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USING LOGISTICS MODELS IN SYSTEM DESIGN AND EARLY SUPPORT PLANNING

R. M. Paulson, R. B. Waina and L. H. Zacks

A Report prepared for

UNITED STATES AIR FORCE PROJECT RAND

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SANTA MONICA, CA. 90406

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PREFACE

This Report describes available modeling techniques that can be used during weapon system conception, development, production, and deployment to investigate the logistics impacts of system design and operational decisions. It systematically analyzes some of the techniques and models available to assist in the development tradeoff processes, with a primary orientation toward techniques that emphasize early support planning and integrated logistics concepts. It also discusses strategies for using such models. Addressed to system designers, system development program managers, logistics planners, and staff planners responsible for implementing Integrated Logistics Support (ILS) concepts, the study is designed to clarify how some of the ILS tasks may be performed.

This Report does not recommend procedures for selecting the preferred one of a set of alternatives. Rather, it discusses methods for developing estimates of support costs, which we assert are a necessary input to the process of selecting system design alternatives.

The research developed out of Rand's continuing interest in early support planning models, and out of Service and Department of Defense programs to provide the methods and procedures for ILS. It was performed for the Air Force acting as an agent for all the military Services. In particular, this work was done for the Assistant for Logistics Planning (AFSLP) as the major portion of Task C, ILS Modeling Techniques and Tradeoffs, for the DOD/Industry Integrated Logistic Support Advisory Committee. We therefore attempted to take as wide a view as possible, instead of restricting ourselves to purely Air Force interests in such modeling.

SUMMARY

Because of the high cost of current weapon acquisition programs and the continuing pressure to reorient national priorities, the Services have been enjoined to improve their techniques for estimating both the investment and operational costs of new systems. Uncertainty surrounds both sets of figures; an estimate in the weapon's conceptual phase, for example, could possibly double by the time the weapon is completed. This "cost growth" phenomenon has focussed the attention of the public, the Congress, and the DOD on the problem, with specific recommendations from committees such as the Fitzhugh panel on guidelines for attaining economies in the acquisition process.*

Estimates attribute more than half of a weapon system's total life cycle costs (LCC) to its logistics costs (i.e., operation, training, and support costs).** Such amounts are fixed by the weapon's design, mode of employment, and management structure. Since 1964, when DOD Directive 4100.35 was published describing the Integrated Logistics Support (ILS) concepts, the Services have been required to consider, estimate, and evaluate the life cycle costs implied by the design alternatives encountered throughout the acquisition process. These alternatives involve the tradeoffs between the Services' preconceived operational, organizational, and resource availability environments with the elements of technological feasibility.

If improved methods for making tradeoff evaluations can be developed and employed early in the weapon's design, then possibly all subsequent development decisions can focus on reducing life cycle costs. Computer modeling offers a decision-aiding technique for this purpose.

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*G. W. Fitzhugh, et al., Defense for Peace: Report to the President and the Secretary of Defense on the Department of Defense, Blue Ribbon Defense Panel, Washington, D.C., 1 July 1970.

**Logistics Management Institute, Methods for Evaluating the Cost/Effectiveness of Alternative Support Plans for Major Weapon Systems, Project 6P Report, September 1965.

***DOD Directive 4100.35, Development of Integrated Logistics Support for Systems and Equipments, U.S. Government Printing Office, Washington, D.C., 19 June 1964.

It allows system and subsystem designers, who define the logistics characteristics of all hardware, to evaluate the consequences of alternative design approaches on the performance, cost, and support characteristics of each proposed system before substantial money and time is spent on its development.

This Rand Report analyzes available modeling techniques that can be used during system conception, development, production and deployment to investigate the logistics impacts of system design and operational decisions. It also discusses strategies for using such models. Seven categories of models are described, categorized by their substantive applications: spares, AGE, personnel, maintenance posture, operations, life cycle cost, and project management.

Logistics models appear to have many possible uses throughout the system acquisition process. These uses revolve around the basic concept that the support implications of all system decisions should be weighed and systematically treated. Some proposed uses follow:

- Make performance/support tradeoffs
- Evaluate design goals for support cost implications
- Define the scope of ILS in development contract
- Select development contractor
- Negotiate and draft development contract
- Evaluate contract incentive structures
- Select detailed design alternatives
- Make level-of-repair and source-coding decisions
- Do support planning for spares, AGE, personnel
- Evaluate proposed product improvement, value engineering, and modification programs
- Monitor progress and system decisions of development contractor

We feel that the model technology is well in hand to do the support cost estimating required for implementing ILS in the conceptual, validation, development, production, and deployment phases of the system acquisition process. Such estimating is most difficult in the early conceptual phase, but techniques are available to handle explicitly the uncertainty inherent in such early data. Even when the uncertainty cannot be easily quantified, models can be used to explore system design/support cost interactions, and thus define at least the desirable ranges of system parameters.

It appears a sufficient stock of basic models and modeling techniques are available, many of them at no cost to the Services. Primary development effort should probably be devoted to adapting existing models to particular applications, and interfacing sets of models into compatible families applicable over a wide range of problems. Increased awareness of the availability of models needs to be achieved, and a training program for potential model users established.

ACKNOWLEDGMENTS

During this investigation, the authors drew on the knowledge of many people at Rand, in the Services, and in other organizations. Although they are too numerous to all be named, we would be remiss if we did not specifically mention the contributions of the following individuals: Colonel John Skaggs and Mr. Don Hallwerck of the AFLC Development Plans Office, SAMSO, for initial guidance and definition of the scope of the problem; Major Thomas Tierney, USAF, for review of the description of the current acquisition process, and generally helpful suggestions on the overall presentation of the research; and Dennis Tihansky of Rand for various comments on analytical techniques and modeling.

CONTENTS

LIST OF TERMS

AGE	Aerospace ground equipment
AWACS	Airborne warning and control system
AWM	Awaiting materiel
BITE	Built-in test equipment
CFP/TDP	Concept formulation package/ technical development plan
DCP	Development concept paper
DSARC	Defense Systems Acquisition Review Council
LCC(L)	Life cycle cost (logistics)
LOR	Level of repair
LRU	Line replaceable unit
NORM	Not operationally ready due to maintenance
NORS	Not operationally ready due to supply
NRTS	Not reparable this station
OPR	Office of primary responsibility
OR	Operationally ready
PCR	Program change request
PSPP	Proposed system package plan
RAD	Required action directives
RFR	Request for response
ROC	Required operational capability
SPD	System program director
SPO	System program office
SPP	System package plan
SSEB	Source selection evaluation board
TBO	Time between overhaul

I. INTRODUCTION

This Rand Report analyzes available modeling techniques that can be used during system conception, development, production and deployment to investigate the logistics impacts of system design and operational decisions. It also discusses strategies for using such models. Our sample of 46 models, although not an exhaustive collection, includes perhaps one-third to one-half of the universe of such models.

BACKGROUND

Because of the high cost of current weapon acquisition programs and the continuing pressure to reorient national priorities, the Services have been enjoined to improve their techniques for estimating both the investment and operational costs of new systems. Uncertainty surrounds both sets of figures; an estimate in the weapon's conceptual phase, for example, could possibly double by the time the weapon is completed. This "cost growth" phenomenon has focussed the attention of the public, the Congress, and the DOD on the problem, with specific recommendations from committees such as the Fitzhugh panel on guidelines for attaining economies in the acquisition process.*

Estimates attribute more than half of a weapon system's total life cycle costs (LCC) to its logistics costs (i.e., operation, training, and support costs).** Such amounts are fixed by the weapon's design, mode of employment, and management structure. Since 1964, when DOD Directive 4100.35*** was published describing the Integrated Logistics Support (ILS) concepts, the Services have been required to

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*G. W. Fitzhugh, et al., Defense for Peace: Report to the President and the Secretary of Defense on the Department of Defense, the Blue Ribbon Defense Panel, Washington, D.C., 1 July 1970. For a discussion of their recommendations, see Appendix B.

**Logistics Management Institute, Methods for Evaluating the Cost/Effectiveness of Alternative Support Plans for Major Weapon Systems, Project 6P Report, September 1965.

***DOD Directive 4100.35, Development of Integrated Logistics Support for Systems and Equipments, U.S. Government Printing Office, Washington, D.C., 19 June 1964.

consider, estimate, and evaluate the life cycle costs implied by the design alternatives encountered throughout the acquisition process. These alternatives involve the tradeoffs between the Services' preconceived operational, organizational and resource availability environments with the elements of technological feasibility.

Because of recent cost growth problems and a reorientation of defense priorities, budgets, and management, the Department of Defense has placed renewed emphasis on Directive 4100.35. As defined in the 1970 version of that document,* ILS is basically twofold, and requires that

1. planning the logistic support requirements shall begin at the Conceptual Phase...(and) proceed with continuity through the life cycle of the program.
2. design of all operational systems...shall take into account the aspects of logistic support.... Tradeoffs appropriate to the stage of development shall be made that will maximize the effectiveness and efficiency of the support system.... The operational environment and the logistic support requirements which are the result, will be addressed during the tradeoff stage of the system design process. Change to either the system or to logistic support needs will be fully evaluated for the impact on the total system.

If improved methods for making tradeoff evaluations can be developed and employed early in the weapon's design, then possibly all subsequent development decisions can focus on reducing life cycle costs. Computer modeling offers a decision-aiding technique for this purpose. It allows system and subsystem designers, who define the logistics characteristics of all hardware, to evaluate the consequences of alternative design approaches on the performance, cost, and support characteristics of each system they propose.

IMPLEMENTING ILS

Historically, support costs have not been of major importance to system designers, partially because of certain institutional funding

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*DOD Directive 4100.35, Development of Integrated Logistics Support for Systems and Equipments, U.S. Government Printing Office, Washington, D.C., 1 October 1970.

considerations such as the separation of dollars into distinct and unmixable "pots," and partially because credible cost estimates were not forthcoming. The current DOD ILS effort is focusing on such costs for two major purposes:

1. To develop logistics plans that optimize the support posture in response to the design decision and minimize the possibility of support and cost surprises.
2. To consider alternatives to the design decision and possibly alter the design.

The second item represents a relatively new interaction if it can be accomplished, but it requires thorough, credible analysis; must occur early in the life cycle; and must receive support from all management and policy levels that can affect decisions. Each of these are equally important, and are discussed below.

Data, models, and personnel are all important for thorough, credible analyses. The data must represent the engineers' best estimates of the system and equipment descriptive parameters. The models must be credible; represent the support process; be readily usable and economical to operate; and their products must be easily interpreted and capable of iteration and adaptation. Personnel within both industry and the Services must be trained and motivated concerning the use of analysis and models and must understand the context of their roles.

Logistics analysis should occur early in the life cycle during specification writing and concept formulation. At this point it is less costly to rectify mistakes; it is easier to adjust design objectives; and it makes studies and tradeoffs more meaningful since they influence the broader set of specifications at the operation and support levels.

All management and policymaking levels that affect acquisition decisions must support the ILS objectives and the support procedures and tradeoffs that reflect this philosophy. It has been stated frequently that ILS represents nothing new, that the directive has been around since 1964, and that many existing regulations and manuals already do the ILS tasks. The current ILS does have some important innovations; namely, the Secretary of Defense has revised his management methods.

Under the new procedures, the Development Concept Papers (DCPs) issued during system development and acquisition require the Services to spell out the full military and economic consequences and risks of each new program.* Further, they must minimize these risks by risk assessment and evaluation, by system and hardware proofing, and by consideration of practical tradeoffs between operating requirements and system design.** The DCPs require the signature of the Assistant Secretary of Defense, Installation and Logistics; he also is a permanent member of the Defense System Acquisition Review Council, which monitors the acquisition progress of all systems. To make ILS work, the tools must be provided for developing the economic consequences of each program decision.

CONDUCT OF THE STUDY

The study began with interviews of over two dozen Air Force, DOD, and Rand personnel knowledgeable about the acquisition process and the use of models therein. It was generally agreed that the Services and the Department of Defense do not address logistics questions by using explicit models until late in the development process; however, there appears to be a trend toward earlier implementation, particularly with the activities of McDonnell Douglas on the F-15 and the development and use of models by a number of Service organizations. Recent commercial aircraft acquisitions also evidence the use of logistics models.

Following the interviews, we collected models from Government and private organizations, and developed an approach for analyzing such models. Concurrently, we began developing some ideas about how such models might be used during the weapon system acquisition process.

ORGANIZATION OF THE REPORT

Section II explains our method of categorizing and analyzing the models. Section III describes the sample by category and application;

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*<u>Defense Industry Bulletin</u>, January 1970, p. 2.

**Memorandum from the Deputy Secretary of Defense, <u>Policy Guidance on Major Weapon System Acquisition</u>, 28 May 1970.

Appendix A describes each model separately. Section IV discusses some ideas about how models might be used during the various phases of the acquisition process. Section V provides our conclusions and recommendations.

Appendix B describes the relation of the Fitzhugh report to ILS. Appendix C gives a brief overview of the current acquisition process. Appendix D addresses the need for a method to consider explicitly the uncertainty inherent in system data, particularly during early development. Appendix E provides an example of how models can be used to simplify logistics analysis during the design process. Appendix F refers to some other catalogs of models that might be useful for logistics analysis.

II. LOGISTICS MODELING

This section broadly defines modeling in a logistics context, touching on data constraints and decision types, as well as simulation and analytical techniques.

DECISION TYPES

Because a model aids a decisionmaker in analyzing some problem, its effectiveness is a function of a particular decision. The logistics area, as it interfaces with system design, concerns three broad, closely related decision situations; and a model that will handle one phase may well handle all three:

1. Conceptual design/concept evaluation--comparing different concepts for achieving some set of performance characteristics or operational objectives, and for establishing envelopes for system characteristics.
2. Detailed system design--selecting a particular hardware design from a number of candidates.
3. Support planning--estimating the kind and quantity of resources required to support a particular design.

To illustrate these three areas, consider the reliability of some piece of avionics. In conception or early development we want to determine the system's optimum reliability for it to achieve the mission performance requirements and to minimize life cycle costs, and the optimum reliability of each of its subsystems. Then, given a certain reliability requirement, and goals for other system parameters, the designer creates one or more hardware designs as candidates for this particular item. He selects a particular design, with awareness of the support cost consequences of each design alternative; he may decide to ignore or give them little weight because of some other overriding consideration, but at least he should know what they are. It is possible that the same model used to establish the reliability design goal can be used to evaluate the cost consequences of the design alternatives. And finally, given that some hardware design has been selected, the logistician needs to devise his support plans for the avionics item--quantity and location of spares, how and where the item is to be repaired, AGE needed, maintenance personnel requirements, and so forth. He may again use the same model to develop these plans, or he may supplement or replace it by more detailed models.

DATA AVAILABILITY

Data requirements vary greatly from model to model--in our sample from minimal to much. Whatever its requirements, however, a model's effectiveness is dependent upon the quantity and quality of the data available to drive it. In general, the longer a system has been in development, the more data there are to describe it. Early in the conceptual phase, the data consist mainly of some broad performance goals and some general ideas of the sort of system that might achieve these goals. Later on, the system can be described in terms of end items--their form, fit, and function, and perhaps estimates of weight, reliability, price, and maintainability. More detailed development/design, possibly including the fabrication of test hardware, will lead to better parameter estimates.

When data on the cost, reliability, and maintainability of end items become available, logistics models can be used for design analysis. But such models can be used even before then with hypothetical numbers, in order to determine desirable values for design parameters from a support viewpoint.

Based on our understanding of operations and examination of our sample of models, we feel that most significant data elements of a logistics model are those shown in Table 1.

Table 1

LOGISTICS MODEL VARIABLES

Item	Repair points
Unit cost[a]	Manhours to repair[a]
Reliability[a]	Maintenance skills
Weight	Parts cost/repair[a]
Volume	Labor rate
Procurement lead time	Repair cycle length
Reprocurement cost	Order and shipping time
R and D cost	NRTS rate
System	Condemnation rate
Program for utilization	Distance for next echelon
Geographic deployment	Packing cost
Force size	Shipping cost
Force life	AGE cost (acquisition, installation, O and M)
OR rate	AGE weight and volume
On-equipment maintenance cost	AGE quantity
Training cost	Facilities cost
Interest rate	Technical data pages
Stock points	Technical data cost
Spares level	Maintenance postures
Supply effectiveness	
Supply administration cost	
Reorder policy	

[a]Most important parameters

Some elements in Table 1 are strictly item characteristics, such as unit price and reliability (mean-time-between-failures or mean-time-between-removals). Others relate to spares storage points (such as organization, base or depot stock). Still others relate to all items in a system. Finally, certain characteristics relate to where and how the item is repaired. Each element may be treated within a model in one of four ways. The first two are model inputs, the latter two are outputs.

1. Engineering estimate. This is the designer's best judgment of the value some parameter will attain when the hardware is deployed. Engineering estimates are commonly made of parameters such as mean-time-to-failure, mean-time-to-repair, weight, and unit price.

2. Standard value. Such a value is often used to describe aspects of the system's operating environment. Typical parameters having standard values would be cost per manhour of repair time, cost per page of technical data, and cost per ton-mile to ship. Most are derived from cost estimating relationships and/or historical analysis of accounting data.

3. Calculation. Many parameters are calculated by a model. Some typical ones might be AGE utilization, spares level, acquisition cost, system effectiveness, and life cycle cost.

4. Optimization. Some models optimize certain parameters: either absolutely in the mathematical sense that no other combination of values would yield a higher (or lower) level of the utility function for the parameter-space considered; or, relatively in that a certain number of cases are considered, and that case having the best value of the utility function is chosen. Two parameters that are often optimized are spares level and distribution, and repair level; spares are often mathematically optimum, while repair level is most usually relatively optimum in the policy space considered.

There are few models that attempt to treat every system parameter. The designer should note important parameters that the model does not explicitly consider.

TYPES OF MODELS

Logistics models deal with various substantive areas--for example, spares, AGE, personnel, maintenance posture. Models relating to these and other areas are discussed in Sec. III. But in addition to the areas addressed, models can be categorized by the methodology used.

Analytical

Analytical models yield a single answer or a unique set of answers for any given set of values of input variables. Usually the solution to this type of model represents the desired consequence or objective sought. While the number of parameters is not restricted, an analytic model is often designed for a minimal amount of computation and mathematical techniques. As the complexity of data and relations within the model structure increase to achieve detailed realism, it becomes likely that the decision problem cannot be solved by either theoretical or numerical methodology, even on computers with extensive storage facilities.

Simulation

Systems characterized by large data banks or sizable solution sets can be handled with simulation models. Simulation traces the system's behavior, frequently over time, under a specific group of constraints, such as initial conditions, exogenous and design variables, target conditions, and internal structural properties. Functional relationships exist between the solution parameters and the control or state variables in the model, and in some cases the solutions are not obtained as point estimates but rather as intervals that contain the correct answer.

Simulation Versus Analytical Models

Although simulation is frequently implemented for complex situations, it is not necessarily true that the solution implied from a given set of input data is optimal. Instead, it represents an approximation to the best answer, and the modeler must introduce various input combinations to compare their implications for the desired goals in the system analysis. Yet, even with the selection of many different input data, the attainment or realization of an optimal solution cannot be assured as it is for the analytical approach.

Although simulation is generally more adaptable to large-scale computational problems than analysis, it also gives approximate solutions whose optimality may, or may not, be justified on theoretical grounds. Further, simulation models are generally larger, more difficult to debug and validate, and more expensive to run than analytical models. They can be used, however, to analyze situations that are just too complex for analytical models to handle. They are thus exceedingly useful for analyzing complicated systems in uncertain environments, <u>if the user understands well the assumptions and limitations of the model.</u>*

ANALYTICAL METHODS

Models can be further categorized by the analytical methodology used to formulate and solve a problem. Many reliability models, for example, are based upon a formulation involving the probability of occurrence of various events. Such models may be particularly useful in predicting the failure rates (and hence, maintenance demands) of various systems or components, given the configuration and certain basic probabilities.

Network or flow models are useful in analyzing the characteristics of systems that involve the movement of material, making them useful for studying the movement of equipment, spares, and reparables from the point of manufacture to the point of use, and often back to repair facilities. Many network models also use probabilistic considerations in determining which path to take when a choice is necessary.

Optimization techniques are required if an optimal system design is desired subject to a constraint set. Linear programming assumes

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*For a more detailed discussion of simulation see P. J. Kiviat, <u>Digital Computer Simulation: Modelling Concepts</u>, The Rand Corporation, RM-5378-PR, August 1967; P. J. Kiviat, <u>Digital Computer Simulation: Computer Programming Languages</u>, The Rand Corporation, RM-5883-PR, January 1969; and G. S. Fishman, <u>Digital Computer Simulation: Estimating Sample Size</u>, The Rand Corporation, RM-5866-PR, August 1969.

that a linear function is optimized with linear inequality (or equality) constraints; this approach is readily applicable to large-scale problems with hundreds of unknown variables and constraints. Nonlinear programming is applicable for smaller models (i.e., ≤ 100 unknowns) when a nonlinear function is optimized with nonlinear constraints (whose intersection is a convex set to guarantee that an optimal solution is reached). Dynamic programming is a method employed if the solution is selected from a discrete set of possible answers with sequentially related constraints; this approach is particularly suitable for system design involving many variables.

Accounting models are commonly used in logistics because support resources are often expressed in terms of dollars (even though various types of resources are not necessarily readily exchangeable--for example, personnel for spare parts). They are basically just a structured way of adding up component costs.

Deciding where to allocate resources, where the biggest payoffs will be, is basically an investment decision. This approach, currently under investigation, has some promise of handling the tradeoff between investment and acquisition costs. Another approach applies resource-constrained network techniques to investigate the tradeoff between development cost and development time.

Still other models involve sets of linear, nonlinear, or differential equations to describe the relationships of the important system parameters. Manipulation of these equations can provide insights into some of the tradeoffs, for example, between system performance and cost.

A particular methodology will probably be dominant rather than exclusive in a model. Most models, for example, will have some cost components. Almost all will involve at least some set of linear equations. Many will have some network characteristics. But any single model will reflect some particular view of the world, some singular approach to formulating the problem, and therefore will tend to fall into some specific category.

OTHER CONSIDERATIONS

Other considerations involve the usability of the model. It is therefore pertinent to note what language the model is programmed in, what computer it runs on, what the core and running time requirements are (where such estimates are available), how easy the data are to prepare, and other such factors as may affect the model's efficiency and ease of use.

III. CURRENT MODEL TECHNOLOGY

This section describes the 46-model sample by category of application as shown in Table 2.*

THE SAMPLE

The models comprising the sample were chosen based on their availability to us, their wide scope of methodology, and the questions they address. Models using cost estimating relationship approaches** were specifically excluded because they are generally aggregated at too high a system level to be sensitive to changes in logistics costs caused by changes in design parameters at the subsystem and lower levels.

No attempt is made to assess the relative utilities of the various models on an overall basis (i.e., statements such as, "LCOM is better than BOMS," are avoided), because each abstracts some part of the real world and implicitly embodies some set of assumptions about the world--hence, each is optimal to some particular application and set of assumptions. It may be useful in other applications than those for which it is specifically designed, if its assumptions and world conceptualization are "close enough" to that of the application being considered.

Each model is a tool for aiding the analysis of some decision. It is incumbent upon the decisionmaker to be sure he has selected the appropriate tools for the task. We have attempted to identify and differentiate some of the available tools, but the final selection must be made by detailed matching of the analytical requirements of the decision situation and the analytical characteristics of particular models.

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*Appendix A contains brief descriptions of the individual models giving their acronym and name; applications; data requirements; programming information and usability comments; references; person to contact for more information; and owner (private contractor or government).

**See, for example, J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The Rand Corporation, RM-3589-PR, June 1963; and C. A. Batchelder, et al., An Introduction to Equipment Cost Estimating, The Rand Corporation, RM-6103-SA, December 1969.

Table 2

LOGISTICS MODELS

Model Name	Acronym	Spares	AGE	Pers	LOR	Opns	LCC	Mgt
Acquisition Based on Consideration of Logistics Efforts	ABLE						X	X
Analysis Method for System Evaluation and Control	AMSEC	X	X	X		X	X	
Aircraft Reliability/Maintainability/Availability Design Analysis	ARMADA	X	X	X		X	X	
Base Depot Stockage Model	BDSM	X						
Base Operations Maintenance Simulation	BOMS	X		X		X		
Cargo Airline Evaluation Model	CAEM					X	X	
Computer Analysis of Maintenance Policies	COAMP	X	X		X		X	
Determining Economic Quantities of Maintenance Resources	DEQMAR		X	X				
Generalized Effectiveness Methodology	GEM					X		
Ground Operations Support Simulation	GOSS					X		
Inventory Policy Model	IPM	X						
Life Cycle Cost Model	LCCM						X	X
Life Cycle Computer Program	LCCP	X	X	X	X	X	X	
Logistics Composite Model	LCOM	X	X	X	X	X		
Logistics Cost	LOGCOST		X	X			X	X
Level of Repair--Aeronautical Materiel	LORAM	X	X		X		X	
Maintenance Assembly and Checkout Model	MACOM					X		
Materiel Readiness Index System	MARIS	X				X		
Military/Commerical Transport Aircraft Simulation	MCTAS	X	X	X		X		
Multi-Echelon Markov Model	MEMM	X				X		
Multi-Echelon Technique for Recoverable Item Control	METRIC	X						
Multi-Indenture NORS Evaluator	MINE	X				X		
Maintainability/Reliability Simulation Model	MRSM		X	X	X	X		
Operations, Maintenance, and Logistics Resources Simulation	OMLRS	X	X	X		X		
Optimum Repair Level Analysis	ORLA				X		X	
Planned Logistics Analysis and Evaluation Technique	PLANET	X	X	X		X		
Project Modelling	PROJMOD							X
Quantification of Uncertainty in Estimating Support Tradeoffs	QUEST				X		X	
Resource Allocation Model	RAM							X
Range Model	RGM	X	X	X	X		X	
Reliability Maintainability Tradeoff	RMT							X
Support Availability Multi-System Operations Model	SAMSOM	X	X	X		X		
System Support Cost Analysis Model	SCAM	X	X	X	X		X	
Support Concept Economic Evaluation Technique	SCEET				X			
Space Craft Operational Performance Evaluation	SCOPE					X		
System Cost and Operational Resource Evaluation	SCORE			X			X	
Support Effectiveness Evaluation Procedure	SEEP	X				X		
Single Echelon Multi-Base Resource Allocation Technique	SEMBRAT		X	X		X		
Spares Kit Evaluator Model	SKEM	X						
Sortie Generation Model	SOGEM					X		
Spares Requirements and Evaluation Model	SPAREM	X				X		
Scheduling Program for Allocating Resources to Alternative Networks	SPARTAN							X
Spares Provisioning Model	SPM	X						
Subsystem Simulation Model	SSM		X	X		X		
Throwaway/Repair Implications on Maintenance Cost	TRIM	X	X		X		X	
Validated Aircraft Logistics Utilization Evaluation	VALUE	X	X	X		X	X	

SUMMARY OF MODELS

The major support planning decisions made during weapon system acquisition fall into the tasks of determining the quantity and distribution of initial spares; the amount of AGE and new facilities; the requirements for (maintenance and support) personnel and their associated training; the level of repair and source coding; and the program for inspection and preventive maintenance. Seven categories of models are discussed. Four relate specifically to the major support planning decisions.

1. Spares. Determining the quality, and possibly the location, of spare units.
2. AGE. Determining the quantity and location of test and repair equipment.
3. Personnel. Determining the number of maintenance personnel needed,
4. Maintenance posture (LOR). Determining the optimum maintenance posture for a particular end item (e.g., repair at base, repair at depot, do not repair).

Three other model categories are useful. One type is helpful in studying the interaction between operational effectiveness and support requirements.

5. Operations. Determining the effect upon operations of changes in various logistics and system parameters.

Most of the maintenance posture models involve life cycle cost calculations. There are other applications for such models.

6. Life cycle cost (LCC). Calculating the life cycle cost implications of particular system and logistics postures.

The last category is indirectly related to support planning.

7. Project management. Aiding in analysis of decision situations project managers face (e.g., resource allocation, scheduling).

Each of these categories is now discussed in turn.

SPARES MODELS

Spares models help determine the initial quantity and location of spare items for recoverable assemblies. The driving parameters are item failure or removal rate (reliability), item usage rate (e.g., flying program), and item repair pipeline time. Some models attempt to optimize a parameter such as operationally ready rate; not operationally ready, supply rate; or backorder rate* subject to one or more constraints, while other procedures merely apply the basic numbers to a standard formula (e.g., ninety days' worth of spare items). To make the most efficient use of available resources, it would generally be preferable to use one of the optimal spares decisions methods.

Weapon system contractors, such as General Dynamics and Lockheed, have developed models for spares provisioning in both military and commercial work (e.g., BDSM for the F-111). One of the primary models in this class is METRIC,** which is to be implemented in the Advanced Logistics System of the Air Force. METRIC distributes stocks of items to bases and depots to minimize total expected backorders at both bases and depots under a budget constraint. Since all assemblies, modules and submodules are considered as simply items, we classify METRIC as a two-echelon, one-indenture model.***

One-indenture models, however, slightly underestimate assembly stock since they ignore assembly/module interactions; therefore, a more sophisticated two-indenture model is required to set optimal assembly <u>and</u> module stock levels. Such models are IPM, a General Dynamics modification of METRIC, that was developed to make recommendations for Navy F-111 stocks, and MINE, a Rand modification of METRIC.

Most models of this class require a constant failure rate that is proportional to flying hours. For many items, however, the

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*For a discussion of the various objective functions, see R.B.S. Brooks C. A. Gillen, and J. Y. Lu, <u>Alternative Measures of Supply Performance: Fills, Backorders, Operational Rates and NORS</u>, The Rand Corporation, RM-6094-PR, August 1969; and B. L. Miller, <u>Unconstrained Optimization in the Integers</u>, The Rand Corporation, RM-6165-PR, January 1970.

**C. C. Sherbrooke, <u>METRIC: A Multi-Echelon Technique for Recoverable Item Control</u>, The RAND Corporation, RM-5078-PR, November 1966.

***Echelons and indentures are described more fully under Maintenance Posture Models.

rate is either increasing (e.g., tires, bearings) or decreasing (e.g., integrated circuits) and is perhaps highly dependent upon sortie and mission type and number (e.g., landing gear), rather than simply flying hours. The lack of accurate failure data, combined with the fact that aggregate failures are exponential, has led all Services and most contractors to assume a constant exponential failure rate for individual items when it has not been warranted, thereby producing overabundant stock levels for many items.

Other models specifically addressing the spares question are SPM for the transport aircraft problem; SKEM for the flyaway kit (multiple constraint) problem; and SEEP and SPAREM for calculating the effectiveness of supply levels. MARIS and MEMM address the interaction between supply policy and operational effectiveness of a deployed unit depending upon on-board spares. AMSEC and LCCP incorporate procedures for considering the failure rate as a function of mission type/segment. Most of the big operational simulations can also be used for analyzing spares, as can the maintenance posture models.

AGE AND PERSONNEL MODELS

Computing the AGE requirement is basically the same as computing the number of channels required to service some set of demands.* Facilities requirements are similar, but less detailed, and are therefore generally a matter of engineering judgment. SEMBRAT is a queueing model approach to determining AGE requirements. SCAM, COAMP, and other maintenance posture models compute AGE requirements based on average utilization under certain rather simple assumptions, so that in general the required quantity computed is greater than what is actually required. The most realistic assessment of AGE requirements can be obtained with simulation models such as SAMSOM and PLANET. RGM attempts to handle the common-AGE problem at the system rather than the assembly level.

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*See, for example, T. L. Saaty, Elements of Queueing Theory, McGraw-Hill Book Company, New York, 1961

Personnel computations are similar to those for AGE, except that more reliance can be placed on average rather than peak workload. Maintenance manhours are the basic determinant of the personnel requirements. Any model (e.g., SCAM) that has as input the manhours to repair an item can thus compute an average quantity of manpower required for a total program. SCAM apportions the manhours by skill type, and is thus able to determine manpower requirements by skill type. This approach does not consider queueing, which requires the large simulation models (or queueing models).

We have seen no models that attempt to establish training requirements as a function of system design parameters. Until such appear, this area will remain the province of experienced educators who apply their judgment to determine what training is necessary and how best to obtain it. There are some models that might be useful as a basis to build on.*

MAINTENANCE POSTURE MODELS (LOR)

General Dynamics reported a fairly comprehensive investigation of the maintenance posture models for the Navy.** It is recommended reading for anyone working in this area. One approach they discuss is the use of screening techniques, particularly graphs, for level of repair (LOR) analysis.

Screening

One of the first screens for use during LOR analysis would be to rank the items in order of their values to the LOR decision. This technique is called the velocity screen. For each item, an index is calculated which is its unit cost times its removals per flying hour. The items are then ranked on this index, and those with the highest values selected for immediate or near-term decision, while those with

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*See, for example, Allen Hammond, Mathematical Models in Education and Training, The Rand Corporation, RM-6357-PR, September 1970.

**General Dynamics, Level of Repair Decision Rules, FZM-12-10586, Fort Worth, 27 March 1969.

low values can be delayed. You thus make the LOR decision first on those items that will have the greatest economic impact on the system.

Various parameters can be subjected to screening. The most useful involve combinations of parameters. Consider, for example, the break-even curves shown in Fig. 1. Each curve defines where total cost of repair equals total cost of discard. Factors tending to favor a discard over a repair decision are: high repair cost as a percentage of unit price; high repair facility setup cost as a percentage of unit price; high item reliability.

Figure 2 shows a similar screening graph, with slightly different parameters for a specific program. Note also that it divides the repair region into base and depot areas.

Any candidate item having assigned cost and maintenance factors is located at a unique point in the plane and falls into either the base or depot repair region, or the discard region. Several evident characteristics of this type of plot may be observed.

1. Decision results are based on generalizations whose validity is not the same for all items. Thus, a specific chart is necessary for each class of item.
2. A decision made on the basis of a point far from any curve is more likely to be valid than one based on a point close to any curve.
3. The region in which a decision is not clear indicates that the decision is not critical--that there really is not much economic advantage favoring one choice over another.
4. From the graph, the decisionmaker cannot predict the influence of a change in any cost element other than the significant parameters (cost, maintenance factor) chosen for the axes of the graph.
5. The graph is peculiar to a given program. For example, an increase in the number of aircraft involved or in the utilization rates would require the construction of a new graph.

The objection concerning the uncertainty of a decision point close to a break-even curve can be overcome by examining the variability of the factors involved and the sensitivity of the decision functions to these factors. In this way, it is possible to replace each curve by

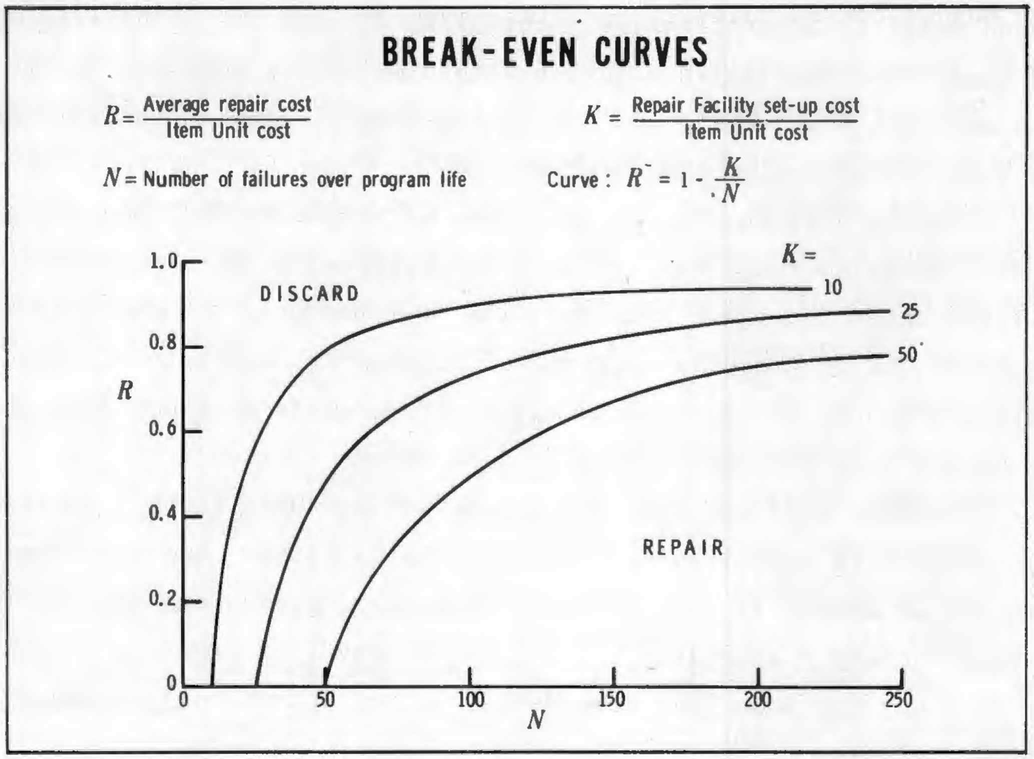
BREAK-EVEN CURVES
R = Average repair cost / Item Unit cost
K = Repair Facility set-up cost / Item Unit cost
N = Number of failures over program life
Curve : R = 1 - K/N
K =
10
25
50
DISCARD
REPAIR
R
1.0
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
N

Fig. 1

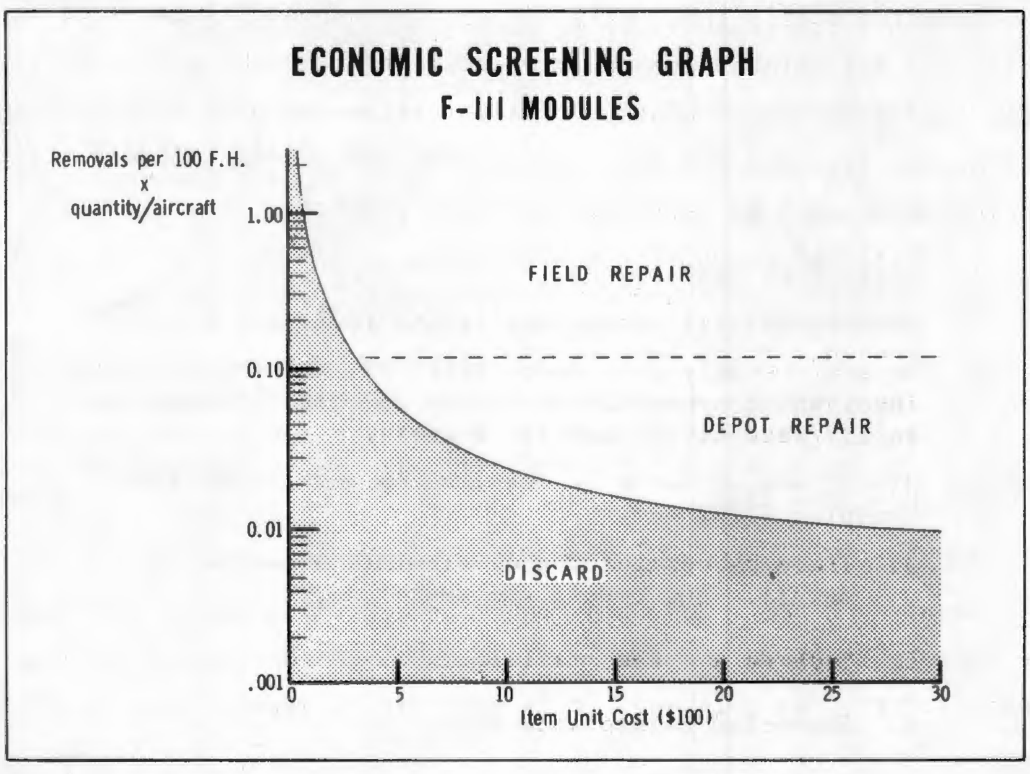
ECONOMIC SCREENING GRAPH
F-111 MODULES
Removals per 100 F.H.
x
quantity/aircraft
1.00
0.10
0.01
.001
FIELD REPAIR
DEPOT REPAIR
DISCARD
0
5
10
15
20
25
30
Item Unit Cost ($100)

Fig. 2

a band based on a quantitatively established criterion of uncertainty. The band then constitutes a region within which the decision is not obtained from a screening aid but rather from a detailed analysis of the specific cost elements involved.

Remember that the use of this type of screening aid does not preclude a detailed total life-cycle cost analysis; it does provide a decisionmaking technique when only the most commonly available factors are known. With properly constructed regions of uncertainty, such decisions should be expected to agree with results obtained from detailed analysis when more complete data become available.

Screening aids have one other limitation. Once the LOR decision has resulted in expenditures for support acquisition, the opportunity for cost avoidance is mostly lost. Therefore, great care must be taken in constructing a screening aid for use midway in a program, and the designer may conclude that some decisions can be made only through detailed analysis.

Models

Computer models inherently include the capability for more detailed analysis. All maintenance posture models compare the predicted life cycle logistics costs, LCC(L), of alternative postures to choose the most appropriate one (if there are no overriding non-economic criteria). The following must be estimated for each posture:

1. Cost of initial spares.
2. Cost of initial repair facilities (AGE, etc.).
3. Repair/resupply cost (men, materiel, and transportation involved in processing a faulty assembly through the repair/resupply system for N years).
4. Miscellaneous costs as required by particular items. Examples might be:
    a. Training costs for the personnel who will maintain and repair the assemblies.
    b. Tech data costs.
    c. Scheduled maintenance costs.

Each of these points is discussed below.

Initial Spares. As a first step, each model computes a stock level for each posture to calculate initial stock costs when comparing the postures. Since the objective in most of these models is to select a level of repair or logistics posture, the stock computation portion is secondary and, consequently, many models do not use service procedures for computing stock levels. We can separate these models by the method (optimal or service) used to set their stock levels, as shown.

Optimal: SCAM, COAMP, QUEST
Service: SCEET, ORLA, TRIM, RGM

The rationale for using optimal levels is that the Air Force (and possibly other Service) levels are inefficient, compared to other possible methods.* Also, Service stockage procedures usually yield various postures with unequal effectiveness, making valid comparisons difficult. Under the ORLA procedure, for example, the situation shown in Fig. 3a might occur. When we compare four different maintenance postures represented by points A, B, C and D, we will clearly prefer A to B and C to D because we can have more effectiveness with less cost; however, the comparisons between A and C or between B and D are not entirely meaningful. It is true that C yields a higher effectiveness than A, but also has a higher cost. Similar comments apply to B and D. Thus some ambiguities will arise in selecting the most cost-effective maintenance posture. A technique using optimal stockage policies might have the results shown in Fig. 3b. In that case, there is no ambiguity about which of the four postures is best. Thus, it is possible to analyze level of repair in a way that achieves a constant level of availability.

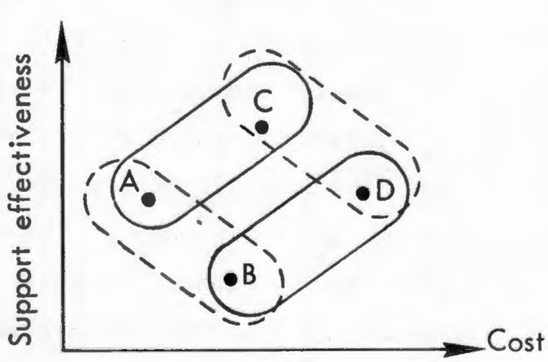

Fig. 3a

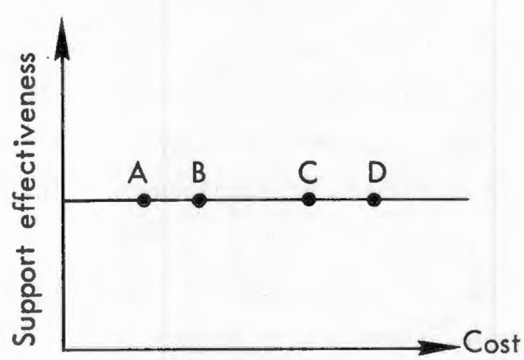

Fig. 3b

*C. C. Sherbrooke, A Management Perspective on METRIC: Multi-Echelon Technique for Recoverable Item Control, The Rand Corporation, RM-5078/1-PR, January 1968.

It is difficult to set optimal spares levels precisely for complex maintenance postures, and the optimal calculations are generally longer and more complicated (although still cost-effective in terms of savings achieved and/or effectiveness gained). So if the Service decides to use less-than-optimal procedures when actually setting stock levels, the model used to make level of repair decisions should probably incorporate the Service procedure as a better estimator of future costs.

AGE and Facilities. Calculating AGE and facility investment costs also involves predicting these costs for each posture, and hence requires basically the cost per unit and the number of units necessary to handle the predicted workload for each posture. The models discussed previously could be used, but they should be kept fairly simple so that the whole LOR analysis can remain computationally feasible.

Joint costs can be a problem; for example, shared AGE and facilities. The repair level decisions for items serviced by a common AGE set must be made jointly, but the decisions need not be based on an arbitrary allocation of the common AGE costs. In fact, any arbitrary allocation of joint costs to one item is irrational if it affects the decision about the most economically optimum maintenance posture for that item. For instance, if a given level of support effectiveness can be achieved by stocking more units of the item than trying to repair it at base level, then it does not make sense to repair the item at the base, even if the use of AGE is free.

The repair level decision involving common costs is conceptually a simple cost-minimization problem. But the computational task can quickly become burdensome if even a moderate number of items share common AGE costs. Consider two items that can be repaired by the same AGE set. For each item, any one of four maintenance postures (in the Air Force) is applicable. This means that theoretically there are sixteen different combinations of maintenance postures, any one of which can provide some specified level of logistic support to these two items at varying costs. To determine the optimum one, we evaluate the cost implication of each combination. The cost involved may be broken into two categories: (1) the sum of stockage costs of the two items computed under the assumed maintenance posture, and (2) the cost of AGE required under the same maintenance postures. We then select the minimum-cost combination. (This sort of approach is implemented in RGM.) The methodology essentially entails solving multi-item, two-echelon inventory problems. One convenient means of accomplishing this computational task is to use a program such as METRIC. Even using METRIC, however, the computational task can quickly become unmanageable if n is of a moderate size. In such a case, some simplifying assumptions are necessary. For instance, n can be reduced by assuming that items reparable by a common AGE set have similar characteristics. Their failure rates can then be combined and they can be treated as a single item type. Another assumption might be that a single maintenance posture will be applied to all items served by the common AGE set. In this way, the cost implications of the four basic maintenance postures can always be evaluated regardless of the number of items involved.

Repair/Resupply. The next cost component involves processing a faulty item through a repair/resupply network for each posture. Logistics postures can be crudely classified by the number of supply echelons and indenture levels. The simplest repair/resupply logistics posture (other than throwaway) is the one-indenture, one-echelon, base posture. Failed assemblies enter the base for repair while new assemblies are taken from base stock and placed in the system. If the failed assembly can be repaired, it is, and the repaired unit placed in base stock. If the unit cannot be repaired, it is condemned and a new assembly procured from the vendor. At any time there may be assemblies in the base repair facility and on the way from the vendor. If this number should exceed the initial base stock level, a backorder occurs.

Most postures are more complicated, involving several indenture levels and several supply echelons. Each repair point, at each indenture level other than the lowest in a complex posture, consists of a fault-isolation function and a remove-and-replace function. Consequently, part of the next lower indenture level will be stocked at each remove-and-replace function. The repair point for the lowest indentured part consists of only a repair cost and no stocks of lower indentured parts will be considered (e.g., the base posture has no module stock, but only a base repair cost). At repair points other than those for the lowest indenture level, the failed next level component is inducted into the repair/resupply system as a failed unit originating at the repair point. This structuring of the logistics posture can become very complicated and encompasses built-in test equipment (BITE), AGE, any number of repair levels, and so on.

Each LOR model computes a value for life-cycle logistics costs for a number of alternative maintenance postures, given the system parameters. For example:

ORLA:	Base, base-depot
RGM:	Large number of detailed postures based on three echelons of repair and multiple indentures of an assembly
SCAM:	base, depot, base-depot, throwaway; 1-indenture level, 2 echelons
TRIM:	repair, throwaway
COAMP:	20 postures, 4 indenture levels, 4 echelons
LORAM:	throwaway, intermediate repair, depot repair

In choosing a model for evaluating LCC(L) for alternative postures, the Service must make the tradeoff between stock level optimality and logistics posture complexity. The more complex the possible logistics posture, the less optimal the spares level. For example, SCAM considers only 4 postures; however, the stock levels set will provide the same backorder rate in each policy, whereas the spares levels set in COAMP only approximately provide for equal backorder rates because its postures are more complex.

Miscellaneous. When computing LCC(L), all LOR models include some costs other than initial spares costs. COAMP is very comprehensive, and includes provisions for setting AGE requirements, which may sometimes be useful but may be a significant simplication when AGE decisions are critical. TRIM is another comprehensive cost model. Some models require AGE as an input, just as training, etc. But all LOR models could easily be made identical with respect to their treatment of non-stock and AGE-related support costs. The distinctions between these models lie in the purposes for which they were developed and their basic modeling of the logistics posture. COAMP can be used for decisions involving BITE, while SCAM and ORLA are suited to the two-echelon Air Force posture. If a Service is considering a maintenance policy of one or two indentures and one or two echelons, optimal spares levels can be computed that provide for a fixed backorder rate at minimum cost, and the Service should consider SCAM. If the maintenance policy includes a number of levels of indenture, BITE, etc., it is impossible (with existing techniques) to compute optimal levels, and quasi-optimal techniques such as COAMP must be used.

Another aspect of the logistics posture is scheduled inspection and maintenance. Most analytic models do not address this aspect of support,* with the exception of AMSEC, but simulation models are useful for studying this problem.

OPERATIONS MODELS

Operations models examine the relationships between operational effectiveness (generally in terms of system availability and sometimes dependability) and support considerations. They are most often simulations, although several analytical models are also available. Table 3 compares seven models that simulate aircraft operations and support. SAMSOM is a multi-base simulation that performs a variety of operations, whereas PLANET is a richer model of the maintenance system. VALUE, ARMADA, and OMLRS are oriented toward Navy operations. LCOM requires specification of the network of maintenance tasks (RGM can be used to generate this network).

As noted previously, MARIS studies the effect of on-board spares levels on operational readiness and dependability. MINE, SEEP, and SPAREM also relate spares levels to operational effectiveness. MCTAS addresses aircraft dispatch reliability in a transport system. MRSM, GOSS, and CAEM, together with SPM, model cargo airline operations. LCCP is oriented toward the operations and maintenance of an Army missile system, and includes a sophisticated failure generator. MACOM

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*This theory is treated in D. W. Jorgenson, J. J. McCall, and R. Radner, Optimal Maintenance of Stochastically Failing Equipment, R-437-PR, April 1966.

Table 3

COMPARISON OF SIMULATION MODEL ATTRIBUTES FOR AIRCRAFT OPERATIONS

Characteristic Simulated	SAMSOM II	BOMS	VALUE IV	LCOM	OMLRS	PLANET	ARMADA
Operations							
Single or multi-base	both	single	single	single	single	both	single
Single or multi-aircraft	multi	two	multi	multi[a]	multi	multi	single
Number of mission types	multi	three	multi	multi	multi	multi	multi
Ground alert commitment	yes	yes	yes	yes	yes	no	yes
Air alert commitment	yes	yes	yes	yes	no	no	yes
Ground abort occurrence	yes	yes	yes	no	yes	yes	yes
Air abort occurrence	yes	no	yes	no	yes	no	yes
Combat attrition	yes	no	yes	no	no	no	no
Aircraft inventory replenish	yes	no	no	no	no	no	no
Diversion mission	yes	no	no	no	no	no	yes
Fixed or random launch	both	both	both	both	both	fixed	both
Sortie/cancel/make-up policies	yes	yes	yes	yes	yes	no	yes
Mission priorities	yes	yes	yes	no	yes	no	no
Launch element, single or multi	both	single	both	multi	both	single	both
Multi-stop routes	yes	no	no	no	yes	no	no
Support							
Aircraft maintenance	yes	yes	yes	yes	yes	yes	yes
Shop repair maintenance	no	yes	yes	yes	no	yes	yes
Personnel, by type and quantity	yes	yes	yes	yes	yes	yes	yes
AGE, by type and quantity	yes	no	yes	yes	yes	yes	yes
Spares, by type and quantity	yes[b]	yes	yes	yes	yes	yes	yes
Facilities, by type and quantity	yes	no	yes	no	no	yes	no
Combat damage repair	yes	no	yes[a]	yes[a]	no	yes[a]	no
Work shift policies	yes	yes	yes	yes	yes	yes	yes
Maintenance priorities	yes	yes	yes	yes	yes	yes	no
Maintenance conflicts	yes	yes	yes	yes	yes	yes	yes
Maintenance sequencing	yes	yes	no	yes	yes	yes[a]	yes
Maximum personnel constraint	yes	no	yes	no	yes	yes	yes
Cannibalization	no	yes	yes	no	no	no	yes
Personnel, by skill	no	yes	yes	no	yes	yes	yes

SOURCE: Adapted from McDonnell Aircraft Corporation, Advanced Logistics Simulation and Mathematical Models, Report PS-465, 15 November 1969.

[a]Indirectly.

[b]No inventory maintenance.

and SCOPE simulate missile operations.

SOGEM is an analytical model for calculating a theoretical maximum number of sorties per day for aircraft, given unlimited maintenance resources. AMSEC and GEM study the availability and dependability of complex systems based on the reliability and maintainability of component parts, and various operational and support considerations. Such models can be used to compute the probability of mission success for a cruise of a ship, Polaris, AWACS, base level operations, or any similar task. They can compute availability as a function of detailed scheduled maintenance program, detailed mission profile, item redundancy, item criticality to mission success, and item failure parameters. Given a fixed mission involving the phased utilization of various systems composed of assemblies, these models can compute the probability distribution of the number of spares of each type required, and the expected uptime. This is especially valuable for determining the probability that n missiles are available for a Polaris cruise, or that AWACS remains operational, with a fixed number of each spare in the system. These can be used to set spares levels exactly if all spares are considered non-recoverable, and can approximate the case of recoverable spares. They are fast and should be used in preference to simulation for such tasks as setting scheduled maintenance programs and computing AGE utilization; however, simulations are necessary if one is to consider inventory problems with reparable spares in complex logistics postures.

LIFE CYCLE COST MODELS*

The models that translate system characteristics and performance into requirements for support resources generally have similar characteristics. They develop estimates of the tasks that the reliability and maintainability estimates imply, and translate these into resource requirements and ultimately into dollar cost estimates.

Early Planning

In the early planning stages, dollar estimates represent the only common denominator among all the resource alternatives that must be considered. In essence, many tradeoff decisions depend on the decision-maker's ability to formulate and apply useful and realistic life cycle cost models. The more realistically these models treat uncertainty and the complete range of support cost imponderables, the greater utility they have. Their greatest contribution to system development

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*For a more complete discussion of the life cycle costing philosophy, see LMI Task 69-10, Life Cycle Costing in System Acquisition, November 1969.

is not in their forecast accuracy of the actual life cycle cost, but in their ability to highlight areas of high cost or resource impact among all the alternatives that must be evaluated at any decision point.

In this context, life cycle costing is not an end in itself. It is not to be used solely or even primarily by budgeteers and contract negotiators. Rather, decisionmakers, designers, and system managers should use it to place in a common context the variables that must be balanced and estimated in the development process. Such models can also be used as a tool for support planners. Properly designed life cycle cost models highlight the interaction between reliability and support postures and between the alternative methods of providing operational readiness with mixes of support resources. We usually use life cycle cost estimates in connection with a system or equipment. Hence, we are dealing with only the increments of cost those systems or equipments represent to the rest of the Service environment, the support system, the other weapons, the facilities in being, and so on. This type of analysis therefore depends upon a functioning support system together with the complementary operating environment into which it must be phased. Since LCCs deal with marginal costs, for single systems their long-term estimates may not be too reliable because so much uncertainty surrounds the total future environment. LCC models do have utility in the ILS context, however, particularly as tools to do the following tasks:

1. Examine the impacts of operational requirements on design and support alternatives (mobility, and so on).
2. Identify areas of high support cost as a consequence of design decisions, and point out preferred design alternatives (performance/support tradeoffs).
3. Make useful comparisons of alternative support postures.
4. Develop budget estimates (economic analysis) during the advocacy process.
5. Act as evaluation tools in the source selection process--and to define incentive goals and other contract guarantees.

Uses

Performance/support tradeoffs generate curves relating cost to some operational parameters. For example, you might want to know the relative costs of a 15-minute versus a 30-minute turnaround time for an aircraft, or a 70-percent versus an 80-percent operationally-ready rate, or a 4000-mile versus a 5000-mile range, or an 8-hour versus a 10-hour mission length. This sort of calculation would probably involve a series of runs of an operational simulation model (or possibly one of the analytic ones) to calculate the required support resources, and then some sort of cost calculation such as PLANET's Cost/Effectiveness report, or LCCP's cost calculator, or CAEM for cargo airline operations. Given this type of prediction, the decisionmaker could then judge whether the increased operational capability is worth the extra costs.

Similarly, the use of LCC(L) models when design parameters have not yet been fixed should enable the design engineer to make decisions based more upon support cost considerations* than has been done in the past. We assume that a designer will use such a model when he is considering two or more alternative designs, both of which meet performance specifications; in fact, in such a case LCC(L) should be the only basis of choice between the two alternatives. More frequently, the designs will have slightly differing performance characteristics, in which case LCC(L) should be only one input to the design process, to be compared with performance characteristics at a higher level of design and tradeoff analysis.

Notice the high degree of parallelism between the detailed design model and the maintenance posture models discussed previously. This occurs because both types of models predict future support costs for a system component in order to choose a most desirable alternative. In the detailed design model, the choice is among alternative designs,

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*In comparing the relative LCC(L) of two alternative item designs, it is necessary to include only those costs that vary between designs. The support costs that we feel are highly design dependent are (1) cost of initial stock, (2) cost of initial AGE equipment, (3) repair/resupply costs, (4) special costs (if relevant). Training costs, tech data costs, on-equipment maintenance costs, and costs such as supply administration are generally excluded, since they will probably not vary significantly between designs; when their inclusion is necessary, they can be lumped together as special costs.

whereas in the maintenance posture model the choice is the optimum support posture for a particular design. In choosing a design alternative, the support posture for _each_ design would have to be optimized before making the choice. Therefore, the same model would probably be used for both design selection and repair level choice. Additionally, if the model is detailed enough, the initial spares level and the requirements for AGE, facilities, and personnel could be set simultaneously. This, then, represents the quintessence of ILS--the process of system design involving consideration of future support requirements, and the virtually simultaneous support planning once the final design is selected.

For these kinds of decisions, cost accuracy is not outstandingly important, as long as the cost _precision_ is adequate. In other words, a comparison is being made; therefore, as long as all costs are treated _relatively_ the same, the absolute accuracy of the cost prediction is unimportant. For example, if the cost of repair facilities is the same in all alternatives being analyzed, that cost can be considered zero and not affect the choice of alternatives.

Budget estimating is an area in which cost accuracy is important, since it concerns predicting a resource requirement to accomplish some set of tasks. Two useful models are SCORE and LCCM. They calculate costs by category by year, and thus give a time profile of resource requirements. Costs can be input directly, or calculated by cost estimating relationships, standard or specially written algorithms, or summation of other costs. LCCM can handle learning curves, discounting, and inflation.

Another use of LCC models involves contract development and source selection. The ABLE approach asserts that support considerations will be given proper treatment in system development only if there are adequate contractual provisions and incentives. It therefore proposes that source selection consider the predicted support costs of the various proposals, and that the bonuses/penalties be partially dependent upon how close actual costs (or their surrogates in terms of such parameters as system reliability and maintainability) are to the predicted costs. Another model oriented to the source selection decision is LOGCOST.

PROJECT MANAGEMENT DECISION MODELS

Project management decisions involve allocating R&D resources, and making tradeoffs between development cost, development time, and system performance and cost. In conceptual design, some tradeoff analysis is done between performance and cost; in detailed design, generally the objective is to minimize cost while meeting specified performance goals. Tradeoffs between development time and cost or time and performance are made at a high level of abstraction and on a judgmental, subjective basis. There are some models, however, that might be useful to the project manager attempting to make difficult analyses/decisions.

RMT is a technique for deciding how best to allocate scarce development resources across items, and also for determining the appropriate apportionment among R&D, acquisition, and O&M money. It is oriented toward reliability/maintainability development tradeoffs.

Project Modeling (PROJMOD) applies linear programming to the development process. Given a set of mathematical relations between performance characteristics, development cost, and development time, and a set of constraints, the technique will optimize cost and/or time within a given performance envelope. It could also be used to predict maximum attainable performance for some fixed cost or time, given the formulation of an overall performance measure. Although theoretically attractive, the difficulties involved in determining functional relationships between time, cost, and performance may make this approach impractical. It is worth research as a planning tool, however,

SPARTAN uses a heuristic technique for scheduling program activities, given limited resources. It evaluates alternative programs (i.e., systems) for achieving some broad objective. It thus falls more in the Quade and Boucher family of systems analysis techniques,* but it could also be applied to narrower goals, such as analyzing the time and cost implications of alternative avionics development programs.

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*E. S. Quade and W. I. Boucher, Systems Analysis and Policy Planning: Applications in Defense, The Rand Corporation, R-439-PR, June 1968.

The Resource Allocation Model (RAM) is a method for either maximizing performance for a given development cost, or minimizing cost to attain a fixed performance, by optimally allocating resources to a number of development activities. The effect of each activity on overall performance is described by a differential equation.

Other project management decision models are discussed in the section on life cycle cost models.

SUMMARY

This section has discussed specific logistics models as they relate to the substantive areas of spares, AGE, personnel, maintenance posture, operations, life cycle cost, and project management. The summary table in Appendix A also indicates those areas in which each model will be most useful. The next section discusses possible uses of the various models in the context of ILS.

IV. USING LOGISTICS MODELS

This section suggests uses for logistics models during the conceptual, validation, development, and production phases of system acquisition.* We preface our observations of the system life cycle and ILS by defining an ILS decision, and by describing five guidelines we think are necessary to develop a viable ILS interaction with the contractor and within the Air Force itself.

Most tradeoffs that include logistics considerations are detailed decisions, involving the relationship of design parameters to support resources or postures. As the system becomes more clearly defined, more tradeoffs can be evaluated until finally actual hardware has been produced, can be tested, and can be fitted into the support posture. However, decisions about the design--its reliability, its accessibility, its test configuration, its power requirements, its packaging, etc.--all have logistics impacts. It is only when the logistician can influence these that he can have some control over his resource requirements and ultimately his ability to perform his support responsibility in an efficient and timely manner. An ILS decision therefore requires that the logistics impacts of all other decisions be weighed and systematically treated. If the logistician can accomplish this in either the conceptual or validation phase--and finally assure explicit consideration in all subsequent phases of the system life cycle--he has successfully accomplished his objective. We see five guidelines necessary for this.

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*Other publications have dealt extensively with suggestions for procedures and processes to follow in putting both an ILS program and a discipline into effect within the contracting structure. See for instance DOD Directive 4100.35G, Integrated Logistics Support Planning Guide for DOD Systems and Equipment, U.S. Government Printing Office, Washington, D.C., October 1968. Since such procedures deal in a level of detail beyond the scope of this Report, we cannot comment on the manning and administrative cost-benefit implications of such detailed procedures.

1. The procedures and methods should be designed for use by available Air Force management personnel. These personnel need not be modelers, but they must understand the application and the use of decision-aiding models. The current Air Force program for training all management levels in the ILS concept should be continued. An additional course will be required, however, for those who must participate in ILS decisions at the development planning or the SPO level. This course should be designed to train them to use models of all types and to make decisions based on the outputs of the models or other evaluative techniques.

2. No single model is suitable for all types of trade-off decisions involving ILS considerations. Therefore, the Services should expect that each procurement or each system acquisition program will require the ILS people to tailor certain standard procedures and models to each problem that occurs during systems development. These procedures must not only be tailored to the Air Force organization, but must also be tailored to the ILS program of the involved system contractor or contractors. If AFR-375 series procedures are not employed and a less than a system procurement is involved, it is obvious that specific procedures should be modified and tailored to the program. Less than a complete ILS program with staffing and modeling is possible. The main thrust of the program should be to engender the discipline of ILS thinking at the contractor level.

3. All ILS programs should be designed to include maximum contractor involvement. The largest payoff in the use of ILS is the inclusion of ILS considerations in the contractor's design process as a matter of routine. Therefore, the Air Force management activity should be focussed on encouraging the contractor either formally or informally to develop a viable ILS program at all levels in his system design and decision process. Contractors' models should be approved and used to the extent possible. To the extent that the Air Force can disengage safely from the detailed decision process, this also should be encouraged as being both economical and timesaving.

4. The Air Force and other service components should develop a method of contracting for and approving the contractor's ILS methods. This can be done during the validation phase and during the subsequent development and production phases of the systems acquisition process. It is assumed by this statement that a procedure can be developed to approve the contractor's ILS models and management system, much in the same manner

that his quality control and/or security procedures are approved. This may imply the ultimate development of a manual of ILS procedures; however, this approach should be a requirement for systems acquisition contracting in the future.

5. Efforts must be expended to develop tailored data interchange techniques between the services and each system contractor. These may be spelled out in accordance with the requirements of AFR-310-1.* To make an ILS program work at the design level, however, we believe the contractor must develop an internal data bank and data interchange system. The Air Force should try to take advantage of this system so that modern information surveillance and processing techniques can be applied at the SPO level. This may require the use of time-sharing equipment at the SPO and/or the possible employment of videographic techniques to monitor the contractor's data bank. Under these conditions, the SPO ILS office would not have to participate in every tradeoff decision that the contractor made; rather he could sample and monitor these decisions selectively. Presumably, his criteria for monitorship would be high dollar value or large impact on the technology to be employed in a particular systems program.

These guidelines are designed to limit the scope of the comments that follow concerning each phase of the weapons system life cycle, without regard to whether any of them are included in current policies. We do not believe that, given these guidelines, an immediate program of ILS management can be developed for every system. But the objective of the overall ILS program is to develop a set of goals and objectives for establishing long-term ILS disciplines within the weapons acquisition process; the guidelines set forth above indicate at least the kind of objectives the ILS system designers should have.

CONCEPTUAL DESIGN DECISIONS AND THE CONCEPTUAL PHASE

In the conceptual phase, ILS involves interaction between logisticians and system designers, availability of logistics models and data, data uncertainty and its explicit treatment, and the role of logistics planners.

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*AFR 310-1, Acquisition and Management of Contractor Data, 16 May 1966.

Designer/Logistician Interaction

Early in the acquisition process, system designers make conceptual design decisions. How large a force is required? How should it be based and supported? What kind of operating schedule should it have? What are the resource requirements? Additionally, the designers are trying to define the operational parameters of the system--speed, range, reliability, turnaround time, etc. The logistician should ideally start to interact with the system designers at this time, with two basic aims in mind: (1) to point out design approaches and operational concepts that have undesirable logistics consequences; (2) to retain as much logistics flexibility as possible in the design specifications, so that more nearly optimal decisions can be made later on in the design process when more information is available. Traditionally, early analyses have not specifically considered in depth the projected logistics impacts of various design concepts. That is understandable, however, because the analysis has to be done at such a high level of system aggregation that the logistic implications of decisions are not obvious. The best logistics input very early in the game is probably the judgment and knowledge of a broadly experienced logistician.

Models and Data

Estimating logistics requirements and capabilities implies that models are available for relating logistics to operations, and also that valid historical data exist about the logistics costs and consequences of various types and levels of operations. Given these, it is possible to begin parametric studies to develop inputs for the tradeoff analyses between system effectiveness and system cost. If the logistician can develop credible estimates of the logistics costs and consequences of system designs, and if he can discriminate with some certainty between the costs of alternative designs, then he can begin to influence the final design. He can point out which design alternatives are most attractive from a logistics point of view, and which designs imply undesirable logistics consequences. For effectiveness/design tradeoffs, simulation models are generally most appropriate. Many life cycle cost models are useful for estimating performance/support cost interactions.

Also during this time the logistician should strive to evaluate design goals for the system's logistic parameters. Traditionally, such factors as the maintenance manhours per flying hour, the maintenance turnaround time, and the basic maintenance concept (e.g., fix by replacing LRUs at the organizational level) have been established with no or only cursory consideration of whether such factors are really optimal from a logistics point of view. It would be preferable to investigate these parameters utilizing the results of parametric studies and tradeoff analyses. Such an approach early in the design game should bring us closer to our goal of realizing in hardware a truly optimum system.

<u>Data Uncertainty</u>

It is important to remember that at this phase in the weapon system life cycle, uncertainties on all dimensioned planning values are extremely large. Definitions of operating modes, operating deployments, surrounding environments and technical feasibility are apt to be rubbery. The logistician can live in this environment if he uses appropriate analytical techniques to define the consequences of all types of uncertainty and highlight the areas in which development efforts have the largest payoffs.

The precision and depth to which this can be done depends on the particular system and its associated technology, whether the design approach is well-established or state-of-the-art, and the resources and time allotted to perform the studies in the concept formulation phase. The engineering data and historical knowledge to support these ILS activities also depend upon the particular system being designed, and how much it pushes the state-of-the-art. It may be that in some instances, good logistics data are just not available, and therefore a much greater study effort is required. Also, some models and analytic techniques require more data than others. Model choice depends on what questions need answering and what data are available.

Role of Logistics Planners

Another important interaction should occur between the logistician on the system design team and the plans office within the support command. Recall that we want to minimize the possibility of logistics surprises further down the design road. The design logistician should give to the plans office any information that would permit it to make more realistic budget projections, based on the support characteristics of upcoming systems.

This should not be just a one-way flow of information, however. The design logistician sees only his particular system, whereas the plans office sees (ideally) all current and projected systems and their support characteristics. Some particular support posture (e.g., establishment of a new centralized repair facility) which might be unattractive in the context of only one weapon system could be highly desirable when its costs are spread across a number of systems. There thus needs to be a high degree of interaction between and among the plans offices and all design logisticians so that logistics alternatives which are optimal when aggregated across all systems are not rejected because they are unattractive in the context of a single system.

The preceding is not an explicit sequential series of activities. There is much looping and much feedback between and among the tasks, and the whole process is highly iterative. The major outputs of the process are influence on the system designer, development of some broad logistics planning factors, and specification of some design goals for logistic parameters in the system development contract.

In summary, the conceptual phase should (and does) include ILS considerations, which will require the contractor to consider support costs in his design and study processes, and will require that the AFLC development planners be trained and understand the use of ILS models for major decisions. The objective is twofold: (1) to make future support costs a strong design criterion; (2) to retain sufficient flexibility in the design specifications so that optimal support choices may be made later on, after a more complete design study. Both criteria imply the use of models, and neither requires detailed support planning. They are thus low-cost design process inputs with probable high-dollar payoffs later on.

VALIDATION PHASE

Models can be employed in at least four identifiable processes incident to validation phase activities in which the Services proceed from specification development to the selection of a development (and possibly production) contractor or prototyper.

Drafting ILS Work Statement

The first phase is drafting of the ILS work statement or formulating the ILS program for inclusion in the RFR. Many decisions are required: for example, whether to include specified models in the evaluation procedures, what parameters to specify, what general tradeoffs are important, whether to include logistics incentives, how to accommodate these incentives to all other incentives, whether to include guarantees on logistics values, and when and how such values should be tested and evaluated. The preferred approach to defining these decisions might be to use a system model--any of the cost models discussed previously--and game some of the possible alternatives using a range of feasible expected values as parameters. While the range of uncertainties might be large, the System Program Offices (SPOs) could identify the impacts and tradeoffs that would be important in the next processes, making the source selection recommendations and defining the ILS requirements in the development contract.

Source Selection

In current source selection procedures,* logistics elements have usually been specifically evaluated and weighed in the overall deliberations of the Source Selection Evaluation Board (SSEB). The evaluation has been independent of a specifically identified ILS program. It has also been independent of the so-called cost-to-the-government evaluations, which have not traditionally employed life cycle costing techniques, but have considered investment expenditures for such logistics elements as AGE, spares, training and facilities.

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*See AFM 70-10, Source Selection Procedures, 22 January 1966, and draft manual, The Source Selection Process, Hq ASD (ASKBS), 15 June 1969.

Since such considerations as maintainability, reliability, supportability, etc., cannot be considered in toto outside of the ILS context, we believe that the logistics evaluation should include at least two additions to current considerations: (1) an evaluation of each bidder's proposed ILS program to ascertain whether it meets the planned program requirements, including adequate corporate organizational and procedural accommodations to the ILS concepts set forth in DOD 4100.35G, and provides an estimate of the life cycle costs implied by the bidder's proposal; and (2) the employment of a suitable system model to provide estimates and verifications of the probable life cycle costs of each bidder's proposals. While these costs are to be based on estimates of relevant parameters obtained from the competing proposals and hence are highly uncertain, they are as reliable as the other cost estimates used in the evaluation. Their chief utility is to provide the SSEB with a systematic comparison of life cycle costs, identify areas of difference between the proposals, and uncover items of high support cost that can be specifically addressed during further negotiations and product development.

Negotiating Contracts

Another use of models during validation is in the negotiation and drafting of the definitive contracts that accompany the proceedings of the SSEB. The obvious use of a cost model is in the gaming and validation of the proposals set forth by the bidders. Since each contract will differ in pricing details, in estimates of AGE, training, spares, tech data and other support costs, as well as in incentive schemes and guarantees, models can help sort out the impacts of each pricing option or alternative implied by the contractor's proposal. The appropriate model helps in the orderly estimation of all costs for a period of years--hence, it is adaptable enough to deal with the explicit uncertainties of any proposal.

Besides gaming and overall evaluation, models can be employed to gauge the cost and support consequences of bidders' deficiencies, to rack up the difference between those that are important and those that are trivial. Properly employed, the model is a far stronger tool of evaluation than subjective experience--because it implies a discipline in assessment that is otherwise difficult to attain.

Whether or not the ILS proposal of the successful or recommended bidder to the source selection authority is the best of all the proposals received does not really become a matter of importance until the source selection authority has finally made its choice. Conceivably, the winning contractor may not have the most effective or complete ILS proposal. During the concurrent contract negotiation process, however, the contracting parties must arrive at an acceptable ILS posture since the SPO must obtain an acceptable signed proposal from each bidder. It is thus imperative to have a set of standard ILS minimum requirements that can be subject to approval in much the same manner as the security requirements or the quality control requirements that are specified in any winning contract.

Incentives

Once source selection has been completed, and a system program has started, there will undoubtedly be difficulties with the kind of incentive, the nature of guarantees, the levels of interactions, and the possibility of disengagement with respect to the contractor selected. While we have no suggestions about the specifics of such considerations or whether any of these considerations are useful or can be justified on ILS grounds, certainly models can be employed to investigate their consequences. The ABLE techniques, for instance, can be adapted to almost any incentive environment. A completely specified ABLE procedure, however, is not necessarily consistent with the concept of an operating ILS environment. If total logistics effects are left to the contractor's discretion in an ABLE environment, then there might not be the same possibility of developing an optimal support base across all systems that there might be if the ILS offices and the selected contractor interacted continuously. ABLE and ILS may be inconsistent in that ABLE tries to optimize the effect of logistics within one weapon system, whereas the total ILS program should attempt to guarantee the best mix of resources across all weapons. This contradiction must be specifically considered whenever contracting arrangements and SPO organizations are structured.

DETAILED SYSTEM DESIGN AND SUPPORT PLANNING IN THE DEVELOPMENT AND PRODUCTION PHASES

System contractor and the AF management organization (SPO) use of models, once system development has started, should be a matter of routine in all senses of the word--all major design and support system decisions should be made only after a full evaluation of the support cost consequences of such decisions. After the start of development, design at the detail and subsystem level must begin; most of the models discussed in Sec. III can be usefully employed in evaluating design alternatives and showing how reliability and maintainability resources should be applied.

Use of Models

The contractor must routinely employ a suitable model (his own or one of the available models) in an interactive manner between his design and engineering organizations, and his ILS and cost, pricing or supporting systems organizations. All feasible design tradeoff alternatives should be modeled, evaluated, and subjected to the joint approval of ILS and engineering review personnel. To facilitate such interaction, the models should be accessible to all design levels on a routine basis. This implies the use of a time-sharing system or a daily batch processing of design details at each engineering center. Such alternatives are well within the state of engineering management.

The SPO should employ models, using the data obtained routinely from the system contractor, to monitor and validate the developer's design and support decisions. Data interchange, model compatibility and design approval procedures would have to be tailored to the individual system and contract requirements. However, the imposition of an ILS discipline through the use of appropriate models at all decision levels is the objective of the exercise, and models seem to be the best tool for accomplishing the objectives of DOD 4100.35. They represent the most rigorous method of organizing and processing information for decisionmakers, independent of the contractor, the system, the service management organization, and the skill of the management resources.

Approval of Contractor ILS

The internal ILS working procedures imposed on the successful development and production contractor will necessarily be tailored to the operations that the contractor traditionally maintains. Under any circumstances it will be difficult to specify interactions between the product engineering and the support services sections of the contractor's plant. Since the ILS approval agency within the SPO will have access to the complete set of Air Force resources, it might be preferable to have a SPO ILS team that can go directly to the contractor's plant and provide specific on-the-spot guidance. Such an organization can logically be part of the planning office or the materiel management office of the headquarters. The number of new systems involving ILS disciplines probably does not warrant the establishment of such an approval agency at the AMA level.

Such an approval program would instill the ILS discipline throughout the contractor's operating design and production procedures. It would also serve as an entry point for on-site provisioning teams and on-site source coding operations, perhaps leading to on-line in-plant source coding and possibly on-line provisioning. Thus the travel and operations expenses of the Air Force can be reduced, since it would minimize the interaction of many support personnel. The only monitoring responsibility that the SPO organization would have would be to check the outputs of the contractor's ILS decision processes periodically and specifically approve those decisions that involve large dollar alternatives or lengthy development programs.

A SPO ILS office at the contractor's plant could also allow the provisioning and modification review processes to continue throughout the system's production and deployment phases. The technologies, models and methods employed to make development design and support cost tradeoffs could apply equally to the modification review process and to the contractor's product improvement and value engineering programs. Hence, it appears that ILS can become a way of life from the development of the end item design to the modification and disposal of the system assets at the end of a program.

Air Force/Contractor Interactions

While we have dealt with each of the system life cycle phases, we can also offer some observations concerning the interactions between the ILS management activity and the ongoing Air Force support activity. From a policy point of view, certain support decisions will be beyond the decision threshold of the SPO, and will necessitate interaction between AFLC, AFSC, and the using commands. ILS processes could be used to inform decisionmakers about which support alternatives appear most attractive, given the limitations of operations, dollar availability, and system performance. The exact operation of these major decision processes will have to be determined and spelled out in an ILS manual that governs operating procedures within the Service. Nonetheless, arrangements must be made to handle such major policy tradeoff levels.

In addition to the flow of information between the Air Force elements concerned with the decision process, there must be timely feedback to the contractor. He must be able to exercise appropriate options in the design process so that neither production, performance, nor cost are affected by slow decisions within the ILS organization. Again, the system for this feedback will have to be tailored to the contractor and the weapon itself. Conceivably, monitoring and surveillance by the ILS office will be sufficient to protect Air Force interests and to insure cost effective coding of all the items requiring decision.

While contractor feedback is important, it is also important to transfer the contractor's support decisions to the Air Force support agency. In particular, some tradeoffs the contractor may make, while cost effective, may require the appropriation of facilities and construction money, may require the modification and development of software for test equipment, and may require the training and acquisition of different skills in the support base. While all of these are implicitly considered in the decision process, specific arrangements must be made for appropriate action by the Air Force support agencies.

V. CONCLUSIONS AND RECOMMENDATIONS

Our investigation indicates that the model technology is well in hand to do the support cost estimating required for implementing integrated logistics support in the conceptual, validation, development, production, and deployment phases of the system acquisition process. Such estimating is most difficult in the early conceptual phase, but techniques are available to handle explicitly the uncertainty inherent in such early data. Even when the uncertainty cannot be easily quantified, models can be used to explore system design/support cost interactions and thus define at least the desirable ranges of system parameters.

It appears that a sufficient stock of basic models and modeling techniques is available, many of them at no cost to the Services. Primary development effort should probably be devoted to adapting existing models to particular applications, and to interfacing sets of models into compatible families applicable over a wide range of problems.

The next desirable step would be to increase awareness of the availability of models to the Services, and to expand the catalog of models in Appendix A. In addition, individuals who could best use models must be instructed in analyzing the support cost consequences of varying operational requirements, different hardware designs, and alternative support postures. ILS will never realize its full utility and application to particular programs without such training for system designers and support planners.

Appendix A

INDIVIDUAL MODEL DESCRIPTIONS

This appendix describes each of the 46 models examined in this study. Given for each model are name and acronym; application; data requirements; type of language and computer programmed for; owner; contact; and references on model, if available. Table 4 offers an overall view of this information.

Table 4

OVERVIEW OF THE 46 MODELS

Model	Source	Owner	Type	Language	Data Reqment	Application: Spares	AGE	Pers	LOR	Opns	LCC	Mgt	Comments
ABLE	Air Force Log Command	Air Force	Accounting	Joss,[a] Fortran	Minimal						x	x	Incentive oriented
AMSEC	Operations Res, Inc	Opns Res	Reliability	Fortran	Moderate	x	x	x		x	x		System reliability
ARMADA	Naval Weapons Systems Analysis Office	Navy	Simulation	Fortran, Simscript[b]	Much	x	x	x		x	x		
BDSM	General Dynamics	Gen. Dyn.	La Grange Mult	Fortran	Minimal	x							
BOMS	The Rand Corp	Air Force	Simulation	Simscript	Much	x		x		x			
CAEM	Lockheed Aircraft Corp	Lockheed	Simulation, Accounting	Fortran	Much					x	x		Transport aircraft
COAMP	Radio Corp of America	RCA	Network, Accounting	Fortran	Moderate	x	x		x		x		
DEQMAR	The Rand Corp	Air Force	Queueing	NP[c]	Minimal		x	x					
GEM	Naval Applied Sci Lab	Navy	Reliability, Differential Eq	Gem, Fortran						x			
GOSS	Lockheed Aircraft Corp	Lockheed	Simulation	Fortran	Moderate					x			Transport aircraft
IPM	General Dynamics	Gen. Dyn.	La Grange Mult	Fortran	Moderate	x							
LCCM	Planning Res Corp	RCA	Accounting	Simscript	Moderate						x	x	Costs by year
LCCP	Raytheon	Raytheon	Simulation, Accounting	Fortran, Cobol	Much	x	x	x	x	x	x		
LCOM	The Rand Corp	Air Force	Simulation	Simscript	Much	x	x	x	x	x			
LOGCOST	Air Force Log Command	Air Force	Accounting	Fortran	Minimal		x	x			x	x	Source selection
LORAM	Naval Air Syst Command	Air Force	Accounting	Fortran	Moderate	x	x		x		x		
MACOM	McDonnell Douglas	Air Force	Simulation	Simscript	Moderate					x			Missile countdown
MARIS	General Electric[d]	Navy	Simulation	Fortran	Much	x				x			
MCTAS	Lockheed Aircraft Corp	Lockheed	Simulation	GPSS	Much	x	x	x		x			System reliability
MEMM	General Electric[d]	Navy	Markov chain	Fortran	Moderate	x				x			
METRIC	The Rand Corp	Air Force	La Grange Mult	Fortran	Moderate	x							
MINE	The Rand Corp	Air Force	La Grange Mult	Fortran	Moderate	x				x			
MRSM	Lockheed Aircraft Corp	Lockheed	Simulation	GPSS	Moderate		x	x	x	x			Transport aircraft
OMLRS	Lockheed Aircraft Corp	Navy	Simulation	GPSS	Much	x	x	x		x			
ORLA	Air Force	Air Force	Accounting	Fortran	Minimal				x		x		
PLANET	The Rand Corp	Air Force	Simulation	Simscript	Much	x	x	x		x	x		
PROJMOD	The Rand Corp	Air Force	Differential Eq	NP	Moderate							x	Time/cost/performance
QUEST	The Rand Corp	Air Force	Probability, Accounting	Fortran	Moderate				x		x		
RAM	Naval Missile Center	Navy	Differential Eq	Fortran	Moderate							x	Resource allocation
RGM	Air Force Log Command	Air Force	Dynam Programming	Simscript	Moderate	x	x	x	x		x		
RMT	Air Force Inst of Tech	Air Force	Math Programming	Fortran	Moderate							x	R/M improvement
SAMSOM	The Rand Corp	Air Force	Simulation	Simscript	Much	x	x	x		x			
SCAM	The Rand Corp	Air Force	La Grange Mult, Accounting	Joss, Fortran	Minimal	x	x	x	x		x		
SCEET	McDonnell Douglas	Air Force	Accounting	Fortran	Moderate				x				
SCOPE	McDonnell Douglas	Air Force	Simulation	Simscript	Moderate					x			Missile flight
SCORE	Naval Air Dev Center	Navy	Accounting	Fortran	Moderate			x			x	x	Costs by year
SEEP	General Dynamics	Gen. Dyn.	La Grange Mult	Fortran	Minimal	x				x			
SEMBRAT	The Rand Corp	Air Force	Queueing	Joss	Minimal		x	x		x			
SKEM	McDonnell Douglas	Air Force	Simulation	Fortran	Minimal	x							
SOGEM	The Rand Corp	Air Force	Markov Chain	Fortran	Minimal					x			Sortie analysis
SPAREM	General Dynamics	Gen. Dyn.	Simulation	Simscript	Moderate	x				x			
SPARTAN	The Rand Corp	Air Force	Network	Fortran	Moderate							x	Development sched
SPM	Lockheed Aircraft Corp	Lockheed	Algebraic	Cobol	Minimal	x							Transport aircraft
SSM	General Dynamics	Gen. Dyn.	Simulation	Simscript, Fortran	Moderate		x	x		x			
TRIM	Raytheon	Army	Accounting	Fortran, Cobol	Moderate	x	x		x		x		
VALUE	Martin Marietta Corp	Navy	Simulation	GPSS	Much	x	x	x		x	x		Aircraft carrier

[a] JOSS is the trademark and service mark of The Rand Corporation for its computer program and services using that program. [b] Simscript or Simscript I.5. Simscript I.5 is a trademark of Consolidated Analysis Center, Inc. [c] Not programmed. [d] Tempo Division.

ABLE (Acquisition Based on consideration of Logistics Effects)

Application: Computes life cycle cost by item by cost type (stockage, repair, training, tech data, etc.) and sums for all items in the system. Could be used as an LCC model in detailed design, but is intended primarily for developing and specifying contract incentives regarding logistics. It is really a concept more than a specific model.

Data Requirements: Minimal. Program input is total flying hours. Also requires item cost, reliability, maintenance cost as percentage of item cost, preceding items for base and depot AGE, NRTS and condemnation rate, on-equipment maintenance manhours per operating (flying) hour, training costs, pages of tech data. Maintenance posture is standard base/depot, one-indenture level. Spares are determined (in the model we evaluated) by ten days' base supply, ninety days' depot supply.

Programmed for: JOSS at Rand. Simple to program, low core and running time requirements. Also programmed at Headquarters AFLC.

Owner: Air Force.

Contact: Irving Katz, Chief, Operations Analysis Office, Hq Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio.

Reference: Project ABLE, Operations Analysis Report No. 8, Operations Analysis Office, Hq Air Force Logistics Command, May 1969; see also Supplement No. 1, Project ABLE Applied to Aircraft Engine Development and Procurement.

AMSEC (Analytic Method for System Evaluation and Control)

Application: A relatively sophisticated technique for computing total system availability and reliability over a mission consisting of a number of sequential mission segments or sorties. Availability and reliability (A/R) computations are carried out for each elemental equipment module that is renewed under either an existing or a postulated maintenance plan. Module A/R's are aggregated to obtain estimates of A/R for the total system or for any subsystem indenture level. It can handle explicit time dependent or mission dependent failure modes and will accept any wearout distributions to describe equipment life characteristics. Probability that system falls into various levels of degraded performance during prescribed mission because of failed modules can be computed. Concurrent with the computation of mission A/R's, AMSEC computes module inventories necessary to execute proposed operational and support plans (e.g., on-board spares levels for submarines and AWACS).

Data Requirements: Minimal to moderate. For each mission segment and for each replaceable system module: maintenance schedule, failure distribution due to random failures, failure distribution due to mission type and wearout, failure distribution due to system servicing, distribution of LRU downtime due to random failure, distribution of LRU downtime due to a failure induced by preventive maintenance, usage rate of LRU during each mission segment.

Programmed In: FORTRAN for CDC 3100. Relatively fast running time (approximately 5 seconds per module in the system).

Owner: Operations Research Inc., Silver Spring, Maryland

Contact: W. H. Cook and D. P. Manahan, Operations Research Inc.

Reference: Reliability/Maintainability Analysis of Army Vehicles ORI Technical Reports 456 and 480; see also ORI Technical Memorandum 112-69.

ARMADA (Aircraft Reliability Maintainability Availability Design Analysis Model)

Application: Simulates flight, maintenance, and supply activities of a land-based or ship-based squadron of aircraft. Computes operational effectiveness (flying hour or sortie rate, ratio of hours flown to hour scheduled, operational readiness rate), support system effectiveness (NORS, NORM, AWM), life cycle costs, cost per flying hour. Consists of five submodels: Inventory Planning Submodel generates optimal spares inventory; Supply Effectiveness Submodel; Systems Simulation Submodel generates failures and maintenance actions; Operations Simulation Submodel integrates the computations of the previous models within a framework of operational and resource availability considerations to simulate the overall response of a squadron to a set of operational requirements; Cost Effectiveness Submodel compute life cycle costs for operation and maintenance, and cost per flying hour. Submodels can be run individually. Use in concept evaluation, system design, support planning.

Data Requirements: Much. Similar to LCOM, SAMSOM, VALUE.

Programmed In: FORTRAN and SIMSCRIPT I.5 on the IBM 360/91. Simulation of a squadron for six months would typically take 320 k bytes of core and run 2 - 5 minutes.

Owner: Navy.

Contact: Don Sunde, Technical Director, Russ Hunt, Greg Opresko, U.S. Naval Weapon Systems Analysis Office, Marine Corps Air Station, Quantico, Virginia.

Reference: Executive Summary of the Aircraft Reliability/Maintainability/Availability Design Analysis Model, U.S. Naval Weapon Systems Analysis Office, WSAO-R-70-3, Quantico, Virginia, May 1970.

BDSM (Base Depot Stockage Model)

Application: Determines base and depot stock levels that will minimize backorders within a fixed spares budget. Assumes compound Poisson demand, n identical bases. Use in support planning.

Data Requirements: Minimal. Basing posture, flying program, failure rates, repair cycle times, NRTS and condemnation rates, procurement costs, procurement lead times, depot reorder quantity, and cost constraints.

Programmed In: FORTRAN for IBM 360. 1000 assemblies for 10 cases (investment constraints) takes about 3 minutes.

Owner: General Dynamics.

Contact: W. M. Faucett, General Dynamics, Fort Worth, Texas.

Reference: Base Depot Stockage Model, Operations Research, Research and Engineering Departments, General Dynamics, ERR-FW-621, December 1967.

BOMS (Base Operations Maintenance Simulator)

Application: Simulates operations and maintenance at a single base. Similar to SAMSOM, but handles base shops maintenance activities, skilled and unskilled personnel, and cannibalization. Use in conceptual design and support planning.

Data Requirements: Moderate to much, being basically the same as SAMSOM or LCOM. Outputs are aircraft availability, sortie launch capability, support resource utilization, demands for spares, shop repair statistics, cannibalization statistics, and downtime by type of maintenance.

Programmed In: SIMSCRIPT for IBM 7040/44 and SIMSCRIPT I.5 for IBM 360 and CDC 6400.

Owner: Air Force.

Contact: Management Sciences Department, The Rand Corporation. See also the contact for SCEET.

Reference: Base Operations Maintenance Simulator, The Rand Corporation, RM-4072-PR, September 1964.

CAEM (Cargo Airline Evaluation Model)

Application: Computes earnings and return on investment for a specified air cargo transportation system. Evaluates economic and operational results for a fixed schedule, route, and aircraft complement. Optimizes operations by varying flight frequency and equipment type. Oriented to commercial airline operations, applicable to MAC. Use in concept evaluation and support planning.

Data Requirements: Much. Aircraft characteristics including payload, range, block fuel, block time, operating weight empty, take-off weight and distance; route definition, distances, revenue yield, airport limitations; cargo types and flows; minimum service required, target load factor; market share and penetration; procurement and operational costs of aircraft; support equipment, facilities. CAEM interfaces with SPM, GOSS, AND MRSM.

Programmed In: FORTRAN.

Owner: Lockheed.

Contact: J. M. Norman, Manager, Commercial Systems Integration Dept., Lockheed-Georgia Company, Marietta.

Reference: Total Airline Profit and Simulation Models, Lockheed-Georgia Company, ER-10110, June 1969.

COAMP (Computer Analysis of Maintenance Policies)

Application: Estimates the support costs of an end item consisting of n similar modules, and parts, for twenty basic maintenance postures. Including all the stockage options, there are eighty distinct 4-echelon, 3-indenture postures that can be analyzed. AGE requirements are estimated by computing the number of service channels required to handle the flows at the various repair points. COAMP also attempts to take into account the fact that flows are a function of the NORS rate, in addition to NORS being a function of flows. This leads to a measure of backorders as a function of stock levels. Can analyze complex decisions including various types of built-in test equipment; however, in order to handle such complex postures, COAMP must approximate the optimal stock levels and the optimal AGE requirements. COAMP supplies default values for all variables. Thus you can start runs initially with very little knowledge, and then become more precise as your data set builds up. Sensitivity tests can be automatically run for a number of specified variables. Use in detailed design, support planning, concept evaluation.

Data Requirements: Moderate to much. Demands for maintenance resulting from scheduled maintenance, failures, attrition, theft, loss, and false failure indications; life cycle length, quantity of item, item costs, stockage policy descriptors; NRTS rate and scrap rate; transportation distances and costs, logistic delay times, etc.

Programmed In: FORTRAN for IBM 7090, RCA Spectra 70/45 and 70/55. Uses about 100 k bytes of Spectra core, runs about 0.1 seconds to analyze one item across 80 policies with sensitivity analysis.

Owner: RCA

Contact: W. A. Triplett, RCA Defense Electronics Products, SEER, Moorestown, New Jersey.

Reference: Evaluating the Economics of Integrated Logistics Support, RCA Defense Electronics Products, SEER, ATE-8-612, September 1968.

DEQMAR/SEMBRAT (Determining Economic Quantities of Maintenance Resources/Single Echelon Multi-Base Resource Allocation Technique)

Application: DEQMAR computes maintenance manpower and equipment requirements, taking into account the randomness of the failure pattern, the workshift policy, and the cost-effectiveness tradeoff. It requires the failure rate, repair time, and cost.

SEMBRAT computes the marginal decrease in system downtime attained by adding one more service channel (i.e., AGE) at a base. It can thus help compute AGE requirements, and also optimally redistribute currently available AGE among bases in response to changed flying program. Use in support planning, possibly in conceptual design to analyze tradeoff between quantity of AGE and system availability.

Data Requirements: Minimal for SEMBRAT. Number of bases, demand rate and service time by base; some cost figures on aircraft and AGE if desired. This is a queueing model that assumes Poisson demand rate (can be modified to compound Poisson) and negative exponential service times.

Programmed On: JOSS at Rand for SEMBRAT. Fairly short running time.

Owner: Air Force.

Contact: Milt Kamins, Management Sciences Department, The Rand Corporation.

References: Determining Economic Quantitites of Maintenance Resources: A Minuteman Application, The Rand Corporation, RM-3308-PR, January 1963. SEMBRAT is documented informally.

GEM (Generalized Effectiveness Methodology)

Application: Evaluates the effectiveness, in terms of reliability without repair, reliability with repair, availability, interval reliability, and mean time to first failure, of a complex system composed of a number of items. Use in concept evaluation.

Data Requirements: Moderate. Reliability block diagram, failure and repair distributions, maintenance resource and spares constraints.

Programmed On: CDC 6600. Requires 135,000 to 300,000 octal 60-bit words of core. GEM is a highly flexible set of routines including a System Definition Language to describe a system and its constraints and operating rules, and a Command Language for requesting specific computations and for modifying the system description. The GEM processor does extensive error checking and translates the system description and commands into a "custom-built" FORTRAN program which is compiled and executed.

Owner: Navy.

Contact: Paul Wong or Sy Friedman, Code 4100, Naval Electronic Laboratory Center, 271 Catalina Blvd., San Diego, California.

Reference: The Generalized Effectiveness Methodology (GEM) Analysis Program; Electronics Division, U.S. Naval Applied Science Laboratory, Lab. Project 920-72-1, Progress Report 1, SF-013-140-3, Task 1604, Brooklyn, New York, May 1968; also Navy Systems Performance Effectiveness Manual, Naval Material Command, NAVMAT P3941-A, July 1968.

GOSS (Ground Operations System Simulation)

Application: Simulates ground operation functions: preparing aircraft for flight, offloading/loading, dispatching; servicing, including replenishing consumables, cleaning, inspection, decontamination; cargo processing, including receiving and sorting cargo, containerizing, documentation and control, move to aircraft when ready for loading. Oriented to commercial airline operations, applicable to MAC. Use in concept evaluation and support planning.

Data Requirements: Moderate to much. For a particular station: flight schedule, aircraft support characteristics, man/machine timing tables, facility and equipment requirements and availability, cargo flows, weights, and types, personnel characteristics.

Programmed In: FORTRAN IV.

Owner: Lockheed.

Contact: J. M. Norman, Manager, Commercial Systems Integration Dept., Lockheed-Georgia Company, Marietta.

Reference: Total Airline Profit and Simulation Models, Lockheed-Georgia Company, ER-10110, June 1969.

IPM (Inventory Policy Model)

Application: Computes optimal stockage policy for an assembly and its component modules at a single base. Repair is done at base and depot with unlimited maintenance resources. Objective function is spares cost plus imputed penalty cost for backorder.

Data Requirements: Moderate. Demand distribution (Poisson, compound Poisson), number of aircraft, flying program, pipeline times, La-Grangian multipliers, penalty costs, failure rates, NRTS rates, con-demnation rates, item costs, maintenance costs, description of assemblies and modules.

Programmed In: FORTRAN for IBM 360/65. 1000 assemblies and 1000 modules require 190 k bytes of storage, 3 minutes running time for 10 cases (with investment constraints).

Owner: General Dynamics.

Contact: W. M. Faucett, Operations Research, Research and Engineering Departments, General Dynamics, Ft. Worth, Texas.

Reference: Inventory Policy Model - Mod II, Operations Research, Research and Engineering Departments, General Dynamics, ERR-FW-790, December 1969.

LCCM (Life Cycle Cost Model)

Application: Calculates life cycle costs by cost item by period. Costs can be entered directly into the model, or calculated by CERs, by standard formulae, or by summation of other costs. Learning curve costing can be handled, as can discounting. Use in project management.

Data Requirements: Moderate. Cost categories, variables and associated calculations (basically subprograms written by the user in the syntax of LCCM).

Programmed In: SIMSCRIPT I.5 on IBM 7090 and RCA Spectra 70.

Owner: RCA.

Contacts: J. Knapp, P. Hume, M. Brossman, Planning Research Corporation, Washington, D.C.; W. A. Triplett, RCA, Defense Electronics Products, Missile and Surface Radar Division, Moorestown, New Jersey.

Reference: Life Cycle Cost Model Final User's Manual and Operating Instructions, Planning Research Corporation, PRC R-1225 (Vol. I), April 1969.

LCCP (Life Cycle Computer Program)

Application: Simulates overall operations and maintenance of a system, and calculates operational effectiveness and life cycle cost over time. Can simulate an entire logistics chain from deployed system back to depot. Consists of a life cycle simulation model, which is basically a very sophisticated failure generator; a logistics simulation model, which reflects utilization of spares, personnel, AGE, and facilities, and the responsiveness of the logistics system; an effectiveness indices calculation program, which determines weapon system operational effectiveness over time; and a life cycle cost program, which calculates dollar payouts over the system life cycle, including R&D, investment, spares and repairs, transportation, etc. Each model can be run independently. Use in concept evaluation and support planning.

Data Requirements: Much. Detailed mission description; failure modes, rates, and effects; fault detection time; maintenance time and resource requirements, delay times; costs of R&D, investment, facilities, supply administration, repair, handling, transportation.

Programmed In: FORTRAN and COBOL on UNIVAC 1108, IBM 7044, and CDC 6400. A missile system of 15,000 recoverable assemblies run for three months will use about one hour of 1108 time and 65 k bytes of core plus some drum storage. 7044 and 6400 running times should be much less.

Owner: Raytheon.

Contact: D. R. Earles, Program Manager, Safeguard Life Cycle Analysis Program, Raytheon Company, Bedford, Massachusetts.

Reference: None available.

LCOM (Logistics Composite Model)

Application: Simulates overall operations and support functions at a single air base. Includes flying of aircraft, servicing tasks such as refueling and weapons loading, incurrence of malfunctions, accomplishment of flight-line aircraft maintenance, parts repair in base shops, utilization and interaction of maintenance resources, and changes in resource availability on different work shifts. Parts cannibalization is permissible. Has capability to optimize resource levels. Can be used to evaluate interaction between maintenance policy, resource availability, and operational effectiveness. Applicable in conceptual design and support planning.

Data Requirements; Moderate to much. Detailed maintenance task network (contributes to model flexibility, but requires more input data), task priorities, durations, resource requirements; resource types (aircraft, personnel, parts,), quantitites, cost, failure parameters, probability distributions; work shift policies; maintenance priority specifications; output report specifications; flying program and sortie data. Of the eleven basic input forms, six are optional. This is a simulation model of an Air Force base with associated input and output programs. Depot activities are not explicitly handled nor is lateral resupply.

Programmed In: SIMSCRIPT 1.5 for UNIVAC 1107, CDC 6400. Data input appears fairly simple for a simulation, because of the input checking and formatting program. A detailed weapon system run considering three days of operation, 700 defined resources, 2500 tasks, and one squadron requires 65 k memory and 1.25 hours of UNIVAC 1107 computer time.

Owner: Air Force.

Contact: William F. Drake, III, Office of DCS/Comptroller, Research Division (ACTRS), Hq Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio.

References: The Logistics Composite Model: An Overall View, The Rand Corporation, RM-5544-PR, May 1968; see also Logistics Composite Model: Users' Reference Guide, AFLC Report 70-1, Headquarters Air Force Logistics Command, January 1970.

LOGCOST (Logistics Cost Model)

Application: Computes life cycle cost by year by cost type (spares, repair parts, shipping, depot, base, and organizational maintenance). Also computes maintenance manhours and AGE utilization. Designed for use in source selection.

Data Requirements: Minimal to moderate. Annual flying hour program by CONUS and overseas bases; ERRC coding; stockage, repair cycle, and order and shipping times; shipping costs; item identification and data based on Work Breakdown Structure; reliability and maintainability data by item. Stock levels determined by so many days' supply depending on type of item.

Programmed In: FORTRAN. Should run fast on a relatively small computer.

Owner: Air Force.

Contact: Alfred J. West, DCS/Comptroller, Hq Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio.

Reference: Logistics Cost Model with Offeror Differentiating Capability, Directorate of Cost Analysis, DCS/Comptroller, Hq Air Force Logistics Command, unpublished paper, July 1969.

LORAM (Level of Repair for Aeronautical Material)

Application: This procedure is similar to ORLA for estimating the life cycle costs associated with the LOR decisions for a single item. For both assemblies and modules and for each of the decisions (discard, intermediate repair on carrier, and depot repair) LORAM presents algebraic formulae for estimating LCC(L). LORAM is described in a new Navy regulation to be implemented as part of the Navy ILS program within 90 days of contract award. It ties in closely with the maintenance engineering analysis program. The LORAM regulation also briefly discusses the noneconomic criteria to consider in repair level decisions. Use in support planning.

Data Requirements: Moderate. LORAM is more extensive than ORLA in that the LCC(L) formulae include the costs of inventory, packaging and transportation, item entry and retention, support equipment, support equipment deck space, repair work deck space, repair material, labor, training and documentation, each of which is estimated from 90 pieces of data, half supplied by the Navy and half by the contractor. The contractor supplies item parameters including MTBF, NRTS rate, unit cost, repair cost at intermediate and depot, AGE costs, and so on, while the Navy supplies standard factors such as cost of repair space, transportation costs, repair cycle times, and inventory parameters. The inventory procedure followed is essentially the Navy system, consisting of stocks allocated to satisfy the rotatable pool, a NRTS or attrition rate, and the repair cycle time, which together are designed to assure a 90-percent fill rate. Other procedures can be considered.

Programmed In: FORTRAN for CDC 6600, UNIVAC 1108, IBM 360/65. Takes about 50 k bytes of core and 1-2 seconds running time per assembly.

Owner: Navy.

Contact: LCDR L. H. Fisler, NAVAIR 4013A, Naval Air Systems Command, Washington, D.C.

Reference: Level of Repair for Aeronautical Material: General Program Requirements, Naval Air Systems Command, Department of the Navy, AR-60, 1 June 1970.

MACOM (Maintenance Assembly and Checkout Model)

Application: Simulates the prelaunch activities of a missile or spacecraft. Identifies delays and component malfunctions, computes manpower and AGE utilization. Use in support planning, system design (for one-shot systems), concept evaluation.

Data Requirements: Moderate. Network of prelaunch activities, activity descriptions, failure and delay probabilities, repair and replacement times.

Programmed In: SIMSCRIPT I.5 for CDC 6400.

Owner: Air Force.

Contact: Howard L. Swaim, Advanced Logistics, Dept. 501, Support Technology, Building 32, Level 3, Station 24573, McDonnell Aircraft Corp., St. Louis, Missouri.

Reference: Product Support Report No. 401, McDonnell Douglas Astronautics Company, 3 July 1967.

MARIS (Material Readiness Index System)

Application: Determines effect on operational readiness of submarine-launched missiles of budget changes for spares or the design of the spares system, including its operating policies and characteristics, and the operating and support environment. Probably most useful in support planning. Possibly useful in conceptual design. Should be applicable to analysis of any system imvolving long mission times and on-board spares (e.g., AWACS).

Data Requirements: Much. Reliability block diagram, criticality of item failure; detailed program data by individual submarine; detailed data describing the supply system; supply policy, may be budget-constrained; item cost. This is a family of analytic and simulation models. It's oriented to a Navy environment.

Programmed In: FORTRAN and machine language on GE-635 of 75 k words. Analysis of "small questions" take minutes; a large problem may run 5 to 6 hours.

Owner: Navy.

Contact: George Tinker, Manager, Marketing Services, or Bill Frederick, Manager, Support Systems Analysis, G. E. Tempo, Santa Barbara, California.

Reference: MARIS Technical Manual, G. E. Tempo, Santa Barbara, California, Report NR 69-TMP-65, August 1969.

MCTAS (Military/Commercial Transport Aircraft Simulation)

Application: Simulates aircraft dispatch capability under conditions including randomly generated system failures, various distributions of times to repair, modified inspection sequences, and logistic delays. Outputs provide the probabilities of scheduled departure, delay and/or cancellation as a function of the specific system design characteristics, maintenance techniques and logistics resources. Model includes fault detection on the ground, unscheduled maintenance for components, scheduled maintenance and servicing for systems. This model is a derivative of OMLRS. Use in concept evaluation and overall system design.

Data Requirements: Much. Flight schedules for up to fifty aircraft, weather characteristics and effect on operations; availability of spare aircraft; availability of personnel by skill, by station, by workshift; spare parts and test equipment by station; probabilities of delay times; reliability, redundancy, criticality, and maintenance requirements of up to 8500 components per aircraft.

Programmed In: GPSS for IBM 360/91. A simulation of 20,000 flights takes about 7 minutes, depending on average length of simulated flight.

Owner: Lockheed-California Company.

Contact: T. F. Weber, Jr., and M. E. Monley, Systems Research (Dept. 74-52), Lockheed- California Company, P. O. Box 551, Burbank, California.

Reference: P3-C Operations, Maintenance, and Logistics Resources Simulation Model Descriptions, Lockheed California Company, LR-22624 and LR-23105, June 1969.

MEMM (Multi-Echelon Markov Model)

Application: Computes downtime of submarine-based ballistic missiles due to a shortage of spares. This is a precursor of MARIS, and models a three-echelon supply system consisting of a depot, bases (the tenders supporting the submarines), and operating units (the submarines) that periodically return to base. Use in concept evaluation and support planning.

Data Requirements: Moderate. Patrol schedule for operating units; reliability, redundancy, criticality, on-board spares level of individual items in the missiles; item costs; supply items; depot repair times, other factors describing the supply system.

Programmed In: FORTRAN for CDC 6400.

Owner: Navy.

Contact: George Tinker or Bill Fredrick, G. E. Tempo, Santa Barbara, California.

Reference: A Multi-Echelon Markov Model for Relating Supply System Performance to Fleet Readiness, G. E. Tempo, Report 67TMP-123, December 1967.

METRIC/MINE (Multi-Echelon Technique for Recoverable Item Control/ Multi-Indenture NORS Evaluator)

Application: METRIC computes the optimal levels and allocation of spare items in a base-depot supply system with compound Poisson demand, with backorders as the supply-effectiveness criterion. MINE extends this work by evaluating the expected number of NORS (Not Operationally Ready Supply) aircraft for a particular supply and maintenance posture. Use in support planning.

Data Requirements: Minimal. Demand rate, NRTS rate, repair cycle times, order and shipping times, unit cost, investment constraint.

Programmed In: FORTRAN for IBM series 7000 and 360 machines, and the GE 645. Running time is relatively fast for this type of computation.

Owner: Air Force.

Contact: John Lu, Management Sciences Department, The Rand Corporation.

Reference: METRIC: A Multi-Echelon Technique for Recoverable Item Control, The Rand Corporation, RM-5078-PR, November 1966; MINE: Multi-Indenture NORS Evaluator, The Rand Corporation, RM-5826-PR, December 1968.

MRSM (Maintenance and Reliability Simulation Model)

Application: Simulates maintenance operations. Calculates dispatch reliability, maintenance manhours, downtime distribution, detailed malfunction data. Oriented to commercial airline operations, applicable to MAC. Use in concept evaluation and support planning.

Data Requirements: Moderate to much. Route structure, flight schedule, aircraft configuration, failure rates, frequency of preventive maintenance and overhauls, maintenance task times and manpower requirements, scheduled ground time and service by station, maintenance capability by station, minimum equipment list.

Programmed In: GPSS for IBM 360/50 and up. On 360/50 a simulation of 6 months, 8 stations, 10 aircraft 3000 LRUs/aircraft, 5000 flights total, would run 75 minutes and use 380 k bytes of core. On 360/91, running time would be 20 minutes for 50,000 flights.

Owner: Lockheed.

Contact: J. M. Norman, Manager, Commercial Systems Integration Dept., Lockheed-Georgia Company, Marietta.

Reference: Total Airline Profit and Simulation Models, Lockheed-Georgia Company, ER-10110, June 1969.

<u>OMLRS (Operations, Maintenance, and Logistics Resources Simulation Model)</u>

<u>Application:</u> Simulates flight operations requirements, scheduled and unscheduled maintenance and the associated logistic support resources (personnel, spares, and AGE). Oriented to the Navy P-3C aircraft. Adaptable to other types and multiple bases. Presently utilized for one squadron at one base. Considers maintenance actions by "when discovered" category. Addresses scheduled maintenance by programming the inspection work cards and sequence control charts to utilize resources. Unscheduled maintenance occurs randomly, and the resources are specified in the input data for each component. "When discovered" categories provide the apportionment of failures to be repaired at various periods of unscheduled and scheduled maintenance. The model can be run at different levels of detail, such as considering only specified systems or certain logistics resources, to permit thorough analysis of a specific problem prior to testing the effects of the solutions. Use in conceptual design and support planning, possibly in detailed system design.

<u>Data Requirements</u>: Much. Number of aircraft, flight schedule, system and item reliability, abort probability, failure detection probabilities, repair time distribution, preflight and postflight inspection times, personnel types and quantities, workshift data, maintenance resource availability, scheduled maintenance program, spares and AGE requirements, and so forth.

<u>Programmed In</u>: GPSS on IBM 360. 10,000 missions take 2 to 30 minutes.

<u>Owner:</u> Navy.

<u>Contact</u>: T. F. Weber, Jr., J. W. Bims, and R. L. Stone, Maintainability (Dept. 7452), Lockheed California Company, Burbank.

<u>Reference</u>: <u>P3-C Operations, Maintenance, and Logistics Resources Simulation Model Descriptions</u>, Lockheed California Company, LR-22624 and LR-23105, June 1969.

ORLA (Optimum Repair Level Analysis)

Application: ORLA is an Air Force procedure for determining whether or not, and at what echelon, to repair an item. It is oriented toward use by contractors making repair level decisions on items they are designing. It considers the throwaway and repair at base and depot postures. Use in detailed design and support planning.

Data Requirements: Minimal to moderate. Fleet size, basing concept, flying program; item weight, failure types and frequencies, man hours to repair; labor costs, packing and shipping costs, pipeline times; supply administration costs; base and depot AGE costs; training costs; tech data costs. ORLA approaches the data uncertainty problem by considering several levels (i.e., a parametric analysis approach) of variable factors such as flying program and item cost.

Programmed In: FORTRAN for IBM 360 by McDonnell Douglas. There are probably other programmed applications in existence.

Owner: Air Force.

Contact: For the McDonnell Douglas version, see the contact for SCEET.

Reference: Optimum Repair-Level Analysis, Air Force Logistics Command/ Air Force Systems Command, AFLCM/AFSCM 375-6, 20 May 1968.

PLANET (Planned Logistics Analysis and Evaluation Technique)

Application: Simulates overall operations and support functions at one or more bases and a depot. Can handle aircraft or missiles and their component parts. Includes flying of aircraft; servicing tasks, preflight, postflight, and other kinds of scheduled maintenance, unscheduled maintenance; consideration of various types of maintenance resources. Use in conceptual design and support planning.

Data Requirements: Much. Similar to LCOM except for maintenance task network.

Programmed In: SIMSCRIPT I.5 for IBM 360.

Owner: Air Force.

Contact: B. J. Voosen, Consultant, The Rand Corporation.

References: Rand Corporation Memoranda: Planet: Planned Logistics Analysis and Evaluation Technique, RM-4950-PR, January 1967; Planet: Part I - Availability and Base Cadre Simulator, RM-4659-PR, April 1967; Planet: Part II - Bench Repair Simulator, RM-4660-PR, April 1967; Planet: Part III - Depot Transportation Simulator, RM-4661-PR, April 1967; Planet: Part IV - Depot Repair and Overhaul Simulator, RM-4662-PR, July 1968; Planet: Part V - Reports and Analysis Library, RM-4663-PR, January 1969.

PROJECT MODELLING

Application: Examines the tradeoffs among time, cost, and performance in a system development project. Can compute minimum project cost, optimal system design specifications, optimal start and finish dates for specific activities, sensitivity information for project variables. Use in project planning.

Data Requirements: Moderate to much. Major system performance characteristics, major engineering specifications, relationships between the two, interrelationships among specifications, feasible ranges of specifications; project activities, resource requirements, activity times, relationships between resources and activity times over a range of those variables for each activity.

Not programmed, but there are many linear programming routines available.

Owner: Air Force.

Contact: E.V.W. Zshau, Consultant, The Rand Corporation.

Reference: Project Modelling: A Technique for Estimaing Time-Cost-Performance Trade-Offs in System Development Projects, The Rand Corporation, RM-5304-PR, July 1969.

QUEST (Quantification of Uncertainty in Estimating Support Tradeoffs)

Application: Reflects uncertainty in input data by computing probability distribution of life cycle costs for individual items or subsystems on which reliability and maintainability data are available. Can also be used for level of repair decisions. The QUEST methodology is currently implemented in a SCAM-type model, but can be easily expanded to consider other algorithms, including cost estimating relationships. Use in concept evaluation and detailed design, possibly in support planning.

Data Requirements: Minimal to moderate. Basically the same as SCAM, except that it is possible to quantify the uncertainty of most variables by specifying their extreme (high and low) and most likely values, and the shape of the distribution (uniform, triangular, etc.).

Programmed In: FORTRAN for IBM 360/65. Needs about 130 k bytes of core.

Owner: Air Force.

Contact: L. H. Zacks, Management Sciences Department, The Rand Corporation.

Reference: QUEST: Quantification of Uncertainty in Estimating Support Tradeoffs, The Rand Corporation (to be published).

RAM (Resource Allocation Model)

Application: Maximizes system performance for a given development cost, or minimizes cost to attain a given performance, by optimally allocating resources to a number of development activities. Use in project planning.

Data Requirements: Moderate to much. Functional relationships between the attained level of some performance variable and the resources applied to some development activity, maximum performance levels attainable with infinite resources, minimum levels attainable at virtually zero cost. Utilizes a differential equation approach. Computer output includes sensitivity curves.

Programmed In: FORTRAN for IBM 7094. Runs 2-10 minutes.

Owner: Navy.

Contact: C. J. Thorne, Code 5170, U.S. Naval Missile Center, Pt. Mugu.

Reference: A Resource Allocation Model, Naval Missile Center, TM-68-61, February 1969.

RGM (Range Model)

Application: Computes life cycle costs for alternative support postures, and delineates optimum repair policies, including spares, personnel, and procedures. Use in system design and support planning.

Data Requirements: Moderate. Description of system and component items, including failure rates, repair times, repair resources, weight, cost, next higher assembly, etc; programmed use; supply policies and support system characteristics.

Programmed In: SIMSCRIPT I.5 for UNIVAC 1107.

Owner: Air Force.

Contact: Jay F. Williams, ACVI, DCS/Comptroller, Headquarters Air Force Logistics Command, Wright-Patterson Air Force Base.

Reference: RGM-1 Executive Summary, Operations Analysis Report No. 9 June 1969 (AD688823); A User's Guide to RGM-1, Operations Analysis Technical Memorandum No. 7, June 1969 (AD690522); The Range Model, Operations Analysis Technical Memorandum No. 8., August 1969, (AD694074); Programmer's Guide to RGM-1, Operations Analysis Technical Memorandum No. 6, June 1969 (AD689400).

RMT (Reliability Maintainability Tradeoff)

Application: Computes optimal allocation of development resources for reliability and maintainability improvement, with the objective of minimizing life cycle costs. Use in concept evaluation and project management.

Data Requirements: Moderate. By subsystem, reliability (failure frequencies) and maintainability (mean time to repair), development costs for several different levels (generally three) of reliability and maintainability; system investment, operation and maintenance costs for each different configuration of subsystem reliability and maintainability (from some life cycle cost model); constraints on development cost, investment, weight, etc. This model uses an integer programming formulation.

Programmed In: FORTRAN on CDC 3600.

Owner: Air Force.

Contact: Major A. F. Czajkowski, Quantitative Studies Department, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio.

Reference: None available.

SAMSOM II (Support Availability Multi-System Operations Model)

Application: Simulates operations events (alert requirements, sortie-generation capabilities and readiness postures) and associated logistics support requirements (manpower, equipment, facilities and, to a limited extent, parts). For one or more aircraft at one or more bases. Takes into account weather, resource shortages, flying schedules, alert commitments, sortie configuration requirements, abort rates, attrition and battle damage estimates, and operations policies governing sortie cancellation and make-up practices. Can be used to evaluate the impact of changes in concepts, policies, and resource mixes upon operational capability. Applicable in conceptual design for performance/support tradeoff analysis, and in support planning.

Data Requirements: Moderate to much, depending on what is simulated. Base location; weather severity levels and distributions; detailed mission data, including routings, flying times, attrition policy, priority, weather constraints, airspeed; aircraft type and permissible missions, failure probabilities; resource availability, workweek, shift policy; aircraft inspection policy; combat, attrition and abort probabilities; sortie requirements and alert schedules; maintenance activities and resource requirements, NRTS rate, item criticality; maintenance activity simultaniety constraints. This is a simulation model with associated input and output programs. Spares requirements and depot activities are not explicitly handled.

Programmed In: SIMSCRIPT for IBM 7090 and SIMSCRIPT I.5 for IBM 360 and CDC 6400. Data input appears to be fairly simple for a simulation model because of the input checking and formatting program. 6400 running time is approximately one hour (plus three hours post-processing) to simulate a single squadron for sixty days and obtain a full set of output reports.

Owner: Air Force.

Contacts: T. C. Smith, Management Sciences Department, The Rand Corporation.

Reference: User's Manual for SAMSOM II, The Rand Corporation, RM-4923-PR, November 1967.

SCAM (System Support Cost Analysis Model)

Application: Computes ten-year discounted LCC by item for a system . Also computes optimal stock levels and determines optimal maintenance posture and AGE quantity requirements. Later version calculates required number of maintenance personnel by type. Use for detailed design and support planning, possibly in conceptual design.

Data Requirements: Minimal to moderate. Flying program by base, base location; discount rate; item cost, reliability, weight, procurement lead time, manhours to repair, breakout of manhours by type (optional), parts cost to repair, NRTS and condemnation rates; base and depot labor cost, repair cycle times; order and shipping time; packing and shipping costs; AGE acquisition, installation, and operating costs, and weight; pages of tech data; expected back-order rate (for supply effectiveness). Spares level is calculated by METRIC technique to minimize cost for a given level of back orders. Maintenance postures are repair at base and depot, base only, depot only, and throwaway.

Programmed In: JOSS, and FORTRAN for IBM 360/65. Typical run of 7 items takes less than one minute and 280 k bytes of core.

Owner: Air Force.

Contacts: R. M. Paulson, R. J. Kaplan, Management Sciences Department, The Rand Corporation.

Reference: SCAM: System Support Cost Analysis Model, The Rand Corporation, RM-6049-PR, November 1967.

SCEET (Support Concept Economic Evaluation Technique)

Application: Determines life cycle support cost differences of a reparable assembly under three maintenance postures: repair at base, repair at depot, and throwaway. Employs basically the ORLA (Air Force Optimum Repair Level Analysis) procedure. Use in conceptual design and support planning.

Data Requirements: Minimal to moderate. Fleet size, base locations, program hours, life cycle; shipping costs; labor costs, pipeline times; failure modes, failure effects, failure rates; composition of assembly, part count, weight, volume, price; repair manhours, repair parts, AGE and facilities.

Programmed In: FORTRAN on IBM 360. Runs 1.2 minutes for five repair candidates with up to five fail/repair modes each.

Owner: Air Force.

Contact: Howard L. Swaim, Advanced Logistics Dept. 501, Support Technology, Building 32, Level 3, Station 24573, McDonnell Aircraft Corp., St. Louis, Missouri.

Reference: Product Support Report Number 77, 1 April 1966; MCAIR Report MDC A0016, McDonnell Aircraft Corp.

SCOPE (Space Craft Operational Performance Evaluation)

Application: A follow-on to MACOM. Simulates operational functions from manned missile launch to flight termination. Use in concept evaluation and system design (for one-shot systems).

Data Requirements: Moderate. Descriptions of operational tasks necessary for mission success, priority and criticality of tasks, failure probabilities.

Programmed In: SIMSCRIPT 1.0 for CDC 6400.

Owner: Air Force.

Contact: Howard L. Swaim, Advanced Logistics, Dept. 501, Support Technology, Building 32, Level 3, Station 24573, McDonnell Aircraft Corp., St. Louis, Missouri.

Reference: see MACOM.

SCORE (System Cost and Operational Resource Evaluation)

Application: Estimates life cycle costs (RDT&E, investment, operations) for up to fifteen years for various component elements and aggregates these into a total cost estimate for a system. Costs may be estimated externally by the user, internally by standard CERs or internally by special programs. Costs are arranged in a two-dimensional (program element x time) matrix. Program elements can be indentured, and subtotals or CERs computed for any higher level. Use in project management.

Data Requirements: Moderate. Work breakdown structure (if other than standard), various cost inputs, special instruction cards.

Programmed In: FORTRAN on CDC 3200 and 3600. Requires 32,000 words of memory.

Owner: Navy

Contacts: L. Rogin and W. H. Raber, Systems Analysis and Engineering Dept., Naval Air Development Center, Warminster, Penn.

References: SCORE Executive Routine, Phase I, Naval Air Development Center, Report Nr. NADC-AW-6734, Feb. 1968; Techniques for Estimating Logistics Support and Operations Costs of Naval Airborne Weapon Systems, Naval Air Development Center, Report Nr. NADC-SD-6925, April 1969.

SEEP (Support Effectiveness Evaluation Procedures)

Application: Computes the effectiveness of a given stock policy in terms of organizational and intermediate level cannibalizations, fill rate, backorder rate, NORS rate. Can handle assemblies and their associated modules. Assumes complete cannibalization. An analytical version of SPAREM. Use in support planning.

Data Requirements: Minimal. Failure rates, NRTS rates, repair cycle times, flying program, stock levels. Maintenance posture is base/depot.

Programmed In: FORTRAN on IBM 360. Short running time, low core requirement.

Owner: General Dynamics.

Contact: W. M. Faucett, General Dynamics, Ft. Worth, Texas.

Reference: Support Effectiveness Evaluation Procedure, Operations Research, Research and Engineering Departments, General Dynamics, ERR-FW-912.

SKEM (Spares Kit Evaluator Model)

Application: Determines optimum types and quantities of spare parts for the support of a deployed unit, subject to multiple constraints. Also computes supply effectiveness in terms of "probability of no stockout" or "expected time to stockout." Use in support planning.

Data Requirements: Minimal to moderate. Failure rates or demand rates for assemblies, parts, and AGE; unit weight, volume, cost, etc., and the associated total constraints on these parameters. The quantity-setting routine employs a finite constructive algorithm, while the effectiveness-calculating program is a simulation.

Programmed In: FORTRAN on IBM 360/75.

Owner: Air Force.

Contact: Howard L. Swaim, Advanced Logistics, Dept. 501, Support Technology, Building 32, Level 3, Station 24573, McDonnell Aircraft Corp., St. Louis, Missouri.

Reference: Product Support Report P.S. 447, 26 February 1968.

SOGEM (Sortie Generation Model)

Application: Estimates maximum expected number of sorties per day that could be attained with unlimited maintenance resources. Useful in concept evaluation.

Data Requirements: Minimal. Length of flying day, length of preflight maintenance, probability of maintenance subsequent to preflight, probability of maintenance following a sortie, repair time distribution.

Programmed In: FORTRAN on IBM 7094 and IBM 360.

Owner: Air Force

Contact: E. V. Denardo, Consultant, The Rand Corporation. See also the contact for SCEET.

Reference: A Simplified Model of Aircraft Sortie Generation Capability, The Rand Corporation, RM-5145-PR, February 1967.

SPAREM (Spares Requirements and Evaluation Model)

Application: Evaluates impact of spares support policies on operational capabilities of aircraft weapon system. Use in support planning and evaluation.

Data Requirements: Moderate. Basically the same as IPM plus stock levels. Maintenance posture is base/depot. This is a simulation model.

Programmed In: SIMSCRIPT for IBM 360 (7090 emulation). 30 aircraft (1000 assemblies) for six months takes about 6 minutes.

Owner: General Dynamics.

Contact: W. M. Faucett, General Dynamics, Fort Worth, Texas.

Reference: Spares Requirements and Evaluation Model - Mod II, Operations Research, Research and Engineering Departments, General Dynamics, ERR-FW-789, December 1968.

SPARTAN (Scheduling Program for Allocating Resources To Alternative Networks)

Application: Generates and evaluates schedules and resource requirements for any project defined by an activity network. Use in project planning.

Data Requirements: Moderate: set of activities to be scheduled, technological ordering relationships among activities; activity completion times, resource requirements, usage rates; resource availability over time; resource costs, costs of changing resource levels, overhead costs if desired. This is a scheduling model using heuristic techniques.

Programmed In: FORTRAN IV. A 32 k word computer can handle a project with 1000 single-resource activities, 500 events, and 11 resource groups over a time span of 200 scheduling periods. Running time on an IBM 7040/7044 for a project with 350 activities, 10 resource groups, and 150 time periods is less than 2 minutes.

Owner: Air Force.

Contact: Jerome D. Wiest, Consultant, The Rand Corporation.

Reference: A Heuristic Scheduling and Resource Allocation Model for Evaluating Alternative Weapon System Programs, The Rand Corporation, RM-5769-PR, August 1969.

SPM (Spares Provisioning Model)

Application: Computes spares levels and fill rates and investment for each station in an airlift network. Oriented to commercial airline operations, applicable to MAC. Use in support planning.

Data Requirements: Minimal. Failure rate, time between overhauls, repair time, condemnation rate, route structure, item cost, item essentiality, spares availability objective, flying program.

Programmed In: COBOL on IBM 360/50. 500 items require about 5 - 10 minutes and 50 k bytes of core.

Owner: Lockheed

Contact: J. M. Norman, Manager, Commercial Systems Integration Department, Lockheed-Georgia Company, Marietta.

Reference: Total Airline Profit and Simulation Models, Lockheed-Georgia Company, ER-10110, June 1969.

SSM (Subsystem Simulation Model)

Application: Estimates maintenance requirements (probability, time distribution, probability and time utilization distribution of personnel and AGE, maintainability-reliability matrix) for a subsystem composed of a number of assemblies. Use for concept evaluation, support planning.

Data Requirements: Moderate. By assembly; maintenance frequency (failure rate) and elapsed time; personnel, AGE, and facilities required; probability and time of waiting for resources, paper work, travel time, etc.

Programmed In: SIMSCRIPT for IBM 360 (7090 emulation). Running time is about 1.5 minutes per major subsystem.

Owner: General Dynamics.

Contact: W. M. Faucett, General Dynamics, Fort Worth, Texas.

Reference: Subsystem Simulation Model, Operations Research, Research and Engineering Departments, General Dynamics, ERR-FW-514, December 1966.

TRIM (Throwaway/Repair Implications on Maintenance Cost)

Application: Calculates the life cycle cost implications and stockage requirements of repairing or throwing away an item. Use in support planning and detailed design.

Data Requirements: Moderate. Item failure rate, quantity, life cycle, price, cost to repair at various echelons, NRTS and condemnation rates, reparable shrinkage factors; supply administration cost; publications cost; AGE and facilities costs; transportation and handling costs; support system configuration.

Programmed In: COBOL and FORTRAN for UNIVAC 1108. Typical single item run takes one minute and 40 k bytes of core.

Owner: Army.

Contact: D. R. Earles, Program Manager, Safeguard Life Cycle Analysis Program, Raytheon Company, Bedford, Massachusetts.

Reference: Throwaway or Repair Implications on Maintenance Cost Program, BR-4298, September 1967 and Expanded TRIM Program Equations, RJL 70-103, April 1970, Raytheon Company, Missile Systems Division SAM-D Support Engineering.

VALUE (Validated Aircraft Logistics Utilization Evaluation)

Application: Simulates flight operations, maintenance policies, support functions, and resource allocation of a Naval airborne weapon system operating in a carrier environment. Its logic transforms a flight schedule, aircraft reliability and maintainability characteristics, and initial logistics support levels (personnel, spare parts) into aircraft performance figures of merit (Readiness; Not Operationally Ready, Supply and/or Maintenance; Direct Maintenance Manhours, etc.). This logic has been statistically validated against data reported from the fleet in the Naval Aviation 3-M (Maintenance and Material Management) reporting system. The current version (VALUE IV) is capable of simulating carrier air wings consisting of multiple aircraft types and squadrons. Possibly applicable to the analysis of any deployed squadron. Use in concept evaluation and support planning.

Data Requirements: Much. Mission type, schedule, priority, length; maintenance time, personnel requirements, priorities; scheduled maintenance requirements; test flight requirements; failure rates and criticalities; maintenance personnel and facilities; NORS and cannibalization probabilities; number of aircraft, carrier operating philosophy (launch preparation time, number of aircraft in alert status, etc.). These inputs are derived primarily from the Navy 3-M system, supplemented by squadron maintenance data.

Programmed In: GPSS on IBM 360. Requires 350 k bytes of core.

Owner: Navy.

Contact: L. Rogin or W. G. Slowik, Systems Analysis and Engineering Department, Naval Air Development Center, Warminster, Penn.

Reference: VALUE IV: An Aircraft Simulation Model, Naval Air Development Center, NADC-SD-6904, January 1969.

Appendix B

THE FITZHUGH REPORT AND ILS

Because of the high cost of current weapon programs and the continuing pressure to reorient national priorities, the Services have been enjoined to do better in estimating both the investment and support costs of new systems. The Fitzhugh report,* for example, had some comments about the acquisition process within the broad sweep of its many recommendations. That report is definitely concerned with item life cycle costs, as it recommends that "repair in lieu of replacement should be an allowable charge against the parent procurement appropriation funding the basic equipment."** It thus recognizes that future maintenance costs are an important part of an item's acquisition cost. This is a major thrust of the ILS concept, that the life cycle costs (including operations and maintenance), as well as the initial acquisition costs, should be an important design consideration.

The Fitzhugh report further recommends greater reliance on hardware proof-testing as opposed to paper studies during engineering and operational systems development,*** and "... assurance of such matters as maintainability, reliability, etc., by other means than detailed documentation by contractors as a part of design proposals."**** The report is basically asserting the desirability of reducing technological uncertainty by obtaining experimental as opposed to judgmental data. This idea is in accord with the ILS concept as we perceive it. Appendix D of this Report comments on the uncertainty of data required as inputs to models, and discusses several techniques for handling uncertainty. ILS analysis tasks would certainly be simplified if hard (factual), experimental data were available. Such data could be

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*G. W. Fitzhugh, et al., Defense for Peace: Report to the President and the Secretary of Defense on the Department of Defense, Blue Ribbon Defense Panel, Washington, D.C., 1 July 1970.

**Ibid., Recommendation II-31.

***Ibid., Recommendation II-5 (c and e).

****Ibid., Recommendation II-5 (j).

provided early in a system's life cycle if "development of selected subsystems and components [is pursued] independent of the development of [particular] weapon systems."*

Prototyping as an acquisition strategy is not without pitfalls of its own. There is the possibility that an experimental prototype may be developed into an operational system too quickly without adequate consideration of the associated support costs. A companion danger is that prototype development which concentrates exclusively on performance factors will leave unexplored some design alternatives that would yield an equally effective but less (life cycle) costly system. It thus seems highly desirable that the system developer be induced to use ILS disciplines even during early development, regardless of whether or not he has to provide the Government with numbers describing the item's or system's maintainability, reliability, life cycle cost, and so on. One way of approaching this under the parallel undocumented development concept would be to stipulate that evaluation of the prototypes include evaluation of those logistics factors affecting life cycle costs. Certainly this would be a strong inducement to the developer to consider such factors during his development program, if for no other reason than it suggests the form of a possible production contract. This approach would also require implementation of recommendation II-5 (k) concerning early planning for subsequent test and evaluation.

The report also recommended that tradeoffs be conducted between new systems and modifications to current systems.** This parallels our discussion in Sec. IV on the applicability of logistics models to analysis in the modification review process and the product improvement and value engineering programs. Such tradeoffs should be conducted with a view toward the life cycle costs, and not just initial acquisition costs.

Overall, then, it appears that the recommendations of the Fitzhugh report support the development of an effective logistics interaction early in the design process.

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*Ibid., Recommendation II-5 (a,b).

**Ibid., Recommendation II-5 (f).

Appendix C

THE ACQUISITION PROCESS

This appendix briefly reviews how materiel requirements are generated within the Air Force and how this process ultimately leads to new systems acquisition programs. This appendix provides a generalized view of the acquisition process as it works within the Air Force, indicates documents that more fully define the process, and highlights those areas in which it seems the Integrated Logistics Support concept will have its greatest impact.

Figure 4 shows the overall system acquisition process, and agency responsibility during the various phases. Figure 5 shows the flow of major documents in the conceptual and validation phases. Rather than trying to capture all the variations in an extremely complicated set of procedures, it portrays only the main flow of documents and decision points as they exist in the summer of 1970. This simplified diagram interfaces with the more complex diagram of the flow of logistics documentation and decisions found in the Support Planning Guide for DOD Systems and Equipment, DOD 4100.35-G.

The conceptual, validation, and development and production phases of acquisition are examined first, followed by a discussion of the role of Hq USAF, AFSC, and AFLC in decisions affecting acquisition.

CONCEPTUAL PHASE

AFR 57-1, Policies, Responsibilities, and Procedures for Obtaining New and Improved Operational Capabilities, specifies the method by which perceived operational deficiencies come to the attention of USAF Headquarters. Any major command may submit a Required Operational Capability (ROC), which must be signed by a general officer or a colonel in a key staff position. The specified content of a ROC is shown in Table 5. If a command chooses to submit preferred technical approaches, it should include tradeoff studies, alternative operational concepts, etc.

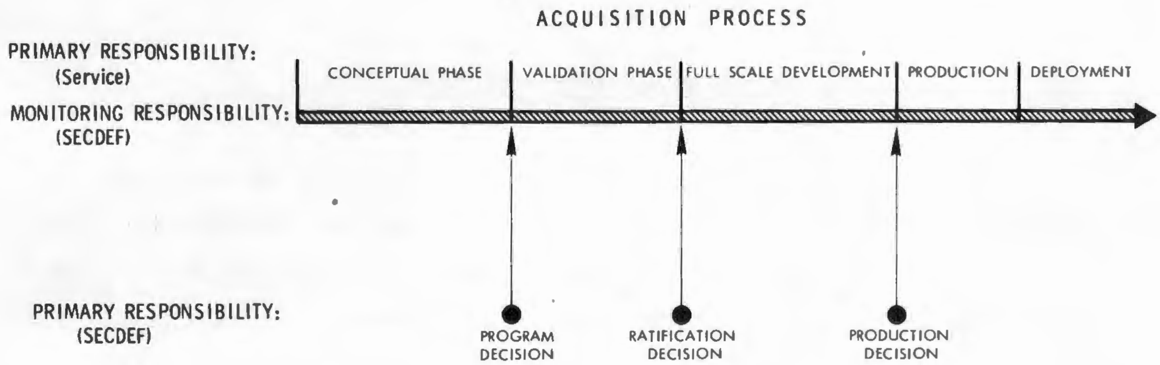

Fig. 4--Functional responsibilities in overall system acquisition process

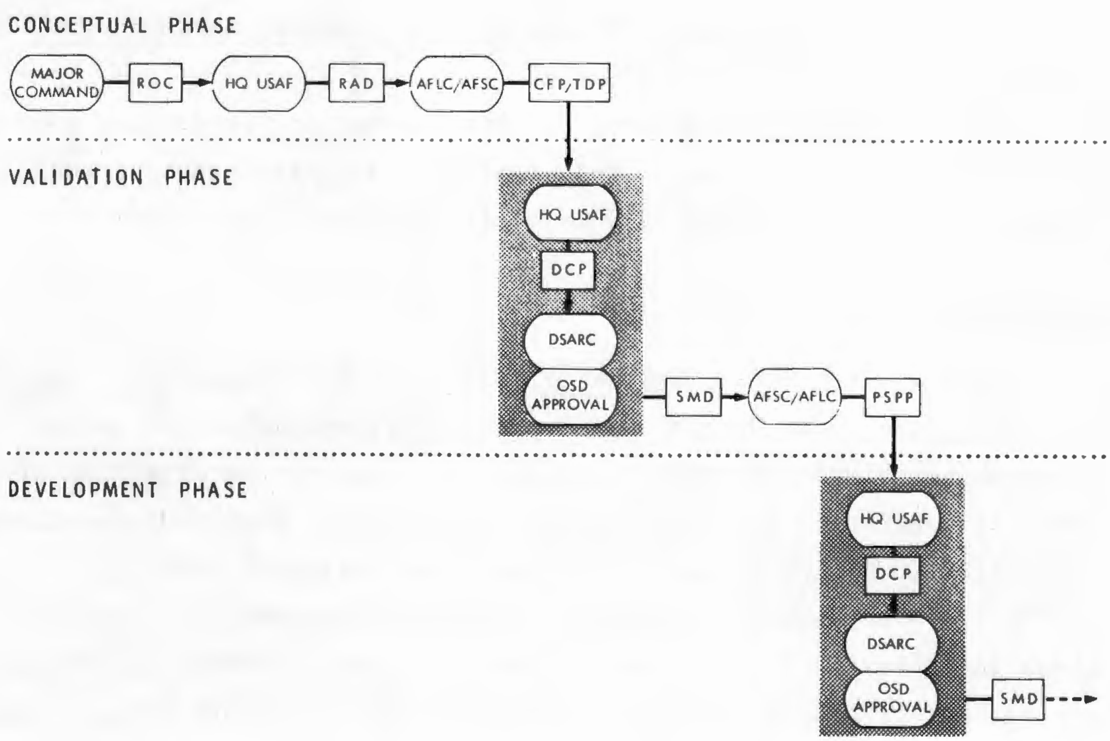

Fig. 5--Simplified document flow in early system development

Table 5

REQUIRED OPERATIONAL CAPABILITY

1. Deficiencies/Needs
2. Required Operational Capability
3. Determination of Deficiencies/Needs and Required Operational Capability
4. Solutions
5. Class V Modifications
6. Harmonization
7. Quantities Involved
8. Aircraft and Munitions/Stores Compatibility
9. Special Comments

   a. Maintainability
   b. Reliability
   c. Supportability
   d. Transportation
   e. Availability
   f. Survivability
   g. Vulnerability
   h. Crew comfort
   i. Crew safety
   j. System safety
   k. Supporting equipment
   l. Communications security
   m. Operational testing and evaluation
   n. Facilities
   o. Physical security
   p. Initial operational capability date
   q. New concepts of operations, deployment, logistics, etc.

The Directorate of Operational Requirements and Development Plans within Hq USAF DCS/Research is the action office for all ROCs. It receives, staffs, and establishes a coordinated Air Staff position on ROCs. It also formulates, staffs, and issues Required Action Directives (RADs) describing the desired operational capabilities and directs the preparation and submission of an appropriate document. Such RADs may direct mission studies, technology studies, concept studies, or concept formulation studies. All may involve tradeoffs.* Our primary interest here is on concept formulation studies, which result in a Concept Formulation Package/Technical Development Plan (CFP/TDP).

AFSC and AFLC are the action agencies for most conceptual study RADs. The CFP/TDP they prepare must include all practical alternatives, plus the expected approach, system characteristics and preliminary design, rationale, utility, logistics concept, and schedule and cost

*AFR 57-1, Policies, Responsibilities, and Procedures for Obtaining New and Improved Operational Capabilities, 17 June 1966, Paragraph 15a(2).

estimates for the validation phase. Further, comprehensive system studies and analyses are to be conducted to determine tradeoffs for cost-effectiveness on life cycle costs, maintenance skills, maintenance facilities, maintenance equipment, spares, technical data, and system performance.* The CFP/TDP is staffed by Hq USAF and put into a format suitable for submission to the Office of the Secretary of Defense. A proposed Program Change Request (PCR) and Development Concept Paper (DCP) are also submitted. The DCP summarizes the development program to date and provides the information necessary for the Defense Systems Acquisition Review Council (DSARC) to decide whether or not to recommend proceeding to the next stage of development.

The conceptual phase generally accomplishes the following:

1. Determines that primarily engineering rather than technical effort is required for system development, and that the needed technology is sufficiently in hand.
2. Defines the mission and performance envelopes.
3. Selects the best technical approaches.
4. Makes a thorough tradeoff analysis.
5. Determines that the system's cost-effectiveness is favorable in relation to that of competing systems DOD-wide.
6. Develops credible and acceptable cost and schedule estimates.

A successful conceptual phase effort results in OSD approval to establish the validation phase. The Directorate of Development and Production then issues a System Management Directive (SMD) to AFSC. At this point, the Directorate of Development and Production becomes the office of primary responsibility (OPR) within Hq USAF. A System Program Office (SPO) is established within AFSC to direct the overall management of the system (AFR 375-2).

VALIDATION PHASE

OSD approval to start validation indicates probable development of

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*AFR 66-1, <u>Equipment Maintenance Policies, Objectives, and Responsibilities</u>, October 1970.

the system, provided no unexpected difficulties arise during validation. While not a firm decision to develop, it definitely suggests a strong intent to do so. Validation determines whether or not the conditional decision to proceed with full-scale development should be ratified. The ultimate goal of validation, where development is to be performed by a contractor, is achievable performance specifications, backed by a firm-fixed-price or fully structured incentive proposal.

Validation confirms the decision to develop when its subsidiary objectives, given below, have been achieved:

1. Provide a basis for a firm-fixed-price or fully structured incentive contract for full-scale development.
2. Establish firm and realistic performance specifications.
3. Precisely define interfaces and responsibilities.
4. Identify high risk areas.
5. Verify technical approaches.
6. Establish firm and realistic schedules and cost estimates for full-scale development (including production engineering, facilities, construction and production hardware that will be funded during development because of concurrency considerations).
7. Establish schedules and cost estimates for planning purposes for the total project (including production, operation and maintenance).

Validation consists of three phases. The first phase calls for contractor selection. Two or more contractors are generally selected to conduct a competition, financed by the Government. The competition includes concept, design approach, tradeoff solutions, management plans, schedules and similar factors, as well as overall cost.

A Request for Proposal soliciting a planning proposal for full-scale development and a firm proposal covering the contractor's effort during validation is sent to eligible contractors. A pre-proposal briefing is held by the System Program Office. Proposals are evaluated and sources recommended to the Source Selection Authority by a Source Selection Evaluation Board. Contracts for validation are negotiated and awarded to two or more contractors.

The second phase of validation consists of the preparation and submission by contractors of complete technical, management, and cost proposals for full-scale development. Under the parallel undocumented development concept, the final products would include delivery of hardware prototypes for Government evaluation. In the meantime, the SPO prepares work statements and works out preliminary effort on contracts for development.

AFSC/AFLC prepares the Proposed System Package Plan (PSPP), formatted as shown below.

PSPP

1. Program Summary
2. Schedules
3. Program Management
4. Intelligence Estimates
5. Operations
6. Acquisition
7. Civil Engineering
8. Logistics
9. Manpower and Organization
10. Personnel Training
11. Financial
12. Requirements
13. Authorizations
14. General Information
15. Security
16. Biomedical

The logistics content is included as Sec. 8, quoted below. A proposed Program Change Request is submitted along with the PSPP by AFSC to Hq USAF.

Section 8--Logistics*

AFLC develops this section, with inputs from, and concurrence of, all participating organizations. This section:

a. Provides a comprehensive description of the logistics concept and the approach whereby the logistics elements (as described in DOD ILS Planning Guide (4100.35-G) are to be integrated into the system/equipment planning, development, testing/demonstration, and operational processes.

b. Includes the logistics planning and programming for maintainability/reliability, maintenance, support and test equipment, supply support, transportability (AFR 80-18), transportation, packaging and handling, technical data and management data for all levels of logistics support. Cite financial, manpower, personnel and training, facilities, and other affected sections.

*AFR 375-4, Attachment 1.

c. Prepare an Integrated Logistics Support Plan (ILSP), previously known as Material Support Plan (MSP), consistent with this section to insure effective logistics support for the Operational Phase, including the part of the Operational Phase that overlaps the Acquisition Phase and the test programs (AFR 80-14).

ILS guidance is also included in Sec. 6 on Acquisition.

In the third phase of validation a Source Selection Evaluation Board assesses each proposal and recommends the winner. The Source Selection Authority, either Secretary of the Air Force or AFSC, reviews the evaluation and designates the winning contractor for development. The System Program Office then negotiates a firm-fixed-price or incentive contract. Upon receipt of DSARC and OSD approval, Hq USAF issues to AFSC a System Management Directive authorizing engineering development to proceed.

DEVELOPMENT AND PRODUCTION PHASES

During the development phase the SPO converts the PSPP to a System Package Plan (SPP), and the selected contractors start development work. The decision to produce a system will normally be made after development and testing have indicated that the design is feasible. In any case, full scale development begins only after a definitive contract has been negotiated. The majority of detail decisions involving operational/support tradeoffs occur as a system passes from design specification to hardware. SPO interactions in these decisions and their relationship to the servicewide system support base is discussed in later sections.

DECISIONMAKING AND DECISION POINTS

Headquarters USAF

Various offices within the DCS/Research and Development are involved in the system acquisition process. The responsible office changes from directorate to directorate as the system goes through the conceptual stage to the validation stage to the final acquisition and production process. Decisions are required at each transition point and they become more critical as system investment increases. The goals at each decision point differ, however, and the kind and extent of logistics analyses required vary widely.

USAF actions start with the receipt of a ROC. These come from many sources, and the treatment they receive depends upon the analysis developed within the Directorate of Operational Requirements and Development Plans. After the system requirement has been validated and funded, the staff management of the validation program becomes the responsibility of the Directorate of Development and Production. Staff management of the program after SPO activities have been initiated is exercised through a Program Element Monitor. He is used primarily for justifying resources for his program element. He may have a limited assisting staff, but the SPO performs the major analysis and evaluation work. All tradeoff studies and logistics interests are centered at that level. Hence, the Air Staff does not employ models to assist them in their contract definition and advocacy functions. Rather, it uses a management concept to insure staff coordination. ILS as a program has primary utility for the SPO function.

The final R&D staff agency involved in the acquisition process has staff responsibility for the weapon's production phase. This is the Directorate of Production and Programming. This office does not have operating and decision responsibilities since the SPO, the Office of the Secretary of the Air Force, and OSD have by this time become directly involved in the results of tradeoff and ILS decisions about the system.

The Air Staff agencies do make some of these evaluations implicitly but have not to date standardized on methods to examine the logistics tradeoffs and economic implications of design decisions. The main thrust of the task of the Directorate of Operational Requirements and Development Plans is the advocacy and evaluation function required as the Air Staff representative in the operational requirements process.

In fulfilling this role the main concern is with the validity of the operational requirement and the technical feasibility that both generates and results from the conceptual phase activities. The requirement for estimates of the costs of the research and development and investment programs has been augmented to include estimates of the life cycle costs of the proposed program. Such augmentation is a current DCP requirement, which is now being used to document new program proposals.

In summary, it appears that the primary responsibilities of the R&D Air Staff agencies consist of collecting, organizing and presenting to OSD and staff level review officers all relevant information on systems needed to satisfy Air Force operating deficiencies. This is an advocacy operation that uses the results of other organizations' studies and analyses, including the selected alternatives that have survived whatever tradeoffs have been examined. Decisions made at the Air Staff level are essentially staff decisions. They review the adequacy of the Air Force case and presentation, order restudy when necessary, and respond to the decisions of the DOD, the President, and the Congress. Staff action and evaluation decisions are required each time the system passes from one life cycle phase to the next.

Air Force Systems Command

AFSC has the primary responsibility for developing new weapon systems for the Air Force. It is thus the major action agency in this process, and participates from ROC conception to system acquisition. AFSC (DCS/Development) comments on ROCs submitted by other commands to USAF.

When a Required Action Directive is issued directing a conceptual study, AFSC (DCS/Plans) may appoint a System Program Director (SPD), and possibly a SPO cadre, depending on the program. This group, often with the help of contractors, develops the CFP/TDP. The CFP/TDP includes information primarily on system characteristics, preliminary design, rationale, utility, costs, and schedules. Tradeoffs are done primarily among performance parameters. Estimated support costs have not been given much consideration during this stage. When the project has been evaluated to meet the requirements of this phase, the CFP/TDP is then submitted to Hq USAF. Upon successful completion of the advocacy process and program funding, Hq USAF issues a System Management Directive. DCS/Systems then becomes the primary staff office within AFSC.

During validation the SPO prepares the Request for Proposal and supports the source selection process. Tradeoff studies are done by the contractors and reviewed by the SPO and the Source Selection Evaluation Board. The SPO does not make the source selection decision on major system acquisitions, but does manage the flow of information between the decisionmakers and the contracting community. Up to the present, there is little evidence that ILS/life cycle cost considerations have played a major role in the source selection process. Nor has there evolved a documented standard procedure indicating the methods employed to compute and evaluate life cycle costs in the source selection process.

In summary, the SPD/SPO has the primary responsibility for insuring that system support costs are considered. Through the validation phase, however, such costs are considered only cursorily. Only after an engineering development contract is let and detailed hardware development begun do any firm estimates of support costs become available.

Air Force Logistics Command

Under current and proposed procedures, AFLC has a considerable interest in and is an action activity throughout the life cycle of a (new) weapon. Since its *raison d'etre* is the logistic support of all Air Force equipment, it is in the information flow both as a coordinating and action agency from the publishing of a ROC through the disposal of the weapon at obsolescence.

First coordination actions within the conceptual phase are in the ROC reviews required under AFR 57-1.* In general, whenever the AFLC has an interest they do send comments on the ROC to AFRDQ, but they do not evaluate or provide logistics guidance to systems requirements at such a preliminary stage. However, ROCs at this stage in many instances include provisions in Sec. 8 that set the tone for many subsequent logistics requirements. AFLC does not make any rigorous studies or tradeoff analysis on these requirements since neither the

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*Section D.14, a-d.

dollars nor sufficient analytical skills are available to study systems that might not be adopted or procured for service use. If the ROC is converted to a RAD and subsequently enters the validation stage, the logistics analysis afforded must be thorough and adequate. During the ROC coordination process then, the logistics evaluations are cursory and pro forma--generally without detailed backups.

After a RAD has been sent to the AFSC Development Plans division, AFLC becomes an element of the CFP/TPD process. Current regulations such as AFR 375-1, AFR 375-3, AFR 375-4, AFR 375-12, and AFLCR 400-10 prescribe the scope of the evaluation process and the extent of AFLC participation. The AFLC component of the SPD office does not usually conduct tradeoffs. Such studies are generally part of the technical development contracts purchased from industry and, in most past cases, the lack of funding of this portion of the study contract limited the logistics analysis severely or omitted it entirely. The main focus of the studies is to obtain information on processes and materials that will be required from a validation phase contractor and to indicate skills and facilities that may depart from traditional support methods. Whatever logistics content there is to the CFP/TDP package is limited to ad hoc efforts of the concerned center's Development Plans Office and the level of participation provided by the AFLC representative at the center. Life cycle cost estimates which should reflect the results of the tradeoff activities have in the past been limited to estimates in a cost estimating formula, approved by the ASD(C) developed by Hq ASD, which essentially fixes a percentage factor to the end system cost as the logistics investment.

The use of optimizing or simulation models to make tradeoffs has not been widespread during this stage of system development either by the Air Force or the contractors. However, some development centers do make parametric studies on certain design/operational options that must be considered. It is logical to assume that the next steps (required in proposed MIL STD-499), namely the transition to logistics and cost tradeoffs, could be included at this stage.

AFLC participation continues on a more formal basis when the system enters the validation phase. The SPO does have AFLC representation from the assigned support AMA when it is established. The responsibilities for tradeoff analysis are set forth in AFR 375-4, paragraph 4c. In addition to tradeoffs, other logistics responsibilities in all functional areas have been identified and are assigned to specific agencies both within the AFLC and the AFSC.

During the validation phase, the AFLC participates in the development of the Request for Proposals containing the requirement for ILS considerations, the evaluation of the contractors' report, and the further refinement of logistics concepts and maintenance postures. The logistics evaluations are made using a variety of analyses specific to the systems being studied. No specific models are employed, but the tradeoffs required by proposed MIL STD-499 are accomplished by analysis of parametric comparisons, employment and evaluation of contractor designed models, and comparison with standards or similar systems previously utilized. Most tradeoffs are concerned with technical alternatives versus performance. Some cost targets are set on various performances and support objectives, but these are primarily for the purpose of developing contract incentive provisions and do not really examine the relationship of the support alternatives that might be employed.

In summary, current and proposed regulations and manuals specify in great detail the kinds of studies and the types of responsibilities for the AFLC base to insure that ILS and other logistics matters be considered in the conceptual and validation phases of a weapon system program. Only one manual presently provides a procedure describing how some of these tradeoffs might be done (AFLCM 375-6). No explicit method has yet been developed to permit AFLC to participate in the early design process. Their role continues to be reactive rather than participatory.

THE CURRENT PROCESS IN SUMMARY

Most tradeoffs that include logistics considerations are decisions in detail, involving the relationship of design parameters to support resources or postures. As the system becomes more clearly defined, more tradeoffs can be evaluated until finally actual hardware has been produced, can be tested, and can be fitted into the support posture.

However, decisions about the design--its reliability, its accessibility, its test configuration, its power requirements, its packaging, etc.--all have logistics impacts. It is only when the logistician can influence these that he can have some control over his resource requirements and ultimately his ability to perform his support responsibility in an efficient and timely manner.

From the above discussions of the decision points and the decision processes, it appears that early in the life cycle most broad decisions are made by organizations removed from detail information. In the conceptual phase ILS tradeoffs and information may be part of the package forwarded for advocacy by the Air Staff. During validation ILS products may be considered separately by the Source Selection Evaluation Board and by the SPO, with more or less emphasis on their impact on the decision, depending on the Source Selection Authority's view of their importance in relation to all other decision variables. Thus, while ILS may be explicitly considered, it can never be considered outside the context of all the other attributes of the weapon itself. An ILS decision, therefore, requires that the logistics impacts of all other decisions be weighed and systematically evaluated. If the logistician can accomplish this in the early life cycle phases--and finally assure explicit consideration in all subsequent phases of the life cycle--he has successfully accomplished his objective.

Appendix D

THE PROBLEM OF DATA UNCERTAINTY

The models discussed in this Report inherently use point estimates of system parameters and compute point estimates of system support costs; i.e., they behave as though the world can be precisely described with certainty. Particularly in the early stages of conceptual design and often even in detailed design, however, there are significant uncertainties about the values of such parameters as system deployment, item reliability, and item repair cost. The attempt to provide cost estimates of future logistics demands involves essentially two changing variables: human decisions and physical attributes of the system itself. In such a complex situation, lack of perfect foresight inhibits the capability to identify system design alternatives accurately and, consequently, cost estimates are likely to be cast in a framework of uncertainty.

Misallocations or over-spending of budget allowances result from erroneous forecasts of logistics supply and demand requirements and the subsequent inefficient resource distribution. Unfortunately, these losses are seldom assessed or even explicitly examined in view of the uncertainties inherent in system design. Several approaches to handle random elements in modelling are: hedging, expectation, risk allowance, sensitivity analysis, frequency distribution.

HEDGING

One of the most traditional approaches toward uncertainty is simply to be conservative by hedging predictions of system development and production expenditures. Given a set of possible values of random elements, the largest member is selected and inserted as an argument in the model. Although the prediction resulting from this choice is a least upper bound and hence eliminates the embarrassment of cost overruns, it has several disadvantages. First, high or exorbitant cost estimates strain the budget or source of funds and, as a result, may reduce funding earmarked for other important projects. Second, the evaluation of an upper bound on the range of the random variable may be difficult, if not impossible, to quantify.

EXPECTATION

The most frequent criterion for choosing among uncertain outcomes is the use of the expectation or mean on the basis that the decisionmaker is indifferent between the mean quantity and a weighted sum of several values of the random element. This measure is commonly applied since it requires only a single point estimate of a parameter, and most users understand its determination. But the expectation does not consider the degree of uncertainty that may affect the final decision.

RISK ALLOWANCE

In acknowledging the presence of variability in a random distribution, the decisionmaker sometimes allows for risk in his actions. He can adjust the expected value by adding a risk allowance or "buffer" amount if he is risk-averse and wants to "play it safe" by overestimating the actual value. In the simplest formulation, this allowance is dependent upon the variance of the frequency distribution. If the decisionmaker is particularly risk-averse, he may increase the size of the buffer by more than a linear proportion as the variability of the parameter increases.

SENSITIVITY ANALYSES

Another common way of treating uncertainty is the parametric study or sensitivity analysis. One factor (e.g., reliability) is varied over some range of possible values, and a set of support costs (for example) is computed. It is thus possible to determine the effect that change in that parameter has on support costs, or how sensitive costs are to the uncertainty about the reliability (for example).

Parametric studies are fine when the user is uncertain about just one or possibly two variables, or if their effects upon support costs are completely separable. When the user is uncertain about the magnitudes of a number of interactive variables though, it becomes difficult to get an estimate of the possible range of support costs by using parametric analysis.

FREQUENCY DISTRIBUTION

There is a technique which is applicable in this situation, however, and which the Services have used upon occasion. It consists of quantifying the uncertainty to the point where information is presented and transmitted in the form of "prior densities" or "priors" that are simply lists of possible outcomes, together with their relative likelihoods as assessed by a decisionmaker.

For example, if a decisionmaker were asked about the chances for Army to win the next Army/AF game he might say

	Probability
Army win	0.6
Army lose	0.3
Tie	0.1

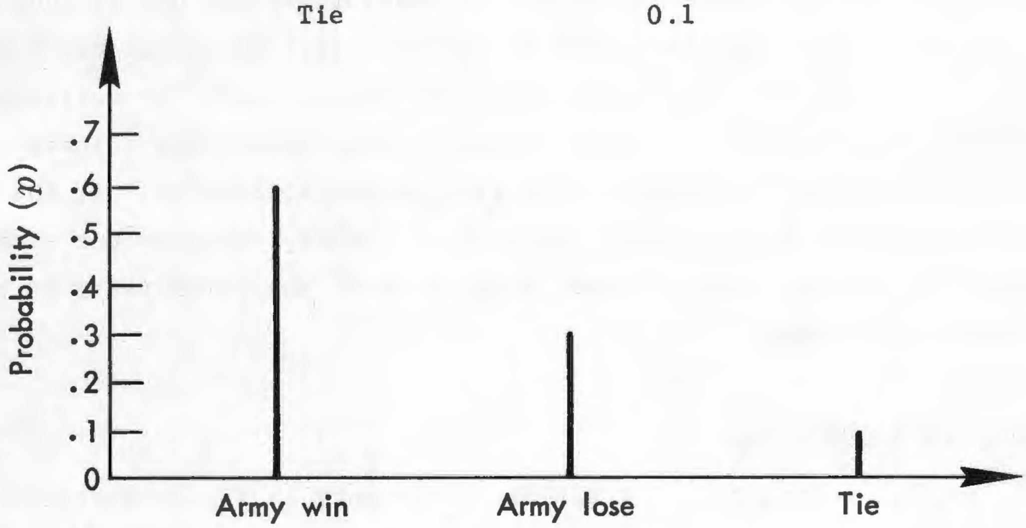

Fig. 6

If he were asked how many touchdowns Army would make, he might answer:

Touchdowns	Probability
0	0.2
1	0.2
2	0.3
3	0.1
4	0.1
5	0.1

He is simply quantifying his uncertainty concerning an uncertain value. These priors can be represented graphically as follows:

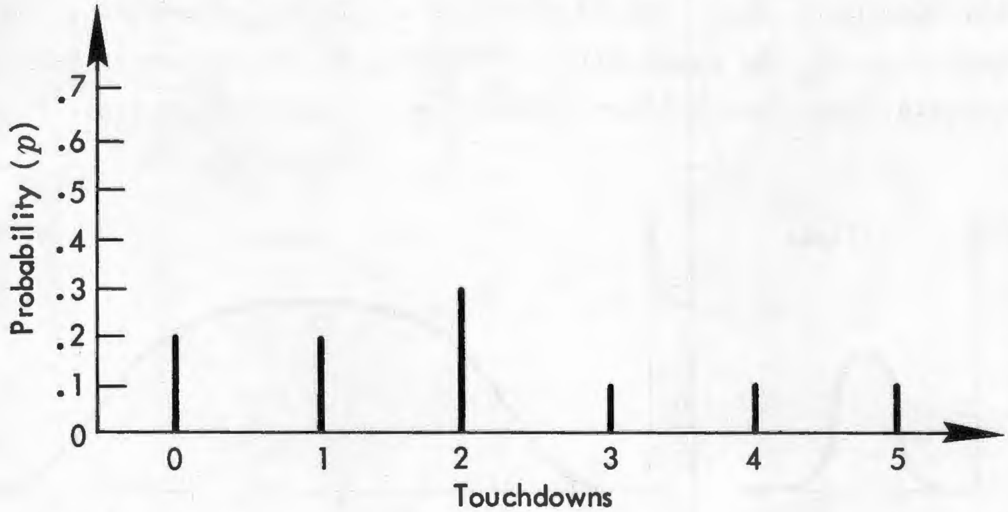

Fig. 7

A decisionmaker operating in an uncertain environment would try to quantify his uncertainty by specifying a prior. For example, someone using this approach would not say "we have never seen a set of beryllium brakes and I have no idea what their failure rate would be," but rather "the failure rate is somewhere between 1 and 20/month, but I do not know where." He would translate his feelings into a probability statement such as, the failure rate is equally likely to be any value from 1 to 20. In graphical form, his "prior" for the failure rate would be that shown in Fig. 8.

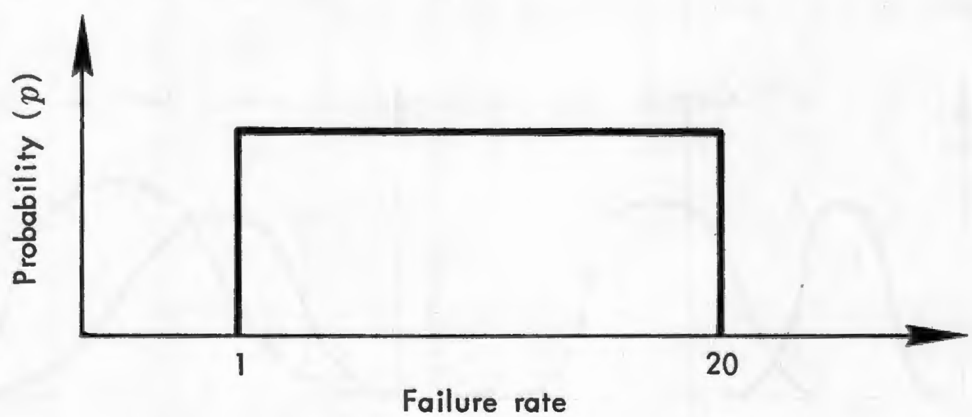

Fig. 8

We recommend that any LCC(L) model utilize priors rather than point estimates for logistics and item parameter values such as failure rate, item cost, depot repair costs, etc. If the parameter value is fairly certain, the prior will be "tight"; if the parameter value is uncertain, the prior will be "loose," as illustrated in Figs. 9a and 9b.

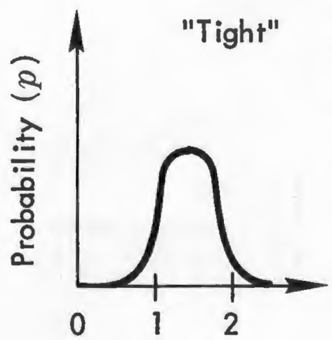

Fig. 9a

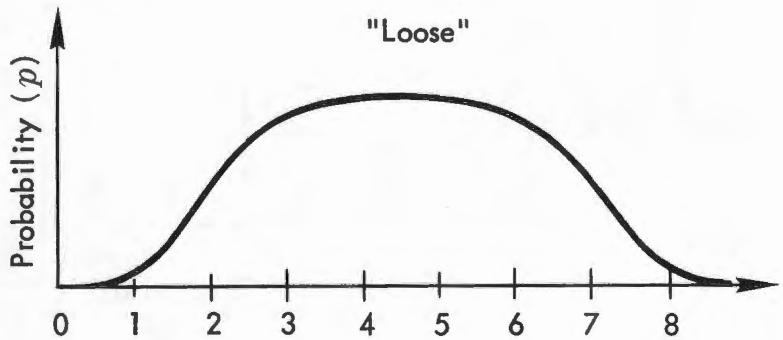

Fig. 9b

Once the designer specifies priors for the parameters, the model will produce a "prior" for the LCC(L) estimate in the form shown in Figs. 10a and 10b. The designer will then compare the two priors for LCC(L) and decide which item to build. If the priors overlap, the designer will know that he does not have enough information to make a decision. For example, in case I the designer would choose item design A, while in case II he will not be able to choose on the basis of LCC(L). He would then request further study or prototyping or decide on the basis of non-economic criteria.

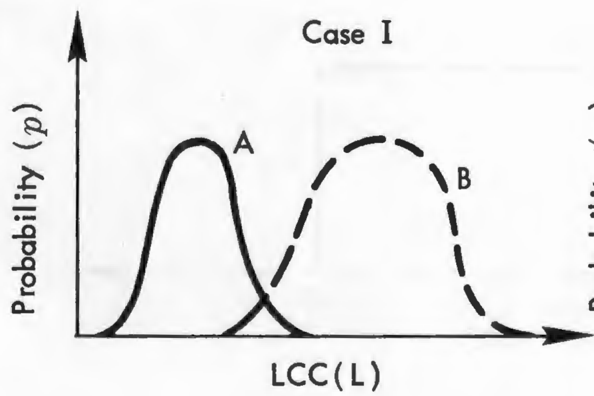

Fig. 10a

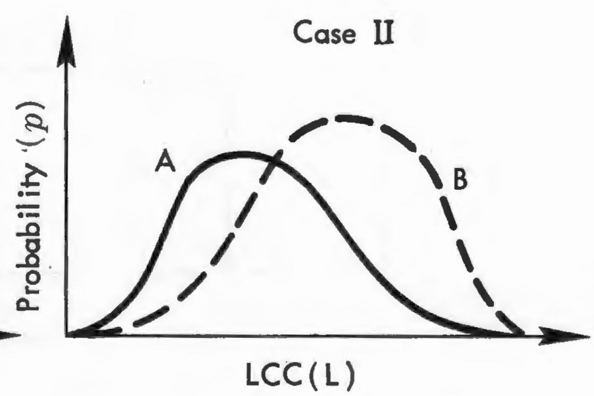

Fig. 10b

There are four advantages to this method of handling uncertainty:

1. The use of priors permits the use of the same decision procedures at any time during design.
2. The designer can tell when he does not have enough information to choose between different item designs on the basis of LCC(L).
3. The Air Force will be aware of uncertainties inherent in early prediction exercises.
4. The method lends itself to the uncertainties that exist in the item parameters, flying program, basing concept, etc.

It is also possible to use a simulation model and random sampling to obtain a distribution for LCC(L). It is easy to incorporate distributions for unknown system parameters (e.g., cost/item, NRTS failure rate) directly into the simulation, thereby only requiring one run of the simulation each time during design when it was necessary to evaluate LCC(L) of the total system as it was then specified. As the design progressed, the distributions estimated by design engineers would decrease in variance and LCC(L) would become tighter about its mean. It is possible for designers to input uniform distributions as a range estimate for system parameter values. This would not be much more difficult than arriving at point estimates of the values, and they could be input directly into the simulation.

The approach has been implemented in a SCAM-based model called QUEST.* The application to CER methodology is reported in Estimating Cost Uncertainty Using Monte Carlo Techniques, RM-4854-PR, January 1966.

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*L. H. Zacks, Quantification of Uncertainty in Estimating Support Tradeoffs, The Rand Corporation (to be published).

Appendix E

ANALYSIS OF ENGINE AIRCRAFT MAINTENANCE POLICIES

This is an example, from a current acquisition program, of how logistics considerations might influence design. It demonstrates the use of an analytic model to determine which of two engine design concepts has the lower life cycle costs. It is an example of differential analysis, since all factors which contribute the same amount of cost in both cases are assigned zero value. This example also demonstrates break-even analysis, and in addition evaluates Air Force against optimal stockage policies. The use of computerized models significantly decreased the time required for this analysis. Had the model capability resided within the SPO, they could have had the analysis within a day.

ENGINE MAINTENANCE PLAN

Problem

Determine the economic feasibility of implementing a modular repair concept for a turbo fan engine in a fighter aircraft application.

Hypothesis

A reduction in engine life cycle costs could be achieved without compromising system effectiveness by eliminating maximum operating time between overhaul (TBO) on complete engines and substituting an "on condition" maintenance concept using module repair/replacement procedures. Engines will be constructed to facilitate module removal without complete engine disassembly. Modules may be repaired or replaced as complete functional units as required by their mechanical condition. Defective modules may be repaired to the maximum extent feasible at the intermediate maintenance level. Due to complete or catastrophic failures, the use of spare modules will not eliminate procurement, shipment and repair of complete engines but should reduce the quantity of spare engines required because of reduced turnaround time at intermediate repair. In addition, the repair of specific modules at both intermediate and depot level will reduce the number of complete engines that would be returned to depot for repair if spare modules were not available.

Complete Engine and Module Data

Data pertaining to logistics support of complete engines and modules are shown on Tables 6 and 7. With the exception of the intermediate level test stand, AGE requirements for organizational and intermediate maintenance are essentially the same, and repair parts requirements for organizational and intermediate maintenance are essentially the same except for the increased costs of adding spare modules. Manning skill levels and tech data also remain essentially the same.

Program Concept

To study this problem, it is desired to show the comparative costs to support one operational wing at an overseas base and one wing at a CONUS base for 30 days. The CONUS wing has three operational squadrons of 24 aircraft and one training squadron of 18 aircraft; the overseas wing will have three squadrons of 24 aircraft each. Each aircraft has two installed engines and will fly 45 hours per month. This yields 8100 engine flying hours per month CONUS, and 6480 overseas. Other pertinent numbers are:

Base repair cost	$9 per manhour
Depot repair cost	$15 per manhour
Shipping cost, CONUS	$0.14 per pound
Shipping cost, overseas	$0.285 per pound

ANALYSIS AND RESULTS

This problem was analyzed using SCAM. The results were also checked with Rand's version of AFLC's ABLE, and QUEST. All models led to the same decision. One run was made for concept A, consisting of the engine only; another for concept B, consisting of the engine and its modules. A NRTS rate of 0.18 was established for engines analyzed under concept B. This indicates that in a number of cases it will be possible to

Table 6

COMPARISON OF MAINTENANCE CONCEPTS

Item	Concept A[a]	Concept B (Modular Concept)[b]
Demand rate/1000 hrs		
Engines	5.4017	5.4017
Modules	--	(c)
Base repair cycle		
Engines	15.0	7.5
Modules	--	7.5
Base repair manhours		
Engines	81.3	37.2
Modules	--	(c)
NRTS rate		
Engines	0.302	0.18
Modules	--	(c)
Depot repair cycle (CONUS/overseas)	31/34	31/34
Depot repair manhours		
Engines	1800	1800
Modules	--	(c)
Hours between overhauls		
Engines	1800	--
Modules	--	(c)
No difference items		
Catastrophic failures		
Tech data		
Repair parts cost		
AGE		

[a]Engine fails, is removed from aircraft, is repaired or NRTSed.

[b]Engine fails, is removed from aircraft; module (if available) is replaced. Module is then repaired or NRTSed.

[c]See Table 7.

Table 7

MAINTENANCE DATA FOR CONCEPT B

Item	Engine	Fan	Core	Turbine	Augmentor	Gearbox
Price ($)	737,000	88,500	296,000	68,600	109,100	13,280
Demand rate/1000 hrs	5.4017	0.75233	1.83788	0.57374	1.65381	0.58400
Base repair manhours	37.2	28.2	81.3	43.2	36.2	2.5
NRTS rate	0.18	0.286	0.3	0.6	0.15	0.5
Depot repair manhours	1800	150	700	45	225	75
Hours between overhauls	--	3700	1800	1800	1800	3700
Shipping weight	5330	1085	1700	1215	2110	690
Shipping cost (F)	1519	309	485	346	601	197

remove a module instead of declaring an engine NRTS. The base-depot repair and transportation costs for random failures for the two concepts were then compared.

In addition, it is necessary to consider the depot repair and transportation costs for overhauls occurring because engines or modules attain their maximum flying hours. At a maximum, this will be 97 engine overhauls per year (174,960 flying hours per year divided by 1800 hours between overhauls) in steady state, or 47 overhauls per year for those modules having a TBO of 3700 hours. At a minimum, 93 percent of the engines would be overhauled (due to failures requiring depot-level maintenance) before they hit the 1800-hour mark. This would significantly decrease this aspect of cost difference between the two concepts. We will adopt this last assumption, and set the overhaul cost difference between the two concepts at $70,000 per year.

Initial stocks were computed by the technique prescribed in AFM 400-1, Selective Management of Propulsion Units. The results are shown in Table 8. The stock levels computed by the AFM 400-1 procedure are significantly greater (about double) than the levels computed

Table 8

STOCK LEVELS

Parameter	Engine A	Engine B	Fan	Core	Turbine	Augmentor	Gearbox	B-Total
ARBUT[a]	18	18	15	14	11	12	11	
Depot repair[b]	32.33	32.33	32.33	32.33	32.33	32.33	32.33	
Base repair	15	7.5	7.5	7.5	7.5	7.5	7.5	
Depot stock	15	15	15	15	15	15	15	
MTBF	185	185	1330	543	1745	604	1710	
TBO	∞	3700	1800	1800	1800	1800	3700	
NRTS	0.30	0.18	0.286	0.30	0.60	0.15	0.50	
Stock level	117	59	21	46	30	34	21	
Cost ($ million)	86.23	43.48	1.86	13.62	2.06	3.71	0.28	65.01

[a]Automatic Resupply and Build-up Time.

[b]31 CONUS, 34 overseas.

by SCAM at a backorder rate of .03 (backorders roughly approximate the NORS condition.) This would indicate that the AFM 400-1 procedure may lead to a higher stock level than necessary for operational effectiveness.*

The cost comparison for the two concepts is shown in Table 9. Note that the large annual saving is in depot repair costs, with base repair actually increasing somewhat. The total annual cost saving of the modular concept, including repair, transportation, and the $70,000 overhaul saving discussed previously, amounts to $1.8 million. In addition, there is a first-year cost saving in initial spares of $21.2 million.

Table 9

COST COMPARISON FOR MAINTENANCE CONCEPTS
(In $ Thousand)

Item	Engine A	Engine B	Fan	Case	Turbine	Augmentor	Gearbox	B-Total
Initial spares	86,229	43,483	1859	13,616	2058	3709	279	65,010
Annual repair								
Base	482.67	316.41	23.85	164.70	15.60	80.10	1.14	601.80
Depot	7706.19	4593.09	84.69	1012.80	40.65	146.40	57.48	5935.11
Total	8188.86	4909.50	108.54	1177.50	56.25	226.50	58.62	6536.91
Annual transportation	622.02	370.74	16.71	67.05	29.91	37.44	14.43	536.28

It might be possible to develop and build the engine more cheaply under the whole engine concept than under the modular concept. Assume that this is true, and that it could be built for 10 percent less.

Concept A:

Total number engines procured (incl. spares) 441

Cost per engine .... $ 663,000

Total procurement cost $292,383,000

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*For further discussion of this problem, see G. S. Fishman, Spare Engine Requirements for the F-5A/B Military Assistance Program, The Rand Corporation, RM-3790-PR, October 1963; and G. S. Fishman, Military and Economic Consequences of Alternative Spare Engine Policies, The Rand Corporation, RM-4475-PR, March 1965.

Concept B:

Total number engines procured (excl. spares)	324
Cost per engine	$ 737,000
Engine procurement cost	238,788,000
Cost of spares (Table 9)	65,010,000
Total procurement cost	$303,798,000

Under concept B the initial procurement cost would be over $11 million greater. This would be offset by the $1.8 million annual saving in repair and transportation over a life cycle of about ten years. Therefore, we can conclude that if the cost saving for a complete engine is more than 10 percent of the cost of the modular engine, the complete engine concept will become the more economically attractive one.

CONCLUSIONS

1. The modular engine repair concept is economically attractive.
2. The complete engine repair concept may become more economically attractive if the cost of complete engines is reduced by a factor of 10 percent or more over the cost of modular engines.
3. Stock levels computed under AFM 400-1 criteria are higher than necessary, based on the acceptability of a 3-percent backorder rate, or possibly less, for modules.

Appendix F

CATALOGS OF MODELS

The Catalog of War Gaming Models, 4th edition, JWGA-200-69, June 1969, published by the Joint War Games Agency of the Joint Chiefs of Staff, includes descriptions of over fifty models oriented to analysis of strategic and tactical logistics requirements. Applications include airlift, combat service support, communications, force planning, logistics support requirements, medical, sea lift, and transportation. These are generally fleet/force operations and support planning models, and would probably not be useful at the system design level. They might have utility, however, in establishing some overall requirements for system and support parameters.

General Dynamics, Ft. Worth, has a very good report for the Navy on Level of Repair Decision Rules, FZM-12-10586, 27 March 1969. It includes 18 studies or models addressing the repair-level decision.

A Survey of Army Automated Cost Models, Office of the Comptroller of the Army, Winter 1968, AD 829321L, briefly describes 27 cost studies and models for the Army. These are mainly of the cost estimating relationship type, and the comments about the Joint War Games Models apply here also.

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