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The research objective was to show weapon system availability as a critical factor that must be evaluated as part of the first Life Cycle Cost (LCC) estimate. A three-part approach was used to substantiate the objective. First, the acquisition directives were examined to determine if availability was an objective. Secondly, some common LCC models were analyzed for purposes of adapting applicable models to calculate availability. Lastly, the output of an adapted model was used in a tradeoff analysis of similar avionics packages to determine if the added availability information was useful. The results of the approach showed that the guidance provided a poor representation of availability. The guidance did show availability could replace readiness as a primary objective. Secondly, a LCC model could be adapted to calculate availability. A third finding was that the added factor of availability improved the Program Manager's (PM) design decision process. Lastly, the LCC management concept could provide stronger support for the DOD acquisition objectives by equally balancing availability instead of supportability with cost, schedule, and performance.

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AN EXAMINATION OF
OPERATIONAL AVAILABILITY
IN LIFE CYCLE COST MODELS

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 Systems Management

By

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September 1983

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This thesis, written by

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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

Overview

The United States Air Force is acutely aware of its requirement to project military strength in situations that require rapid response. Our nation can draw from a military arsenal equipped with some of the most sophisticated and high performance weapon systems in use today. However, sophistication and performance mean nothing if a system is not available for use. Incidents when systems cannot respond or complete a mission, such as the Iran rescue attempt, cause great consternation and often lead to concern about the military's state of combat readiness (10:119,131; 12:30,33). When deciding to commit a military force, its capability and availability should be known before employment and not questioned afterwards. The capability and availability of a weapon system is a critical factor that is determined and fixed in the design phase, long before a system is used. Once a system is deployed, any changes to a system's capability or availability via systems modification is often very expensive.

When developing and procuring a system in a peacetime, cost-conscious atmosphere, a system's wartime availability can be secondary in importance to a system's cost. Such concern about cost becoming the driving factor during peacetime acquisition is discussed in an article by Funaro and Fletcher (9:33), who state: "The acquisition philosophies of the early 70s emphasized cost and schedule rather than a system's ability to meet its specified mission goal." The DOD has been procuring systems in a peacetime atmosphere for the past ten years and can expect to do so for the near future. Whether a system is developed in a peacetime or wartime atmosphere, its war fighting capability should be as important as any other aspect of the system. This capability must be addressed not only in terms of performance, but also in terms of availability to make a quick, unexpected response.

Even though reducing a system's cost, and more specifically, its Life Cycle Cost (LCC), appears to be a critical criteria during peacetime acquisitions, we should have the ability and analytical tools to examine and optimize tradeoffs between combat readiness (availability) and cost. If these analytical tools are to assist in providing a system with a combat ready capability, they must do two things. First, the tools must specifically define availability and secondly, examine different levels of availability and the relative cost for those levels.

The analytical models must go beyond individual parameters of reliability and maintainability (R&M) and look at their synergistic effect on availability. A LCC model that maximizes availability subject to cost constraints may increase our ability to use the weapon system as part of a quick and successful military response. This research examined some current LCC models to determine how their structure and theory are used to determine availability as a system parameter. The objective was to determine whether or not the models could provide insight into effective tradeoffs between an optimal (or even adequate) level of availability and LCC.

Definitions

This research was centered on two concepts which will be defined in this section. First, the cost of a system will be discussed in terms of its Life Cycle Cost (LCC), where "LCC includes acquisition, ownership (operation, maintenance, support, etc.), and where applicable, disposal costs [26:1]." A LCC model will estimate these costs for a given set of parameters and data over any portion of a weapon system's life such as the design phase, investment phase, or the operating phase. Cost estimates for each of the phases are summed together to give a total life cycle cost estimate. A LCC model may be used during a phase of the system's life (e.g., development) to provide an estimate for another future phase (e.g., operating), as well as the phase it is used in.

Secondly, availability is a function of reliability and maintainability (R&M) (3:20). The two terms that comprise the function are defined here.

> Reliability: The probability that an item will perform its intended function for a specified interval of time under stated conditions [30:7].
>
> Maintainability: A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources [30:5].

The objective of maintainability is to design equipment that can be maintained in terms of minimum time, cost, and expenditure of supply resources without adversely affecting the item's performance (4:1).

Lastly, availability is defined as follows:

> Availability: A measure of the degree to which an item is in the operable and committable state at the start of the mission, when the mission is called for at an unknown (random) point in time [30:2].

Four mathematical expressions for availability are provided; the first is for general applications (31:4-2):

$$\text{Availability, } A = \frac{\text{Uptime}}{\text{Total Time}}$$

where:

Uptime = Operating Time + Standby Time

Total Time = Uptime + Downtime (but downtime does not include offtime which is the time in storage or shipping)

Another expression for availability which is defined with respect to operating time and corrective maintenance is inherent availability (31:4-3):

$$\text{Availability, } A_i = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

where:

MTBF = Mean time between failures

MTTR = Mean time to repair

The above expression is used under idealized conditions, where standby and delay times (i.e., scheduled preventive maintenance as well as administrative and logistic down time) are ignored and the MTBF term for A_i then becomes the mean time between unscheduled maintenance action (MTBUMA) (31:4-3). A more detailed form of availability is operational availability and expressed as (31:4-4):

$$\text{Operational Availability, } A_o = \frac{\text{OT} + \text{ST}}{\text{OT} + \text{ST} + \text{TPM} + \text{TCM} + \text{ALDT}}$$

where:

OT = Operational time

ST = Standby time (equipment assumed operable)

TPM = Total preventive (scheduled) maintenance per specified time period

TCM = Total corrective (unscheduled) maintenance per specified time period

ALDT = Administrative and Logistic downtime (waiting for parts, administrative processing, maintenance personnel or transportation) per time period

Blanchard also provides an expression for A_o in terms of Mean Time Between Maintenance Actions (MTBM) and Mean Down Time (MDT) (3:67).

$$A_o = \frac{MTBM}{MTBM + MDT}$$

Guidelines for System Development

The initial guidelines for developing and acquiring a weapon system are provided in the 5000 series of DOD directives. The general policy provided in DOD Directive (DODD) 5000.1, entitled "Major Systems Acquisition," is to ensure that the acquisition of a major weapon system achieves the operational objectives of the Armed Forces in support of national policy (27:1). The directive also provides the following more specific policy:

> Improved readiness and sustainability are primary objectives of the acquisition process. Resources to achieve readiness will receive the same emphasis as those required to achieve schedule or performance objectives. As a management precept, operational suitability of deployed weapon systems is an objective of equal importance with operational effectiveness [27:2].

These policy statements establish mission accomplishment through readiness and sustainability as goals for the acquisition process. Attainment of these goals is through operational effectiveness and suitability, which are defined as:

> <u>Operational Effectiveness</u>: The overall degree of mission accomplishment of a system used by representative personnel in the context of the organization, doctrine tactics, threat, and environment in the planned operational employment of the system [27:3].
>
> <u>Operational Suitability</u>: The degree to which a system can be placed satisfactorily in field use, with consideration being given to availability, compatibility, transportability, interoperability, safety, human factors, manpower, supportability, logistics supportability, and training requirements [27:3].

Thus a relationship has been developed, although only implied up to this point, between these goals and availability. The relationship becomes more explicit in DOD Directive 5000.40, entitled "Reliability and Maintainability," which equates availability to readiness (28:11). However, this relationship is not discussed in the body of the directive, but is discussed in one of the attachments. Placing this discussion in an attachment leads to another implied relationship in the main body of a directive. However, the main body is where this relationship needs to be developed as a major factor of the acquisition process.

Availability does become one of the goals of systems acquisition by substituting it for readiness, as in the attachment to DOD Directive 5000.40. This substitution changes the policy statement in DOD Directive 5000.1 to read:

> Improved availability and sustainability are primary objectives . . . As a management precept, operational suitability of deployed weapon systems is an objective of equal importance with operational effectiveness.

This substitution explicitly establishes availability as a primary factor and goal in a systems development, and on an equal level with cost, schedule, and performance as stated in DOD Directive 5000.1:

> Readiness [i.e., availability] goals and related design requirements and activities shall be established early in the acquisition process and shall receive emphasis comparable to that applied to cost, schedule and performance objectives [27:7].

Cost, schedule, and performance have long been the basis for life cycle cost (LCC) management and for tradeoff analysis in LCC models, but more on this later.

The direct relationship between availability and the goals of the acquisition process is a valid relationship, even though it was made through a substitution of terms. This relationship is supported by and is a function of the Reliability and Maintainability Directive. Specifically, DOD Directive 5000.40 states as an objective that "operational effectiveness [is to] increase operational readiness [availability] and mission success of fielded items [28:1]." Additionally, the mathematical tasks to determine R&M allocation requirements will be measured as directly relating to operational readiness [availability] (28:2). By substituting the word "availability" for "readiness" the objective becomes less abstract and is quantifiable as shown by the equations presented earlier. Availability, even though supported by the above excerpts, was not included as a parameter in DOD Directive 5000.40. Its omission is explained by Swett in an article about DOD Directive 5000.40:

> Availability was not selected as a major reliability and maintainability characteristic because availability is derived from maintenance reliability and maintainability (downtime) and that is not directly measurable during systems acquisitions [25:130].

Availability should be a major characteristic because it provides the synergistic effects of reliability and maintainability. Even though it may not be directly measurable during acquisition, estimates can be obtained from 1) contractor data, and 2) extrapolation of field data for similar systems. These estimates can be used to provide an estimate of availability for a system and could aide the design decision process.

LCC Management

There are many kinds of LCC models which could have been examined. The models which this research examined are discussed in later chapters--but first, some background on the management philosophy behind LCC is in order. The thrust of life cycle costing is not just to minimize cost, but rather to optimize life cycle cost through tradeoffs in design and cost. As stated in Air Force Regulation (AFR) 800-11, entitled "Life Cycle Cost Management Program," "The objective is to acquire products which satisfy operational needs yet to provide the lowest feasible life cycle cost characteristics [26:1]." This objective supports those of DOD Directive 5000.1. LCC models serve as the analytical tools used to determine what effect design decision tradeoffs will have on acquisition, and operating and support costs. Thus, these models can be the appropriate tool for examining tradeoffs between cost and different levels of availability, provided availability is adequately defined in the models. The DOD directives have operational parameters as goals, but AFR 800-11 requires that peacetime deployment conditions be used for LCC studies and analysis (26:2). Hence, there appears to be a dichotomy between the goals of the DOD directives and AFR 800-11 that needs to be resolved.

LCC management (LCCM) provides the theory behind the practice of Life Cycle Costing. LCCM requires the estimation of LCC for alternative items before making decisions on any of the alternatives (14:1). More specifically:

> LCCM levies a requirement on us to estimate these alternative costs . . . trying to select the optimum alternative with the best combination of benefits and cost. Points considered under benefits are performance, schedule, and cost [14:1].

DOD Directive 5000.1 goes a step further and relates the mission goal to this cost balance:

> A cost-effective balance must be achieved among acquisition costs, ownership costs of major systems, and system effectiveness in terms of the mission to be performed [27:7].

If LCCM were to be viewed as a scale, its objective would be to equally balance a set of four weights. These four weights would be cost, schedule, and performance as outlined in the DOD directive and with a new weight, supportability, being recently added (16:1).

Based on a review of the guidance and literature on LCC management, we must examine some of the LCC models used in the front end development of a system to insure that these models allow for the examination of cost and availability. An in-depth analysis of some of the LCC models will be provided in the third chapter.

Research Questions

The following questions resulted from the literature review and are examined in detail in later chapters.

1. Do the directives, regulations, and LCC models provide a definition of availability to use in tradeoff analysis between design changes that affect a system's availability and cost?

2. Would a manager's decision-making process be improved (or benefit from) by using operational availability as a parameter in the LCC estimating process?

3. Should the LCC management "scale" be revised to consider or balance availability (or readiness) as the fourth weight?

Objective

Based on the above questions it was the purpose of this research to show that availability is a critical factor of a weapon system that can be and must be evaluated as part of the first LCC estimates. If availability is well defined and integrated into a LCC model, improved insight may be provided into the decision-making process for design decisions.

CHAPTER II

METHODOLOGY

This chapter provides the sequencing of steps to be used in answering the research questions raised in Chapter I. This approach is intended to provide thorough coverage of the problem and lead to a sound conclusion.

Orientation to Subject Matter

The first step was to gain an understanding of the two major components of this research, availability and life cycle costing. This information was gathered from the following sources:

1. Technical Reports provided basic definitions and mathematical relationship in applied situations.

2. Government directives and regulations showed how a manager is to plan for and apply these concepts within the required guidelines.

3. Textbooks provided the theory behind the concepts and further insight into definitions and mathematical relationships.

4. Periodicals showed current attitudes, practices, shortcomings, and other pertinent information related to the subject.

Completion of this step provided the sound basis for establishing the research questions and objective.

Model Analysis

Once an understanding of the subject had been gained, the second step was to examine some of the LCC models used by the Air Force. A LCC model provides an estimate for one of the three major phases of a weapon system's life. These phases are development, acquisition, and ownership (O&S). The results of the model used for each phase are summed together to provide a single estimate representing the cost of the system over its entire life. No one model exists to provide an estimate covering all three phases of the system's life.

Orientation to the models below was gained through a personal interview with the Chief of the Life Cycle Cost Management division for HQ Aeronautical Systems Division (ASD), Mr. Lavern Menker (19), and Rand Report R-2287-AF entitled "An Appraisal of Models Used in Life Cycle Cost Estimation for USAF Aircraft Systems" (22). Models were selected based on their applicability to the development and acquisition phase and use of R&M parameters. Five models were selected and are listed here:

1. Cost-Oriented Resource Estimating (CORE)
2. Development and Production Costs of Aircraft (DAPCA)

3. Logistic Support Cost (LSC)
4. Logistics Composite (L-COM)
5. Programmed Review of Information for Costing and Evaluation (PRICE)

Each model was analyzed in-depth with the following being major areas of concentration used in the analysis:

1. Which of the phases of a system's life is the model directed at?
2. Does the model evaluate, estimate, or use availability and/or R&M parameters?
3. Can the model be adapted to evaluate availability?

The objective of this analysis was to find a model that could specifically address availability and evaluate the impact of design decisions with respect to system availability and costs.

Applications Analysis

After the models had been analyzed, R&M and cost data were gathered to show how a LCC model could be used in evaluating system cost and availability. An example of how this evaluation could help decision-makers is provided in a later chapter. The example is provided to illustrate and highlight the objectives of this research and not to criticize in any manner past decisions or programs. The requisite data was gathered for like systems to provide an appropriate tradeoff decision situation. Selection of data from combat systems was stressed as their readiness or availability is more critical than non-combat systems. The data selected was for the subsystem level rather than the entire system, to simplify the computations, but to maintain the thrust of the objective. In an actual tradeoff analysis, the evaluation of cost and availability would be conducted for the entire system.

For purposes of this research and in accordance with DOD policy, R&M parameters were expressed in operational values rather than inherent values whenever possible (28:3). The purpose for using operational values is that they include the combined effects of item design quality, installation, environment, operation, and maintenance (28:10).

Operational availability, A_o, should be selected as an evaluation criteria in LCC models not only to conform with DOD policy, but also because it is a measure of system effectiveness in that it relates system hardware, support, and environmental characteristics into one meaningful parameter (31:4-3). System effectiveness is the probability that a system can successfully meet an operational demand within a given time when operated under specified conditions (4:12).

System Effectiveness (4:15)

Availability	Dependability	Capability
Measure of system conditions at start of mission	Measure of system conditions during performance of a mission	Measure of the results of a mission
Reliability	Repairability	Range
Maintainability	Safety	Accuracy
Human Factors	Flexibility	Power
Logistics	Survivability	Lethality

Implications and Conclusions

Applying an adjusted model to a hypothetical example provided implications and conlcusions that either 1) answered the research questions and met the objective, or 2) for the information and data collected did not answer the questions or meet the objective. Based on the implications and conclusions, areas for further research were identified.

CHAPTER III

MODEL ANALYSIS

This chapter provides an in-depth analysis of the five Life Cycle Cost (LCC) models identified earlier. Each of the models was examined using the following criteria to determine the model's potential for evaluating costs and availability:

1. During which phase of the system's life is the model used?
2. What costs are the model estimating?
3. Does the model currently use R&M parameters?
4. Can the model be adapted to evaluate availability?

The last criterion is an important one in that, from an intuitive approach, an extra equation could be added to any model. However, the problem is to insure that the new equation falls within the framework of the model. That is, inputs from the model must be in terms of the output of the new equation and vise versa. In addition, the output of the new equation must be compatable and useful with the output of the model.

Development and Procurement Costs of Aircraft (DAPCA-III)

Development of Procurement Costs of Aircraft (DAPCA) is a computer model for estimating costs and was developed by the Rand Corporation for the Air Force. This model is to be used during the early design phase and applies " . . . parametric estimating relationships to calculate the development and procurement costs of two major flyaway subsystems of the aircraft: airframe and engines [21:V]." The major inputs to this model are airframe weight, speed, and thrust. The outputs or aircraft production costs are expressed in manufacturing hours rather than the dollar costs of production. DAPCA does not use R&M parameters as inputs in any manner. Adapting DAPCA to evaluate availability would require collecting additional data as inputs to use in the availability equation. More importantly, the availability equation does not provide an output compatable with an output expressed in manufacturing hours. To provide such an output would require the relationship for availability to be built with inputs relating to weight, thrust, speed, lot quantities, and manufacturing hours in order to be compatable with the model. Such an effort is beyond the scope of this research.

Based on the analysis, the DAPCA model is inappropriate for evaluating availability because 1) the model does not use R&M parameters; 2) the inputs of the model are not easily converted to those required for the availability equation; and 3) the output of the availability equation is not compatable with the output of the model.

Programmed Review of Information for Costing and Evaluation (PRICE)

The PRICE model is owned by the Radio Corporation of America (RCA). Each application must be purchased from RCA. This model, like DAPCA, is to be used early in a system's life to estimate development and procurement costs of systems with electronic and mechanical subsystems. The inputs to this model are 1) level of technological sophistication; 2) overall weight and volume; 3) lengths of the engineering and production cycles; 4) starting year of the program; 5) assumed rate of cost escalation; and 6) type of service (ground, air, etc.) (29). Again, this model does not use R&M parameters. The inputs and outputs of the model and availability equation are not compatable. In addition, the major problem with the PRICE model is the inability to examine the algorithms used in the model due to their proprietary nature (22; 23; 31). Since access to the algorithms is not possible, adapting the PRICE model to evaluate availability cannot be addressed.

The PRICE model was not selected because of 1) lack of access to the model's algorithms; 2) proprietary rights of the model; and 3) the input and outputs of the model and the availability equation are not compatable.

Cost-Oriented Resource Estimating (CORE)

The CORE model was developed by the Air Force to provide a standardized method of computing annual operations and support costs. This model is to be used early in a system's life to determine how weapon system decisions affect resource requirements of that system in the long run (18:3). The model measures the cost of the resource requirements for a given decision. The inputs consist of 113 factors which are categorized into the following seven groups (18:7):

1. Program Factors
2. Manpower Factors
3. Program Support Factors
4. Common Factors
5. Maintenance Personnel Factors
6. Depot Maintenance Factors
7. Miscellaneous Factors

Although within these seven groups there are some R&M parameters, the model does not address those required for the availability equation. The CORE model would be easier to adapt to evaluate availability than the previous models as inputs and output are more compatable. However, to do this would require additional input variables which fit the inputs required for the availability equation. This may seem simple, but is still more work than required, as the Logistic Support Cost (LSC) model analysis will show.

The CORE model was not selected due to the need to expand the input variable list. This model, however, appears to have potential for evaluating costs and availability.

Logistics Composite (L-COM)

The L-COM model was jointly developed by the Air Force and the Rand Corporation. The model is used during the design phase of new weapon systems to determine the impact of design decisions on the logistic support requirements (20:9,97). Of the five models being analyzed, L-COM is the only simulation model. It simulates a composite of aircraft operations and main supporting functions at one base (20:4). The output is measured in the number of personnel needed at a work center (20:25). Input data is in the form of resource levels, reliability factors, policy parameters, and other elements of operations.

This model is similar to CORE in that it uses some R&M parameters, but it does not use the requisite parameters for the availability equation. Additionally, this model could be adapted as inputs and outputs are compatable with the availability function. Again, the list of input variables would have to be expanded to accomodate the availability equation.

The L-COM model was not chosen because of the need to expand the variable list and the primary output of the model being measured in terms of the number of personnel required at a base. L-COM can be useful in evaluating cost and availability if coupled with other models which evaluate availability, or if L-COM were expanded to use the necessary inputs to produce an availability parameter. Such an adaptation seems to be within the framework of the L-COM model.

Logistic Support Cost (LSC)

The LSC model was developed by the Air Force to be used as a tool for computing estimates of expected support costs that may be incurred by adopting a particular design or choosing a design alternative. The output measures not the absolute value of support costs, but the magnitude of the difference between alternatives (1:3-4). The inputs to this model include R&M parameters, shipping costs, Force flying hours, labor rates, maintenance times, quantity of spares, and other variables related to operations. These inputs can be combined to form the necessary inputs for the availability equation, allowing for easy adaptation, as all the variables are already collected for use in the model.

Adapting the model to evaluate availability consists of only two steps. The first is to combine the LSC inputs to derive the variables for the operational availability equation presented in Chapter I. The second step is to add the availability equation to the ten equations comprising the LSC model. Then the model can evaluate the availability and costs of adopting a design decision or design alternative.

This model was selected as being the most appropriate model of the five presented to evaluate costs and availability because of its 1) ease of adaptation; 2) compatability of inputs; 3) usefulness of availability parameter as an output for the model; and 4) because the input list does not need to be expanded. The LSC is similar to the L-COM in that it looks at the support cost of a particular system. It was chosen over L-COM because it was intended to be used in determining design decisions in the early stages of the system's life. The impact of a design decision on the system can be seen through the changes in 1) unit cost; 2) the spares costs, and 3) the cost of maintenance for a particular configuration. Adaptation will allow a decision-maker to evaluate a configuration's impact on availability, how much that availability will cost, and maybe avoid costly modifications later in the system's life.

Adapting the LSC model to evaluate availability allows the decision-maker an opportunity to find a minimum cost system subject to constraints and to maximize availability subject to a set of constraints. Adding the availability equation expands the information available to the decision-maker when determining a system' design.

There are ten cost categories estimated by the LSC model, which are presented here:

1. First Line Unit (FLU)[1] Spares
2. On-Equipment Maintenance
3. Off-Equipment Maintenance
4. Inventory Management
5. Support Equipment
6. Personnel Training
7. Management and Technical Data
8. Facilities
9. Fuel Consumption
10. Spare Engines

The last two categories are used if the system being analyzed has engines or motors. Otherwise, these are ignored. As stated, an eleventh category and equation

---

[1] A First Line Unit (FLU) is defined as the first level of assembly below the system level that is carried as a line item of supply at base level and is usually the highest level of assembly that is removed and replaced, as a unit, on the complete system or subsystem in order to return the equipment to an operational condition [1:1-1].

can be added to the model to evaluate availability. The equation which evaluates operational availability, A_o, was introduced in Chapter I and presented here for clarification:

$$A_o = \frac{OT + ST}{OT + ST + TPM + TCM + ALDT}$$

As stated earlier, the terms or variables collected for the model would have to be combined in some manner to make up the variables for the equation above. The necessary combinations are presented below using base level or intermediate level time values. The reason for using base level values is that if a system/subsystem fails and requires depot maintenance, a replacement system/subsystem could be made available from the War Reserve Material (WRM) stock. This assumes a wartime scenario. Therefore, the calculation for operational availability is a flight line availability estimate.

LSC Variable Combinations

OT: Operating time; consists of the inputs necessary to determine the ratio of operating time of the FLU to flying hours or UF.

ST: Standby time; this is simply the time the FLU is not operating but assumed operable.

TPM: Total preventive maintenance time; this would include 1) the average manhours to perform scheduled or periodic or phased inspection on the system (SMH) (1:8.67); 2) the average manhours to perform a shop bench check, screening, and fault verification on a removed FLU prior to initiating repair action or condemning (BCMH) (1:8.68); 3) the average manhours expended in place on the installed system for preparation and access of the FLU (PAMH) (1:8.68); and 4) the average manhours to perform intermediate level (baseshop) maintenance on a removed FLU, including fault isolation, repair, and verification (BMH) (1:8.68).

$$TPM = SMH + BCMH + PAMH + BMH$$

TCM: Total corrective maintenance time; this would include 1) BCMH; 2) BMH; 3) the average manhours to perform corrective maintenance of the FLU in place or on line without removal including fault isolation, repair, and verification (IMH) (1:8.68); 4) PAMH; and 5) the average base repair cycle time in months from the time an item is removed until it is returned to serviceable stock (BRCT) (1:8.66).

$$TCM = BCMH + BMH + IMH + PAMH + BRCT$$

ALDT: Administrative and logistic downtime; this would include 1) the average manhours per failure to complete off-equipment maintenance records (MRF) (1:8.63);

2) the average manhours per failure to complete on-equipment maintenance records (MRO) (1:8.63); 3) the weighted average order and shipping time in months (OST) (1:8.63); 4) the average manhours per failure to complete supply transaction records (SR) (1:8.63); and 5) the average manhours per failure to complete transportation transaction forms (TR) (1:8.64).

$$\text{ALDT} = \text{MRF} + \text{MRO} + \text{OST} + \text{SR} + \text{TR}$$

Except for operating and standby time (OT&ST) the time factors must be adjusted to a monthly time value to derive a unitless value of availability. The remaining terms must be multiplied by the frequency of occurance per month which will change their units of measure from hours per inspection and hours per failure to hours per month. An example of this calculation is provided for clarity.

$$\frac{10 \text{ hours}}{1 \text{ failure}} \times \frac{.5 \text{ failures}}{1 \text{ month}} = \frac{5 \text{ hours}}{1 \text{ month}}$$

The total preventive maintenance (TPM) time for a month is calculated as follows:

$$\text{TPM} = (\text{SMH} + \text{BCMH} + \text{PAMH} + \text{BMH}) \frac{\text{Inspections}}{\text{Month}}$$

Where inspections per month are derived from dividing flying hours per month by the flying hours between inspection or in equation form:

$$\frac{\text{Inspections}}{\text{Month}} = \frac{\text{Flying Hours}}{\text{Month}} \times \frac{\text{Interval of Flying Hours}}{\text{Inspection}}$$

For the total corrective maintenance (TCM) time the equation is broken into two parts. The first part is for all failures regardless of where they are to be repaired. The second part is for those failures to be repaired at base level. This part is multiplied by the fraction of FLUs to be reparied at base level (RTS) (1:8.69). The total calculation is as follows:

$$\text{TCM} = \left[(\text{BCMH} + \text{PAMH}) + (\text{BMH} + \text{IMH} + \text{BRCT})\ \text{RTS}\right] \frac{\text{Failures}}{\text{Month}}$$

The Administration and Logistics downtime (ALDT) is for that fraction of failures to be repaired at base level. The calculations would be as follows:

$$\text{ALDT} = \left[(\text{IMRF} + \text{MRO} + \text{OST} + \text{SR} + \text{TR})\ \text{RTS}\right] \frac{\text{Failures}}{\text{Month}}$$

Failures per month for TCM and ALDT is derived from the Mean Time Between Failure (MTBF) (1:8.68) divided into the operating time (OT) per month, or in equation form:

$$\frac{\text{Failures}}{\text{Month}} = \frac{\text{OT (hrs)}}{\text{Month}} \Big/ \text{MTBF (hrs)}$$

Based on the transformations provided, operational availability at the base level can be calculated using the LSC model variables as follows:

$$A_o = \frac{OT + ST}{\left\{ \begin{aligned} &OT + ST + \left[(SMH + BCMH + PAMH + BMH) \frac{\text{Inspections}}{\text{Month}} \right] \\ &+ \left[(BCMH + PAMH) + (BMH + IMH + BRCT)\, RTS \right] \frac{\text{Failures}}{\text{Month}} \\ &+ \left[(MRF + MRO + OST + SR + TR)\, RTS \right] \frac{\text{Failure}}{\text{Month}} \end{aligned} \right\}}$$

Summary

The preceding evaluation of the five Life Cycle Cost (LCC) models has shown that the LSC model is the most compatible for the purpose of evaluating availability. This was shown through the variable list's ease of adaptation for use in the availability equation. Adding the availability equation was consistent and meaningful to the purpose of the model. The expanded LSC model allows decision-makers an opportunity to maximize availability subject to a set of constraints and minimize costs subject to a set of constraints and decide on the optimal mix between the results. Additionally, it shows the decision-maker what a particular design will do to the cost of the system and the cost to support it as well as the level of availability that will be attained. The next chapter will illustrate how the decision-maker may go through this process.

CHAPTER IV

APPLICATIONS ANALYSIS

Introduction

The model analysis showed how a Life Cycle Cost (LCC) model was adapted to estimate operating and support (O&S) costs and evaluate availability during the design phase of a weapon system. This chapter shows how a decision maker or Program Manager (PM) could apply the LSC model in its adapted form to the design decision process.

Applying the Model

This chapter was concerned with the application of four equations--three from the original LSC model, and the added equation for operational availability. All the equations are not necessary because in determining the final design configuration, the PM need only concentrate on the differential costs between design alternatives. In the example to be presented the differential costs are calculated by the following four equations:

1. FLU Spares
2. On-Equipment Maintenance
3. Off-Equipment Maintenance

4. Operational Availability

The differential costs from the above equations will be used by the PM to decide between two avionics packages. The other equations in the LSC model are assumed to produce the same results for either package.

Inputs and Variables

This section identifies the sources of the variables and their inputs needed for the equations. The variable list and explanation is provided in Appendix A while the values for these variables are provided in Appendix B. Appendix A lists the variables according to equation, but the details of each equation are provided later in this chapter.

The source of Appendix A is the LSC model handbook (1:8.63-8.69). Some of the values in Appendix B are given in the model's handbook. The variables whose values come from the handbook are referred to as fixed input variables. These variables are not affected by a specific design decision, but are a function of the model and are factors representing the logistic support system. The PM cannot affect these variables, but does decide upon the variable inputs which impact the system and maintenance frequency.

The data collected in Appendix B is broken into packages by individual piece of avionics. The avionics packages consist of a multi-mode radar and a radar warning receiver. Package A represents the equipment selected for use on the HH60-D helicopter and package B is the equipment from the PAVE-LOW III program. The specific makeup is shown here.

Avionics Package Equipment

Equipment Type	Package A	Package B
Multi-Mode Radar	Lantern	APQ-158
Radar Warning Receiver	APR-39	ALR-46

The values for the variables listed in Appendix B were obtained from technical reports, LCC reports, and subjective estimates based on a sample size of one. The values identified with a superscript one were provided by Lieutenant Kerry Eickhof, a Reliability and Maintainability (R&M) engineer for the Aeronuatical Systems Division (ASD) Airlift and Trainer System Program Office (5). Lieutenant Eickhof developed the R&M requirement for the HH60-D helicopter using PAVE-LOW III data. Based on his calculations for the HH60-D system, some of the values for the second avionics package could be recalculated. The values with a superscript two or three were obtained from the respective item technicians at Warner Robbins Air Logistic Center. The source for the technicians information were various Technical Orders (TO) and personal knowledge.

An Illustration Using the Model

The last section identified the variables, inputs, and the details of the avionics packages. Now the illustration in which they are used is explained in detail.

The Program Manager (PM) is confronted with a choice between two avionics packages (previously identified) to fulfill a mission requirement. Either package can be installed on the new search and rescue helicopter designated the HH60-D.

The equipment in a package is mission critical hardware (7:3-17), where mission critical hardware is defined as:

> those equipments whose failure will result in mission failure . . . it is assumed any failure will result in a complete loss of that element, which may not be true but it presents a safe assumption [7:3-16].

The PM must choose one of the packages for the system. Using the modified LSC model the PM can evaluate the packages based on the following differential cost criteria:

1. Unit Cost
2. Spares Cost
3. Maintenance Cost
4. Operational Availability

As stated in Chapter II, this illustration is to support the objectives of the research and not to make any judgements on decisions made or to be made.

The LSC model handbook is dated August 1976 and cost data given in the handbook are Fiscal Year (FY) 7T values. Fiscal Year 7T was a three-month period and resulted from a change in the starting date of the federal FY from 1 July to 1 October.

All cost values will be normalized to a FY 7T base year dollar. Using the Air Force Systems Command August 1982 update of the Generic Inflation Indexes, cost data can be deflated to any desired base year. To deflate cost data to a base year value the index for the year to be deflated is divided by the index for the base year. The result is a base year factor which is divided into the dollar value of the year to be deflated. The entire process is shown here (23:)[2]:

$$\text{Base Year Factor} = \frac{\text{Index of Year to be Deflated}}{\text{Index of Base Year}}$$

$$\text{Base Year \$} = \frac{\text{\$ of Year to be Deflated}}{\text{Base Year Factor}}$$

---

[2] The calculations shown are to deflate constant year dollars to a base year. The cost data requiring deflation in this research is assumed to be constant year dollars. This assumption is due to a lack of information in the source documents.

Table 1 provides the indexes of the years involved in the deflation calculations (2:6). Table 2 summarizes the results of the base year factors calculations in Appendix C. The base year factors will be used in later calculations to normalize unit cost, cost to repair a failed FLU at base level (BMC), and cost to repair a failed FLU at depot level (DMC).

Normalizing the cost data to a base year of FY 7T allows the comparison of the magnitude of costs from an identical reference point. It is the magnitude of the differential costs between alternatives that is important to the PM, not the absolute value (1:3-4).

Using the LSC model's equations the PM or an analyst can calculate the differential costs identified earlier. The equations will be presented as shown in the LSC model handbook using the summation symbol. The calculations for the differential costs are shown in Appendix D through G for each item in a package over a twenty-year life. The summation process was deleted and will be shown only as a summary in Table 9. The summation step was not shown in the calculations to show the differences in data and results for like systems (i.e., N = 1).

The first differential costs to be calculated are for spares. Refer to Appendix A for variable explanations and Appendix D for details of the calculations.

TABLE 1

INFLATION INDEXES

Year	Index
7T	.880
78	.942
81	1.190
83	1.356

TABLE 2

SUMMARY OF BASE YEAR 7T FACTOR CALCULATIONS

Year to be Deflated	Base Year Factor
78	1.07045
81	1.35227
83	1.54091

The equation used for the calculating spares is presented below.

C_1 = Cost of FLU Spares (1:8.71)

$$C_1 = M \sum_{i=1}^{N} (STK_i)(UC_i)$$

$$+ \sum_{i=1}^{N} \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)(DRCT_i)}{MTBF_i}(UC_i)$$

$$+ \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)(COND_i)}{MTBF_i}(UC_i)$$

The first two terms are the cost to fill the base and depot repair pipelines, respectively. The third term is the cost to replace FLUs condemned at base level (1:8.71).

Before any calculations are done the cost data required for C_1 must be normalized. A summary of the calculations in Appendix D normalizing the cost data is provided in Table 3. The results of the calculations for C_1 are listed in Table 4.

The second cost to be calculated is for on-equipment maintenance. The results of the calculation are presented in Table 5, while the details are provide in Appendix E.

TABLE 3

SUMMARY OF NORMALIZED COST DATA (UNIT COST)

Type of Cost	Previous Value & Year	Normalized Value
LANTIRN	$ 175,000 (78)	$ 163,482.65
APR-39	8,000 (78)	7,473.49
APQ-158	250,000 (81)	
	100,000 (83)	249,771.00
ALR-46	24,000 (83)	15,575.21

TABLE 4

C_1 CALCULATION RESULTS

Equipment	Cost
LANTIRN	$4,573,406,710.00
APR-39	65,976,973.96
APQ-158	7,214,008,588.00
ALR-46	90,915,269.67

TABLE 5

C_2 CALCULATION RESULTS

Equipment	Cost
LANTIRN	$581,381.72
APR-39	117,793.85
APQ-158	3,087,100.36
ALR-46	173,154.67

The equation used for calculating on-equipment maintenance is presented below.

C_2 = Cost of On-Equipment Maintenance (1:8.73)

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

The first term represents the labor manhour cost of unscheduled maintenance. The second term represents the labor manhours of scheduled maintenance. The maintenance concept for the HH60-D helicopter requires no scheduled maintenance (5). Maintenance is performed on an as needed basis. Therefore the time interval between scheduled maintenance actions (SMI) could be expressed as an infinite amount of time. Then the TFFH divided by SMI approaches zero. This is multiplied by SMH which also equals zero and hence the entire third term drops out.

The third cost to be calculated is for off-equipment maintenance. Again the details of the calculations, using the equation below, are provided in Appendix F with the results listed in Table 6. This equation requires the use of unit costs, which have been normalized (see

TABLE 6

C_3 CALCULATION RESULTS

Equipment	Cost
LANTIRN	$43,582,629.09
APR-39	936,470.88
APQ-158	48,885,773.23
ALR-46	1,897.858.77

TABLE 7

SUMMARY OF NORMALIZED COST DATA

Type of Cost	Previous Value & Year	Normalized Value
BMC:		
LANTIRN	$ 105.90 (81)	$ 78.31
APR-39	23.39 (81)	17.30
APQ-158	191.54 (83)	124.30
ALR-46	90.17 (83)	58.52
DMC:		
LANTIRN	$ 156.22 (83)	$ 101.38
APR-39	100.52 (83)	65.23
APQ-158	212.50 (83)	137.91
ALR-46	166.61 (83)	108.12

Table 3), and the cost to repair at base and depot levels (BMC and DMC). The latter two values must be normalized before calculating the cost of off-equipment maintenance. Details of the steps to normalize BMC and DMC are provided in Appendix F and the results listed in Table 7.

C_3 = Cost of Off-Equipment Maintenance (1:8.74)

$$C_3 = \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)}{MTBF_i} \Bigg\{ (BCMH)(BLR)$$

$$+ RTS_i \Big[(BMH_i)(BLR + BMR) + (BMC_i)(UC_i) \Big]$$

$$+ NRTS_i \Big[(DMH_i)(DLR + DMR) + (DMC_i)(UC_i) \Big]$$

$$+ \Big[2(NRTS) + COND_i \Big] \Big[(PSC)(1-OS) + (PSO)(OS) \Big] (1.35W_i) \Bigg\}$$

Using the unadjusted LSC model the differential costs calculated above are the basis for the PM design decision. A decision made by the PM at this point would be for a least cost alternative. If the differential costs provided above were relatively small, the PM would have to find an additional differential cost as a basis for a decision. If the adjusted LSC model were used, that additional decision factor would be provided along with these initial LSC differential cost results.

To calculate availability the equation presented in Chapter III is used and is presented below to refresh the readers memory. Details of the calculation for operational availability rate per month are provided in Appendix G with the results listed in Table 8.

A_o = Operational Availability (Base Level) Rate per Month

$$A_o = \frac{OT + ST}{\left\{\begin{aligned}&(OT + ST + \left[(SMH + BCMH + PAMH + BMH)\right]\frac{\text{Inspections}}{\text{1 Month}}\\ &+ \left[(BMH + PAMH) + (BMH + IMH + BRCT)RTS\right]\frac{\text{Failures}}{\text{1 Month}}\\ &+ \left[(MRF + MRO + OST + SR + TR)RTS\right]\frac{\text{Failures}}{\text{1 Month}}\end{aligned}\right\}}$$

TABLE 8

A_o CALCULATION RESULTS

Equipment	Cost
LANTIRN	.33259
APR-39	.79569
APQ-158	.32937
ALR-46	.83748

All of the results of the calculations in Appendix D through G are summarized in Table 9. The table provides the PM with a line item breakout as well as an aggregate for each package.

TABLE 9

SUMMARY DATA OF DIFFERENTIAL COSTS

Cost	LANTIRN	APR-39	APQ-158	ALR-64
C_1	$4,573,406,710.00	$65,976,973.96	$7,214,008,588.00	$90,915,269.67
C_2	581,381.72	117,793.85	3,087,100.36	173,154.67
C_3	43,582,629.09	936,470.88	48,885,773.23	1,897,858,77
A_o	.33259	.79569	.32937	.83748

	PACKAGE A	PACKAGE B
C_1	$4,639,383,683.96	$7,304,923,857.67
C_2	699,175.57	3,260,255.03
C_3	44,519,099.97	50,783,632.00
TOTAL	$4,684,601,959.50	$7,358,967,744.70
A_o	.26464	.27584

The Adjusted LSC Results in the Decision Process

The PM now has enough information to base a decision on. The delta costs of Package A relative to Package B are provided in Table 10.

TABLE 10

DELTA COSTS

Cost Category	Delta Cost
Unit Cost	- $191,000.00
Spares	- $ 2,266,540,174.29
On-Equipment	- $2,561,079.46
Off-Equipment	- $6,264,532.03
Availability	- .01120

The information shows the PM that Package A is the least cost alternative in every dollar category. It also shows that Package A has a lower availability rate per month at the base level. Choosing the least cost alternative indicates a sacrifice in the availability rate. The PM must decide if the dollar cost savings is worth the reduction in the availability rate. The PM must decide if availability should be maximized subject to cost constraints or dollar costs minimized subject to an availability constraint.

To decide the PM could divide the costs into the phases of the systems life cycle; that is acquisition and operating and support costs. In the acquisition phase the PM could choose Package A to save $191,000, but lose .0112 from the availability rate of Package B. Deciding on a package based on the costs associated with the acquisition phase, the PM could decide on Package B and forego the $191,000 of savings for an .01120 increase in the availability rate. However, the O&S cost of this decision increases by approximately $2.7 billion over a twenty-year life. The PM must decide if a 1 percent increase in the availability rate is worth the increased O&S costs.

The objective of the research was not to decide on a package, but to show that the adjusted LSC model could provide additional information to the PM to use in the design decision process. In the illustration provided the PM could choose the least cost alternative and know that the availability rate was not compromised. Knowing the line item cost difference the PM could evaluate different configurations of the two packages. That is, exchange the two pieces of equipment with the highest individual availability rates and recalculate the O&S costs for this new package.

Summary

Using the adjusted LSC model presented in Chapter III, the LCC differential dollar cost and availability rates were calculated. The results were used by the PM in determining the best combination of benefits for the cost. The PM could determine if availability was compromised by selecting the least cost alternative. For the illustration provided, the lease cost alternative did not compromise the availability rate. The PM could also use the information to examine alternative combinations of equipment to form new packages.

CHAPTER V

FINDINGS AND CONCLUSIONS

Summary

The research objective was to show weapon system availability as a critical factor that must be evaluated as part of the first Life Cycle Cost (LCC) estimates. First, the guidance was examined to substantiate availability as an objective of the DOD acquisition process. Secondly, some of the more common LCC models were analyzed from the standpoint of evaluating and estimating availability. Lastly, a modified LCC model was used to provide an availability estimate for a tradeoff analysis of similar avionics packages that might be installed in a new rescue helicopter. This methodology was the basis for the findings and conclusions to answer the following research questions:

1. Do the directives, regulations, and LCC models provide a definition of availability to use in tradeoff analysis between design changes that affect a system's availability and cost?

2. Would a manager's decision-making process be improved (or benefit from) by using operational

availability as a parameter in the LCC estimating process?

3. Should the LCC management "scale" be revised to consider or balance availability (or readiness) as the fourth weight?

Findings and Conclusions

Following the methodology described above, six conclusions were drawn from the findings presented here. Part of the first finding resulted from a review of the directives and regulations for the acquisition process showing very little reference to availability. However, one of the objectives readily identified was readiness, which, in an attachment to DOD Directive 5000.40, was equated to availability (28:1). The second part of the finding was that the LCC models examined herein do not address availability.

The two conclusions drawn from the finding are first, the word "availability" could be substituted for "readiness." This establishes availability as a primary objective of the DOD acquisition process. Availability as an objective provides a quantifiable and less abstract term, unlike readiness. The second conclusion is that LCC models used during the design phase need to address availability.

The second finding was that the Program Manager's (PM) design decision making process could be improved if availability was calculated as part of a LCC estimate. The LCC models were analyzed to find a model that could be adapted to calculate availability. The Logistic Support Cost (LSC) model was adaptable with only minor changes while others showed potential for evaluating availability.

The modified LSC model was used to provide decision factors for a tradeoff analysis of similar avionics packages. A LCC estimate and availability rate were calculated for each package. The results provide the PM an opportunity to examine the loss or gain of availability for an increased expenditure or least cost alternative. The PM could also use the results to maximize availability or minimizing cost subject to constraints. The conclusions drawn from this finding are 1) a LCC model can calculate availability rates as well as costs, and 2) the additional decision factor which could be calculated aids the PM in determining a final design configuration.

The third finding follows from the first. Specifically, the LCC management (LCCM) concept helps achieve the objectives of the DOD acquisition process by providing the best combination of benefits and cost. Initially, LCCM tried to achieve its objective by equally balancing three factors: cost, schedule, and performance. These three factors are also objectives of the DOD directives. More recently LCCM added supportability as a fourth equal factor. However, the DOD Directive equaled readiness with cost, schedule, and performance. The conclusion formed was that LCCM could better support the objectives of the DOD acquisition process using the same factors as identified in the DOD directives.

The last conclusion was an aggregate of all of the above. The findings showed that availability is a critical factor of a weapon system that must be addressed during the design phase. Using a LCC model to calculate availability the PM could 1) provide the best availability rate subject to the LCC cost limitations, and 2) minimize cost and know the impact on the availability rate.

Recommendations

The recommendations presented here are based on the conclusions presented in the previous section. The first recommendation is to substitute availability for readiness in the DOD directives. This would clearly establish availability as a primary objective of the acquisition cycle. Secondly, a LCC model used in determining a design configuration must calculate availability to achieve the availability objective established above. Not only would this help achieve the objective, but it would help the PM select a configuration that provides the best availability rate and cost. Lastly, LCCM should equally balance cost, schedule, performance, and availability in trying to provide the best combination of benefits and cost.

Availability would replace supportability as the fourth factor because it includes supportability and follows from the new DOD directive objective. Availability is a measure of system effectiveness in that it relates system hardware, support, and environmental characteristics into one meaningful parameter (31:4-3). LCCM would provide stronger support to the DOD acquisition process if it had the same objectives as outlined by the DOD directives.

Areas for Further Research

The following areas have been identified to expand upon the research presented. The calculations in Appendices D through F used data that was a subjective estimate from sample sizes of one. The results may be improved through a more extensive data gathering effort.

A second area to consider would be the incorporation of linear programming models into the LCC models. This would provide a method to maximize availability and minimize costs subject to constraints. The depth of the information provided by a LCC model would be increased.

The last area for further research is to analyze the remaining LCC models. Other models may be adaptable for the purpose of examining the tradeoff between availability and cost. The criteria in Chapter III provide a starting point for the analysis.

APPENDIX A

LIST OF VARIABLES

EQUATION 1. Cost of FLU Spares

FIXED INPUT

	Variable Name	Explanation
1.	Weighted Average Depot Repair Cycle Time in Months (DRCT)	Elapsed time for an 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.

VARIABLE INPUT

	Variable Name	Explanation
2.	Number of spares of a FLU (STK)	The number of spares of a FLU required for each base to fill the base repair pipeline including a safety stock.
3.	Unit Cost (UC)	Expected unit cost of the FLU at the time of initial procurement.
4.	Peak Force Flying Hours (PFFH)	Expected fleet flying hours for one month during the peak usage period.
5.	Quantity of like FLUs (QPA)	The number of like FLUs within the parent system.
6.	Operating hours to flying hours (UF)	The ratio of operating hours to flying hours for the FLU.
7.	FLU failures that can be repaired in place (RIP)	The fraction of FLU failures which can be repaired in place or on line without removals.
8.	FLU failures to be returned (NRTS)	The fraction of removed FLUs expected to be returned to the depot for repair.

	Variable Name	Explanation
9.	Mean time between Failures (MTBF)	Mean time between failures in operating hours of the FLU in the operational environment.
10.	Total Force Flying Hours (TFFH)	The expected total force flying hours over the Program Inventory Usage Period.
11.	Condemnation Rate (COND)	The fraction of removed FLUs expected to result in condemnation at base level.
12.	Repair Locations (M)	Number of intermediate repair locations.

Equation 2. Cost of On-Equipment Maintenance

FIXED INPUT

	Variable Name	Explanation
1.	Base Labor Rate (BLR)	Base Labor Rate per manhour.

VARIABLE INPUT

	Variable Name	Explanation
2.	Total force flying hours (TFFH)	See Equation 1, No. 10.
3.	Quantity of like FLUs (QPA)	See Equation 1, No. 5.
4.	Operating hours to flying hours (UF)	See Equation 1, No. 6.
5.	Mean Time between Failures (MTBF)	See Equation 1, No. 9.
6.	Preparation and Access (PAMH)	The average manhours expended in place on the installed system for preparation and access for the FLU.
7.	FLU failures that can be repaired in place (RIP)	See Equation 1, No. 7.

Variable Name	Explanation
8. Time to perform corrective maintenance in place (IMH)	The average manhours to perform corrective maintenance of the FLU in place or on line without removal, including fault isolation, repair, and verification.
9. Time to isolate, remove, and replace (RMH)	The average manhours to fault isolate, remove, and replace the FLU on the installed system to operational status.
10. Time to do scheduled inspection (SMH)	The average manhours to perform a scheduled periodic or phased inspection on the system.
11. Time between inspection (SMI)	The flying hours interval between scheduled periodic or phased inspections on the system.

EQUATION 3. Cost of Off-Equipment Maintenance

FIXED INPUTS

Variable Name	Explanation
1. Base consumable material consumption rate (BMR)	Consumable material consumption rate which includes minor items of supply (nuts, washers, rags, etc.) which are consumed during repair of items.
2. Depot Labor Rate (DLR)	Depot labor rate per manhour.
3. Overseas packing and shipping (PSO)	Average packing and shipping cost per pound to overseas locations.
4. Packing and shipping cost (PSC)	Average packing and shipping cost per pound to CONUS locations.
5. Base labor rate (BLR)	See Equation 2, No. 1.

Variable Name	Explanation
6. Depot consumable material consumption rate (DMR)	Same as BMR but at the depot but at the depot level.

VARIABLE INPUT

Variable Name	Explanation
7. Total force flying hours (TFFH)	See Equation 1, No. 10.
8. Quantity of like FLUs (QPA)	See Equation 1, No. 5.
9. Operating hours to flying hours (UF)	See Equation 2, No. 4.
10. FLU failures to be repaired in place (RIP)	See Equation 1, No. 7.
11. Mean time between failures (MTBF)	See Equation 2, No. 5.
12. Time to perform shop bench check, screening, and fault verification (BCMH)	The average manhours to perform a shop bench check, screening, and fault verification on a removed FLU prior to initiating repair action or condemning the item.
13. FLUs to be repaired at base (RTS)	The fraction of removed FLUs expected to be repaired at base level.
14. Time to do intermediate level maintenance (BMH)	The average manhours to perform intermediate-level (base shop) maintenance on removed FLU including fault isolation repair and verification.
15. Cost per failure for a FLU repaired at base level (BMC)	The average cost per failure for a FLU repaired at base level for stockage and repair of lower level assemblies expressed as a fraction of the FLU unit cost (UC). This is the implicit repair disposition cost for a FLU

Variable Name	Explanation
	representing labor, material consumption, and stockage/replacement of lower indenture repairable components within the FLU (e.g., shop replacement units or modules).
16. Unit Cost (UC)	See Equation 1, No. 3.
17. FLU failures to be returned to depot (DMH)	See Equation 1, No. 8.
18. Time to perform depot-level maintenance (DMH)	Same as BMH above, but for depot level maintenance.
19. Cost per failure for a FLU repaired at depot-level (DMC)	Same as BMC above.
20. Condemnation Rate (COND)	See Equation 1, No. 11.
21. Force deployed overseas (OS)	Fraction of total force deployed overseas.
22. Weight in pounds (W)	FLU unit weight in pounds.

EQUATION 4. Operational Availability

FIXED INPUT

Variable Name	Explanation
1. Time per failure to do off-equipment records (MRF)	Average manhours per failure to complete off-equipment maintenance records.
2. Time per failure to do on-equipment records (MRO)	Average manhours per failure to complete on-equipment maintenance records.
3. Order and shipping time (OST)	Weighted average Order and Shipping time in months. The elapsed time between the initiating of a request for

	Variable Name	Explanation
		a serviceable item and its receipt by the requesting activity.
4.	Time to complete supply transaction records (TR)	Average manhours per failure to complete supply transaction records.
5.	Time to complete transportation records (TR)	Average manhours per failure to complete transportation transaction forms.
6.	Base Repair Cycle time (BRCT)	The average base repair cycle time in months. The elapsed in for an item from removal of the failed item until it is returned to base serviceable stock.

VARIABLE INPUT

	Variable Name	Explanation
7.	Time to do scheduled inspection (SMH)	See Equation 2, No. 10.
8.	Time to perform shop bench check, screening, and fault verification (BCMH)	See Equation 3, No. 12.
9.	Preparation and Access (PAMH)	See Equation 2, No. 6.
10.	Time to intermediate-level maintenance (BMH)	See Equation 3, No. 14.
11.	Time to perform corrective maintenance in place (IMH)	See Equation 2, No. 8.
12.	Standby time (ST)	The time the equipment is not operating but assumed operable.
13.	Operating time (OT)	The time the equipment is operating on the ground and during flight.

APPENDIX B

INPUT VALUES

Variable Name	PACKAGE A		PACKAGE B	
	LANTIRN	APR-39	APQ-158	ALR-46
DRCT[4]				
A. CONUS	1.35 mo.	same	same	same
B. Overseas	1.48 mo.	same	same	same
C. Total	2.83 mo.	same	same	same
STK (No. of items)	204[5]	66[5]	198[2]	50[3]
UC (FY $)	$175,000 (78)[8]	$8,000 (78)[8]	$250,000 (81)[2] $100,000 (83)	$24,000 (83)[3]
QPA[6]	1	same	same	same
UF[6]	2:1	same	same	same
RIP[6]	0	same	same	same
NRTS	.27[5]	.05[5]	.35[2]	.15[3]
MTBF*	29 hrs[6]	249 hrs[6]	35 hrs[1]	325 hrs[1]
TFFH[5] (for 20 years)				
A. CONUS	1,390,240 hrs	same	same	same
B. Overseas	335,320	same	same	same
C. Total	1,727,560 hrs	same	same	same
COND	.12857[5]	.51[5]	.16[2]	.40[3]

*Note: The MTBF shown is actually the mean time between maintenance (corrective) MTBM(C). MTBM[1] (C) is what is expected in the field and gives a better indication of cost.

Variable Name	LANTIRN	APR-39	APQ-158	ALR-46
M[7]	24	same	same	same
BLR[4]	$13.03/hr	same	same	same
PFFH[5]				
A. CONUS	118,453 hr	same	same	same
B. Overseas	28,820 hr	same	same	same
C. Total	147,273 hr	same	same	same
OT[6]	80	same	same	same
ST[1]**	526	same	same	same
PAMH	.087 hr[6]	.07833 hr[6]	.8 hr[1]	.5 hr[1]
IMH	1.6255 hr[6]	2.7 hr[6]	1.4 hr[1]	.85 hr[1]
RMH	.2875 hr[6]	.57317 hr[6]	1.6 hr[1]	.75 hr[1]
SMH[1] & SMI[1]	0	same	same	same
BMR[4]	$3.19/hr	same	same	same
DLR[4]	$18.50/hr	same	same	same
PSO[4]	$1.22/lb	same	same	same
PSC[4]	$.59/lb	same	same	same
DRM[4]	$5.19/hr	same	same	same

**Note: Calculated at 80% Fully fission capable rate for total time less operating time.

Variable Name	LANTIRN	APR-39	APQ-158	ALR-46
BCMH[1]	1.3 hr	.4 hr	2.3 hr	.9 hr
RTS	.70[5]	.92[5]	.60[5]	.80[3]
BMH[1]	2.6 hr	1.2 hr	1.6 hr	1.5 hr
BMC (FY $)	$105.90 (81)[7]	$23.39 (81)[7]	$191.54 (83)[2]	$90.17(83)[3]
DMH	11.8 hr[7]	15.3 hr[7]	7.26 hr[2]	19.13 hr[3]
DMC (1983 $)	$156.22[2]	$100.52[3]	$212.50[2]	$166.61[3]
OS[1]	.30	same	same	same
W (pounds)	160 lb[7]	11.02 lb[2]	294.8 lb[2]	22 lb[2]
MRF[4]	.24 hrs	same	same	same
MRO[4]	.08 hrs	same	same	same
OST (CONUS)[4]				
A. Months	.394 mo	same	same	same
B. Hours	283.68 hr	same	same	same
SR[4]	.25 hr	same	same	same
TR[4]	.16 hr	same	same	same
BRCT (Black Box)				
A. Months	.33 mo	same	same	same
B. Hours	237.6 hr	same	same	same

[1] (5)
[2] (32)
[3] (13)
[4] (1)
[5] (8)
[6] (7)
[7] (6)
[8] (24)

APPENDIX C

BASE YEAR FACTOR CALCULATIONS

BASE YEAR FACTORS

Year to be Normalized	Indexes	Base Year Factor
78	$\frac{.942}{.880}$	1.07045
81	$\frac{1.190}{.880}$	1.35227
83	$\frac{1.356}{.880}$	1.54091

APPENDIX D

CALCULATIONS FOR C_1 - COST OF FLU SPARES

Base Year 7T Calculations

Package A

LANTIRN:

$$\frac{\$175,000}{1.07045} = \$163,482.65$$

APR-39:

$$\frac{\$8,000}{1.07045} = \$7,473.49$$

Package B

APQ-158:

$$\frac{\$250,000}{1.35227} + \frac{\$100,000}{1.54091} = \$249,771.04$$

ALR-46:

$$\frac{\$24,000}{1.54091} = \$15,575.21$$

C_1 Calculations

Package A

LANTIRN:

$$\begin{aligned}
C_1 &= 24(204)(163,482,65) \\
&+ \left[\frac{(147,273)(1)(2)(1-0)(.27)(2.83)}{29}(163,482.65)\right] \\
&+ \left[\frac{(1,727,560)(1)(2)(1-0)(.12857)}{29}(163,482.65)\right] \\
&= (800,411,054.40 + 1,268,752,760 + 2,504,242,896 \\
C_1 &= \$4,573,406,710.00
\end{aligned}$$

APR-39:

$$\begin{aligned}
C_1 &= (24)(66)(7,473.49) \\
&+ \left[\frac{(147,273)(1)(2)(1-0)(.05)(2.83)}{249}(7,473.49)\right]
\end{aligned}$$

$$+ \left[\frac{(1,727,560)(1)(2)(1-0)(.51)}{249}(7,473.49)\right]$$

$$= 11,838,008.16 + 1,250,931.94 + 52,288,033.86$$

$$C_1 = \$65,976,973.96$$

<u>Package B</u>

APQ-158:

$$C_1 = (24)(198)(249,771.04)$$

$$+ \left[\frac{(147,273)(1)(2)(1-0)(.35)(2.83)}{35}(249,771.04)\right]$$

$$+ \left[\frac{(1,727,560)(1)(2)(1-0)(.16)}{35}(249,771.04)\right]$$

$$= 1,186,911,982.00 + 2,082,004,419.00$$

$$+ 3,945,092,187.00$$

$$C_1 = \$7,214,008,588.00$$

ALR-46:

$$C_1 = (24)(50)(15,575.21)$$

$$+ \left[\frac{(147,273)(1)(2)(1-0)(.15)(2.83)}{325}(15,575.21)\right]$$

$$+ \left[\frac{(1,727,560)(1)(2)(1-0)(.40)}{325}(15,575.21)\right]$$

$$= 18,690,252.00 + 5,992,132.03 + 66,232,885.64$$

$$C_1 = \$90,915,269.67$$

APPENDIX E

CALCULATIONS FOR C_2 - COST OF ON-EQUIPMENT MAINTENANCE

Package A

LANTIRN:

$$C_2 = \frac{(1,727,560)(1)(2)}{29}\left[.087+(0)(1.6255)+(1-0)(.28755)\right]13.03$$

$$+\ 0$$

$$= (119,142.069)(.37450)(13.03)$$

$$C_2 = \$581,381.72$$

APR-39:

$$C_2 = \frac{(1,727,560)(1)(2)}{249}\left[.07833+(0)(2.7)+(1-0)(.57317)\right]13.03$$

$$+\ 0$$

$$= (13,875.98394)(.65150)(13.03)$$

$$C_2 = \$117,793.85$$

Package B

APQ-158:

$$C_2 = \frac{(1,727,560)(1)(2)}{35}\left[.8+(0)(1.4)+(1-0)(1.6)\right]13.03$$

$$+ 0$$

$$= (98,717.71429)(2.4)(13.03)$$

$$C_2 = \$3,087,100.36$$

ALR-46:

$$C_2 = \frac{(1,727,560)(1)(2)}{325}\left[.5+(0)(.85)+(1-0)(.75)\right]13.03$$

$$+ 0$$

$$= (10,631.13846)(1.25)(13.03)$$

$$C_2 = \$173,154.67$$

APPENDIX F

CALCULATIONS FOR C_3 - COST OF OFF-EQUIPMENT MAINTENANCE

Normalizing BMC

Package A

LANTIRN:

$$\frac{\$105.90}{1.35227} = \$78.31$$

APR-39:

$$\frac{\$23.39}{1.54091} = \$17.30$$

Package B

APQ-158:

$$\frac{\$191.54}{1.54091} = \$124.30$$

ALR-46:

$$\frac{\$90.17}{1.54091} = \$58.52$$

Normalizing DMC

Package A

LANTIRN:

$$\frac{\$156.22}{1.54091} = \$101.38$$

APR-39:

$$\frac{\$100.52}{1.54091} = \$65.23$$

Package B

APQ-158:

$$\frac{\$212.50}{1.54091} = \$137.91$$

ALR-46:

$$\frac{\$166.61}{1.54091} = \$108.12$$

Calculation for C_3

Package A

LANTIRN:

$$\begin{aligned} C_3 = {} & \frac{(1,727,560)(1)(2)(1-0)}{29}\Bigg\{(1.3)(13.03) \\ & + .70\Big[(2.6)(13.03 + 3.19) \\ & + (.00848)(163,482.65)\Big] + .27\Big[(11.8)(18.50 + 5.19) \\ & + (.00062)(163,482.65)\Big] \\ & + \Big[2(.75)+(.12857)\Big]\Big[.59(1-.30)+(1.22)(.30)\Big](1.35)(160)\Bigg\} \\ & = (119,142.07)\Big[16.94 + 84.33740 + 102.84894 + 161.67752\Big] \end{aligned}$$

$$C_3 = \$43,582,629.09$$

APR-39:

$$\begin{aligned} C_3 = {} & \frac{(1,727,560)(1)(2)(1-0)}{249}\Bigg\{(.4)(13.03) \\ & + .92\Big[(1.2)(13.03 + 3.19) \\ & + (.00231)(7,473.49)\Big] + .05\Big[(15.3)(18.50 + 5.19) \\ & + (.00873)(7,473.49)\Big] \\ & + \Big[2(.05) + (.51)\Big]\Big[.59(1 - .30) \\ & + (1.22)(.30)\Big](1.35)(11.02)\Bigg\} \\ & = (13,875.98)\Big[5.212 + 33.82288 + 21.38435 + 7.0694\Big] \end{aligned}$$

$$C_3 = \$936,470.88$$

Package B

APQ-158:

$$
\begin{aligned}
C_3 = {} & \frac{(1,727,560)(1)(2)(1-0)}{35} \Bigg\{ (2.3)(13.03) \\
& + .60 \Big[(1.6)(13.03 + 3.19) \\
& + (.0005)(249,771.04) \Big] + .35 \Big[(7.26)(18.50 + 5.19) \\
& + (.00055)(249,771.04) \Big] \\
& + \Big[2(.35) + (.16) \Big] \Big[.59(1 - .30) \\
& + (1.22)(.30) \Big] (1.35)(294.8) \Bigg\} \\
& = (98,717.71429) \Big[29.969 + 90.15120 + 108.46479 \\
& + 266.62272 \Big]
\end{aligned}
$$

$$C_3 = \$48,885,773.23$$

ALR-46:

$$
\begin{aligned}
C_3 = {} & \frac{(1,727,560)(1)(2)(1-0)}{35} \Bigg\{ (.9)(13.03) \\
& + .80 \Big[(1.5)(13.03 + 3.19) \\
& + (.00376)(15,575.21) \Big] + .15 \Big[(19.13)(18.50 + 5.19) \\
& + (.00694)(15,575.21) \Big] \\
& + \Big[2(.15) + (.40) \Big] \Big[.59(1 - .30) \\
& + (1.22)(.30) \Big] (1.35)(22) \Bigg\} \\
& = (10,631.13846) \Big[11.727 + 66.40 + 84.19646 + 16.19541 \Big]
\end{aligned}
$$

$$C_3 = \$1,897,858.77$$

APPENDIX G

CALCULATIONS FOR OPERATIONAL AVAILABILITY

$$A_o \text{ (LANTIRN)} = \frac{80 + 526}{\begin{aligned}&\Big\{80 + 526 + \Big[(0 + 1.3 + .087 + 2.6)0\Big]\\ &+ \Big[(1.3 + .087)\\ &+ (2.6 + 1.6255 + 237.6).70\Big]\frac{80}{29}\\ &+ \Big[(.24 + .08 + 283.68 + .25 + .16).70\Big]\frac{80}{29}\Big\}\end{aligned}}$$

$$= \frac{606}{606+(0)+(241.8255)2.758+(199.087)2.758}$$

$$A_o \text{ (LANTIRN)} = .33259$$

$$A_o \text{ (APR-39)} = \frac{80 + 526}{\begin{aligned}&\Big\{80 + 526 + \Big[0 + .4 + .07833 + 1.2)0\Big]\\ &+ \Big[(.4 + .0783)\\ &+ (1.2 + 2.7 + 237.6).92\Big]\frac{80}{249}\\ &+ \Big[(.24 + .08 + 283.68 + .25 + .16).70\Big]\frac{80}{249}\Big\}\end{aligned}}$$

$$= \frac{606}{606+(0)+(222.6583).32129+(261.6572).32129}$$

$$A_o \text{ (APR-39)} = .79569$$

$$A_o \text{ (APQ-158)} = \frac{80 + 526}{\begin{aligned}&\Big\{80 + 526 + \Big[0 + 2.3 + .8 + 1.6)0\Big]\\ &+ \Big[(2.3 + .8)\\ &+ (1.6 + 1.4 + 237.6).60\Big]\frac{80}{35}\end{aligned}}$$

$$+ \left[(.24 + .08 + 283.68 + .25 + .16).60\right] \frac{80}{35} \Bigg\}$$

$$= \frac{606}{606+(0)+(147.46)2.28571+(284.41)2.28571}$$

A_o (APQ-158) = .32937

$$A_o \text{ (ALR-46)} = \frac{80 + 526}{\Big\{80 + 526 + \left[0 + .9 + .5 + 1.5)0\right]}$$

$$+ \Big[(.9 + .5)$$

$$+ (1.5 + .85 + 237.6).80\Big] \frac{80}{325}$$

$$+ \left[(.24 + .08 + 283.68 + .25 + .16).80\right] \frac{80}{325} \Bigg\}$$

$$= \frac{606}{606+(0)+(193.36).24615+(284.41).24615}$$

A_o (ALR-46) = .83748

To find the availability of the packages, the probability of the package working is calculated as the probability of both pieces of equipment working. A failure of either piece of equipment results in the failure of the package, but does not affect the probability of the other piece of equipment. Therefore, the probability of the package is the probability of two independent events. In equation form the probability is calculated as follows (11:17; 17:143; 33:46):

$$P\ (\text{PACKAGE}) = P\ (\text{Multi-Mode Radar} \cap \text{Radar Warning Receiver})$$

$$= \left[P\ (\text{Multi-Mode Radar})\right] \times \left[P\ (\text{Radar Warning Receiver})\right]$$

$$P\ (\text{PACKAGE A}) = (.33259)(.79569)$$

$$= .26464$$

$$P\ (\text{PACKAGE B}) = (.32937)(.83748)$$

$$= .27584$$

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