)(QPA_i)}{MTBF_i}$$

then the total manhours expended per failure is

$$[MRO + (1-RIP_i)(SR+TR+MRF)].$$

MRO represents average manhours per failure to complete the on-equipment maintenance records, MRF represents average manhours to complete the off-equipment maintenance records, SR represents average manhours per failure to complete the supply transaction records and TR represents average manhours per failure to complete the transportation records. The fraction of off-equipment maintenance action is $(1-RIP_i)$. The cost for completion of the maintenance and supply records and the transportation forms for N number of TRUs is:

$$\sum_{i=1}^{n} \frac{(TOH)(QPA_i)}{MTBF_i}[MRO+(1-RIP_i)(SR+TR+MRF)]BLR$$

where BLR is the base labor rate.

The preventive maintenance actions also result in manhours expended in record keeping. The total number of preventive maintenance actions over the life of the system is

$$\frac{TOH}{SMI}$$

and the average manhours per action to complete the on-equipment maintenance records is MRO. If the percentage of the preventive maintenance time associated with the completion of maintenance and supply forms is 10 percent, then the manhours are 0.1 (SR+TR), and the total cost for completing forms as a result of preventive maintenance actions is

$$\frac{TOH}{SMI}\,[MRO + 0.1(SR+TR)]\,BLR$$

The technical data cost is the cost of maintaining the organizational and depot level technical orders. The average cost to maintain a page of either the organizational or the depot level technical orders is TD. If the number of pages of the organizational level technical orders is JJ and the number of pages of the depot level technical orders is H, then the total cost of maintaining the technical orders is

$$TD(JJ+H)$$

The total cost of management and technical data is then,

$$\sum_{i=1}^{n} \frac{(TOH)(QPA_i)}{MTBF_i} [MRO+(1-RIP_i)(SR+TR+MRF)]BLR$$

$$+ \frac{TOH}{SMI} [MRO+0.1(SR+TR)]BLR + TD(JJ+H)$$

Calibration Requirements Cost (C_8). This equation was derived using dimensional analysis (12). The equation is shown in Table 8.

For the purpose of the equation derivation calibration occurs at two levels, system level and TRU level. Calibration cost is the sum of the costs at the two calibration levels.

The system level variables and their basic units are as follows:

1. LIFE (days)
2. SCI (days/calibration)
3. SCMH (MH/calibration)
4. CIVLR ($/MH)
5. C ($)

where: *LIFE is the operational service life of the* ATE in days; SCI is the calibration interval in days per calibration; SCMH is the manhours per calibration; CIVLR is the labor rate for calibration at Class IV calibration shop, *in dollars per manhour;* and C is the cost for calibration

TABLE 8

CALIBRATION REQUIREMENTS (C_8)

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{365(PIUP)(SMH_i)(CIVLR)}{(SCI_i)} + \sum_{j=1}^{N} \frac{365(PIUP)(QPA_{ij})}{(TRUCI_{ij})} \left\{ (TRUCMH_{ij})[(CI)(CILR) \right.\right.$$

$$\left.\left. + (CII)(CIILR) + (CIV)(CIVLR)] + (CARF)[(CI)(CILR)(FICR) + (CII)(CIILR)(FIICR) + (CIV)(CIVLR)(FIVCR)] \right\}\right\}$$

N - Number of different TRUs within the systems, within the ATE

NSYS - Number of systems within the ATE

PIUP - Operational service life of the ATE in years

SCI_i - Scheduled calibration interval for the system

$SCMH_i$ - Manhours to perform calibration on the system

$TRUCI_{ij}$ - Calibration interval for a TRU

$TRUCMH_{ij}$ - Manhours to calibrate a TRU

CI - Factor which is 0 if no calibration at Class I lab is required or 1 if calibration at Class I lab is required

TABLE 8--Continued

CII - Factor which is 0 if no calibration at Class II lab is required or 1 if calibration at Class II lab is required

CIV - Factor which is 0 if no calibration at class IV lab is required or 1 if calibration at Class IV lab is required

CILR - Labor rate at a Class I lab

CIILR - Labor rate at a Class II lab

CIVLR - Labor rate at a Class IV lab

FICR - Manhours spent on repair of items to be calibrated at Class I lab

FIICR - Manhours spent on repair of items to be calibrated at Class II lab

FIVCR - Manhours spent on repair of items to be calibrated at Class IV lab

QPA_i - Quantity of like TRUs

CARF - Fraction of units (calibrated) requiring repair in dollars. LIFE and SCI take into account that calibration is accomplished on a calendar-time basis.

Since there are five variables and four basic units, there is one dimensionless Pi term, and

$$\Pi_1 = K^1 = (LIFE)^a (SCI)^b (SCMH)^c (CIVLR)^d (c)^e \qquad (1)$$

or:

$$\Pi_1 = K^1 = (DAYS)^a \left(\frac{DAYS}{CAL}\right)^b \left(\frac{MH}{CAL}\right)^c \left(\frac{\$}{MH}\right)^d (\$)^e \qquad (2)$$

Since the result is a dimensionless product, then,

$$(DAYS)^0 (CAL)^0 (MH)^0 (\$)^0 = (DAYS)^a (DAYS)^b (CAL)^{-b}$$

$$(MH)^c (CAL)^{-c} (\$)^d (MH)^{-d} (\$)^e$$

Then:

$0 = a + b$ for DAYS

$0 = -b - c$ for CAL

$0 = c - d$ for MH

$0 = d + e$ for \$

To solve these four equations with five unknowns, let $a = 1$

Then:

$b = -1;\ c = 1;\ d = 1;\ e = -1$

Substitution in (1) yields

$$K^1 = (LIFE)^1 (SCI)^{-1} (SCMH)^1 (CIVLR)^1 (C)^{-1}$$

solving for C

$$C = K(LIFE)(SCMH)(CIVLR)/(SCI),\ K=1/k^1$$

or $$C_{81} = (LIFE)(SCMH)(CIVLR)/(SCI),\ K=1$$

The TRU calibration level variables and their basic units are as follows:

1.	LIFE	(days)
2.	TRUCI	(days/calibration)
3.	TRUCMH	(MH/calibration)
4.	CILR	(\$/MH)
5.	CIILR	(\$/MH)
6.	CIVLR	(\$/MH)
7.	CARF	(repair/calibration)
8.	FICR	(MH/repair)
9.	FIICR	(MH/repair)
10.	FIVCR	(MH/repair)
11.	C	(\$)

where: LIFE is the operational service life of the ATE in days; TRUCI is the TRU calibration interval in days; TRUCMH is the manhours per calibration; CILR, CIILR, and CIVLR are the labor rates for calibration at Class I, II, and IV calibration shop respectively, in dollars; CARF is the proportion of repairs per calibration; FICR, FIICR, and FIVCR are the manhours per repair at Class I, II and IV calibration shop respectively; and C is the cost for calibration in dollars. Calibration is accomplished on a calendar-time basis.

Since there are 11 variables and 5 basic units, there are 6 dimensionless Pi terms, and

$$\Pi = (\text{LIFE})^{a}(\text{TRUCI})^{b}(\text{TRUCMH})^{c}(\text{CILR})^{d}(\text{CIILR})^{e}(\text{CIVLR})^{f}$$

$$(\text{CARF})^{g}(\text{FICR})^{h}(\text{FIICR})^{i}(\text{FIVCR})^{j}(\text{C})^{k} \qquad (3)$$

or:

$$\Pi = (\text{DAYS})^{a}\left(\frac{\text{DAYS}}{\text{CAL}}\right)^{b}\left(\frac{\text{MH}}{\text{CAL}}\right)^{c}\left(\frac{\$}{\text{MH}}\right)^{d}\left(\frac{\$}{\text{MH}}\right)^{e}\left(\frac{\$}{\text{MH}}\right)^{f}\left(\frac{\text{REP}}{\text{CAL}}\right)^{g}$$

$$\left(\frac{\text{MH}}{\text{REP}}\right)^{h}\left(\frac{\text{MH}}{\text{REP}}\right)^{i}\left(\frac{\text{MH}}{\text{REP}}\right)^{j}(\$)^{k} \qquad (4)$$

Since the result is a dimensionless product, then:

$$(\text{DAYS})^{0}(\text{CAL})^{0}(\text{MH})^{0}(\$)^{0}(\text{REP})^{0} = (\text{DAYS})^{a}(\text{DAYS})^{b}(\text{CAL})^{-b}$$

$$(\text{MH})^{c}(\text{CAL})^{-c}(\$)^{d}(\text{MH})^{-d}(\$)^{e}(\text{MH})^{-e}(\$)^{f}(\text{MH})^{-f}$$

$$(\text{REP})^{g}(\text{CAL})^{-g}(\text{MH})^{h}(\text{REP})^{-h}(\text{MH})^{i}(\text{REP})^{-i}$$

$$(\text{MH})^{j}(\text{REP})^{-j}(\$)^{k}$$

Then

$0 = a + b$ for DAYS

$0 = -b - c - g$ for CAL

$0 = c - d - e - f + h + i + j$ for MH

$0 = d + e + f + k$ for \$

$0 = g - h - i - j$ for REP

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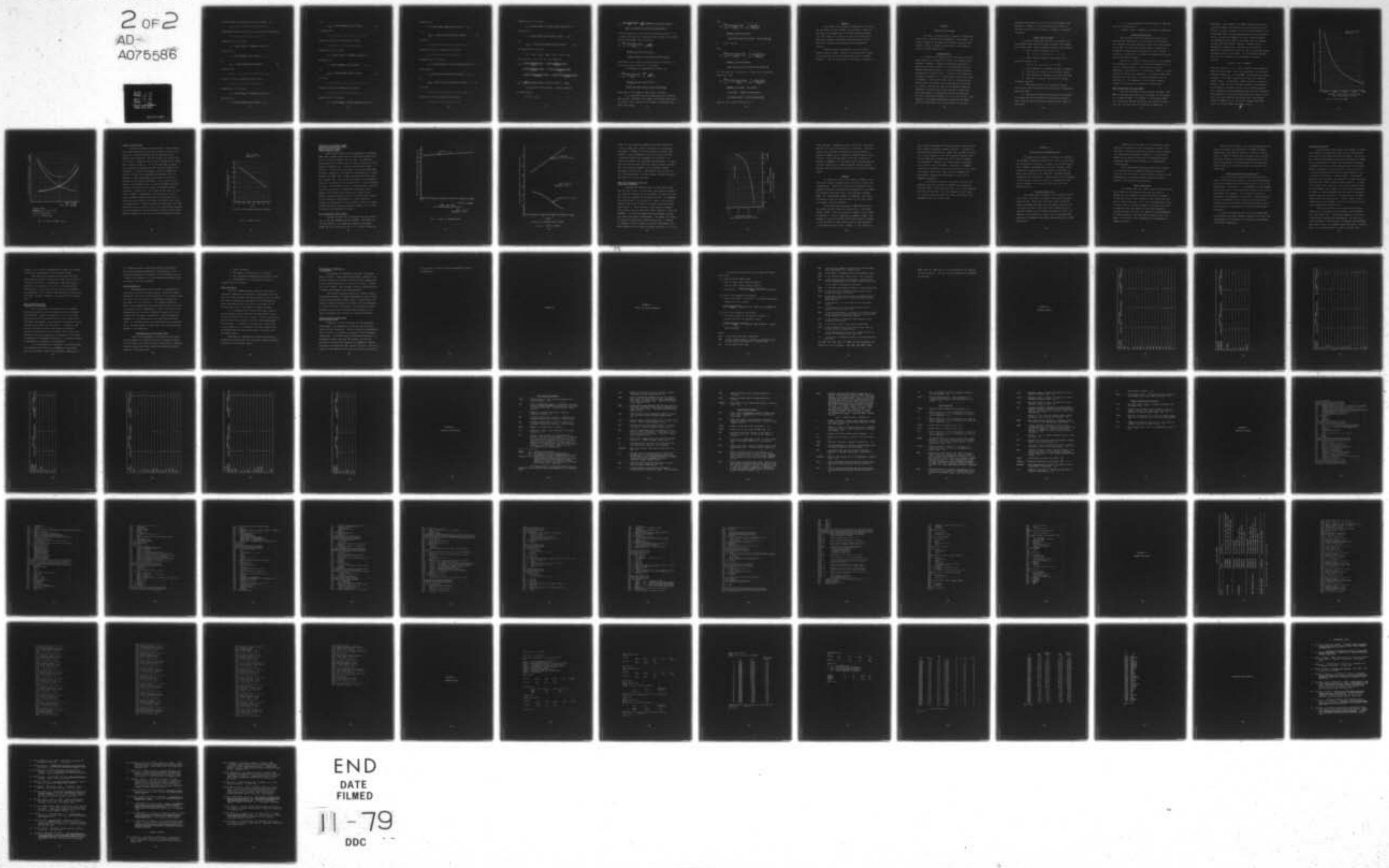

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To solve these five equations with 11 unknowns, let

$$h = 0;\ i = 0;\ j = 0;\ e = 0;\ f = 0;\ a = 1$$

Simultaneous solution of the five equations will then yield

$$b = -1;\ c = 1,\ d = 1;\ k = -1,\ g = 0$$

Substitution in (3) gives

$$\Pi_1 = (LIFE)^1 (TRUCI)^{-1} (TRUCMH)^1 (CILR)^1 (C)^{-1}$$

Solving for C

$$C = (LIFE)(TRUCMH)(CILR)/(TRUCI),\quad \Pi_1 = 1$$

or:

$$C_{821} = (LIFE)(TRUCMH)(CILR)/(TRUCI) \tag{5}$$

If we now let

$$h = 0,\ i = 0,\ j = 0,\ d = 0,\ f = 0,\ a = 1,$$

solution of the five equations will yield

$$b = -1;\ c = 1;\ e = 1;\ k = -1;\ g = 0$$

Substitution in (3) gives

$$\Pi_2 = (LIFE)^1 (TRUCI)^{-1} (TRUCMH)^1 (CIILR)^1 (C)^{-1}$$

Solving for C

$$C = (LIFE)(TRUCMH)(CIILR)/(TRUCI),\quad \Pi_2 = 1$$

or:

$$C_{822} = (LIFE)(TRUCMH)(CIILR)/(TRUCI) \qquad (6)$$

If we now let

$h = 0;\ i = 0;\ j = 0;\ d = 0;\ e = 0;\ a = 1,$

solution of the five equations will yield

$b = -1;\ c = 1;\ f = 1;\ k = -1;\ g = 0$

Substitution in (3) gives

$$\Pi_3 = (LIFE)^1(TRUCI)^{-1}(TRUCMH)^1(CIVLR)^1(C)^{-1}$$

Solving for C

$$C = (LIFE)(TRUCMH)(CIVLR)/(TRUCI), \quad \Pi_3 = 1$$

or:

$$C_{823} = (LIFE)(TRUCMH)(CIVLR)/(TRUCI) \qquad (7)$$

If we let

$c = 0;\ e = 0;\ f = 0;\ i = 0;\ j = 0;\ a = 1,$

solution of the five equations will yield

$b = -1;\ g = 1;\ d = 1;\ k = -1;\ h = 1$

Substitution in (3) gives

$$\Pi_4 = (LIFE)^1(TRUCI)^{-1}(CILR)^1(CARF)^1(FICR)^1(C)^{-1}$$

Solving for C

$$C = (LIFE)(CILR)(CARF)(FICR)/(TRUCI), \quad \Pi_4 = 1$$

or:

$$C_{824} = (LIFE)(CILR)(CARF)(FICR)/(TRUCI) \qquad (8)$$

If we let

$$c = 0;\ d = 0;\ f = 0;\ h = 0;\ j = 0;\ a = 1,$$

solution of the five equations will yield

$$b = -1;\ g = 1;\ e = 1;\ k = -1;\ i = 1$$

Substitution in (3) gives

$$\Pi_5 = (LIFE)^1 (TRUCI)^{-1} (CIILR)^1 (CARF)^1 (FIICR)^1 (C)^{-1}$$

Solving for C

$$C = (LIFE)(CIILR)(CARF)(FIICR)/(TRUCI), \quad \Pi_5 = 1$$

or:

$$C_{825} = (LIFE)(CIILR)(CARF)(FIICR)/(TRUCI) \qquad (9)$$

If we let

$$c = 0;\ d = 0;\ e = 0;\ h = 0;\ i = 0;\ a = 1,$$

solution of the five equations will yield

$$b = -1;\ g = 1;\ f = 1;\ k = -1;\ j = 1$$

Substitution in (3) gives

$$\Pi_6 = (LIFE)^1(TRUCI)^{-1}(CIVLR)^1(CARF)^1(FIVCR)^1(C)^{-1}$$

Solving for C

$$C = (LIFE)(CIVLR)(CARF)(FIVCR)/(TRUCI), \quad \Pi_6 = 1$$

or:

$$C_{826} = (LIFE)(CIVLR)(CARF)(FIVCR)/(TRUCI) \qquad (10)$$

By experience we can write

$$C_{82} = C_{821} + C_{822} + C_{823} + C_{824} + C_{825} + C_{826}$$

Then, from (5), (6), (7), (8), (9), and (10)

$$C_{82} = \frac{(LIFE)(TRUCMH)(CILR)}{(TRUCI)} + \frac{(LIFE)(TRUCMH)(CIILR)}{(TRUCI)}$$

$$+ \frac{(LIFE)(TRUCMH)(CIVLR)}{(TRUCI)} + \frac{(LIFE)(CILR)(CARF)(FICR)}{(TRUCI)}$$

$$+ \frac{(LIFE)(CIILR)(CARF)(FIICR)}{(TRUCI)} + \frac{(LIFE)(CIVLR)(CARF)(FIVCR)}{(TRUCI)}$$

$$C_{82} = \frac{LIFE}{TRUCI}\Big\{(TRUCMH)[(CILR)+(CIILR)+(CIVLR)] + (CARF)$$

$$[(CILR)(FICR)+(CIILR)(FIICR) + (CIVLR)(FIVCR)]\Big\}$$

As stated above,

$$C_8 = C_{81} + C_{82}$$

$$C_8 = \frac{(LIFE)\,(SCMH)\,(CIVLR)}{SCI} + \frac{LIFE}{TRUCI}\Big\{(TRUCMH)\,[\,(CILR)+(CIILR)+(CIVLR)\,]\ +$$

$$(CARF)\,[\,(CILR)\,(FICR)+(CIIILR)\,(FIICR)+(CIVLR)\,(FIVCR)\,]\Big\}$$

Then above equation C_8 holds for one system and one TRU. If we take into account all systems within the ATE and all TRUs within the systems, the C_8 would be

$$C_8 = \sum_{i=1}^{NSYS} \frac{(LIFE)\,(SCMH_i)\,(CIVLR)}{(SCI_i)} + \sum_{j=1}^{L} \frac{LIFE}{(TRUCI_j)}$$

$$\Big\{(TRUCMH_j)\,[CILR)+(CIIILR)+(CIVLR)\,]\ +$$

$$(CARF)\,[\,(CILR)\,(FICR)+(CIIILR)\,(FIICR)+(CIVLR)\,(FIVCR)\,]\Big\}$$

where NSYS is the number of systems within an ATE and L is the total number of TRUs for all systems.

If the TRUs are aggregated by system, then

$$C_8 = \sum_{i=1}^{NSYS} \frac{(LIFE)\,(SMH_i)\,(CIVLR)}{(SCI_i)} + \sum_{j=1}^{NTRU} \frac{LIFE}{(TRUCI_{ij})}$$

$$\Big\{(TRUCMH_{ij})[\,(CILR)+(CIIILR)+CIVLR)\,]\ +$$

$$(CARF)[\,(CILR)\,(FICR)+(CIIILR)\,(FIICR)+(CIVLR)\,(FIVCR)]\Big\}$$

where NTRU is the number of TRUs within a system.

If we consider that the system might have identical TRUs and QPA represents the number of identical TRUs within the system, and N represents the number of different TRUs within the system, Then,

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{(LIFE)(SMH_i)(CIVLR)}{(SCI_i)} + \sum_{j=1}^{N} \frac{(LIFE)(QPA_{ij})}{(TRUCI_{ij})} \right.$$

$$\left\{ (TRUCMH_{ij})(CILR+CIILR+CIVLR) + \right.$$

$$\left. \left. CARF[(CILR)(FICR) + (CIILR)(FIICR) + (CIVLR)(FIVCR)] \right\} \right\}$$

If LIFE = 365 PIUP

Then,

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{365(PIUP)(SMH_i)(CIVLR)}{(SCI_i)} + \sum_{j=1}^{N} \frac{365(PIUP)(QPA_{ij})}{(TRUCI_{ij})} \right.$$

$$\left\{ (TRUCMH_{ij})(CILR+CIILR+CIVLR) + \right.$$

$$\left. \left. CARF[(CILR)(FICR) + (CIILR)(FIICR) + (CIVLR)(FIVCR)] \right\} \right\}$$

If a TRU goes for calibration to a particular calibration level only, then,

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{365(PIUP)(SMH_i)(CIVLR)}{(SCI_i)} + \sum_{j=1}^{N} \frac{365(PIUP)(QPA_{ij})}{(TRUCI_{ij})} \right.$$

$$\left\{ (TRUCMH_{ij})[(CI)(CILR) + (CII)(CIILR) + \right.$$

$$(CIV)(CIVLR)] + (CARF))[(CI)(CILR)(FICR) +$$

$$\left. \left. (CII)(CIILR)(FIICR) + (CIV)(CIVLR)(FIVCR)] \right\} \right\}$$

where CI, CII, and CIV can be 0 or 1.

Summary

This chapter has provided an explanation of how the O&S Cost Model for ATE (OSCATE) was developed. Basically, the model is an adaptation of the AFLC Logistics Support Cost (LSC) model, with special provisions for ATE, and an additional equation representing ATE calibration costs. This latter equation was developed using dimensional analysis.

OSCATE has been programmed to run on the AFLC CREATE computer system. Chapter V discusses various sensitivity analyses that were accomplished using the OSCATE program. A copy of the program is contained in Appendix D.

CHAPTER V

ANALYSIS OF THE MODEL

Any model is valid only for a specific purpose and only within a certain set of parameters. This chapter contains a summary of the sensitivity analysis that was performed in order to establish guidelines for the model's potential future application.

Computer Model

In order to perform sensitivity analysis on the proposed Operation and Support Cost Model for Automatic Test Equipment (OSCATE), a computer program was developed by modifying applicable portions of the AFALD/XRSC Logistics Support Cost Model Version 1.1 (10) and by adding programming which was unique to ATE. A listing of the program is contained in Appendix D. A representative data base, shown in Appendix E, was created using the F-15 Avionics Intermediate Shop (AIS) depot and base maintenance information as a guide. The data for some of the variables were not immediately available and values assigned to these variables were based on estimates obtained from discussions with field and depot personnel (3; 4; 11; 16; 18; 22). Consequently, the results obtained by exercising the model using this data should not be construed as the actual operating and support cost of the F-15 AIS Automatic Test Equipment. However, the data did provide the means to test the sensitivity of the model to changes in different variables.

Output from the Model

In order to facilitate analysis, the output from the computer model contains several different cost components of O&S costs. These components include the following:

1. Total logistics support cost; i.e.,

$$(C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8).$$

2. Total logistics support cost broken out by specific category; i.e.,

$$(C_1, C_2, C_3, C_4, C_5, C_6, C_7, \text{ or } C_8).$$

3. Cost breakout of a specific system by category.
4. Cost ranking of TRUs for a particular system.
5. Cost breakout by category for a particular TRU.
6. Analysis of types and quantities of support equipment required.
7. TRU spares analysis to include the system availability, TRU availability and quantities, and expected backorders (XBO).
8. Maintenance generation analysis which includes the maintenance actions generated during peak operating hours (POH) and during the total operating hours (TOH) of the system.

9. A cross-reference of the TRU work unit code and the noun identification.

A sample output of OSCATE is contained in Appendix F.

Sensitivity Analysis

The variables that were selected for sensitivity analysis were those which, in the opinion of the authors, the contractor has some degree of control over during design of the ATE. By using the proposed model to analyze the variables to which Logistic Support Cost (LSC) is most sensitive, a contractor could improve equipment LSC through appropriate design changes.

Many of the trade-off analyses possible using OSCATE are suggested by the sensitivity analysis accomplished during this research effort. The following areas were addressed in this analysis: (1) reliability (MTBF), (2) maintainability (maintenance manhours), (3) repair concept (condemnation rate and repair in place percentage), and (4) availability. The remainder of this chapter discusses results of the sensitivity analysis in these areas.

Mean Time Between Failure (MTBF)

The first variable that was analyzed was MTBF. The MTBF of each TRU was varied from 100 percent to 500 percent of its baseline MTBF. For example, if the baseline MTBF for a particular TRU was 1000 hours, its value at 200 percent was 2000 hours and at 300 percent its MTBF was

3000 hours. This change in TRU MTBF resulted in the total logistics support cost ranging from \$15.93 million to \$5.4 million. A graph, Figure 2, of total logistic support cost versus MTBF shows the relationship over the entire range of values. As one might expect, the total logistics support cost decreases as the MTBF is increased; this is assuming the TRU unit cost remains constant. However, such an assumption is unrealistic. The TRU unit cost can be expected to increase as actions are taken to increase system reliability and, in turn, MTBF. The relationship between TRU unit cost and MTBF can be expressed as follows (20:421):

$$\text{TRU Unit Cost} = c(\text{MTBF})^a$$

where the values of c and a can be derived using historical data for like systems. Using this expression for the relationship between unit cost and MTBF, the designer can effect tradeoffs in his design regarding minimum total logistics support costs. A theoretical tradeoff analysis is shown in Figure 3, where the total logistics support cost decreases as the MTBF is increased and the total logistics support cost increases as the corresponding TRU unit cost increases. The combination of these two cost curves will result in the total cost curve shown by the dotted line. The optimum values for MTBF and unit cost can be obtained from that point on the curve where the slope is zero.

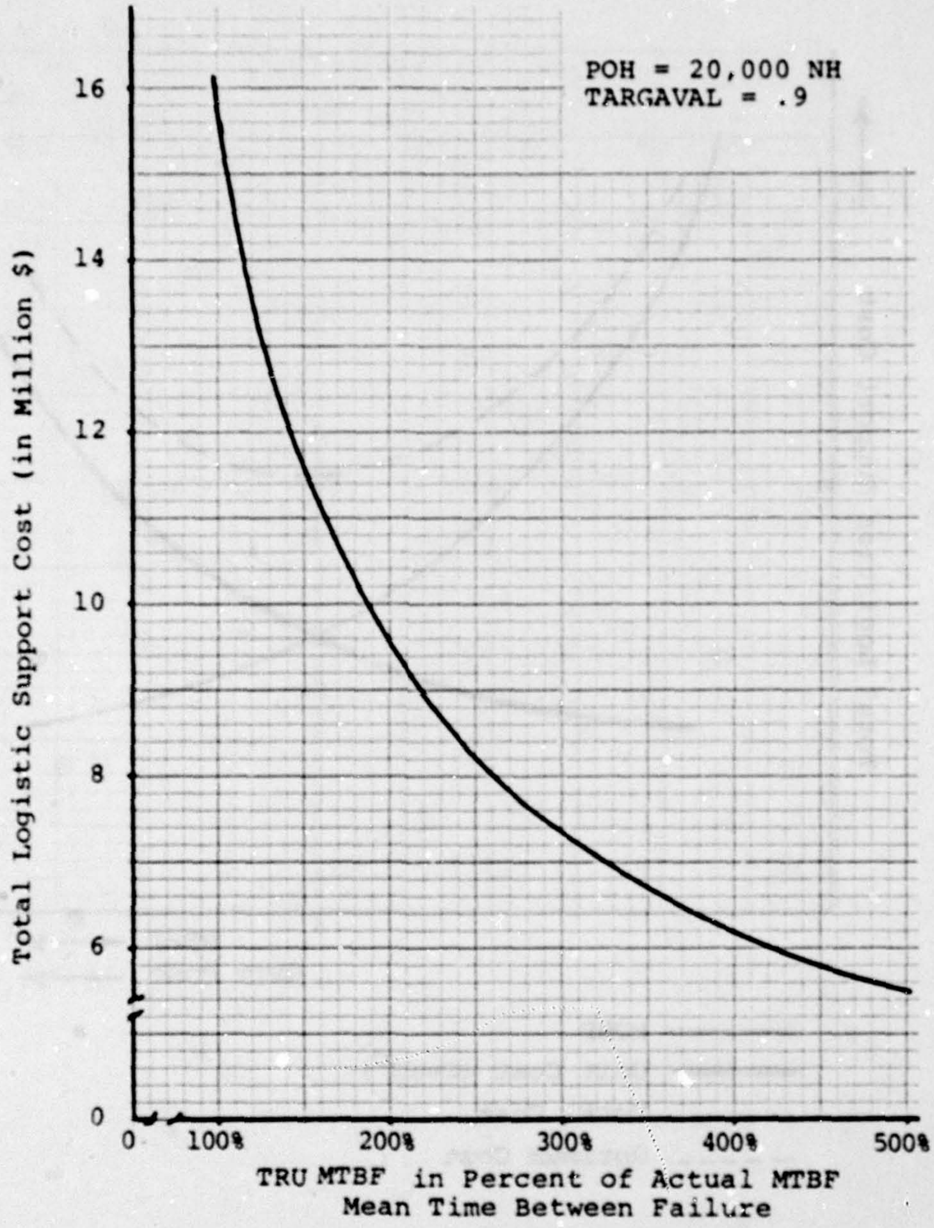


Fig. 2. TLSC vs. MTBF

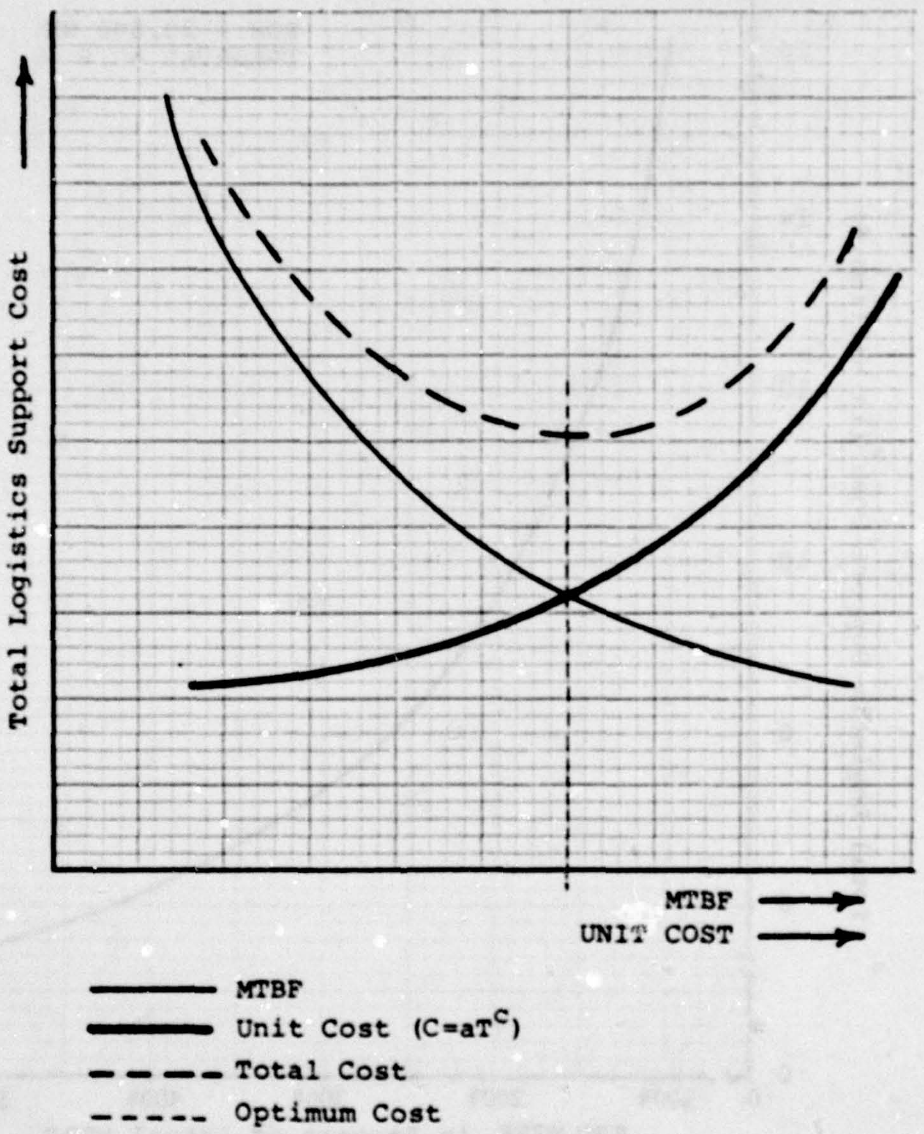


Fig. 3. TLSC vs. MTBF and UC

Repair in Place (RIP)

The next variable analyzed was RIP. This variable was chosen because the contractor has some latitude in the selection of components which can be repaired without removing the failed TRU. The RIP variable was varied from 0.1 to 0.65. A graph of total logistics support cost versus RIP is shown in Figure 4. It can be seen from the graph that as RIP was increased the total logistics support cost decreased. If RIP was increased it would be expected to cause an increase in on-equipment maintenance costs, a decrease in the off-equipment maintenance costs, and a decrease in TRU spares requirement. This result would be based on the assumption that a constant TRU MTBF was maintained as the fraction of in-place maintenance actions increased. Realistically, the higher the RIP value is, the lower the MTBF. Consequently, the designer will have to make a tradeoff between increasing his maintainability or decreasing his reliability in order to minimize total logistics support cost. Other considerations must enter into this decision, such as the skill level of the technicians performing the maintenance, and the possible addition of extra base support equipment to facilitate the RIP maintenance actions.

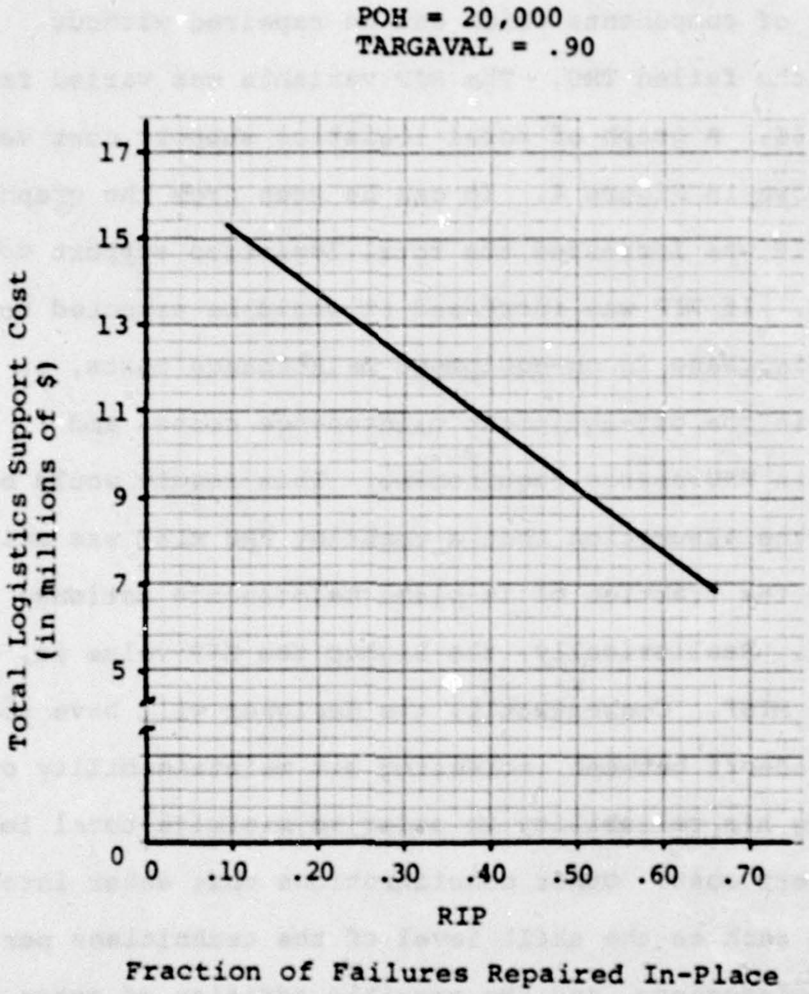


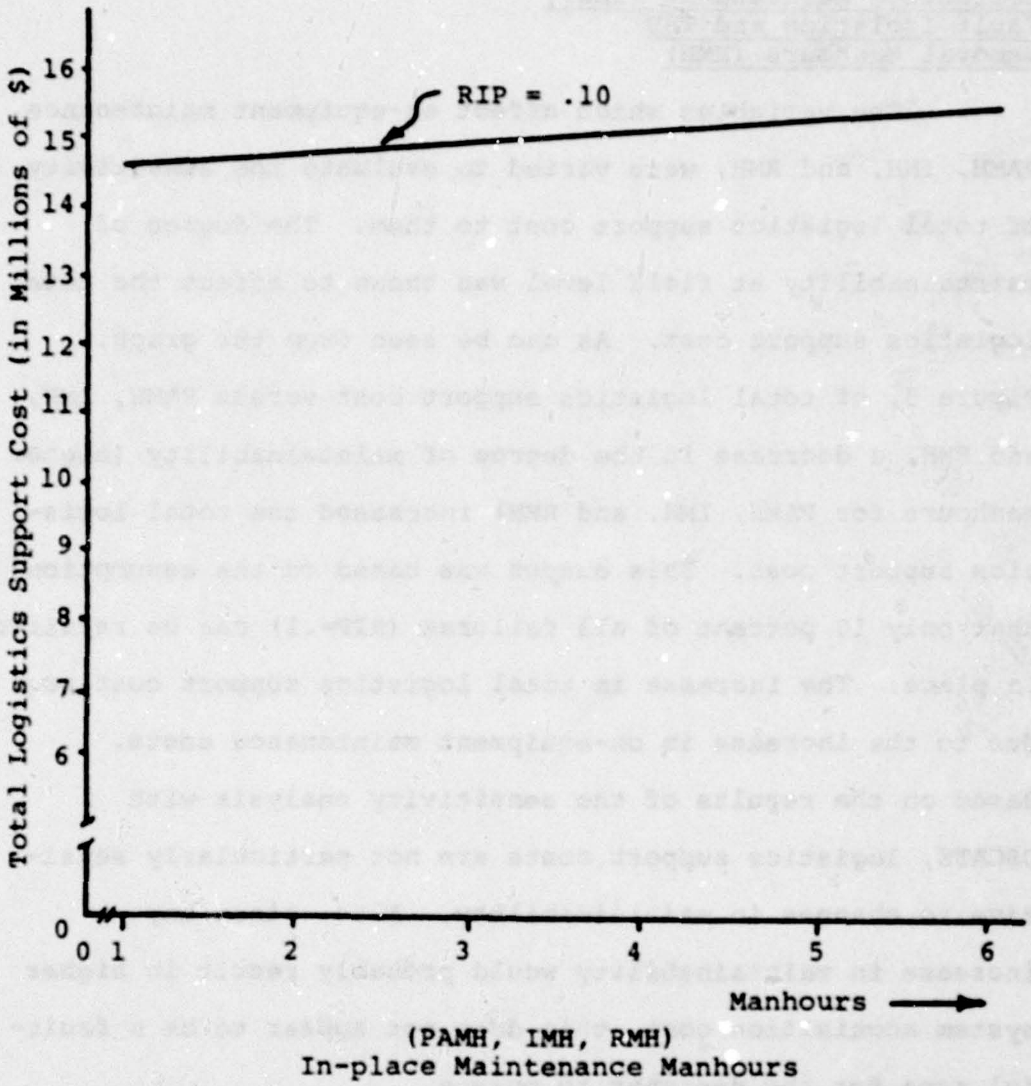
Fig. 4. TLSC vs. RIP

Preparation and Access (PAMH), Corrective Maintenance (IMH), Fault Isolation and TRU Removal Manhours (RMH)

The variables which affect on-equipment maintenance, PAMH, IMH, and RMH, were varied to evaluate the sensitivity of total logistics support cost to them. The degree of maintainability at field level was shown to affect the total logistics support cost. As can be seen from the graph, Figure 5, of total logistics support cost versus PAMH, IMH, and RMH, a decrease in the degree of maintainability (higher manhours for PAMH, IMH, and RMH) increased the total logistics support cost. This output was based on the assumption that only 10 percent of all failures (RIP=.1) can be repaired in place. The increase in total logistics support cost was due to the increase in on-equipment maintenance costs. Based on the results of the sensitivity analysis with OSCATE, logistics support costs are not particularly sensitive to changes in maintainability. Also, since any increase in maintainability would probably result in higher system acquisition cost, this does not appear to be a fruitful area for the designer to pursue.

TRU Condemnation Rate (DCOND)

Another variable that the designer has some control over is the TRU condemnation rate (DCOND). The DCOND for the TRU depends on the component selection philosophy. DCOND was first varied from .05 to .8. Figure 6 shows the



POH = 20,000
TARGAVAL = .90

Fig. 5. TLSC vs. PAMH IMH RMH

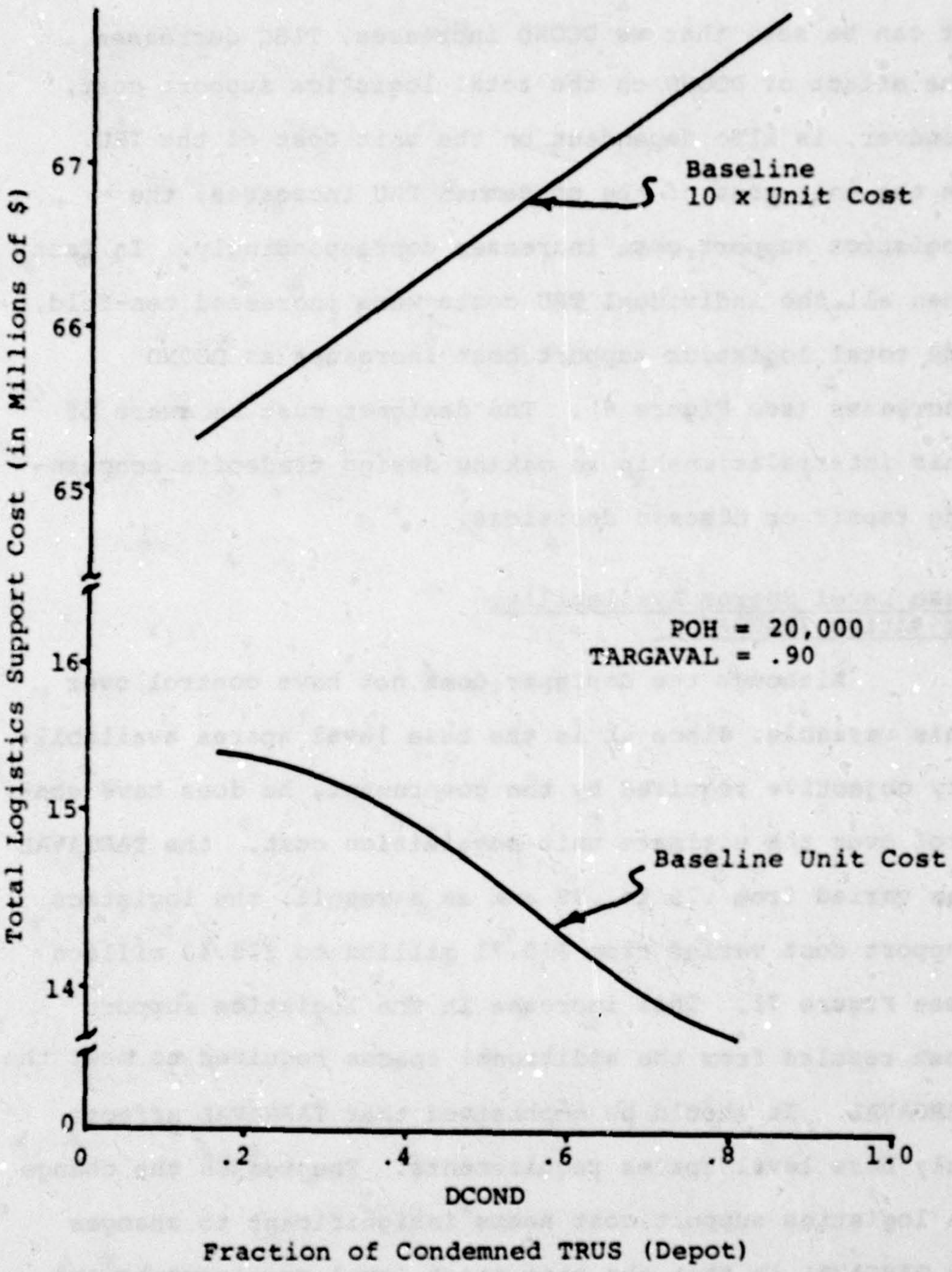


Fig. 6. TLSC vs. DCOND

graph of total logistics support cost versus DCOND rate. It can be seen that as DCOND increases, TLSC decreases. The effect of DCOND on the total logistics support cost, however, is also dependent on the unit cost of the TRU. As the unit cost of the condemned TRU increases, the logistics support cost increases correspondingly. In fact, when all the individual TRU costs were increased ten-fold, the total logistics support cost increases as DCOND increases (see Figure 6). The designer must be aware of this interrelationship in making design tradeoffs concerning repair or discard decisions.

Base Level Spares Availability Objective (TARGAVAL)

Although the designer does not have control over this variable, since it is the base level spares availability objective required by the government, he does have control over the ultimate unit acquisition cost. the TARGAVAL was varied from .75 to .99 and as a result, the logistics support cost varied from $15.71 million to $16.40 million (see Figure 7). This increase in the logistics support cost results from the additional spares required to meet the TARGAVAL. It should be emphasized that TARGAVAL affects only base level spares requirements. The reason the change in logistics support cost seems insignificant to changes in TARGAVAL is that the base stock level requirements are small compared to the number of spares required to fill the

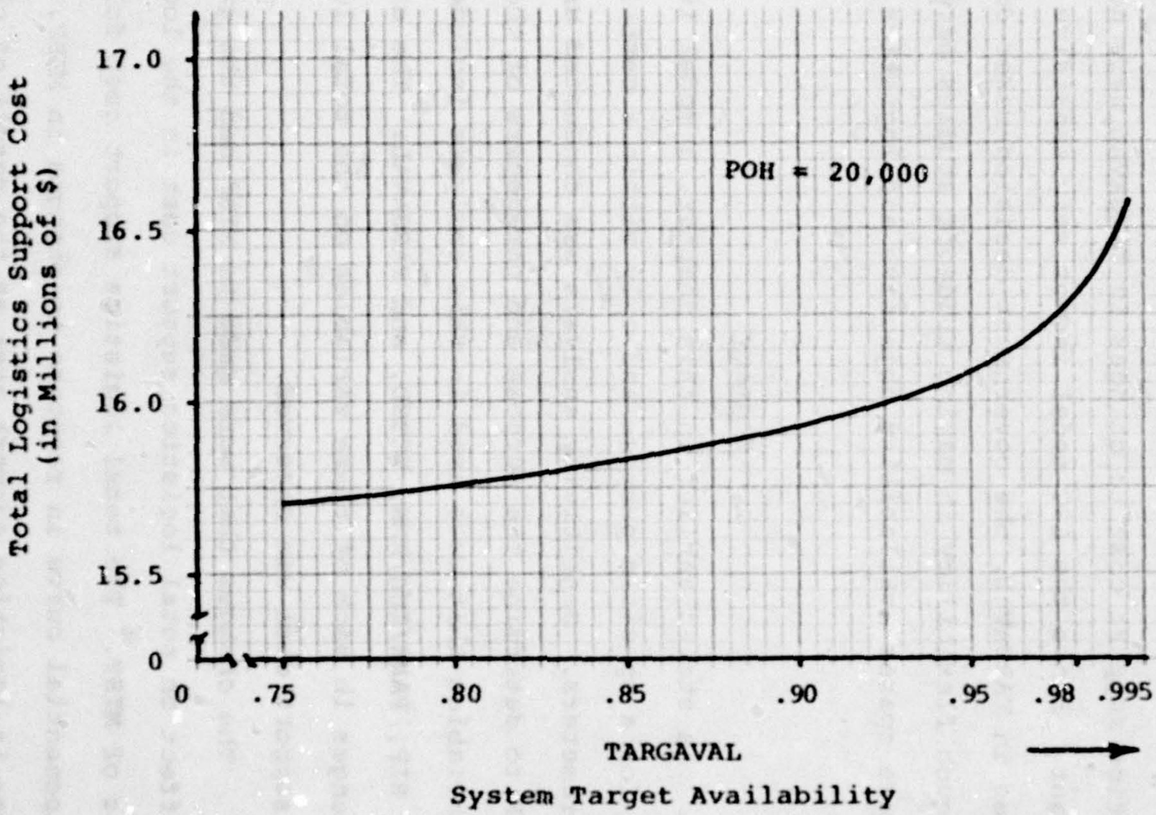


Fig. 7. TLSC vs. TARGAVAL

depot pipeline. TARGAVAL was again varied, but this time the TRU unit cost was increased by 100 percent. Logistics support cost increased significantly but the change in logistics support cost to changes in TARGAVAL were not significant. Since the LSC model is not very sensitive to changes in TARGAVAL, the government decision-maker does not have much flexibility in making tradeoff studies between the base spares availability objective and logistics support costs.

Summary

As stated earlier in this chapter, a model is only valid for a specific purpose and only within a certain set of parameters. Sensitivity analysis was conducted using OSCATE to determine the purpose and parameters of the model. The variables that were used in this analysis included MTBF, RIP, PAMH/IMH/RMH, DCOND, and TARGAVAL. The effect of changes in each of these variables on the total logistics support cost was observed.

The changes that were made to MTBF had the greatest effect on total logistics support cost in the lower ranges of MTBF. The total logistics support cost followed an exponential curve in response to changes in MTBF. The changes in logistics support cost as the result of changes in RIP indicated a linear relationship of decreasing LSC to increasing values of RIP. However, it was pointed out that careful consideration should be given to other factors when conducting tradeoff studies using RIP. Increases in in-place maintenance manhours (PAMH, IMH, and RMH) resulted in a linear increase in the total logistics support cost. As the DCOND rate increased the total logistics support cost decreased. However, this relationship is dependent upon the unit cost of the TRUs. Variations in TARGAVAL resulted in a negative linear relationship with total logistics support cost at the lower values of TARGAVAL and exhibited an exponential relationship as the value of TARGAVAL approached 1.

It should be noted that the results obtained are dependent upon the structure of OSCATE, the assumptions that were made in exercising the model, and on the accuracy of the data base used. The final chapter of this thesis will discuss potential model use, model limitations, and recommend areas for further study.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The Operation and Support Cost Model for Automatic Test Equipment (OSCATE) developed as a result of this study has the potential for being a valuable tool in ATE acquisition. However, the model must first be validated. After validation, potential model users must be instructed on when, where, and how to use the model, considering model assumptions and limitations. These issues will be discussed in this chapter, which will end with recommendations for further research in the area of Life Cycle Cost (LCC) models for ATE.

Potential Model Uses

The OSCATE model developed in this research effort can be used to estimate and measure operation and support costs for ATE. Since ATE is the major cost item within support equipment and operation and support costs make up 60 percent or more of Life Cycle Cost, OSCATE can be an important addition to LCC techniques applied to ATE. For example, it can serve as a useful tool in evaluating ATE operation and support costs during source selection of ATE contractors.

OSCATE can also be used to aid in award fee determination or establish criteria for penalty clauses, when the model is used in conjunction with the Logistics Support Cost Commitments discussed in Chapter II. Additionally, OSCATE can be used for evaluation of engineering change proposals, where O&S cost changes are a consideration in ECP approval.

Other areas where OSCATE may prove useful include the investigation of tradeoffs concerning technician training, the evaluation of repair-discard options, and the determination of optimum balances between preventive, remedial, and on-condition maintenance.

Model Limitations

The OSCATE model, not unlike other accounting models, has limitations the potential user must be aware of. OSCATE does not necessarily project the actual increment of LSC that results from introducing the proposed ATE into the Air Force inventory. It is only a representative figure for real costs of logistics support. The model only gives a summary of the cost impacts of projected demands for support resources, but will not address the interdependence of those resources. The user should understand that the model is not meant to be a substitute for comprehensive support planning.

When using this model, the risk considerations concerning estimation and verification of TLSCs and MLSCs, respectively, mentioned in Chapter III, should be understood. In order to reduce the statistical risk involved during verification, the number of parameters to be verified can be reduced or the parameters from an aggregate number of TRUs can be verified instead of treating individual TRUs.

Other Considerations in Model Use

One of the prime considerations when using this model in the acquisition process is the problem associated with the government obtaining variable data for use in the OSCATE model. Therefore, it is recommended that the OSCATE model be provided to the prospective contractors as part of the Request for Proposal. The contractor should be required by the Statement of Work (SOW) or Work Specification to use OSCATE to obtain operation and support cost estimates which would become contractually binding should the contractor be selected as the full-scale development contractor.

Other considerations when using the OSCATE model are availability of data needed to exercise the model, user understanding and acceptance of the model, and knowledge of the model assumptions.

Availability of Data

Plans should be made as early as possible to obtain data necessary to establish values for all the variables which will be used when exercising the model. One of the main problems encountered during the development of OSCATE was the availability of data. The data used to exercise the model was primarily field data obtained from the DO56 Product Performance Collection System. This data, part of the Maintenance Data Collection System (AFM 66-1), was not readily available in a useable form. A significant amount of time and effort was required to extract and combine data from several computer output products. In addition, several data items such as the total operating hours of the equipment, the condemnation rate, and the fraction of repair in place maintenance actions were not available because they are not normally included items in the Maintenance Data Collection System. Another aspect of data limitation was the problem of maintaining control by functional rather than systemic areas.

The field data which was obtained was primarily broken out in accordance with the weapon system ATE Work Unit Code Manual (29). One notable exception to this was in the area of calibration requirements. The work unit codes assigned to TRUs requiring calibration were different than those listed in the weapon system ATE manual. Furthermore, if the calibrated TRU is used on several other systems, it is virtually impossible to discern the calibration actions attributable to each specific system.

This same type of problem occurs under the D056 system where an item of a particular stock class is sent to the depot for repair or calibration. When the repair or calibration is completed, the action is charged against that particular stock class and not against the Automatic Test Equipment. By collecting data functionally rather than by system, valuable information is obscured if not totally lost.

User Understanding and Acceptance of the Model

First and foremost the potential user of OSCATE should be acquainted with the purpose for which the model was developed. OSCATE is intended as a tool in the Life Cycle Cost (LCC) technique which has as its ultimate goal the design, development, and acquisition of systems--in this case ATE--with lower life cycle costs. In addition, the user of this model should be familiar with variables involved, the sensitivity of the model, and the values of parameters that are furnished to a contractor. The values of parameters like TARGAVAL furnished to a contractor should be responsible, meaningful, and attainable.

It is not enough for a contractor to use this model for estimating O&S costs of his equipment if provisions have not been made to verify this estimate. Therefore, it it is important that an evaluation plan be established which the contractors understand, is acceptable to both parties and which can be verified. The contractor, also as a user of the OSCATE, has to have complete knowledge of how his results are to be evaluated.

Model Assumptions

The assumptions which were made in development of this model should not be taken lightly. Neglecting these assumptions can lead to misinterpretation of the model output and could lead to problems or disagreements between the government and the contractor. Both parties should be aware of the assumptions since they form the basis for some of the most critical computations. Such is the case of the assumptions which were made (reference Chapter IV) in calculating the TRU spares requirements. Other assumptions regarding (1) variables such as the Peak Operating Hours (POH), (2) the maintenance technician quantities and skills, and (3) the maintenance concept, have to be considered when OSCATE is to be employed.

Recommendations for Further Study

During the development of the model several topics were considered for research which were outside the scope of this thesis, but warrant further investigation. Emphasis should be placed upon these areas when conducting future research. Those areas are:

1. Model validation
2. Development of Equation C_9 for software
3. Test assumptions regarding availability of ATE
4. Establishment of an information system to provide data for the model.

Model Validation

Now that OSCATE has been developed, the task of validation remains to be performed. The purpose of validation is to test how well the model represents the real world. This test is necessary to determine if any modifications and/or adjustments need to be made to the model and to provide some level of confidence in OSCATE estimates.

It is suggested that future researchers choose an existing weapon system using ATE and apply OSCATE to historical data obtained on that system. Predicted costs from the model should be compared to actual costs established from the data. In addition to the sources of data cited in this research, it is suggested that more complete data be obtained from the operational bases, contractor, and applicable depots.

Additionally, OSCATE can be further validated by comparing its output with that of parallel modeling efforts conducted in the civilian sector.

Development of Equation C_9 for Software

An equation for determining the cost of software used in support of ATE should be developed. OSCATE in its present form does not address the cost of ATE software due to the limited availability of data in this area. Indications are, however, that software costs are large and will increase as ATE becomes more sophisticated.

One possible approach would be to contact several contractors engaged in software development to gain insight into how they estimate software costs. Additionally, the Computer Research Branches at the ALCs could be considered as possible sources of expertise. Data concerning actual software costs could be obtained from contractors, the support equipment SPO, and specific weapon system SPOs.

Test of Assumption Regarding Availability of ATE

Presently, in the calculation of the TRU spares requirements, the assumption is that any failed TRU will render the ATE inoperable. This is a simplifying assumption that is valid only when ATE is required to be 100 percent operational. If the ATE could be considered functional at operational levels less than 100 percent, it would be desirable to develop the capability in OSCATE to identify and prioritize those TRUs that are most critical. With this capability ATE managers could then give special attention to critical TRUs in order to prevent unacceptable levels of operability.

APPENDICES

APPENDIX A

BASIC LSC MODEL FRAMEWORK

The following is an outline of a basic LSC framework (6:1):

C_1 = Cost of initial spare items

$$= \text{(Cost of base repair pipeline spares)} + \text{(Cost of depot repair pipeline spares)}$$

$$= (M)(STK)(UC) + \frac{(PFFH)(UF)(QPA)(1-RIP)(NRTS)}{MTBF}(DRCT)(UC)$$

C_2 = Cost of on-equipment maintenance

$$= \text{(total mean number of failures)} \times \text{(average on-equipment repairs cost per failure)}$$

$$= \left[\frac{(TFFH)(UF)(QPA)}{(MTBF)}\right]\left[(PAMH)+(RIP)(IMH)+(1-RIP)(RHM)\right](BLR)$$

C_3 = Cost of off-equipment maintenance

$$= \text{(total mean number of off-equipment repairs)} \times \text{(average cost per off-equipment repair)}$$

$$= \left[\frac{(TFFH)(UF)(QPA)(1-RIP)}{MTBF}\right]\left[(RTS)(BMH)(BLR+BMR) + (NRTS)(DMH)(DLR+DMR)\right]$$

where:

BLR	is the base labor rate ($/manhour);
BMH	is the average number of manhours to perform intermediate level maintenance on a removed item;
DLR	is the depot level rate;

DMH	is the average number of manhours to perform depot level maintenance on a removed item;
DMR	is the depot consummable material consumption rate;
DRCT	is the average depot repair cycle time in months;
IMH	is the average number of manhours to perform corrective maintenance of the item in place or on line;
M	is the number of operating locations;
MTBF	is the mean time between failures in operating hours;
NRTS	is the fraction of removed items expected to be returned to depot for repair;
PFFH	is the peak force flying hours; the expected total fleet flying hours for one month during the peak usage period;
QPA	is the quantity of like items within the parent system;
RIP	is the fraction of item failures which can be repaired in place or on line;
RMH	is the average number of manhours to isolate a fault, remove and replace the item, and verify restoration of the system to operational status;
RTS	is the fraction of removed items expected to be repaired at the base;
STK	is the stock level of the item at each base;
TFFH	is the expected total force flying hours over the program inventory usage period;
UC	is the negotiated unit cost of a spare item as of the end of the verification test; and
UF	is the ratio of operating hours to flying hours for the item.

BLR, BMR, DLR, DMR, DRCT, M, PFFH, and TFFH parameters are supplied by the government. BMH, DMH, IMH, MTBF, NRTS, PAMH, QPA, RIP, RMH, RTS, UC and UF parameters are supplied by the contractor. The rest of the parameters are computed by the model.

APPENDIX B

VARIABLE MATRIX

ATE System Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
CARF	X			X
IMC	X	X	X	
M	X	X	X	
MRF	X	X	X	
MRO	X	X	X	
NSYS	X	X		X
OS	X	X	X	
OST	X	X	X	
PIUP	X	X	X	
PMB	X	X	X	
PMD	X	X	X	
POH		X		X
PSC	X	X	X	
PSO	X	X	X	
RMC	X	X	X	
SA	X	X	X	

ATE System Variables Continued	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
SR	X	X	X	
TARGAVAL		X	X	
TD	X	X	X	
TOH	X	X		X
TR	X	X	X	
TRB	X	X	X	
TRD	X	X	X	
UEBASE	X	X	X	

Subsystem Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
BCA		X		X
BLR	X	X	X	
CASYS	X			X
CIVLR	X		X	
DAA	X	X	X	
DCA		X		X
DLR	X	X	X	
DMR	X	X	X	
DPA		X		X
DRCT	X	X	X	
H	X	X		X
JJ	X	X		X
N	X	X		X
SCI	X			X
SCMH	X			X

Subsystem Variables Continued	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
SMH	X	X		X
SYSNOUN		X		X
TCB	X	X		X
TDC	X	X		X
TE	X	X		X
XSYS	X	X		X

TRU Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
CATRU	X			X
CI	X		X	X
CII	X			X
CIILR	X			X
CILR	X			X
CIV	X			X
DBCMH	X	X		X
DCOND		X		X
DMC	X	X		X
DMH	X	X		X
FICR	X			X
FIICR	X			X
FIVCR	X			X
IMH	X	X		X
K	X	X		X

TRU Variables Continued	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
MTBF	X	X		X
PAMH	X	X		X
PP	X	X		X
QPA	X	X		X
RIP		X		X
RMH	X	X		X
SP	X	X		X
TRUCI	X			X
TRUCMH	X			X
TRUNOUN	X	X		X
UC	X	X		X
W	X	X		X
XTRU	X	X		X

Support Equipment Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
CAD	X	X		X
COD	X	X		X
DOWN		X		X
DUR	X	X		X
XSE	X	X	X	

APPENDIX C

VARIABLE DEFINITIONS

ATE System Variables*

CARF - The fraction of units to be calibrated that require repair. (C)

IMC - Initial management cost to introduce a new line item of supply (ASSEMBLY or piece part) into the Air Force inventory. (S=$166.25/item) (AFLCR 173-10)

M - Number of intermediate repair locations (operating bases). (P)

MRF - Average manhours per failure to complete off-equipment maintenance records. (S=.24 hours)

MRO - Average manhours per failure to complete on-equipment maintenance records. (S=.08 hours)

NSYS - Number of systems within the ATE.

OS - Fraction of total force deployed to overseas locations. (P)

OST - Weighted average Order and Shipping Time in months. The elapsed time between the initiation of a request for a serviceable item and its receipt by the requesting activity. For CONUS locations, S=0.394 months (12 days) input as OSTCON. For overseas locations, S=0.526 months (16 days) input as OSTOS. (AFLCR 173-10)
OST=(OSTCON)(1-OS)+(OSTOS)(OS)

<u>NOTES:</u> (C) = contractor-furnished
(S) = Government-furnished standard value
(P) = Government-furnished program-peculiar value
(AFLCR 173-10) = denotes data source is AFLCR 173-10; all cost factors have been escalated from their respective base year dollars to common FY79 dollars using the O&M factors found in AFR 173-10, Vol I, Table 49.

* The categorization of variable definitions is consistent with variable input requirements of the computer model.

PIUP - Operational service life of the ATE in years. (Program Inventory Usage Period) (P)

PMB - Direct productive manhours per man per year at base level (includes "touch time," transportation time, and setup time). (S=1728 hours/man/year) (AFLCR 173-10)

PMD - Direct productive manhours per man per year at the depot (includes "touch time," transportation time, and setup time). (S=1728 hours/man/year) AFLCR 173-10)

POH - Peak Operating Hours--expected operating hours for one month during the peak usage period. (C)

PSC - Average packing and shipping cost to CONUS locations. (S=$0.72/pound)(AFLCR 173-10)

PSO - Average packing and shipping cost to overseas locations. (S=$1.49/pound) (AFLCR 173-10)

RMC - Recurring management cost to maintain a line item of supply (assembly or piece part) in the wholesale inventory system. (S=$166.25/item/year) (AFLCR 173-10)

SA - Annual base supply line item inventory management cost. (S=$8.39/item) (AFLCR 173-10)

SR - Average manhours per failure to complete supply transaction records. (S=.25 hours)

TARGAVAL - Base-level spares availability objective for ATE. (P)

TD - Average cost per original page of technical documentation. The average acquisition cost of one page of the reproducible source document (does not include reproduction costs). (S=$200.07/page) (AFLCR 173-10)

TOH - Expected Total Operating Hours over the Program Inventory Usage Period. (C)

TR - Average manhours per failure to complete transportation transaction forms. (S=.16 hours)

TRB - Annual Turnover rate for base personnel. (S=.134)

TRD - Annual Turnover rate for depot personnel. (S=.15)

UEBASE - The number of unit equivalent ATE per operating base. (P)

Subsystem Variables*

BCA - Total cost of additional items of common base shop support equipment per base required for the system. (C)

BLR - Base labor rate, including indirect labor, indirect material and overhead. (S=$15.18/hour) (AFLCR 173-10)

CASYS - Number of systems to be calibrated. (C)

CIVLR - Labor rate at the Class IV PMEL lab. (P)

DAA - Available work time per man at the depot in manhours per month. (S=168 hours) (AFLCR 173-10)

DCA - Total cost of additional items of common depot support equipment required for the system. (C)

DLR - Depot labor rate, including other direct costs, overhead and G&A. (S=$26.20/hour) (AFLCR 173-10)

DMR - Depot consumable material consumption rate. Includes minor items of supply (nuts, washers, rags, cleaning fluid, etc.) which are consumed during repair of items (S=$2.11/hour) (AFLCR 173-10)

DPA - Total cost of peculiar depot shop support equipment per base required for the system which is not directly related to repair of specific TRUs or when the quantity required is independent of the anticipated workload (such as overhead cranes and shop fixtures). (C)

DRCT - Weighted average Depot Repair Cycle Time in months. The elapsed time for a NRTS item from removal of the failed item until it is returned to depot serviceable stock. This includes the time required for base-to-depot transportation and handling and the shop flow time within the specialized repair activity required to repair the item. For CONUS locations, S=1.40 months (52 days) for organic repair, S=2.06 (62 days) for contractual repair, input as DRCTC. For overseas locations, S=1.90 months (57 days) for organic repair, S=2.20 months (66 days) for contractual repair, input as DRCTO. (AFLCR 173-10)

$$DRCT = (DRCTC)(1-OS) + (DRCTO)(OS)$$

H - Number of pages of depot level technical orders and special repair instructions required to maintain the system. (C)

JJ - Number of pages of organizational and intermediate level technical orders required to maintain the system. (C)

N - Number of different TRUs within the ATE. (C)

SCI - Scheduled calibration interval for the system. (C)

SCMH - Manhours required to perform calibration. (C)

SMH - Average manhours to perform a scheduled periodic or phased inspection of the system. (C)

SMI - Operating hour interval between scheduled periodic or phased inspections on the system. (C)

SYSNOUN - Name of the system--up to 60 alphanumeric characters. (C)

TCB - Cost of peculiar training per man at base level including instruction and training materials. (C)

TCD - Cost of peculiar training per man at the depot including instruction and training materials. (C)

TE - Cost of peculiar training equipment required for the system. (C)

XSYS - System identification. The assigned five-character alphanumeric Work Unit Code of the system. (C)

TRU Variables*

CATRU - Number of TRUs requiring calibration. (C)

CI - Factor which is 0 if no calibration at Class I lab is required or 1 if calibration at Class I lab is required. (C)

CII - Factor which is 0 if no calibration at Class II lab is required or 1 if calibration at Class II lab is required. (C)

CIILR - Labor rate at a Class II lab. (C)

CILR - Labor rate at a Class I lab. (C)

CIV - Factor which is 0 if no calibration at Class IV lab is required or 1 if calibration at Class IV lab is required. (C)

DBCMH - Average manhours ot perform a shop bench check, screening, and fault verification on a removed TRU prior to initiating repair action or condemning the item. (C)

DCOND - Fraction of TRUs returned to the depot for repair expected to result in condemnation at depot level. (C)

DMC - Average cost per failure for a TRU repaired at depot level for stockage and repair of lower level assemblies expressed as a fraction of the TRU unit cost (UC). This is the implicit repair disposition cost for a TRU representing labor, material consumption, and stockage/replacement of lower indenture reparable components within the TRU (e.g., shop replaceable units or modules). (C)

DMH - Average manhours to perform intermediate-level (base shop) maintenance on a removed TRU including fault isolation, repair, and verification. (C)

FICR - Manhours spent on repair of items to be calibrated at Class I lab. (C)

FIICR - Manhours spent on repair of items to be calibrated at Class II lab. (C)

FIVCR - Manhours spent on repair of items to be calibrated at Class IV lab. (C)

IMH - Average manhours to perform corrective maintenance of the TRU in place or on line without removal including fault isolation, repair, and verification. (C)

K - Number of line items of peculiar shop support equipment used in repair of the TRU. (C)

MTBF - Mean Time Between Failures in operating hours of the TRU in the operational environment. (C)

PAMH - Average manhours expended in place on the installed system for Preparation and Access for the TRU for example, jacking, unbuttoning, removal of other units and hookup of support equipment. (C)

PP - Number of new "P" coded consumable items within the TRU. (C)

QPA - Quantity of like TRUs within the parent system. (Quantity per Application) (C)

RIP - Fraction of TRU failures which can be repaired in place or on line without removal. (C)

RMH - Average manhours to fault isolate, remove, and replace the TRU on the installed system and verify restoration of the system to operational status. (C)

TRUCI - Calibration interval for a TRU. (C)

TRUCMH - Manhours required to calibrate a TRU. (C)

TRUNOUN - Word description or name of the TRU--up to 60 alphanumeric characters. (C)

UC - Expected unit cost of the TRU at the time of initial provisioning. (C)

W - TRU weight in pounds. (C)

XTRU - TRU identification. The assigned five-character alphanumeric Work Unit Code of the TRU. (C)

Support Equipment Variables*

CAD - Cost per unit of peculiar support equipment for the depot shop. (C)

COD - Annual cost to operate and maintain a unit of support equipment at depot level expressed as a fraction of the unit cost (CAD). (C)

DOWN - Fraction of downtime for a unit of support equipment for maintenance and calibration requirements. (C)

DUR - Combined utilization rate for all like items of support equipment at depot level. (C)

XSE - SE identification--up to 20 alphanumeric characters. (C)

APPENDIX D

COMPUTER PROGRAM

```
1000*#RUN *=(CORE=30K)
1010C**************************************
1020C*************** OSCATE ***************
1030C**************************************
1040      DIMENSION TRUMAT(100,20),SEMAT(100,9),SYSMAT(30,15),SECUM(50,5)
1050      DIMENSION SORTRU(100,20),EQTOT(12),AVTAB(1000,5),UCTAB(100)
1060      DIMENSION KEY(1),MODE(1),LINK(1000),SETAB(50,2)
1070      CHARACTER XSYS*5(30),XTRU*5(100,2),XSE*20(100),SORTXTRU*5(100,2)
1080      CHARACTER SYSNOUN*60(30),TRUNOUN*60(100),SETRU*5(100,2),CANS*5
1090      CHARACTER XSECUM*20(50),DATE*8,CMAT*5(1,1)
1100      DATA SYSMAT,TRUMAT,EQTOT/2331*0./
1110      REAL H,IMC,IMH,JJ,LS,M,MRO,MRF,MTBF
1120 CALL FPARAM(1,80)
1130      TOTLSC=0.
1140      AVI=1.
1150      NUMAVT=0
1160      MAXAVT=1000
1170C****************************************
1180C********** READ ATE VARIABLES **********
1190C****************************************
1200      READ(10,2) LN, TOH,POH,PIUP,M,OS,NSYS,UEBASE,TARGAVAL
1210      READ(10,2) LN, OSTCON,OSTOS,IMC,RMC,PSC,PSO,TRB,TRD
1220      READ(10,2) LN, TD,SA,MRO,MRF,SR,TR,PMB,PMD,CARF
1230    2 FORMAT(V)
1240      OST=OSTCON*(1.-OS)+OSTOS*OS
1250      IF(NSYS.LE.30) GO TO 30
1260      PRINT 3
1270    3 FORMAT("REDIMENSION SYSMAT, XSYS, SYSNOUN")
1280      STOP
1290   30 INEXT=1
1300      JNEXT=1
1310C**********************************************
1320C************ READ SYSTEM VARIABLES ***********
1330C**********************************************
1340      DO 1000 IS=1,NSYS
1350      READ(10,2) LN,XSYS(IS),SYSNOUN(IS)
1360      READ(10,2) LN,BCA,DCA,DPA,N
1370      READ(10,2) LN,H,JJ,SMH,SMI,TCB,TCD,TE
1380      READ(10,2) LN,BLR,DLR,DMR,DAA,DRCTC,DRCTO
1390      READ(10,2) LN,SCI,SCMH,CIVLR,CASYS
1400      DRCT=DRCTC*(1.-OS)+DRCTO*OS
1410      SYSMAT(IS,2)=TOH*SMH*BLR/SMI
1420      SYSMAT(IS,3)=(1+0.1*PIUP)*(DCA+DPA+M*BCA)
1430      C6X=TCB*(1.+(PIUP-1.)*TRB)/(PIUP*PMB)
1440      C6Y=TCD*(1.+(PIUP-1.)*TRD)/(PIUP*PMD)
1450      SYSMAT(IS,6)=C6X*TOH*SMH/SMI+TE
1460      SYSMAT(IS,7)=TOH*BLR*(MRO+0.1*(SR+TR))/SMI+TD*(JJ+H)
1470      IF(CASYS.EQ.0) GO TO 34
1480       SYSMAT(IS,8)=365*PIUP*CIVLR/SCI
1490   34 IF(N.EQ.0) GO TO 1000
1500C****************************************
1510C********** READ TRU VARIABLES **********
1520C****************************************
```

```
1530       IMAX=INEXT+N-1
1540       IF(IMAX.LE.100) GO TO 38
1550       PRINT 37
1560   37  FORMAT("REDIMENSION TRUMAT,XTRU,TRUNOUN,SORTRU,SORTXTRU,KC,KD,KE")
1570       STOP
1580    38 DO 999 I=INEXT,IMAX
1590       READ(10,2) LN,XTRU(I,1),TRUNOUN(I)
1600       READ(10,2) LN,QPA,UC,MTBF,RIP,DCOND,DMC
1610       READ(10,2) LN,PAMH,IMH,RMH,DBCMH,DMH,W,PP,SP,K
1620      READ(10,2) LN,TRUCI,TRUCMH,CILR,CIILR,FICR,CI,CII,CIV,
1630&       FIICR,FIVCR,CATRU
1640       IF(CATRU.EQ.0) GO TO 39
1650      CAL1=365*PIUP*QPA*TRUCMH*((CI*CILR+CII*CIILR+
1660&     CIV*CIVLR)/TRUCI)
1670      CAL2=365*PIUP*QPA*CARF*((CI*CILR*FICR+CII*CIILR*FIICR+
1680&     CIV*CIVLR*FIVCR)/TRUCI)
1690      TRUMAT(I,20)=CAL1+CAL2
1700   39  XTRU(I,2)=XSYS(IS)
1710       PKGEN=POH*QPA/MTBF
1720       TRUMAT(I,9)=PKGEN
1730       PKOEGEN=PKGEN*(1.-RIP)
1740       TRUMAT(I,10)=PKOEGEN
1750       TOTGEN=TOH*QPA/MTBF
1760       TRUMAT(I,11)=TOTGEN
1770       TOTOEGEN=TOTGEN*(1.-RIP)
1780       TRUMAT(I,12)=TOTOEGEN
1790       DMDMEAN=PKOEGEN*OST/M
1800       TRUMAT(I,14)=DMDMEAN
1810C*******************************************************
1820***COMPUTE MIN BASE TRU SPARES STOCK LEVELS SUCH THAT***
1830*** EACH TRU HAS AN AVAILABILITY>=TARGAVAL. COMPUTE ***
1840*** ADD'L INFO REQUIRED FOR MARGINAL ANALYSIS "BUYS."  ***
1850*******************************************************
1860       XBO=DMDMEAN
1870       PROBX=EXP(-DMDMEAN)
1880       STK=0.
1890       STKI=0.
1900       SUM=0.
1910       UCTAB(I)=UC
1920       AVO=(1.-XBO/(QPA*UEBASE))**QPA
1930       AVI=AVI*AVO
1940       AV=AVO
1950       TRUMAT(I,17)=0
1960       TRUMAT(I,15)=XBO
1970       TRUMAT(I,16)=AV
1980 41 IF(AV.GT.0.99999) GOTO 45
1990       SUM=SUM+PROBX
2000       XBO=XBO+SUM-1.
2010       STK=STK+1.
2020       PROBX=PROBX*DMDMEAN/STK
2030       AV=(1.-XBO/(QPA*UEBASE))**QPA
2040       RIMP=AV/AVO
2050       SV=ALOG(RIMP)/UC
2060       AVO=AV
```

```
2070       IF(AV .GT. TARGAVAL) GO TO 42
2080       STKI=STKI+1.
2090       AVI=AVI*RIMP
2100       TRUMAT(I,15)=XBO
2110       TRUMAT(I,16)=AV
2120       GO TO 41
2130    42 NUMAVT=NUMAVT+1
2140       IF(NUMAVT .LE. MAXAVT) GO TO 44
2150       PRINT 43
2160    43 FORMAT("REDIMENSION AVTAB, LINK AND RESET MAXAVT")
2170       STOP
2180    44 AVTAB(NUMAVT,1)=SV
2190       AVTAB(NUMAVT,2)=RIMP
2200       AVTAB(NUMAVT,3)=FLOAT(I)
2210 AVTAB(NUMAVT,4)=XBO
2220 AVTAB(NUMAVT,5)=AV
2230 GOTO 41
2240  45   TRUMAT(I,17)=STKI
2250       DPIPE=CEIL(PKOEGEN*(1-DCOND)*DRCT)
2260       TOTCOND=CEIL(TOTOEGEN*DCOND)
2270       TRUMAT(I,18)=DPIPE
2280       TRUMAT(I,19)=TOTCOND
2290       TRUMAT(I,1)=UC*(STKI*M+DPIPE+TOTCOND)
2300       TRUMAT(I,2)=TOTGEN*(PAMH+RIP*IMH+(1.-RIP)*RMH)*BLR
2310       TRUMAT(I,3)=TOTOEGEN*((DBCMH*DLR+(1-DCOND)
2320&      *DMH*(DLR+DMR)+DMC*UC)+2*((1.-OS)*PSC+OS*PSO)*1.35*W)
2330       TRUMAT(I,4)=(IMC+PIUP*RMC)*(1.+PP)+M*SA*PIUP
2340  47   TRUMAT(I,6)=C6X*TOTGEN*(PAMH+RIP*IMH+(1.-RIP)*RMH)+
2350&      C6T*TOTOEGEN*(DBCMH+(1.-DCOND)*DMH)
2360       TRUMAT(I,7)=TOTGEN*(MRO+(1.-RIP)*(SR+TR))*BLR
2370       IF (K.EQ.0) GO TO 999
2380C*************************************
2390C********** READ SE VARIABLES **********
2400C*************************************
2410       JMAX=JNEXT+K-1
2420       IF(JMAX.LE.100) GO TO 49
2430       PRINT 48
2440  48   FORMAT("REDIMENSION SEMAT,XSE,SETRU")
2450       STOP
2460   49 DO 998 J=JNEXT,JMAX
2470       READ(10,2) LN,XSE(J),CAD,COD,DUR,DOWN
2480       SETRU(J,1)=XTRU(I,1)
2490       SETRU(J,2)=XTRU(I,2)
2500       SEMAT(J,5)=PKOEGEN*(DBCMH+(1-DCOND)*DMH)/(DUR*DAA*(1.-DOWN))
2510       SEMAT(J,7)=CAD
2520       SEMAT(J,9)=COD
2530  998 CONTINUE
2540       JNEXT=JNEXT+K
2550  999 CONTINUE
2560       INEXT=INEXT+N
2570 1000 CONTINUE
2580*********************************************
2590*** "BUY" ADDITIONAL SPARES SO THAT PRODUCT ***
2600*** AVAILABILITY FOR ALL TRUS>=TARGAVAL ***
```

```
2610C*******************************************************
2620          KEY(1)=1
2630          MODE(1)=2
2640     CALL SORTL(AVTAB,NUMAVT,5,KEY,MODE,1,MAXAVT,1,LINK,CMAT,1,0)
2650          NUMPTR=0
2660     60 IF(AVI .GT. TARGAVAL) GO TO 65
2670          NUMPTR=NUMPTR+1
2680          RIMP=AVTAB(NUMPTR,2)
2690          IFLUPT=AVTAB(NUMPTR,3)
2700          TRUMAT(IFLUPT,15)=AVTAB(NUMPTR,4)
2710          TRUMAT(IFLUPT,16)=AVTAB(NUMPTR,5)
2720          TRUMAT(IFLUPT,17)=TRUMAT(IFLUPT,17)+1.
2730          TRUMAT(IFLUPT,1)=TRUMAT(IFLUPT,1)+UCTAB(IFLUPT)*M
2740 AVI=AVI*RIMP
2750 GOTO 60
2760 65 CONTINUE
2770C*************************************
2780C********** ESTABLISH SECUM ***********
2700C*************************************
2800          IF(J.EQ.0) GO TO 91
2810          JH=0
2820          DO 90 JE=1,J
2830          IF(XSE(JE).EQ."0") GO TO 90
2840          UFLU=0.
2850          USYS=0.
2860          JH=JH+1
2870          IF(JH.LE.50) GO TO 84
2880          PRINT 82
2890     82 FORMAT("REDIMENSION SECUM, XSECUM, SETAB")
2900          STOP
2910     84 XSECUM(JH)=XSE(JE)
2920          XSE(JE)="0"
2930          SCCUM(JH,4)=SEMAT(JE,5)
2940          JM=JE+1
2950          DO 80 JF=JM,J
2960          IF(XSE(JF).NE.XSECUM(JH)) GO TO 80
2970          XSE(JF)="0"
2980          SECUM(JH,4)=SECUM(JH,4)+SEMAT(JF,5)
2990          UFLU=1.
3000          IF(SETRU(JF,2).EQ.SETRU(JE,2)) GO TO 80
3010          USYS=1.
3020     80 CONTINUE
3030          SECUM(JH,5)=CEIL(SECUM(JH,4))
3040          C5Q=SECUM(JH,5)*SEMAT(JE,7)*(1.+PIUP*SEMAT(JE,9))
3050        IF(USYS.GT.0.) GO TO 89
3060        IF(UFLU.GT.0.) GO TO 87
3070          DO 86 JC=1,I
3080          IF(XTRU(JC,1).NE.SETRU(JE,1)) GO TO 86
3090          TRUMAT(JC,5)=TRUMAT(JC,5)+C5Q
3100           SETAB(JH,1)=1.
3110          SETAB(JH,2)=FLOAT(JC)
3120          GO TO 90
3130     86 CONTINUE
3140     87 DO 88 IQ=1,NSYS
```

```
      IF(XSYS(IQ).NE.SETRU(JE,2)) GO TO 88
      SYSMAT(IQ,5)=SYSMAT(IQ,5)+C5Q
       SETAB(JH,1)=2.
       SETAB(JH,2)=FLOAT(IQ)
      GO TO 90
   88 CONTINUE
   89 EQTOT(5)=EQTOT(5)+C5Q
       SETAB(JH,1)=3.
   90 CONTINUE
C*************************************
********* COMPUTE TRU COST *********
C*************************************
   91   CALL DETACH(10,ISTAT, )
        DO 101 IB=1,I
       DO 92 IC=1,7
       TRUMAT(IB,8)=TRUMAT(IB,8)+TRUMAT(IB,IC)
   92 CONTINUE
       TRUMAT(IB,8)=TRUMAT(IB,8)+TRUMAT(IB,20)
   101  CONTINUE
C*******************************************
C********* COMPUTE SYSTEM COST *************
C*******************************************
       DO 96 IK=1,NSYS
       DO 95 IL=1,I
       IF(XTRU(IL,2).NE.XSYS(IK)) GO TO 95
   STSMAT(IK,8)=SYSMAT(IK,8)+TRUMAT(IL,20)
       DO 94 IM=1,7
       SYSMAT(IK,IM)=SYSMAT(IK,IM)+TRUMAT(IL,IM)
   94 CONTINUE
   95 CONTINUE
   96 CONTINUE
       DO 99 JN=1,NSYS
        DO 97 JP=1,8
        SYSMAT(JN,13)=SYSMAT(JN,13)+SYSMAT(JN,JP)
   97 CONTINUE
   99 CONTINUE
C************************************************
C********* COMPUTE ATE COST *********
C************************************************
       DO 98 IN=1,NSYS
        TOTLSC=TOTLSC+SYSMAT(IN,13)
   98 CONTINUE
         TOTLSC=TOTLSC+EQTOT(5)
C*********************************
C********* PRINT OUTPUT *********
C*********************************
       CALL TADATE(DATE)
       CALL TTIME(ITIME)
       PRINT 112,DATE,ITIME/100000+10000
  112 FORMAT(//"RUN OF ",A8," -- ",I4," HOURS")
       IF(TOTLSC.LT.10**6) GO TO 121
       IF(TOTLSC.LT.10**9) GO TO 117
       PRINT 115,TOTLSC/10**9
  115 FORMAT(//"TOTAL LSC = $",F7.2," BILLION.")
```

```
3690      GO TO 140
3700  117 PRINT 119,TOTLSC/10**6
3710  119 FORMAT(//"TOTAL LSC = $",F7.2," MILLION.")
3720      GO TO 140
3730  121 PRINT 123,TOTLSC
3740  123 FORMAT(//"TOTAL LSC = $",F7.0)
3750C********************************************************************
3760C****** KC,KD,KE MUST AGREE WITH DIMENSIONS OF TRUMAT AND XTRU ******
3770C********************************************************************
3780  140 DO 132 KC=1,100
3790      DO 130 KD=1,20
3800  130 SORTRU(KC,KD)=TRUMAT(KC,KD)
3810      DO 131 KE=1,2
3820  131 SORTXTRU(KC,KE)=XTRU(KC,KE)
3830  132 CONTINUE
3840        KEY(1)=13
3850        MODE(1)=2
3860      CALL SORTL(SYSMAT,NSYS,15,KEY,MODE,1,30,1,LINK,XSYS,1,1)
3870 KEY(1)=8
3880 MODE(1)=2
3890      CALL SORTL(SORTRU,IMAX,20,KEY,MODE,1,100,1,LINK,SORTXTRU,2,1)
3900  141 PRINT 142
3910  142 FORMAT(/"DO YOU WANT AN EXPLANATION OF YOUR AVAILABLE ",
3920&     "OPTIONS?")
3930      READ 2003,CANS
3940      IF(CANS.NE."Y") GO TO 150
3950      PRINT 145
3960  145 FORMAT(/"OPTION 1 - TOTAL LSC BROKEN OUT BY EQUATION"/
3970&     "OPTION 2 - ALL SYSTEMS RANKED ON COST"/
3980&     "OPTION 3 - COST BREAKOUT BY EQUATION FOR A PARTICULAR SYSTEM"/
3990&     "OPTION 4 - COST RANKING OF TRUS FOR A PARTICULAR SYSTEM"/
4000&     "OPTION 5 - COST BREAKOUT BY EQUATION FOR A PARTICULAR TRU"/
4010&     "OPTION 6 - DETAILED SUPPORT EQUIPMENT ANALYSIS"/
4020&     "OPTION 7 - DETAILED SPARES ANALYSIS"/
4030&     "OPTION 8 - MAINTENANCE GENERATIONS ANALYSIS"/
4040&     "OPTION 9 - TRU WORK UNIT CODE/NOUN CROSS-REFERENCE"/
4050&     "OPTION 10 - STOP PROGRAM")
4060  150 PRINT 151
4070  151 FORMAT(/"WHICH OPTION?")
4080  155 READ:IANS
4090      IF(IANS.GT.10) GO TO 141
4100      GO TO (200,250,300,350,400,450,500,550,600,650),IANS
4110
4120C***************************************
4130C********* OUTPUT OPTION 1 *************
4140C***************************************
4150 200   DO 210 MP=1,8
4160      DO 210 MR=1,NSYS
4170  210 EQTOT(MP)=EQTOT(MP)+SYSMAT(MR,MP)
4180      PRINT 335
4190       PRINT 337,(EQTOT(MS),MS=1,5)
4200      PRINT 340
4210       PRINT 345,(EQTOT(MS),MS=6,8)
4220      GO TO 150
```

```
4230
4240C************************
4250C*** OUTPUT OPTION 2 ****
4260C************************
4270  250 PRINT 260
4280  260 FORMAT(10X,"SYSTEM",4X,"COST(IN MILLIONS)",4X,
4290&     "FRACTION OF TOTAL LSC")
4300      DO 280 IX=1,NSYS
4310       SYSMAT(IX,14)=SYSMAT(IX,13)/TOTLSC
4320       SYSCOST= SYSMAT(IX,13)/10**6
4330      PRINT 270,XSYS(IX),SYSCOST,SYSMAT(IX,14)
4340  270 FORMAT(11X,A5,F18.2,F19.2)
4350  280 CONTINUE
4360      GO TO 150
4370
4380C************************
4390C*** OUTPUT OPTION 3 ****
4400C************************
4410  300 PRINT 2006
4420  310 READ 2004,CANS
4430      DO 320 IE=1,NSYS
4440      IF(XSYS(IE).EQ.CANS) GO TO 330
4450  320 CONTINUE
4460      PRINT 2002
4470      GO TO 310
4480  330 PRINT  335
4490  335 FORMAT(/"EQUATION",10X,"#1",10X,"#2",10X,"#3",10X,"#4",10X,"#5")
4500       PRINT 337,(SYSMAT(IE,IG),IG=1,5)
4510 337   FORMAT(12X,5F12.0//)
4520      PRINT 340
4530 340   FORMAT("EQUATION",10X,"#6",10X,"#7",10X,"#8")
4540       PRINT 345,(SYSMAT(IE,ID),ID=6,8)
4550 345   FORMAT(12X,3F12.0//)
4560      GO TO 150
4570
4580C************************
4590C*** OUTPUT OPTION 4 ****
4600C************************
4610  350 PRINT 2006
4620  355 READ 2004,CANS
4630      DO 360 IP=1,NSYS
4640      IF(XSYS(IP).NE.CANS) GO TO 360
4650
4660      GO TO 365
4670  360 CONTINUE
4680      PRINT 2002
4690      GO TO 355
4700  365 PRINT:"HOW MANY TRUS TO BE INCLUDED IN RANKING?"
4710      READ:IANS
4720      PRINT 370
4730  370 FORMAT(49X,"FRACTION OF"/16X,"TRU",12X,"COST",14X,
4740&     "SYSTEM COST"//)
4750      PCTG=0.
4760      IR=0
```

```
4770       DO 380 IY=1,I
4780       IF(SORTXTRU(IY,2).NE.CANS) GO TO 380
4790       IR=IR+1
4800       PCT=SORTRU(IY,8)/SYSMAT(IP,13)
4810       PCTG=PCTG+PCT
4820       PRINT 375,IR,SORTXTRU(IY,1),SORTRU(IY,8),PCT
4830   375 FORMAT(I9,A11,F18.0,F18.2)
4840       IF(IR.EQ.IANS) GO TO 385
4850   380 CONTINUE
4860       IF(IR.EQ.IANS) GO TO 385
4870       PRINT: "THESE ARE ALL THE TRUS IN THIS SYSTEM."
4880       IANS=IR
4890   385 IPCTG=PCTG*100
4900       PRINT 390,IANS,IPCTG
4910   390 FORMAT(/"CONTRIBUTION OF TOP",I3,"TRUS=",I3,
4920&      " PER CENT OF TOTAL SYSTEM COST.")
4930       PRINT 395,SYSMAT(IP,13)/10**6
4940   395 FORMAT("SYSTEM COST = $",F8.2," MILLION.")
4950       GO TO 150
4960
4970C*************************
4980C*** OUTPUT OPTION 5 ****
4990C*************************
5000   400 PRINT 2008
5010   405 READ 2004,CANS
5020       DO 410 IU=1,I
5030       IF(SORTXTRU(IU,1).NE.CANS) GO TO 410
5040       GO TO 415
5050   410 CONTINUE
5060       PRINT 2002
5070       GO TO 405
5080   415 PRINT 420
5090   420 FORMAT(/"EQUATION",7X,"#1",12X,"#2",12X,"#3",12X,"#4")
5100       PRINT 425,(SORTRU(IU,IV),IV=1,4)
5110   425 FORMAT(7X,4F14.0//)
5120       PRINT 430
5130 430    FORMAT("EQUATION",7X,"#5",12X,"#6",12X,"#7",12X,"#8")
5140        PRINT 435,(SORTRU(IU,JL),JL=5,7),SORTRU(IU,20)
5150   435 FORMAT(7X,4F14.0)
5160       GO TO 150
5170
5180C*************************
5190C*** OUTPUT OPTION 6 ****
5200C*************************
5210   450 CONTINUE
5220       PRINT:"     COL 1 - SE IDENTIFICATION"
5230       PRINT:"     COL 2 - FRACTIONAL SE RQMT-BASE (COMPUTED)"
5240       PRINT:"     COL 3 - TOTAL SE RQMT-BASE (INTEGERIZED)"
5250       PRINT:"     COL 4 - FRACTIONAL SE RQMT-DEPOT (COMPUTED)"
5260       PRINT:"     COL 5 - TOTAL SE RQMT-DEPOT (INTEGERIZED)"
5270       PRINT 460
5280   460 FORMAT(/6X,"1",19X,"2",9X,"3",12X,"4",9X,"5"//)
5290       DO 480 JK=1,JR
5300       PRINT 470,XSECUM(JK),(SECUM(JK,JR),JR=2,5)
```

```
5310  470 FORMAT(1X,A20,F8.2,F9.0,F14.2,F9.0)
5320  480 CONTINUE
5330      GO TO 150
5340
5350C     **************************************
5360C     ********** OUTPUT OPTION 7 *********
5370C     **************************************
5380  500 PRINT 510
5390  510 FORMAT(28X,"TRUS"//4X,"WUC",7X,"DMDMEAN",8X,"X30",8X,
54006      "AV",11X,"STK",8X,"DPIPE",4X,"TOTCOND"//)
5410     DO 530 MU=1,I
5420      PRINT 520,XTRU(MU,1),(TRUMAT(MU,MX),MX=14,19)
5430 520 FORMAT(3X,A5,2F12.2,F12.4,3F12.0)
5440 530 CONTINUE
5450     PRINT 540,AVI
5460 540 FORMAT(1X//18X,"SYSTEM AVAILABILITY",F5.3)
5470     GO TO 150
5480C*****************************
5490C******* OUTPUT OPTION 8 *******
5500C*******************************
5510  550 PRINT 560
5520  560 FORMAT(31X,"PEAK",25X,"TOTAL"/20X,"PEAK",5X,"OFF-EQUIP",10X,
55306     "TOTAL",5X,"OFF-EQUIP"/7X,"WUC",10X,"GENS",7X,"GENS",14X,"GENS",
55406     8X,"GENS"//)
5550      DO 570 MV=1,I
5560      PRINT 565,XTRU(MV,1),(TRUMAT(MV,MY),MY=9,12)
5570  565 FORMAT(6X,A5,6X,F8.2,F11.2,F18.2,F12.2)
5580  570 CONTINUE
5590      GO TO 150
5600
5610C*************************************
5620C****** OUTPUT OPTION 9 *************
5630C*************************************
5640  600 PRINT 610
5650  610 FORMAT(/3X,"WUC",7X,"NOUN"//)
5660      DO 625 JZ=1,I
5670      PRINT 620,XTRU(JZ,1),TRUNOUN(JZ)
5680  620 FORMAT(2X,A5,3X,A60)
5690  625 CONTINUE
5700      GO TO 150
5710
5720 2002 FORMAT("IMPROPER IDENTIFICATION--RETYPE")
5730 2003 FORMAT(A1)
5740 2004 FORMAT(A5)
5750 2006 FORMAT("SYSTEM IDENTIFICATION?")
5760 2008 FORMAT("TRU IDENTIFICATION?")
5770
5780  650 STOP
5790      END
5800
5810C*********************************************************
5820C********* FUNCTION TO INTEGERIZE ROUNDING UP ***********
5830C*********************************************************
5840      FUNCTION CEIL(X)
```

```
5850      Y=AINT(X)
5860      Z=X-Y
5870      IF(Z),,1
5880      CEIL=X
5890      RETURN
5900    1 CEIL=Y+1.
5910      RETURN
5920      END
5930C***********************************************************************
5940 SUBROUTINE SORTL(A,NREC,NWPR,KEY,MODE,NKEY,ID,IP,LINK,CMAT,ICCOL,ICIND)
5950C***********************************************************************
5960C A GENERAL PURPOSE SORTING SUBROUTINE USING LINK ADDRESSING
5970C:A          ARAAY OF SIZE NREC BY NWPR WHOSE ROWS COMPRISE
5980C:           THE DATA RECORDS TO  BE SORTED
5990C:
6000C:NREC       NUMBER OF RECORDS=NUMBER OF ROWS OF A
6010C:
6020C:NWPR       NUMBZR OF WORDS/RECORD=NUMBER OF COLUMNS OF A
6030C:
6040C:KEY        ARRAY OF SIZE NKEY WHOSE ELEMENTS ARE POINTERS TO
6050C:           THE COLUMNS OF A CONTAINING THE SORT KEYS
6060C:
6070C:MODE       ARRAY OF SIZE NKEY WHOSE ELEMENTS DEFINE THE
6080C:           ORDERING RELATION PLACED ON EACH KEY
6090C:           -2 INCREASING,UNSIGNED ORDER
6100C:           -1 INCREASING,SIGNED ORDER
6110C:           +1 DECREASING,UNSIGNED ORDER
6120C:           +2 DECREASING,SIGNED ORDER
6130C:
6140C:NKEY       NUMBER OF KEYS=SIZE OF ARRAYS KEY AND MODE
6150C:
6160C:ID         FIRST DIMENSION OF A IN THE PROGRAM CALLING UNIT
6170C:
6180C:IP         IF IP=0 THE RECORDS REMAIN IN THEIR ORIGINAL LOCATION,
6190C:           OTHERWISE, THE RECORDS ARE MOVED INTO THE DESIRED
6200C:           ORDER FOLLOWING THE SORT
6210C:
6220C:LINK       OUTPUT ARRAY OF SIZE NREC WHOSE ELEMENTS ARE
6230C:           POINTERS TO THE RECORDS IN A IN SORTED SEQUENCE
6240C:
6250C:CMAT       CHARACTER ARRAY OF SIZE NREC BY ICCOL WHOSE ROWS
6260C:           ARE MOVED IN CONJUNCTION WITH THE ROWS OF ARRAY A
6270C:
6280C:ICCOL      NUMBER OF COLUMNS OF CHARACTER VALUES IN ARRAY CMAT;
6290C:           EACH VALUE HAS 5 CHARACTERS
6300C:
6310C:ICIND      "FLAG" VALUE FOR SORTING CMAT;
6320C:           =0 DO NOT OPERATE ON CMAT
6330C:           NOT=0 REARRANGE THE VALUES IN CMAT
6340      DIMENSION A(ID,NWPR),KEY(NKEY),MODE(NKEY),LINK(NREC)
6350      INTEGER A,TEMP(100)
6360      CHARACTER CTEMP*5(20)
6370      CHARACTER CMAT*5(ID,ICCOL)
6380      LOGICAL EQV,P,Q
```

```
      EQV(P,Q) = (P.AND.Q).OR.(.NOT.(P.OR.Q))
      NROW=NREC
      NCOL=NWPR
C
C INITIALIZE LINKS
C
      DO 10 I=1,NROW
   10 LINK(I)=I
      IF (NROW.EQ.1) RETURN
C
C FORM INITIAL INCREMENT
C
      M1=(NROW+5)/6
      M=1
   20 M=2*M
      IF (M.LT.M1) GO TO 20
      M=M-1
C
C BEGIN NEXT SORT PASS
C
   30 M1=M+1
      DO 100 J=M1,NROW
      LJ=LINK(J)
      I=J-M
C
C COMPARE KEYS IN RECORDS LINK(I) AND LINK(J)
C
   40 LI=LINK(I)
      DO 50 L=1,NKEY
      K=KEY(L)
      KI=A(LI,K)
      KJ=A(LJ,K)
      IF (EQV(KI.LT.0,KJ.GE.0)) GO TO 60
      IF (KI.NE.KJ) GO TO 70
   50 CONTINUE
   60 IF(EQV(KI.LT.0,KJ.GE.0))GOTO 90
      GO TO 80
   70 IF (EQV(KI.LT.KJ,MODE(L).LT.0)) GO TO 90
C
C RECORDS LINK(II), LINK(J) OUT OF ORDER
C
   80 II = I+M
      LINK(II)=LINK(I)
      I=I-M
      IF (I.GT.0) GO TO 40
C
C  RECORDS LINK(I), LINK(J) ALREADY IN ORDER
C
   90 II = I+M
      LINK(II)=LJ
  100 CONTINUE
C
C END OF SORT PASS
C
```

```
6930       IF (M.GT.15) M=M/2
6940       M=M/2
6950       IF (M.NE.0) GO TO 30
6960C
6970C END OF SORT, TEST WHICH OPTION
6980C
6990       IF (IP.EQ.0) RETURN
7000C
7010C REARRANGE RECORDS IN A ACCORDING TO LINK
7020C
7030       DO 150 I=1,NROW
7040       IF (LINK(I).EQ.I) GO TO 150
7050       DO 110 K=1,NCOL
7060       TEMP(K)=A(I,K)
7070   110 CONTINUE
7080       IF(ICIND.EQ.0)  GO TO 117
7090       DO 115 I115=1,ICCOL
7100       CTEMP(I115)=CMAT(I,I115)
7110   115 CONTINUE
7120   117 CONTINUE
7130       J=I
7140C
7150C  BEGIN CYCLE
7160C
7170   120 LJ=LINK(J)
7180       DO 130 K=1,NCOL
7190   130 A(J,K) =A(LJ,K)
7200       IF(ICIND.EQ.0)  GO TO 137
7210       DO 135 I135=1,ICCOL
7220       CMAT(J,I135)=CMAT(LJ,I135)
7230   135 CONTINUE
7240   137 CONTINUE
7250       LINK(J)=J
7260       J=LJ
7270       IF (LINK(J).NE.I) GO TO 120
7280C
7290C END OF CYCLE
7300C
7310       DO 140 K=1,NCOL
7320   140 A(J,K) =TEMP(K)
7330       IF(ICIND.EQ.0)  GO TO 147
7340       DO 145 I145=1,ICCOL
7350       CMAT(J,I145)=CTEMP(I145)
7360   145 CONTINUE
7370   147 CONTINUE
7380       LINK(J)=J
7390   150 CONTINUE
7400       RETURN
7410       END
```

APPENDIX E

SAMPLE DATA BASE

DATA FILE FORMAT

Level	Source	Variables
ATE SYSTEM	GOVERNMENT	LN* TOH POH PIUP M OS NSYS UEBASE TARGAVAL
	GOVERNMENT	LN OSTCON OSTOS IMC RMC PSC PSO TRB TRD
	GOVERNMENT	LN TD SA MRO MRF SR TR PMB PMD CARF
SUBSYSTEM	CONTRACTOR	LN XYS SYSNOUN
	CONTRACTOR	LN BCA DCA DPA N
	CONTRACTOR	LN H JJ SMH SMI TCB TCD TE
	CONTRACTOR	LN BLR DLR DMR DAA DRCTC DRCTO
	CONTRACTOR	LN SCI SCMH CIVLR CASYS
TEST REPLACEABLE UNIT	CONTRACTOR	LN XTRU TRUNOUN
	CONTRACTOR	LN QPA UC MTBF RIP DCOND DMC
	CONTRACTOR	LN PAMH IMH RMH DBCMH DMH W PP K
	CONTRACTOR	LN TRUCI TRUCMH CILR CIILR FICR CI CII CIV FIICR FIVCR CATRU
SUPPORT EQUIPMENT	CONTRACTOR	LN XSE CAD COD DUR DOWN

*LN is the data line number in the data file.

```
1000 40000 20000 10 9 .3 3 2 .9
1010 .4 .5 57 127 .72 1.5 .14 .15
1020 200 8.4 .08 .24 .25 .16 1728 1728 .25
1030 FAA00 COMPUTER TEST STA GSM231
1040 10000 20000 5000 35
1050 100 200 5 120 10000 10000 6000
1060 16 30 8 168 1.4 1.9
1070 90 20 16 1
1080 FAAA0 PANEL POWER DIST
1090 7 1800 800 .6 .05 .1
1100 1 1 2 2 2 10 0 .5 1
1110 0 0 0 0 0 0 0 0 0 0 0
1120 TESTSET1 5000 .1 .2 .1
1130 FAAB0 MAINTENANCE TEST PACK
1140 1 2000 1000 .9 .02 .1
1150 1 1 2 2 2 5 0 .5 0
1160 120 20 30 16 20 0 1 0 8 0 1
1170 FAAC0 PANEL LRU
1180 2 800 700 .2 .1 .2
1190 1 1 2 2 2 2 0 .5 1
1200 90 10 30 16 5 0 1 0 5 0 1
1210 TESTSET1 5000 .1 .2 .1
1220 FAAE0 CARD FILE AUX B
1230 12 1000 500 .05 .1 .2
1240 1 1 2 2 2 2 0 .5 1
1250 90 10 30 16 5 0 1 0 5 0 1
1260 TESTSET1 5000 .1 .2 .1
1270 FAAG0 CONVERTER ASSY TRANS
1280 16 1200 600 .2 .1 .1
1290 1 1 2 2 2 2 0 .5 1
1300 180 10 30 16 10 0 1 0 5 0 1
1310 TESTSET2 10000 .1 .2 .1
1320 FAAJ0 CARDFILE AUX A
1330 2 2500 800 .2 .1 .1
1340 1 1 2 2 2 2 0 .5 1
1350 90 10 30 16 5 0 1 0 5 0 1
1360 TESTSET1 5000 .1 .2 .1
1370 FAAL0 GENERATOR SIGNAL WAVE
1380 17 900 550 .2 .1 .1
1390 1 1 2 2 2 2 0 .5 1
1400 90 10 30 16 5 0 1 0 5 0 1
1410 TESTSET1 5000 .1 .2 .1
1420 FAAP0 CONVERTER SIGNAL
1430 10 900 650 .1 .05 .1
1440 1 1 2 2 2 2 0 .5 1
```

```
1450 90 10 30 16 5 0 1 0 5 0 1
1460 TESTSET1 5000 .1 .2 .1
1470 FAARO GENERATOR PRESSURE
1480 14 500 400 .1 .05 .1
1490 1 1 2 2 2 2 0 .5 1
1500 0 0 0 0 0 0 0 0 0 0 0
1510 TESTSET3 10000 .1 .2 .1
1520 FAAUO PRESSURE SUPPLY
1530 5 200 500 .1 .05 .1
1540 1 1 2 2 2 2 0 .5 1
1550 0 0 0 0 0 0 0 0 0 0 0
1560 TESTSET3 10000 .1 .2 .1
1570 FAAWO IMPEDENCE UNIT
1580 17 800 400 .1 .05 .1
1590 1 1 2 2 2 2 0 .5 1
1600 90 10 30 16 5 0 1 0 5 0 1
1610 TESTSET1 5000 .1 .2 .1
1620 FAAYO PANEL AUX DIGITAL
1630 17 600 550 .1 .05 .1
1640 1 1 2 2 2 2 0 .5 1
1650 120 10 30 16 5 0 1 0 5 0 1
1660 TESTSET1 5000 .1 .2 .1
1670 FAA2O POWER SUPPLY PRE
1680 6 400 850 .1 .05 .1
1690 1 1 2 2 2 2 0 .5 1
1700 180 10 30 16 5 0 1 0 5 0 1
1710 TESTSET2 10000 .1 .2 .1
1720 FAA5O POWER SUPPLY ASSY
1730 6 350 900 .1 .05 .1
1740 1 1 2 2 2 2 0 .5 1
1750 0 0 0 0 0 0 0 0 0 0 0
1760 TESTSET2 10000 .1 .2 .1
1770 FAA7O SYNCHRO UNIT
1780 8 700 600 .1 .05 .1
1790 1 1 2 2 2 2 0 .5 0
1800 120 10 30 16 5 0 1 0 5 0 1
1810 FABO PANEL CONTROL
1820 41 1000 1100 .1 .05 1
1830 1 1 2 2 2 2 0 .5 1
1840 180 10 30 16 5 0 1 0 5 0 1
1850 TESTSET1 5000 .1 .2 .1
1860 FABJO PRINTER
1870 9 500 600 .1 .05 1
1880 1 1 2 2 2 2 0 .5 1
```

```
1890 120 10 30 16 5 0 1 0 5 0 1
1900 TESTSET1 5000 .1 .2 .1
1910 FABKO MULTIMETER DIGITAL
1920 14 800 1000 .1 .05 1
1930 1 1 2 2 2 2 0 .5 1
1940 180 10 30 16 5 0 1 0 5 0 1
1950 TESTSET1 5000 .1 .2 .1
1960 FABMO OSCILLOSCOPE
1970 13 400 1000 .1 .05 .1
1980 1 1 2 2 2 2 0 .5 0
1990 180 10 30 16 5 0 1 0 5 0 1
2000 FABRO READER PUNCH TAPE
2010 10 800 400 .1 .05 .1
2020 1 1 2 2 2 2 0 .5 1
2030 0 0 0 0 0 0 0 0 0 0 0
2040 TESTSET1 5000 .1 .2 .1
2050 FABTO ANALYZER SAMPLING
2060 11 1200 500 .1 .05 .1
2070 1 1 2 2 2 2 0 .5 1
2080 180 10 30 16 5 0 1 0 5 0 1
2090 TESTSET1 5000 .1 .2 .1
2100 FABZO COUPLER DATA
2110 12 300 100 .1 .05 .1
2120 1 1 2 2 2 2 0 .5 1
2130 120 10 30 16 5 0 1 0 5 0 1
2140 TESTSET1 5000 .1 .2 .1
2150 FAB30 POWR SUPPLY ASSY
2160 9 800 1100 .1 .05 .1
2170 1 1 2 2 2 2 0 .3 1
2180 0 0 0 0 0 0 0 0 0 0 0
2190 TESTSET1 5000 .1 .2 .1
2200 FAB50 TRANSFORMER POWER
2210 5 300 1100 .1 .05 .1
2220 1 1 2 2 2 2 0 .5 1
2230 0 0 0 0 0 0 0 0 0 0 0
2240 TESTSET2 10000 .1 .2 .1
2250 FAB70 COUNTER DIGITAL
2260 14 500 900 .1 .05 .1
2270 1 1 2 2 2 2 0 .5 1
2280 180 10 30 16 5 0 1 0 5 0 1
2290 TESTSET1 5000 .1 .05 .1
2300 FACDO SWITCHING COMPLEX
2310 60 500 1500 .1 .05 .1
2320 1 1 2 2 2 2 0 .5 1
```

```
2330 180 10 30 16 5 0 1 0 5 0 1
2340 TESTSET4 20000 .1 .05 .1
2350 FACK0 ADAPTER
2360 1 1500 1200 .1 .05 .1
2370 1 1 2 2 2 2 0 .5 1
2380 0 0 0 0 0 0 0 0 0 0 0 0
2390 TESTSET4 20000 .1 .05 .1
2400 FACP0 SCOSBY TABLE
2410 3 2000 1500 .1 .05 .1
2420 1 1 2 2 2 2 0 .5 0
2430 0 0 0 0 0 0 0 0 0 0 0 0
2440 FACR0 RATE OF TURN SYSTEM
2450 1 1600 1200 .1 .05 .1
2460 1 1 2 2 2 2 0 .5 1
2470 120 10 30 16 5 0 1 0 5 0 1
2480 TESTSET1 5000 .1 .05 .1
2490 FAC40 TIME BASE DUAL
2500 1 600 1500 .1 .05 .1
2510 1 1 2 2 2 2 0 .5 1
2520 120 10 30 16 5 0 1 0 5 0 1
2530 TESTSET1 5000 .1 .05 .1
2540 FACT0 AMP DUAL TRACE
2550 4 1000 1200 .1 .05 .1
2560 1 1 2 2 2 2 0 .5 1
2570 120 10 30 16 5 0 1 0 5 0 1
2580 TESTSET1 5000 .1 .05 .1
2590 FADB0 EXT CONTROL PANEL
2600 9 3000 800 .1 .05 .1
2610 1 1 2 2 2 2 0 .5 1
2620 120 10 30 16 5 0 1 0 5 0 1
2630 TESTSET1 5000 .1 .05 .1
2640 FADD0 SAMPLING HEAD
2650 3 400 1200 .1 .05 .1
2660 1 1 2 2 2 2 0 .5 1
2670 120 10 30 16 5 0 1 0 5 0 1
2680 TESTSET1 5000 .1 .05 .1
2690 FADK0 BATT TEST SET
2700 3 400 2000 .1 .05 .1
2710 1 1 2 2 2 2 0 .5 0
2720 0 0 0 0 0 0 0 0 0 0 0 0
2730 FAEA0 MASS STORAGE UNIT
2740 1 2000 500 .1 .05 .1
2750 1 1 2 2 2 2 0 .5 1
2760 0 0 0 0 0 0 0 0 0 0 0 0
```

```
2770 TESTSET1 5000 .1 .05 .1
2780 FAMOO DISPLAYS TEST STATION
2790 10000 20000 5000 2
2800 100 200 5 120 10000 10000 6000
2810 16 30 8 168 1.4 1.9
2820 9C 20 16 1
2830 FAMAO PANEL POWER DISTRIB
2840 7 1800 800 .6 .05 .1
2850 1 1 2 2 2 2 0 .5 1
2860 0 0 0 0 0 0 0 0 0 0 0
2870 TESTSET1 5000 .1 .2 .1
2880 FAMCO GENERATOR PULSE
2890 1 2000 1000 .9 .02 .1
2900 1 1 2 2 2 2 0 .5 0
2910 1 20 20 30 16 20 0 1 0 8 0 1
2920 FAYOO MICROWAVE TEST STATION
2930 5000 20000 5000 1
2940 100 200 5 120 10000 6000 6000
2950 16 30 6 168 1.4 1.9
2960 120 20 16 1
2970 FAYBO MAINT TEST PACK.
2980 1 2000 1500 .6 .05 .1
2990 1 1 2 2 2 2 0 .5 1
3000 1 20 20 30 16 30 0 1 0 8 0 1
3010 TESTSET4 20000 .1 .05 .1
```

APPENDIX F

SAMPLE OUTPUT

```
RUN OF 08/23/79 -- 1312 HOURS

TOTAL LSC = $  15.93 MILLION.

DO YOU WANT AN EXPLANATION OF YOUR AVAILABLE OPTIONS?
=YES

OPTION 1 - TOTAL LSC BROKEN OUT BY EQUATION
OPTION 2 - ALL SYSTEMS RANKED ON COST
OPTION 3 - COST BREAKOUT BY EQUATION FOR A PARTICULAR SYSTEM
OPTION 4 - COST RANKING OF TRUS FOR A PARTICULAR SYSTEM
OPTION 5 - COST BREAKOUT BY EQUATION FOR A PARTICULAR TRU
OPTION 6 - DETAILED SUPPORT EQUIPMENT ANALYSIS
OPTION 7 - DETAILED SPARES ANALYSIS
OPTION 8 - MAINTENANCE GENERATIONS ANALYSIS
OPTION 9 - TRU WORK UNIT CODE/NOUN CROSS-REFERENCE
OPTION 10 - STOP PROGRAM

WHICH OPTION?
=1

EQUATION            #1          #2          #3           #4          #5
               4681700.     328285.    1415602.      79154.    7700000.

EQUATION            #6          #7          #8
                 69771.     219805.    1439641.


WHICH OPTION?
=2
         SYSTEM    COST(IN MILLIONS)     FRACTION OF TOTAL LSC
          FAA00             9.03                  0.57
          FAM00             0.46                  0.03
          FAY00             0.26                  0.02

WHICH OPTION?
=3
SYSTEM IDENTIFICATION?
=FAA00

EQUATION            #1          #2          #3           #4          #5
               4542100.     271439.    1404636.      72905.    1150000.

EQUATION            #6          #7          #8
                 52947.      98170.    1438506.


WHICH OPTION?
=
```

```
 3
SYSTEM IDENTIFICATION?
=FAMOO

EQUATION          #1          #2          #3          #4          #5
               115600.      29952.      10175.       4166.     230000.

EQUATION          #6          #7          #8
                 8618.      60966.        649.


WHICH OPTION?
=3
SYSTEM IDENTIFICATION?
=FAYOO

EQUATION          #1          #2          #3          #4          #5
                24000.      26894.        791.       2083.     140000.

EQUATION          #6          #7          #8
                 8206.      60668.        487.


WHICH OPTION?
=4
SYSTEM IDENTIFICATION?
=FAYOO
HOW MANY TRUS TO BE INCLUDED IN RANKING?
=1
                                                FRACTION OF
              TRU             COST              SYSTEM COST

       1     FAYBO            27150.               0.10

CONTRIBUTION OF TOP  1TRUS= 10 PER CENT OF TOTAL SYSTEM COST.
SYSTEM COST = $    0.26 MILLION.

WHICH OPTION?
=4
SYSTEM IDENTIFICATION?
=FAMOO
HOW MANY TRUS TO BE INCLUDED IN RANKING?
=2
                                                FRACTION OF
              TRU             COST              SYSTEM COST

       1     FAMAO           109256.               0.24
       2     FAMCO            24730.               0.05

CONTRIBUTION OF TOP  2TRUS= 29 PER CENT OF TOTAL SYSTEM COST.
SYSTEM COST = $    0.46 MILLION.

WHICH OPTION?
=
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 4
SYSTEM IDENTIFICATION?
=FAA00
HOW MANY TRUS TO BE INCLUDED IN RANKING?
=35
                                                    FRACTION OF
                TRU                COST             SYSTEM COST

         1      FAB0              872462.               0.10
         2      FABZ0             623834.               0.07
         3      FAAW0             553162.               0.06
         4      FACD0             501133.               0.06
         5      FADB0             447935.               0.05
         6      FAAL0             447163.               0.05
         7      FAAE0             432825.               0.05
         8      FAAG0             412979.               0.05
         9      FABT0             374481.               0.04
        10      FAAY0             348833.               0.04
        11      FABK0             294701.               0.03
        12      FABR0             264964.               0.03
        13      FAAP0             264564.               0.03
        14      FAAR0             251877.               0.03
        15      FABJ0             219627.               0.02
        16      FAA70             178966.               0.02
        17      FAB70             170591.               0.02
        18      FABM0             137139.               0.02
        19      FAAA0             109697.               0.01
        20      FAAJ0             107316.               0.01
        21      FAB30              99230.               0.01
        22      FACT0              81154.               0.01
        23      FAA20              73898.               0.01
        24      FACP0              70586.               0.01
        25      FAEA0              70586.               0.01
        26      FAAC0              60149.               0.01
        27      FAAS0              45758.               0.01
        28      FAAU0              45396.               0.01
        29      FADD0              40636.               0.00
        30      FACK0              40459.               0.00
        31      FAAB0              35444.               0.00
        32      FACR0              34001.               0.00
        33      FABS0              30180.               0.00
        34      FAC40              22779.               0.00
        35      FADK0              19840.               0.00

CONTRIBUTION OF TOP 35TRUS= 86 PER CENT OF TOTAL SYSTEM COST.
SYSTEM COST = $    9.03 MILLION.

WHICH OPTION?
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```

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 5
TRU IDENTIFICATION?
=FABO

EQUATION        #1              #2              #3              #4
             361000.          15373.        339138.           2083.

EQUATION        #5              #6              #7              #8
                  0.           2838.          2380.         149650.

WHICH OPTION?
=6
    COL 1 - SE IDENTIFICATION
    COL 2 - FRACTIONAL SE RQMT-BASE (COMPUTED)
    COL 3 - TOTAL SE RQMT-BASE (INTEGERIZED)
    COL 4 - FRACTIONAL SE RQMT-DEPOT (COMPUTED)
    COL 5 - TOTAL SE RQMT-DEPOT (INTEGERIZED)

   1                     2           3             4          5

TESTSET1                 0.          0.         277.89      278.
TESTSET2                 0.          0.          21.34       22.
TESTSET3                 0.          0.          23.21       24.
TESTSET4                 0.          0.          84.87       85.

WHICH OPTION?
=
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                                TRUS

  WUC         DMDMEAN           XBO          AV               STK           DPIPE      TOTCOND

  FAAAO         0.74           0.01       0.9959               3.             23.           2.
  FAABO         0.02           0.00       0.9999               1.              1.           1.
  FAACO         0.49           0.00       0.9991               3.             15.           3.
  FAAEO         4.84           0.01       0.9967              11.            142.          21.
  FAAGO         4.53           0.01       0.9946              10.            133.          19.
  FAAJO         0.42           0.01       0.9948               2.             13.           2.
  FAALO         5.25           0.00       0.9977              12.            154.          22.
  FAAPO         2.94           0.00       0.9977               8.             91.           7.
  FAARO         6.69           0.00       0.9988              15.            207.          14.
  FAAUO         1.91           0.00       0.9995               7.             59.           4.
  FAAWO         8.12           0.01       0.9963              16.            251.          17.
  FAAYO         5.91           0.01       0.9975              13.            183.          13.
  FAA2O         1.35           0.00       0.9984               5.             42.           3.
  FAA5O         1.27           0.00       0.9988               5.             40.           3.
  FAA7O         2.55           0.01       0.9968               7.             79.           6.
  FABO          7.12           0.01       0.9944              14.            220.          15.
  FABJO         2.87           0.00       0.9981               8.             89.           6.
  FABKO         2.68           0.00       0.9988               8.             83.           6.
  FABMO         2.48           0.00       0.9993               8.             77.           6.
  FABRO         4.78           0.01       0.9971              11.            148.          10.
  FABTO         4.20           0.01       0.9970              10.            130.           9.
  FABZO        22.93           0.00       0.9985              38.            707.          48.
  FAB3O         1.56           0.01       0.9966               5.             49.           4.
  FAB5O         0.87           0.00       0.9988               4.             27.           2.
  FAB7O         2.97           0.00       0.9975               8.             92.           7.
  FACDO         7.64           0.00       0.9980              16.            236.          16.
  FACKO         0.16           0.00       0.9997               2.              5.           1.
  FACPO         0.38           0.01       0.9961               2.             12.           1.
  FACRO         0.16           0.01       0.9940               1.              5.           1.
  FAC4O         0.13           0.00       0.9998               2.              4.           1.
  FACTO         0.64           0.00       0.9976               3.             20.           2.
  FADBO         2.15           0.03       0.9844               5.             67.           5.
  FADDO         0.48           0.00       0.9992               3.             15.           1.
  FADKO         0.29           0.00       0.9999               3.              9.           1.
  FAEAO         0.38           0.01       0.9961               2.             12.           1.
  FAMAO         0.74           0.01       0.9959               3.             23.           2.
  FAMCO         0.02           0.00       0.9999               1.              1.           1.
  FAYBO         0.06           0.00       0.9992               1.              2.           1.

                    SYSTEM AVAILABILITY0.903

WHICH OPTION?
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8
                              PEAK                      TOTAL
                 PEAK      OFF-EQUIP         TOTAL    OFF-EQUIP
     WUC         GENS        GENS            GENS       GENS

    FAAA0        38.89       15.56           77.78      31.11
    FAAB0         4.44        0.44            8.89       0.89
    FAAC0        12.70       10.16           25.40      20.32
    FAAE0       106.67      101.33          213.33     202.67
    FAAG0       118.52       94.81          237.04     189.63
    FAAJ0        11.11        8.89           22.22      17.78
    FAAL0       137.37      109.90          274.75     219.80
    FAAP0        68.38       61.54          136.75     123.08
    FAAR0       155.56      140.00          311.11     280.00
    FAAU0        44.44       40.00           88.89      80.00
    FAAW0       188.89      170.00          377.78     340.00
    FAAY0       137.37      123.64          274.75     247.27
    FAA20        31.37       28.24           62.75      56.47
    FAA50        29.63       26.67           59.26      53.33
    FAA70        59.26       53.33          118.52     106.67
    FAB0        165.66      149.09          331.31     298.18
    FABJ0        66.67       60.00          133.33     120.00
    FABK0        62.22       56.00          124.44     112.00
    FABM0        57.78       52.00          115.56     104.00
    FABR0       111.11      100.00          222.22     200.00
    FABT0        97.78       88.00          195.56     176.00
    FABZ0       533.33      480.00         1066.67     960.00
    FAB30        36.36       32.73           72.73      65.45
    FAB50        20.20       18.18           40.40      36.36
    FAB70        69.14       62.22          138.27     124.44
    FACD0       177.78      160.00          355.56     320.00
    FACK0         3.70        3.33            7.41       6.67
    FACP0         8.89        8.00           17.78      16.00
    FACR0         3.70        3.33            7.41       6.67
    FAC40         2.96        2.67            5.93       5.33
    FACT0        14.81       13.33           29.63      26.67
    FADB0        50.00       45.00          100.00      90.00
    FADD0        11.11       10.00           22.22      20.00
    FADK0         6.67        6.00           13.33      12.00
    FAEA0         8.89        8.00           17.78      16.00
    FAMA0        38.89       15.56           77.78      31.11
    FAMC0         4.44        0.44            8.89       0.89
    FAYB0         2.96        1.19            5.93       2.37

WHICH OPTION?
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9

 WUC        NOUN

FAAA0   PANEL
FAAB0   MAINTENANCE
FAAC0   PANEL
FAAE0   CARD
FAAG0   CONVERTER
FAAJ0   CARDFILE
FAAL0   GENERATOR
FAAP0   CONVERTER
FAAR0   GENERATOR
FAAU0   PRESSURE
FAAW0   IMPEDENCE
FAAY0   PANEL
FAA20   POWER
FAA50   POWER
FAA70   SYNCHRO
FAB0    PANEL
FABJ0   PRINTER
FABK0   MULTIMETER
FABM0   OSCILLOSCOPE
FABR0   READER
FABT0   ANALYZER
FABZ0   COUPLER
FAB30   POWR
FAB50   TRANSFORMER
FAB70   COUNTER
FACD0   SWITCHING
FACK0   ADAPTER
FACP0   SCOSBY
FACR0   RATE
FAC40   TIME
FACT0   AMP
FADB0   EXT
FADD0   SAMPLING
FADK0   BATT
FAEA0   MASS
FAMA0   PANEL
FAMC0   GENERATOR
FAYB0   MAINT

WHICH OPTION?
•10

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