4

Analysis of Models Linking Skilled Maintenance Manpower to Military Capability

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This report presents the results of research designed to improve the ability of the Department of Defense to relate manpower resources to defense capabilities. It provides an analysis of the four large Monte Carlo simulation models: LCOM, SPECTRUM, ALOM, and TSAR; it also describes the similar structure of maintenance-manpower/sortie-generation models. The report also discusses several ground-force models, although their role in detailed manpower planning is not quite so directly applicable.

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PREFACE

This report evaluates the actual and potential use of the principal maintenance-manpower/military-capabilities models for deriving military manpower requirements from a specified level of military capability. While models may someday link all of the different types of military manpower to an accurate measure of military capability, the comprehensive models that have been developed are being used to link maintenance manpower to the sorties that can be generated. Recommendations for improvements in these models and suggestions for more extensive use are provided in this study. Some comments on the current use of ground-force models are also provided.

This research was sponsored by the Assistant Secretary of Defense (Force Management and Personnel). It was conducted by the Defense Manpower Research Center, part of The RAND Corporation's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense.

SUMMARY

The objective of this research is to improve the ability of the Department of Defense (DoD) to relate manpower resources to defense capabilities. Because manpower provides a vital contribution to military capability, models that link it to a measure of the capability to apply force in combat could play an extremely important role during the manpower requirements process. In practice, however, the principal empirical models that have been used during this process link maintenance manpower to the aircraft sorties that can be generated during a specified combat scenario. This report provides an analysis of the four large Monte-Carlo simulation models: LCOM, SPECTRUM, ALOM, and TSAR. The first three models are being used by the Air Force, Navy, and Army, respectively, to analyze manpower requirements. TSAR is being used by The RAND Corporation and several other organizations to analyze certain manpower issues. Several ground-force models are also discussed, although their role in detailed manpower planning is not quite so directly applicable.

The study describes the similar structure of maintenance-manpower/sortie-generation models. These models can derive a level and composition of maintenance manpower demands from a specified number of aircraft sorties required to be flown. If there is an excess demand for certain types of manpower skills, the models can adjust the military activity level so that it can be supported with the available manpower resources. This latter capability permits the models to evaluate the effect on military capability of a change in manpower from requirements to authorizations.

The models can also be used to optimize maintenance manpower. For example, they can be used to determine the maximum number of sorties that can be flown with a given number of maintenance personnel. This optimization capability is particularly interesting from a policy standpoint for it enables these models to be used to evaluate such issues as the composition of maintenance skills, the amount of Cross Utilization Training (CUT), and the minimum manning requirements. In fact, our analysis suggests that changes in these variables can have a significant effect on the sorties that can be generated holding the total number of maintenance personnel constant.

To fully analyze changes in these variables, resource cost estimates need to be used more systematically. In this way, the models could help assess whether a certain skill composition, amount of CUT, or minimum manning requirement is cost effective.

Several areas are noted where the models might be used more effectively. One area has to do with the issue of doctrine versus practice. Because the models are used to specify manpower requirements, the mandated set of personnel skills is frequently used as the basis for analysis. This approach is taken because military doctrine must often be carefully specified in the area of aircraft maintenance. Nevertheless, we feel that both the actual skills possessed and maintenance practices should be more extensively used in the analysis of the readiness and sustainability of specific units. As well as enhancing one's understanding of current capability, such analysis would also aid in the determination of doctrine.

The trade-offs between manpower and other resources such as spare parts also need to be considered more carefully. In some applications, other resources are unconstrained, and this may lead to somewhat exaggerated changes in manpower when certain policy variables are changed. In other applications being conducted during the manpower requirements process, restrictions are imposed on the permissible changes in non-manpower resources. There may also be inconsistencies between the assumptions made by manpower analysts and those made by individuals responsible for analyzing other resources.

The uncertainty associated with combat needs to be addressed more extensively. Part failures and repair times are assumed to be random in typical applications. However, the mean failure rate and mean repair time are usually assumed to be known perfectly. Accounting for the real uncertainties in these inputs could greatly increase the variance in the calculated sorties and decrease the mean expected sorties. More flexible maintenance resources would respond better to such uncertainties. Additional uncertainty resulting from battle damage and air base attack should be incorporated into the analyses to ascertain whether these types of factors also indicate the need for more flexible maintenance resources.

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CONTENTS

FIGURES

TABLE

I. INTRODUCTION

BACKGROUND

The capability to exert military force in potential combat situations is the basis of conventional military defense and deterrence, and such capability flows both from military manpower and the equipment possessed by a defense establishment. In this report, we examine some aspects of the ability of the Department of Defense (DoD) to relate manpower resources to defense capability.

The relationship of combat personnel and weapons to military capability is direct and generally quantified through combat models. The critical factors in this area are the relative effectiveness of different weapons systems in a given situation, attrition and ground movement as a function of the force levels, and the composition of military equipment. Therefore, the key issues are related to combat modeling and the relative effectiveness of different weapons systems rather than to manpower issues for combat personnel.

Modern conventional military capability also depends heavily on maintenance activities. Although one must account for uncertainty about precise parametric quantities, the causal mechanism of this dependence can be approximately quantified. Weapons systems fail randomly, but regularly, and they can be returned to combat status by appropriate maintenance personnel equipped with the correct tools, test equipment, and spare parts, performing a specified series of tasks.

For categories of military manpower other than combat and maintenance, little detailed modeling has been done. When accounted for, the contributions of these categories are generally estimated based on "rules of thumb" or subjectively estimated relationships and the like. The problem of medical personnel—"maintaining" human beings—is in principle quite similar to the problem of maintenance personnel—maintaining weapons systems. While those involved in maintenance manpower modeling believe their modeling techniques could be applied effectively to medical personnel, too little modeling has been done in this area for us to cover it here. For other categories of military personnel such as management or communications, the causal mechanism of the relationship of manpower to military capability cannot be easily quantified. Thus these categories are not readily amenable to a quantitative modeling approach. Therefore, we concentrate on models that link maintenance manpower to military capability.

Careful analysis of maintenance manpower demand is particularly relevant during periods of rapid improvements in the area of weapons technology. Paralleling these improvements is a demand for specialized maintenance personnel who operate in a type of "alert status." Individuals need to be available if a particular critical but infrequent failure occurs, and this results in the fairly low utilization rate of maintenance manpower.

The utilization rate can be affected by changes in the composition of skills, including those changes obtained through additional Cross Utilization Training (CUT), and also by adjustments to the minimum manning requirements. Changes in other resources can also affect the manpower utilization rate. For example, spares or test equipment may constrain manpower utilization.

The relationship between maintenance personnel and overall military capability is far too complex, however, to be reduced to simple arithmetic. Rather, a manpower model is needed to account for the random nature of specific failures, the multiplicity of skills needed for the various tasks, the dependence on other scarce resources, and the scheduling of tasks in this complex environment.

OUTLINE OF STUDY

In this report, we concentrate primarily on models that focus on the manpower component and develop it in some detail. We list and discuss the major models that are being used, while touching on some other models developed for narrower purposes or with less emphasis on manpower. These additional models were chosen to allow us to broaden the coverage of our analysis, since the models with the most satisfactory manpower components relate maintenance manpower to aircraft sorties. We describe how these models are being used in practice and their important characteristics. We also discuss their theoretical and practical limitations. Qualitative statements are made regarding the amount of effort that either has been or might be directed toward developing and revising such models.

Section II begins with some methodological factors that need to be considered when constructing a maintenance-manpower/military-capabilities model. This is followed by a discussion of some aspects of the demand and supply of maintenance manpower within the resource allocation process.

In Sec. III, we discuss the major models that are currently in use, including the Air Force's LCOM, Navy's SPECTRUM, Army's ALOM, and The RAND Corporation's TSAR. Each relates maintenance manpower to aircraft sorties. We address why this type of model predominates and discuss a second type of model that links maintenance personnel to ground-force capability. These include the Army's PROLOGUE, FORCEM, and VIC models and RAND's AURA model.

The report investigates the nature and limitations of current models and how they are used in the manpower requirements process. However, we are also concerned with whether these models could be used for analyses of broader policy questions. Section IV addresses these issues and provides some recommendations for future use of the models. Our conclusions take into consideration both current versions of available models and feasible model enhancements for the investigation of these policy questions.

II. MILITARY MODELS AND RESOURCE ALLOCATION

METHODOLOGY

In the abstract, a quantitative model of a relationship incorporates (1) its mathematical description and (2) an algorithm to solve for one set of quantities that are determined, by the relationship, from any other set of input quantities. However, in the real world such ideal models are feasible only for relationships far simpler than those between maintenance manpower and military capability.

For complex relationships, the structure of a feasible model may include great precision and detail in some areas and less detail and simpler assumptions in others. The feasible levels of detail in different areas limit what questions may be usefully addressed. Not only are computer programs to implement such models by nature expensive and time consuming to write, debug, and maintain, but the questions they are used to address change over time, somewhat unpredictably. Therefore, models must be developed that are flexible and that can address a wide range of questions.

As models become more flexible, however, they depend more on lengthy detailed data input to define the modeled relationships and less on the assumptions embodied in the model. Ultimately, the computer model itself becomes more of a modeling tool or a framework than a true model. Then almost any relationship may be modeled, *given the right input data and enough computer time.* The most detailed computer models of the relationship between maintenance manpower and military capability fall into this category.

Most questions posed to such flexible models are originally formulated as a simple English sentence. An example relevant to this project would be: "What is the minimum number, and distribution of skills, of maintenance personnel necessary to sustain, during wartime, three sorties per day from a squadron of F-16s?" To answer such a question using a flexible computer model of maintenance manpower, one would have to specify a large number of related data inputs. These inputs would include the skills and combinations of skills that are allowed to be considered, any constraints on the manning levels (such as the minimum manning levels), and the levels of spare parts and equipment available.

Furthermore, even the description of the structure of F-16 maintenance would be input as data. This would include the number and type of personnel needed for each task, the time needed to perform each task, and much more. This combination of computer model and related data can be considered *a model* of the maintenance of an F-16 squadron. In fact, it is frequently convenient to consider this combination of a computer model and such defining data as a model. Without the related data, the computer model is only a framework on which a model may be built.

When flexible computer models are used to address manpower questions, the specific model used to address a given question is determined more by the "data" inputs than by the computer model per se. Because most of the information behind these critical defining data inputs is known only imprecisely, model builders must use judgment to select their data inputs. Where to simplify and to what extent must be decided as well. As a consequence, the final model and the resultant answers depend primarily on the purposes, capabilities, and biases of the model users. These, in turn, are determined largely by the institutional structure in which these models are operated and the associated institutional incentives. This dependence is a key aspect of our discussion of the possible use of these models to address broader policy questions.[1]

MAINTENANCE-MANPOWER DEMAND AND SUPPLY

Before proceeding to a detailed discussion of maintenance-manpower/military-capabilities models, it may be helpful to present a simplified view of the demand and supply of maintenance manpower. Figure 1 portrays the manpower determination process. Each arrow represents an information flow mediated by policy information. The solid arrows are necessary for the functioning of the process. The dotted arrows represent optional feedback loops. From the military point of view, the ideal system would contain no gap between demand and supply.

First, the needed level of military activity would be determined from the potential military threats to the United States. Chosen military activity would in turn be directly translated into maintenance

[1]The precise way the question is framed has an impact similar to the way the input data define the model. For instance, sustaining three sorties a day may be defined as "achieving an average of three sorties flown per day if four sorties are demanded per day," or "achieving three sorties per day, 90 percent of the time if three sorties per day are demanded," or in many other ways. The results might be very different in each case. However, this issue is better known and easier to address by directives from above.

manpower demands. Ideally, Congress would then implement a package of military pay, benefits, etc., that would produce a supply that met requirements and thus, in this case, demand. There would be no gap between demand and supply or, if forecasting errors led to such a gap, military personnel policy would quickly adjust to eliminate it.[2]

In practice, the system never works so simply. The military frequently defines need in terms of minimum risk. However, the Congressionally authorized level of military activity is typically less than the "needed" level; the structure of the mandated military activity will also differ from the needed structure. This leads to a situation in which manpower authorizations are determined, in part, by a variety of political and bureaucratic considerations. The authorizations may be different from the requirements, and much manpower supply can be, and is in practice, determined by "status quo" policies that may be dif-

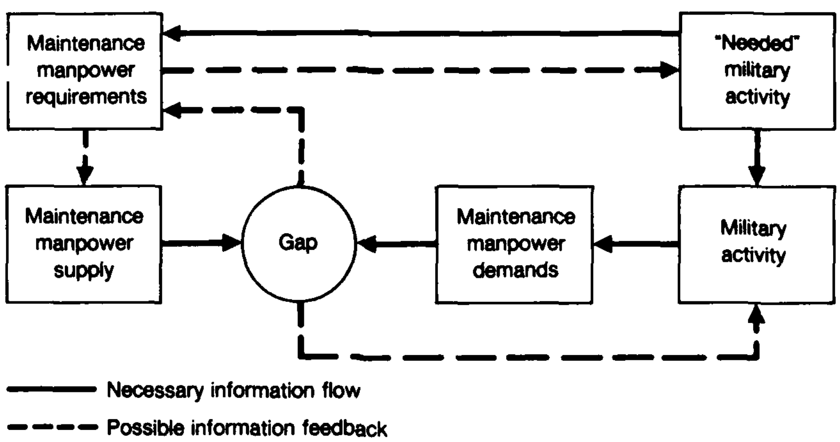

Fig. 1—Maintenance-manpower demand and supply

[2]For simplicity, we include in the term "military activity" all activities needed to provide military capability (e.g., readiness, sustainability). This report is primarily concerned with peacetime manpower levels, etc. However, much of this is determined by wartime contingencies. It is important to be aware of the distinction between military activities performed and those for which a contingent capability is maintained. We use, however, terminology such as "wartime sorties" to typically refer to a contingent capability.

ficult to change. It is for this reason that the line from requirements to supply is dashed.[3]

Additionally, a shortage of maintenance manpower may reduce the achievable military activity. Thus, an arrow from the indicated gap to military activity has been included.

In fact, an individual interested in an optimally efficient system would favor the inclusion of more feedbacks than are indicated in Fig. 1. The cost of alternative detailed manpower structures and the current manpower supply should influence the structure of activity chosen to meet a given level of needed military capability. The overall cost of a given military capability should be one factor in the political decision over whether it is needed.

The bulk of manpower modeling work is done in support of policy formation associated with the arrow from manpower requirements to manpower supply, the arrow from military activity to manpower demands, or the arrow from needed military activity to manpower requirements. When the levels of policy instruments chosen are based directly on model results, one may say the model has incorporated the policy in its structure. As a model becomes more sophisticated, it portrays more of the relationships. This naturally leads to optimizing more variables and incorporating more policy in the model's structure. However, bureaucratic divisions of responsibility tend to make the effective use of such models difficult. We will return to these subjects later in the report.

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[3]One concept of need is the "Minimum Risk Force." This is the force developed by the Joint Chiefs of Staff (JCS) "that achieves national objectives with minimum risk." See Joint Chiefs of Staff (April 1984, p. 236).

III. MAINTENANCE-MANPOWER/MILITARY-CAPABILITIES MODELS

MAJOR MAINTENANCE MODELS

We turn now to the large-scale, empirically detailed maintenance-manpower models that are being used by the DoD. To require detailed modeling, manpower activities must be sufficiently complex; they must also be associated with well-structured problems that are adequately understood.[1]

The manpower activities must produce a quantitative output. That output must either be the overall level of military capability (an ideal case beyond the current state of the art) or else be a separate input into military capabilities that is produced primarily with factors distinct from those that produce other inputs into military capability. For example, it would not be appropriate to examine F-16 sorties by holding constant F-15 sorties, if the F-15's flew from the same base using many of the same maintenance resources. To do so would be to implicitly assume that not even a very large number of additional F-16 sorties would make it worthwhile to forgo a single F-15 sortie.

The models that currently have the greatest immediate potential for applicability are those that link maintenance manpower to aircraft sorties. There are several reasons why the large-scale modeling activities have focused on aircraft maintenance manpower. Military aircraft maintenance requires trained personnel working with specialized equipment to undertake a complex and interdependent but well-structured sequence of repair activities before a sortie can be flown. These factors permit maintenance activities to be usefully addressed by analytical models.

Although the maintenance task structure can become quite complex, and may even incorporate random effects that influence such factors as whether a particular task needs to be accomplished, the decision process is sufficiently well known and characterized that it can be dealt with analytically.

To estimate the quantitative values of key parameters, one can use the significant relationship that exists between peacetime and wartime

[1]That is, the structure must be fairly well known, including major decision points and other branching factors. The important parameters and the approximate value must also be known. However, the quantitative values of important parameters usually need not be precise.

activities. During peacetime, a great deal of information is generated about the demands for maintenance resources, including failure rates and time to repair, that is relevant to wartime.

Finally, military aircraft maintenance can be related to a well defined quantitative measure of military output, the number of sorties flown. As these sorties would be in direct support of some national security objective, we have a clear link between manpower and military capability. Further, maintenance manpower resources used to maintain aircraft contribute substantially to sorties flown, but little to other dimensions of military capability. Also, the importance of additional sorties depends only weakly on the levels of other inputs to military capability.[2]

In contrast, the wartime activities of many types of personnel other than maintenance personnel cannot yet be so well defined. Better combat models are required before some specialized classes of personnel can be effectively defined in a well-structured sequence of activities that determine their contribution to military capability. Also, the data collected in the peacetime environment do not have as clear a relationship to wartime activities for other types of personnel as they have for maintenance personnel.

At the end of this section, we describe several models that can link maintenance personnel to ground-force operations. Their application to the specification of manpower requirements is, however, not so directly applicable. Therefore, we begin our discussion with LCOM, SPECTRUM, ALOM, and TSAR, which are the large Monte-Carlo simulation models currently being used to analyze the relationship between maintenance activities and aircraft missions. All four models have a similar structure that can be represented with a series of simple flow diagrams. We first identify some of the particular aspects of these four models.

AIRCRAFT MAINTENANCE MODELS

LCOM

The Logistics Composite Model is a base-level Air Force maintenance model used by Tactical Air Command (TAC) and other organizations to analyze the maintenance manpower requirements needed to

[2] The total sorties flown is not a perfect indicator of or contribution to military capability. Some sorties are more valuable than others. However, the major factor here is that early sorties are likely to be more valuable than later sorties. This complication is easily included in models.

meet planned missions with some degree of confidence. LCOM contains significant detail, which aids its ability to analyze the effect of elaborate task and skill breakdowns within the maintenance system. Factors other than manpower, such as spare parts and test equipment, enter the computations but are generally held fixed during analyses. LCOM is written in SIMSCRIPT.

When LCOM is used for detailed cases, the time and expense for operating the model can be considerable. Maintaining all up-to-date base-specific data can also be costly, and Air Force doctrine only requires data on a set of fairly standard personnel skills. Therefore, the model is not typically used with base-specific maintenance manpower data. Rather, LCOM uses "mandated" personnel skills. Issues such as CUT are typically not analyzed with this model, even when they are mandated. Finally, we should note that the overall flexibility of LCOM is limited by the large amount of computer time required and the complexity of data needs.[3]

TSAR

The Theater Simulation of Airbase Resources Model, which was developed by RAND for the Air Force, can analyze the relationship between resources (including maintenance) and aircraft sorties in a dynamic environment. The model would normally be used to analyze the maintenance activities of a particular base, but also contains the capability to account for possible logistic interactions among several bases. The model employs a moderately detailed skill and task breakdown, and there would typically be some aggregation of the maintenance tasks specified in LCOM. In addition to maintenance manpower, other specific resources that can constrain the generation of sorties are spares, munitions, aircrews, aircraft, petroleum, oil, and lubricants (POL), support equipment, tanks, racks, adapters and pylons (TRAP), and air base attack recovery materials. Unlike LCOM, TSAR can be used to analyze air base attack where both conventional and chemical effects can be studied. TSAR has also been used to analyze CUT issues. It is written entirely in FORTRAN.[4]

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[3]The original version of LCOM was developed at RAND in the late 1960s. It was initially designed to optimize different manpower and logistics resources. For an overview of this work, see Fisher et al. (May 1968). Considerable detail on the current version of LCOM is provided in U.S. Air Force (May 15, 1984). Today, LCOM is used by Hq TAC Manpower Studies and Analysis Team to analyze maintenance manpower with logistics resources typically held constant. At one time, the Logistics Directorate of Hq TAC used LCOM to analyze logistics issues under specified manpower assumptions.

[4]Donald Emerson, the architect of TSAR, has written extensively on the model. For an overview, see Emerson (February 1982). Also see Emerson and Wegner (August 1985)

SPECTRUM

The Simulation Package for the Evaluation by Computer Techniques of Readiness, Utilization and Maintenance Model is operated by the Naval Air Development Center. The overall model consists of a series of independent modules that together consider the entire naval aviation logistics system. One of these modules, PRISM, is a model of aircraft maintenance on a single carrier or naval air station and has been used to analyze readiness and sustainability issues. This model contains a detailed skill and task breakdown, and unlike LCOM the model has been frequently used with the actual primary and secondary maintenance skills of the base and with the base-specific failure rates. It can also be used in conjunction with operations and support (O&S) costs, and has been used to determine the least costly method of maintaining the F-18. SPECTRUM is written entirely in FORTRAN.[5]

ALOM

The Aviation Logistics Operation Model was developed by the Logistics Center of the U.S. Army and has been primarily used to analyze helicopter maintenance activities during a wartime scenario. It has been used in support of the Manpower Requirements Criteria (MARC) process, and as such, the model is designed to help develop the maintenance component of a Combat Support Aviation Company's Table of Organization and Equipment (TOE). Historical experience is used to determine the needed failure rate data. Army doctrine on both the task structure of aircraft maintenance and the Military Occupational Specialties (MOS) required for specific repair activities is used. ALOM is written primarily in FORTRAN.

Table 1 compares some of the key features of these four Monte-Carlo simulation models. For comparison purposes, information on the U.S. Army's PROLOGUE, which is discussed below, is also provided.[6]

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which mentions several other reports in this series that document TSAR. For an application using TSAR, see Berman et al. (August 1985). Besides being used by RAND, TSAR is currently being used by Hq Air Force (XOCJ) to analyze an integrated capability assessment system including a range of combat support resources, by the Air Force Assistant Chief of Staff, Studies and Analyses (AFSCA/SAGP) to assist in the development of the yearly update to the Airbase Operability Investment Strategy Plan, and by AFSC/ADYQ of Eglin AFB. It has also been used by contractors such as General Dynamics, Fort Worth, in the analysis of specific aircraft manpower and logistics issues.

[5]For a discussion of this model, see Perazza and Temkin (November 15, 1986).

[6]The ALOM model is discussed in Miller (October 1986).

Table 1

COMPARISON OF MAINTENANCE-MANPOWER/MILITARY-CAPABILITIES MODELS

Model	Strengths/ Limitations	Current Use	Other Possible Uses	Institutional Factors
LCOM	Most detailed Most expensive and time-consuming Modifications difficult Oldest model High data requirements	Manpower planning Variety of uses within Air Force, particularly in logistics	Analysis of broader questions Analysis of CUT/force structure	Use restricted by directives
TSAR	Designed for wartime analysis Fast Easily updated with proper expertise Moderate to high data requirements	Manpower and logistics analysis with air base attack Readiness and sustainability analysis	Analysis of broader questions Sensitivity analysis	Used by RAND researchers, several Air Force organizations, and selected contractors
SPECTRUM	Uses base-specific data Relatively fast High data requirements	Readiness and sustainability analysis Manpower planning Some CUT and force structure analysis	Analysis of broader questions Sensitivity analysis	Contractual use only

Table 1—continued

Model	Strengths/ Limitations	Current Use	Other Possible Uses	Institutional Factors
ALOM	Designed for doctrine-based MARC studies Reasonably fast Too new for extensive hands-on experience	Doctrinal TOE design	Analysis of broader questions Possibly sensitivity analysis	Current use restricted to doctrine-based studies
PROLOGUE	Lacks feedbacks No uncertainty Less detailed Very fast Efficient use of available data	Compares maintenance logistics and manpower resources with contingency plan needs	Comparison of results to more detailed models	Limited use as part of Logistics Evaluation Agency

AIRCRAFT FLIGHTS AND MAINTENANCE SEQUENCE

Before addressing the structure of the models, it is helpful to present a simplified view of the gross activities an aircraft goes through during the recovery time between sorties flown. Figure 2 describes this flight preparation process.

After completing a flight, an aircraft passes through the scheduled maintenance activities as soon as the appropriate maintenance personnel and other assets used in this process are available. Included in the scheduled maintenance activities are periodic inspections, fueling, and weapons loading. The duration of these activities is fairly well specified, and the scheduled maintenance activities should be completed at a predictable time. Conventional manpower engineering methods, therefore, can be used to calculate the total time required to conduct these scheduled activities.[7]

In contrast, unscheduled maintenance occurs when there is a failure or malfunction of the aircraft's equipment. These types of failures are probabilistic, and although one may be able to specify a failure rate distribution function, the total time a particular aircraft spends in unscheduled maintenance is random. Should a failure occur, an aircraft would move through the relevant maintenance task network in order to deal with the malfunction.

It is also helpful to understanc' the distinction between "on-equipment" and "off-equipment" repair. On-equipment repair takes place on the aircraft at the organizational level, while off-equipment repair takes place in maintenance shops that specialize in such functions as avionics, weapons buildup, engine, and inspection. Much of the latter repair is called intermediate maintenance. Note from Fig. 2 that after the completion of unscheduled maintenance, the aircraft moves into a pool, awaiting the next sortie. Flights of aircraft are formed during this period, and the recovery time (the total time between sorties) includes the period spent in the pool.

AIRCRAFT-MAINTENANCE MODEL STRUCTURE

With this background, we can discuss the basic structure of the aircraft maintenance models. All four of these large scale models (LCOM, TSAR, SPECTRUM, and ALOM) have the same basic structure and, as an aid to understanding their operation, we present several simple flow diagrams. We start with the simplified deterministic version of the model in which manpower demands are computed and

[7]During wartime, some of the scheduled activities might be deferred, and this can be built into the set of required activities that must be accomplished now and later.

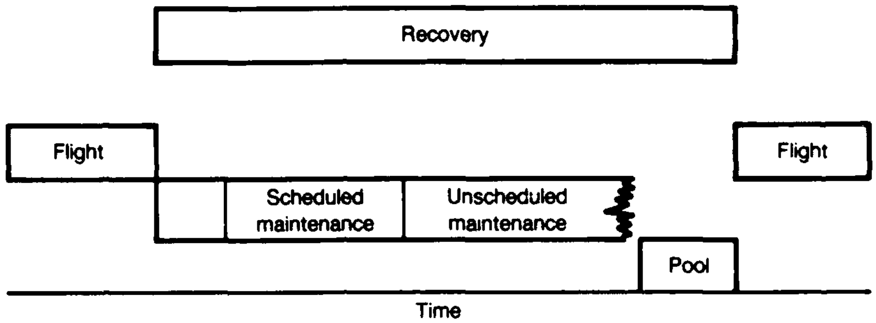

Fig. 2—Flight and maintenance sequence

compared with manpower supply, but in which there is no calculation of possible military activity level. Although none of the aircraft models would typically be operated in such a fashion, the diagram does act as a helpful introduction.[8]

In this and the subsequent diagrams, the ovals represent computations while the rectangles represent inflows of exogenous information. In Fig. 3, all computations are deterministic and the model proceeds from left to right.

We start with the specified force structure and planned level of military activity in the upper left-hand corner of the figure. This simply means that we have a set of combat forces as well as an operations plan describing the specific military operations demanded during some specified period.

With this input, the model now computes the specific features of a detailed time-dependent scenario, such as the number and types of aircraft flying particular missions against specified target sets. Of course, how failure rates vary with activity level must also be specified for us to calculate the part failures that must be addressed.

As one moves to the next part of the model, note that the model also requires information on the mean time to repair the damaged parts, as well as specific maintenance skills, spare parts, and test equipment needed for repairs. This brings us to the stage of the model in which the needed manpower resources are computed. To calculate the manpower demands, however, one also needs to take account of the minimum-manning levels.

[8]We might note that PROLOGUE, one of the major ground-force models that we will address later in this section, can be represented by Fig. 4.

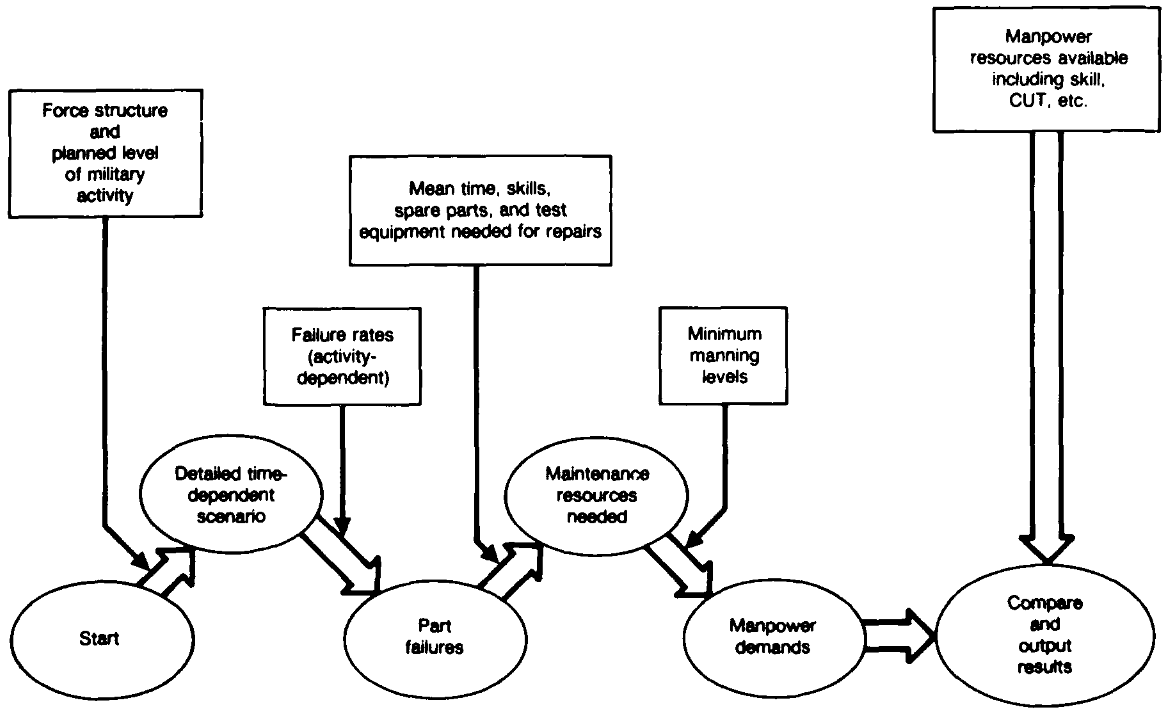

Fig. 3—Deterministic maintenance model

The minimum manning constraints have an important bearing on these models, and we need to consider them carefully. For example, in most aircraft models, the minimum manning level in each specialty area is set equal to two shifts of the number of people necessary for the task that requires the most people. This means, as an example, that no matter how unlikely it is that five experts will ever be needed in one specialty area in a particular shop, if there is any task that will require this number, the shop must have two full shifts of these specialists.

Given the calculated maintenance resources needed (or demanded) and the specified minimum manning levels, the model calculates a set of manpower demands. By this we mean both a total number and a particular composition of maintenance personnel who can maintain the desired activity level.

The model now takes account of the manpower resources available (or supplied). Included in the description of skills would be the effect of CUT on skill availability. By comparing the demand for manpower with its supply, one can identify manpower shortages that would need to be alleviated in order to achieve the planned activity level.

Figure 4 contains two additional factors that are present in the four aircraft maintenance models. The upper part of the loop describes a feedback information flow in which the difference between the manpower demands and the manpower resources available is used to compute a possible activity level. The shortages would be allocated across the maintenance specialty areas in accordance with a priority rule such as "repair that aircraft that can be available to fly the earliest." The possible activity level achieved might be represented as the percentage of sorties demanded that is achieved and can be viewed as a technologically efficient use of the available maintenance resources.

We have also indicated in Fig. 4 the manner in which part failures are handled randomly. This is represented by the lower part of the loop, which has been labeled, "Redo with new random numbers." This addition to the flow diagram is the reason why these models are called Monte-Carlo simulation models. Essentially what happens is this: The probability that a part will fail during a mission (the failure rate) is specified; then, a random number generator determines whether the part actually fails during a particular "run" of a simulation. Another random number determines, from a specified distribution, the time used in repairing the part. Typically, the uncertainty associated with the *mean* repair times and *mean* failure rates is not dealt with randomly, though we suggest in Sec. IV that this may be advisable in order to capture more accurately the uncertainty of combat operations.

The use of random part failures is a particularly important feature of these models. In the area of aircraft maintenance, a large number of

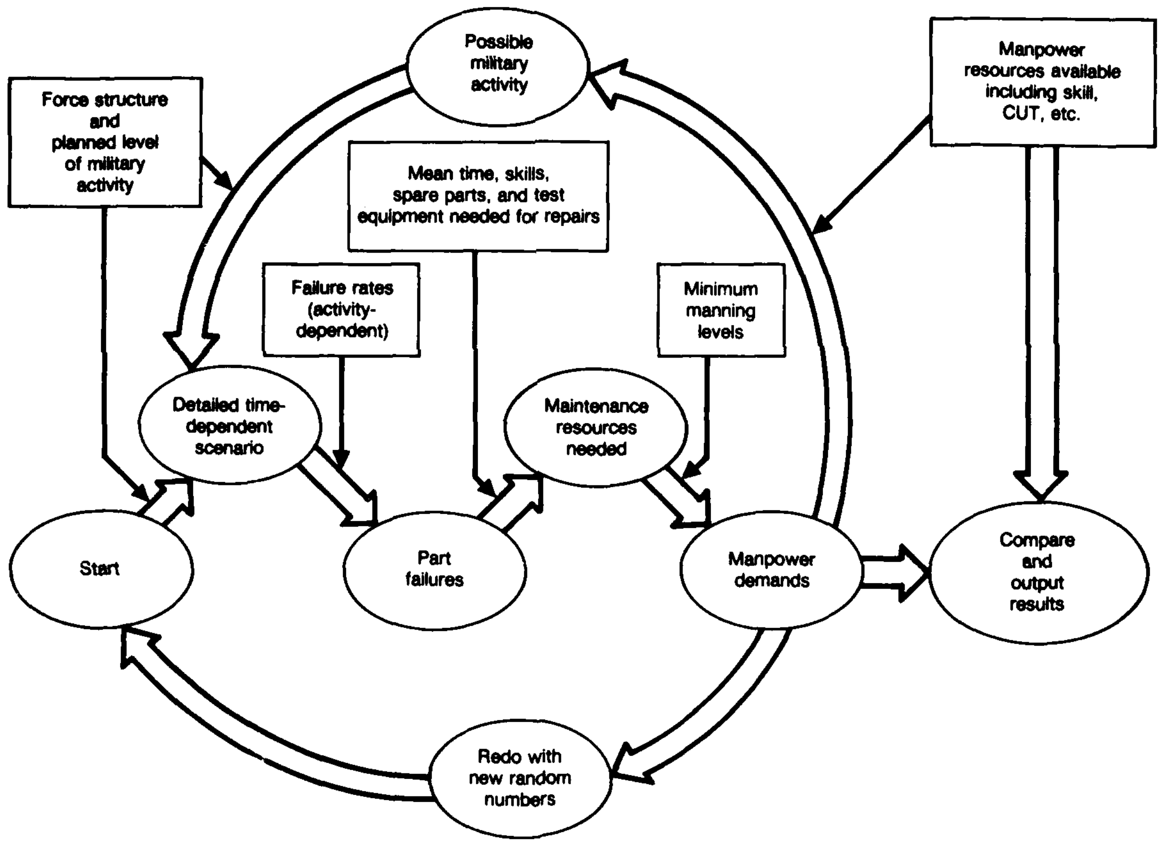

Fig. 4—Stochastic maintenance model with feedback

tasks and specific skills are required to maintain equipment. In each of the skills, the number of personnel available is only a modest percent of the total maintenance personnel. The implication of this is that it is not appropriate to specify manpower requirements based on the average level of manpower demand. For example, say the average failure rate for some part is one per day but may actually be as much as three per day or as little as zero per day. This variation in demand must be taken into account during manpower planning in order to prevent a serious bottleneck on the day that has three failures. Because each iteration of these models will produce different results, the criteria that define a solution must be based on the average of several runs or some other statistic of the distribution over the runs. The probabilistic variation in the demand for particular types of maintenance also bears on the issue of minimum manning levels.

We have represented in Fig. 5 the final feature of the models that can be employed. One can investigate whether maintenance has been optimized by changing the composition of the maintenance force and observing whether a greater number of sorties can be achieved with a given number of people. In practice, the individual analyst would play an important judgmental role in the optimization process. For each simulation conducted, there would be indicative output on such variables as the average utilization rate of each specialty area and the average queue length. By carefully examining this type of data, and resimulating the model for different skill compositions, the analyst is able to obtain a sense of the marginal product of each choice variable and make adjustments toward an optimal solution. Although this procedure cannot, as yet, be accomplished automatically by any of the four models, a skilled analyst should be able to achieve a close approximation of an optimal solution.

Before describing several model results, it may be helpful to characterize the maintenance-manpower/sortie-generation relationship and provide some observations about how model results might change as the underlying assumptions vary.

MAINTENANCE-MANPOWER/SORTIE-GENERATION RELATIONSHIP

It is important to recognize that the available maintenance manhours per flying hour are not likely to be constant as we increase the number of sorties by means of an increase in the number of maintenance personnel. As represented in Fig. 6, we expect a relationship that reflects diminishing returns when maintenance personnel are

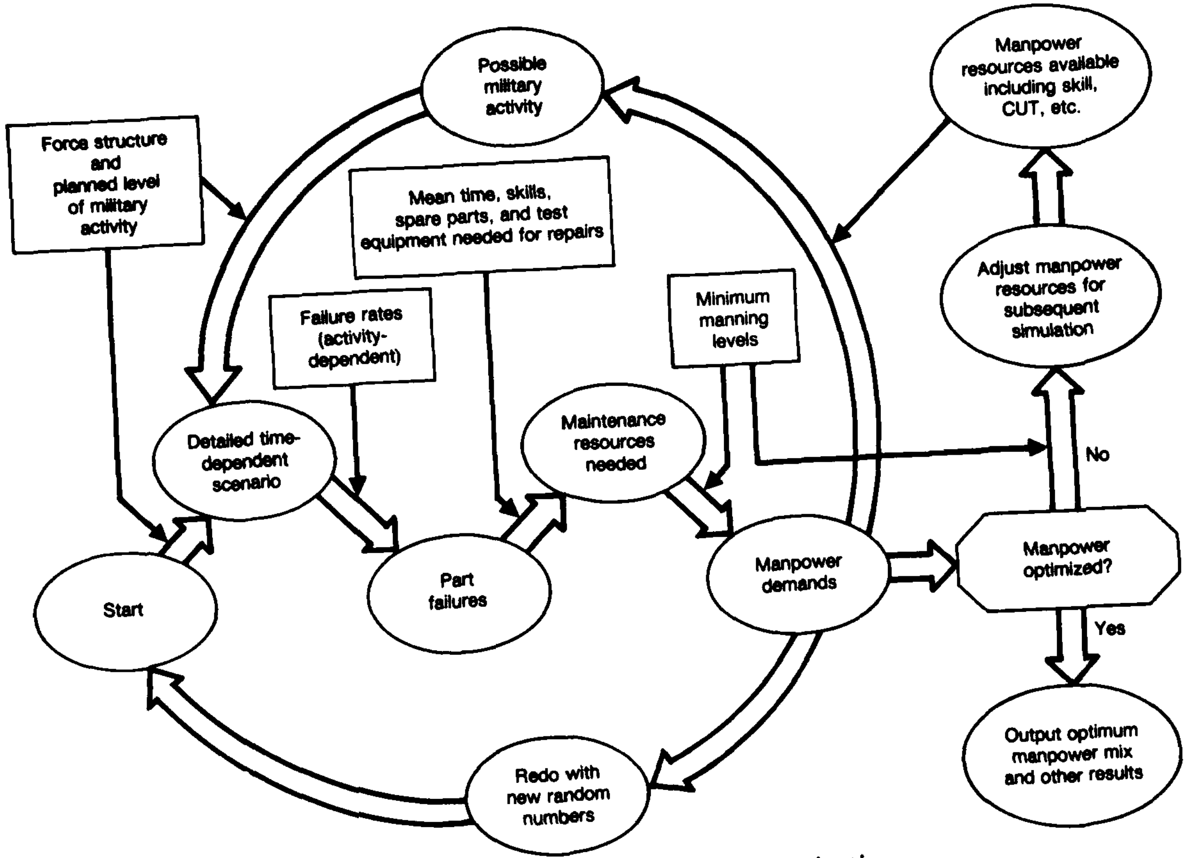

Fig. 5—Maintenance model with optimization

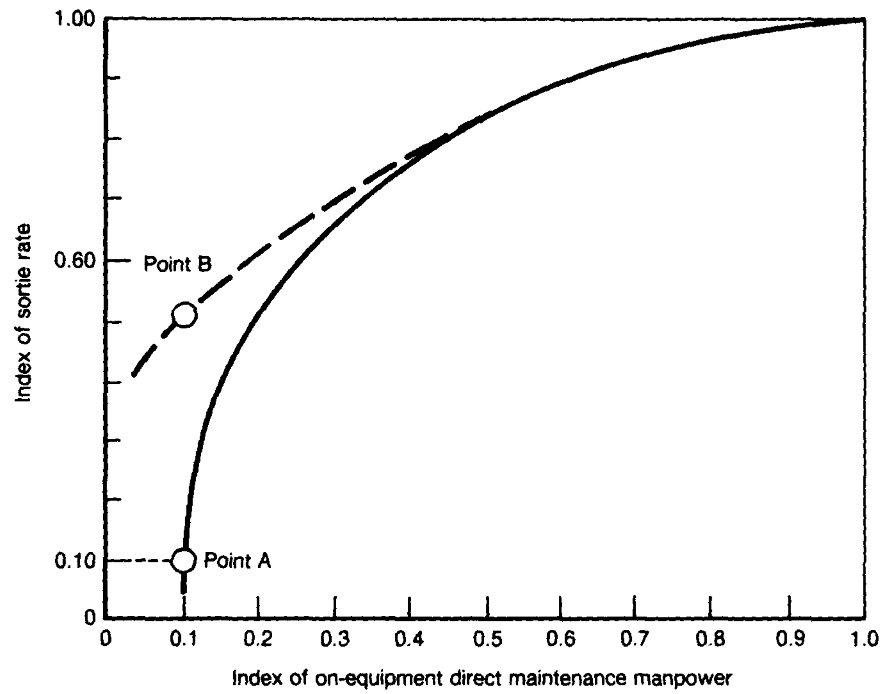

Fig. 6—Sortie rate versus maintenance personnel

added. For small numbers of maintenance personnel, the average demands may be high enough to use most or all of the available maintenance manhours. As more manpower is added, some maintenance personnel will be waiting for relatively rare circumstances when they will be needed. Sorties may, however, be approximately linear in the maintenance manhours actually used. Thus, the diminishing returns evident in this curve reflect a declining utilization rate as manpower resources increase.[9]

On the horizontal axis, we have an index of on-equipment direct maintenance manpower; on the vertical axis is an index of the sortie rate, which might be measured as the average number of sorties that can be flown each day during a campaign. The shape of this relationship between resource input and military output, called the total

[9]One of the first representations of this relationship appeared in Bell and Stucker (May 1971, p. 15).

product curve in the theory of production, is determined by the minimum manning levels, the bottleneck constraints that emerge more frequently at lower manning levels, and the upper limit on the number of sorties that can be flown per day.

The solid line in Fig. 6 represents the trade-offs for a model that includes the minimum manning constraint in a Monte-Carlo simulation. The minimum manning constraint is represented by Point A. The minimum staffing level of each shop or work center defines the minimum number of personnel required to conduct *any* operations in the model. As we have indicated above, the minimum manning level would typically be specified as two shifts of the number of people required to do the task that requires the greatest number of people.

The dashed line shows what would happen in a model that did not impose the minimum manning constraints. Typically for low manpower levels, the minimum manning constraints force an inefficient mix of personnel so the dashed line lies above the solid line. At high enough levels of manpower, the minimum manning constraints are not binding and the dashed line meets the solid line. Point B has the same manpower level as point A. When the minimum manning constraints are not imposed, the Monte-Carlo simulation models can function at smaller manpower levels than those represented by the manpower level associated with points A and B. Thus, the dashed line continues to the left of point B.

We have also indicated a maximum value for the sortie rate index of 1.00. Even with unlimited maintenance personnel and crews, the sortie rate would be limited. The sortie duration is of a particular length, and there is a set of scheduled maintenance activities that require, even without delays, some length of time. Therefore, even if no unscheduled maintenance is required, only so many sorties can be generated per day.

It is interesting to consider the effect of the bottleneck constraints on the curvature of the graph. At low maintenance manpower levels, we can expect demands for maintenance to be regularly generated that cannot be immediately satisfied. Queues will form quickly, and typically some queues will remain positive throughout the scenario. An additional maintenance person with the skill needed to work down such a queue would be heavily used and would have a large impact on the sorties that could be generated. Initially, fairly small increases in maintenance manpower will lead to fairly large increases in the sortie rate. As one continues to add maintenance personnel, the queues that remain are at the zero level more and more of the time. Thus additional maintenance personnel will be used less, and additional increases in maintenance personnel will result in smaller increases in the sortie rate. Eventually, of course, one runs up against the upper sortie rate limit that is based on the length of a sortie and the time needed to perform maintenance. We conclude, therefore, that as one increases maintenance personnel, sorties increase at a decreasing rate.

We might add one further point about Fig. 6. As we indicated above in Fig. 4, all of the four models we are considering here are Monte-Carlo simulation models. For a given manpower level, the failure rates and, in turn, demand for unscheduled maintenance are determined randomly. The sortie rate specified in Fig. 6 is, then, the average obtained for the specified maintenance level over the various simulations.

If, however, during a particular simulation, the randomly generated set of demands is unusually high or badly matched to the available set of maintenance skills, a somewhat lower sortie rate will be achieved. On the other hand, there may be a particularly lucky roll of the die that yields a slightly higher sortie rate. But each simulation covers a substantial period of combat days and a significant number of aircraft. Thus there are numerous opportunities for each possible failure to occur. Just as 1000 coin flips will most often yield very near to 500 heads and 500 tails, most randomly generated scenarios can be expected to place a similar set of demands for unscheduled maintenance. One would not expect, therefore, much dispersion about the curve indicated in Fig. 6 that is generated by each Monte-Carlo simulation. (If a single random event, for instance, an air base attack, or failure of a key piece of test equipment, has a particularly large impact, this argument might not apply.) We will consider in Sec. IV whether this approach of randomly generating failures adequately captures the various types of uncertainty that one may face in wartime.

SENSITIVITY TO ASSUMPTIONS

In complex models, it is important to consider how sensitive the results are to one's assumptions. Often the assumptions may not be based on very precise knowledge and generally sensitivity tests have not been done in adequate detail. Detailed sensitivity tests based on precise assumptions should be included in any good model validation studies.

However, from the logic of these models and based on the empirical analyses that have been accomplished, it is possible to make some judgments about the sensitivity of results to small percentage changes in the assumptions concerning repair time, force structure, minimum manning requirements, and CUT.

Repair Time

If we change repair time uniformly across the different repair tasks that may need to be undertaken, model output would not change much. This is because maintenance shops are frequently manned to meet peak demand rather than the lower average level. Therefore, on average, many classes of maintenance personnel would have a fairly low utilization rate. As a result, if there were a small reduction in repair-time input data, there would not be a significant number of items waiting to be repaired, and there would not be a significant increase in the number of sorties flown.

Force Structure

Small changes in the number of aircraft participating in the scenario would result in moderate changes in the number of sorties generated. This is because, as we increase the number of aircraft, the existing bottleneck constraints would ensure a less-than-proportional increase in the average utilization rate of maintenance personnel. There would, therefore, be a less-than-proportional increase in the number of sorties generated with the additional aircraft, and the sortie rate per aircraft would decline.

Minimum Manning Requirements

The minimum manning requirements are an important determinant of manpower. As we indicated above, two shifts of the task requiring the greatest number of people are frequently specified as the manning requirement for a shop or work center, even though the particular job may be performed only infrequently. By changing the minimum manning and redistributing the released manpower, a significant increase in the average utilization rate can be obtained. Therefore, this can have a significant effect on the number of sorties that can be flown with some specified total of maintenance manpower.

CUT[10]

Cross Utilization Training can also have a significant effect on the sorties generated because it can markedly increase the utilization rate. Suppose that Skill A is not being used at some time during a simulation, but there is a positive queue for repair activities using Skill B. Then, maintenance personnel with Skill A who are cross-trained in Skill B can increase their utilization rate.

An additional effect of CUT would be to eliminate some of the minimum manning requirements. Then, individuals with low utilization rates, whose role is to respond to occasional demands for their specialized service, can be replaced with cross-trained individuals. Of course, the cost and feasibility of CUT need to be evaluated carefully.

MODEL RESULTS

We display below some representative results for LCOM, TSAR, and ALOM in order to provide the flavor of these models' capabilities. The first example, depicted in Fig. 7, was obtained when LCOM was applied to the direct maintenance personnel of an F-16 squadron. The study, therefore, focuses on on-equipment maintenance and does not address the non-squadron, off-equipment maintenance personnel requirements. In practice, delays from shortfalls in off-equipment maintenance requirements can affect aircraft turnaround. To eliminate the effect of such shortfalls from the squadron maintenance analysis, non-manpower resources are unconstrained in the study.[11]

This application is an analysis of the implications of aggregating work centers and maintenance specialties on the sorties generated. When more than one work center composed of like specialists is aggregated to form a single work center, one need only satisfy the largest minimum manning requirement of the original work centers instead of the sum of the minimum manning requirements. Reducing the number of specialties reflects a possible implementation of CUT. Therefore the

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[10]Although "cross-trained" has some formal definitions, e.g., *full* qualification in *one* skill, we use it as a general qualitative term for *some* qualification with *multiple* skills. Our definition, therefore, would include task-assist training, which qualifies an individual to "fill out" a team if the person has a related skill, knows the relevant safety procedures, etc. Task-assist training can have a significant effect on requirements and may entail lower costs than does fully qualifying an individual. Both possibilities are supported in TSAR.

[11]This analysis is reported in Moore et al. (December 1985, pp. 24–32). The analysis was conducted for a 30-day simulation in which one first solved for the number of sorties that could be generated with unlimited resources. Each of the cases presented yields 90 percent as many sorties as can be obtained in the unconstrained case.

benefits of releasing the minimum manning restrictions and increasing CUT are considered in this analysis.[12]

We begin with Case 1 in which there are 30 work centers and 17 specialties. In this situation, we require 111 maintenance personnel to conduct the specified air operations. Of this total, 52 people are based on the specified crew size or minimum manning requirement.

In Case 2, we reduce the number of work centers from 30 to 17 with no change in the number of specialties. This reduces the manning requirement to 85. This result is derived from the fact that we halved the number of people assigned based on the minimum crew-size requirement.

For Case 3, the number of work centers and specialties is reduced to 6 each. The specialties are combined in a logical manner so that all avionics specialists are combined into one specialty area, all aircraft systems specialists into another, and so forth. As we have indicated, this is a way of representing the effect of substantial CUT, for it

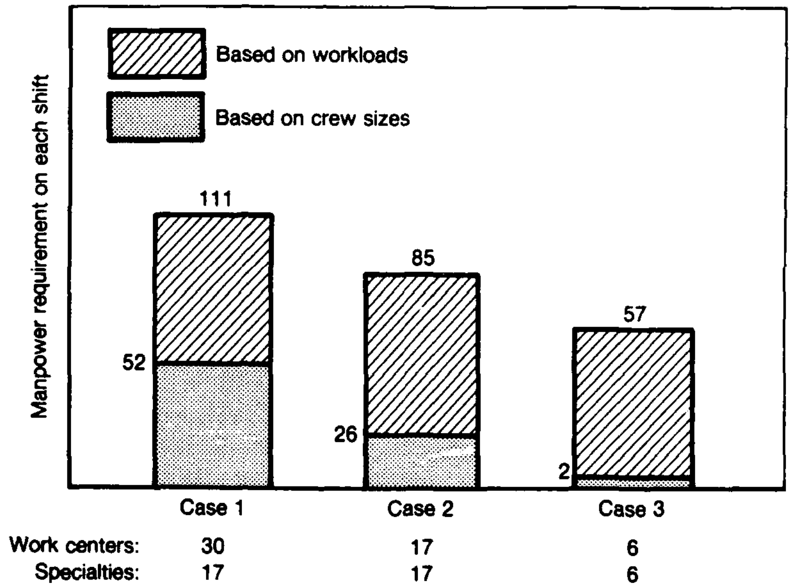

Fig. 7—Manpower requirements using LCOM

[12]Note that an additional benefit of CUT is an increase in the capability to shift manpower in response to the random fluctuations in specific demands.

basically assumes that, for example, any avionics job can be done by any avionics technician.

In this final case, one has virtually eliminated the manning based on crew size, and now a total of 57 people are required. In other words, the consolidations of work centers and specialties have resulted in about a 50 percent reduction in squadron maintenance personnel. This analysis does not address the feasibility of such a consolidation or the cost—nor does it assess the reduction that would be achieved if other resources were constrained. It does suggest, however, that one might search for potential savings in this area.

The next example is an application of TSAR. In Fig. 8, we describe the number of F-16A/B sorties per aircraft per day that can be generated as a function of wing maintenance personnel for normal failure rates, for 0.5 times the normal rates, and for 0.25 times the normal

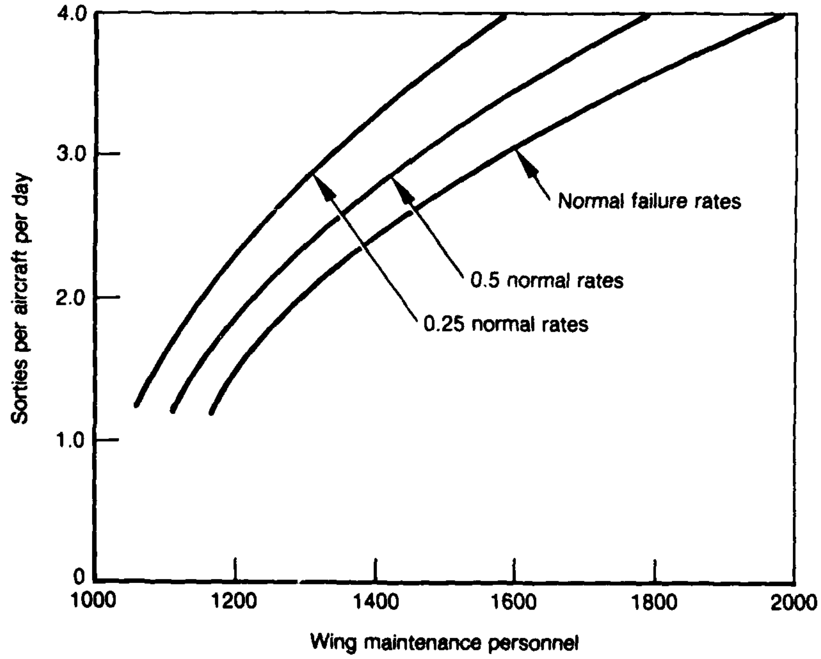

Fig. 8—Manpower requirements using TSAR

rates. The curvature of the sortie-personnel relationship is nonlinear and consistent with the discussion above concerning Fig. 6.[13]

In Fig. 9, we display part of the information from Fig. 8 in a slightly different manner. On the vertical axis we represent the reliability improvement factor. A value of 1 indicates normal failure rates, a value of 2 indicates half the normal rates, and so forth. The horizontal axis represents the number of wing maintenance personnel.

The figure shows the trade-off curve that describes the relationship between the reliability improvement factor and wing maintenance personnel and indicates where 3 sorties per aircraft per day falls on that

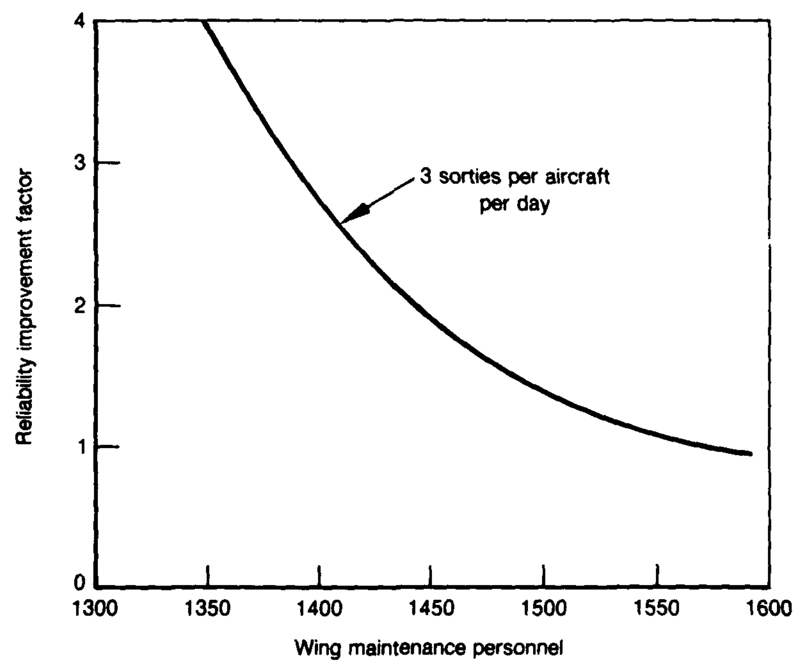

Fig. 9—Maintenance personnel/failure-rate trade-off

[13]This example is based on the analysis of Abell et al. (March 1988). The analysis was conducted for a seven-day wartime surge in which non-maintenance manpower resources are unconstrained. For each sortie level, the day-shift and flight line direct-maintenance personnel in each specialty area were set at a level that ensured a need for more personnel in only 5 out of 100 simulations. Night-shift and support shop direct-maintenance personnel were manned at the maximum total manhours required for the shift over the seven days of simulation. Indirect maintenance work was determined using Air Force planning factors.

curve. Notice that reductions in the reliability improvement factor can be offset with increases in maintenance personnel. However, as one continues to decrease the improvement factor, greater numbers of additional maintenance personnel are required to compensate for the decreased reliability.

One can understand the shape of this curve by considering the following: When the equipment is, on average, extremely reliable (high reliability improvement factor) and the number of wing maintenance personnel is small, there will remain rare peak demands that cannot be easily met. However, the average utilization rate of personnel will be relatively low. Some maintenance personnel will frequently be waiting for the part to fail that they are trained to fix. In this situation, reductions in reliability will primarily result in demands that can be met with idle personnel, and small additions in personnel will be needed to offset the lower reliability. With a larger number of personnel, however, the peak demand problem becomes attenuated, and one would be less likely to find maintenance personnel idle. This implies that one would need a larger number of maintenance personnel to offset a reduction in reliability.

We might also note that Fig. 9 can form the basis for manpower demand analysis. The least costly combination of maintenance personnel and reliability improvement would occur at the point where the substitution rate of maintenance personnel for reliability improvement just equals the relative costs of these two military inputs. Given the costs of maintenance manpower resources and improvements in reliability, then, for any level of sortie rate demanded, one can determine the efficient level of maintenance personnel needed to support that rate.

We turn next to an illustration of the Army's ALOM model, which has been used to analyze helicopter maintenance for a combat support aviation company consisting of 23 UH1H utility helicopters. As indicated above, this model has been developed to support the Army's MARC process. The application we have chosen is interesting because as a result of a change in the composition of maintenance skills, we can identify a dramatic effect. This effect occurs, in part, because the model employs a precise interpretation of Army doctrine with respect to both the structure of routine maintenance tasks and the designated skills required to perform these tasks.[14]

Figure 10 describes the "annualized" flying hours as a function of the number of mechanics. These achieved flying hours are performed during a specified combat scenario but are presented here for

[14]This example is discussed in Miller (1986). Also see Lanagan (October 1986). Non-maintenance resources are unconstrained in this analysis.

convenience on an annualized basis. As indicated on the graph, 1438 hours are requested of the aviation company. This is somewhat more demanding than the Army's specified flying program of 948 hours, which can be viewed as a minimum standard for a combat scenario.

The Base Table of Organization and Equipment point on the graph represents the BTOE total of 41 mechanics and shows that, under the existing composition of maintenance skills, 227 annual flying hours can be achieved during the specified scenario with the BTOE mix of maintenance resources. Although this result is for a wartime scenario, it is interesting that the activity level achieved is quite similar to the 200–300 hours per year flown during peacetime by the UH1H units.

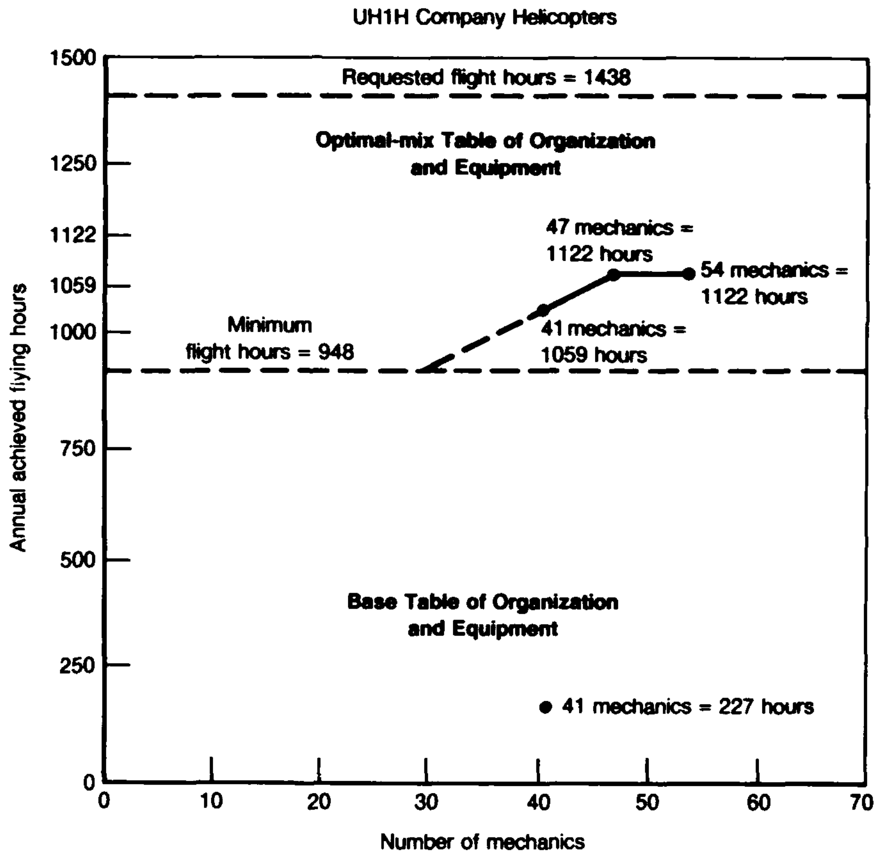

Fig. 10—Manpower requirements using ALOM

An analysis of this result indicated that the average daily MOS utilization was only 5.8 hours per mechanic and that the primary bottleneck constraints were technical inspectors and airframe mechanics. The specialty with the most slack was primary repairer. As a result of these bottleneck and slack indications, the mechanic mix was changed. The point directly above BTOE is called the optimal-mix TOE. In this solution, there are still 41 maintenance personnel. With the new and more optimal configuration of skills, the aviation company is able to generate 1059 annualized flying hours. This represents over a four-fold increase in flying hours due to the specified change in skill composition. The average daily MOS utilization has now increased to 10.6 hours.

The graph also indicates two additional solutions that are obtained by increasing the number of mechanics to 47 or 54. Although a modest increase in flying hours is obtained from six additional mechanics (1122 hours are achieved), a further increase of seven more mechanics does not increase flying hours at all. At this point we are apparently at the sortie rate limit for these helicopters.

The results of this analysis must be interpreted carefully. Because this study was conducted within the Army's MARC process, doctrine defines the tasks that can be performed by each MOS; yet the historical data include repair activities not performed by the appropriate MOS. Review of historical records indicates that there were cases in which, for example, a cavalry scout (a combat person) replaced a window on an AH1S aircraft and a flight engineer performed some type of airframe maintenance. In this doctrinally based model, however, these activities must be performed by the doctrinally correct MOS.

One may ask, therefore, whether technical inspectors and airframe mechanics were merely doctrinal constraints or whether they were constraints that would have been applicable in the real world. We will address this question at greater length in Sec. IV.

GROUND-FORCE MODELS

Ground-force models present a more difficult challenge than aircraft maintenance models. First of all a measure of capability is not as well defined. For ground operations, there is nothing quite so attractive as the sortie measure for aircraft operations. The U.S. Army Logistic Center is currently exploring models for tracked vehicles that are similar in structure to ALOM, and are considering a measure such as the operational availability of the vehicle.

Of course, the combined arms aspect of ground-force operations is what one needs to ultimately model if there is an interest in assessing the trade-offs among the resources supporting the different classes of equipment. For such operations, a gauge of capability might be some measure of the force ratio at the Forward Line of Own Troops (FLOT) or movement of the Forward Edge of the Battle Area (FEBA). At the present time, however, there are no models that link the detailed structure of maintenance activities to this type of aggregate capability measure.

To gain a better appreciation of the role that ground-force models can play in analyzing manpower requirements, let us consider several models that have been used: PROLOGUE, FORCEM, VIC, and AURA.

PROLOGUE

Planned Resources of Logistics Units Evaluator is currently operated by the U.S. Army Logistics Evaluation Agency. It is a small- to medium-sized deterministic model that is used to evaluate the logistics aspects of an existing or alternative force structure and contingency plans. The primary purpose of this model is to compute (1) the expected maintenance demands on personnel and (2) other logistics resources used to implement the time-phased theater operations plan (OPLAN). These demands are compared with the current resources on hand and with those specified in the TOE and the Modified TOE (MTOE). (See Sec. IV for a discussion of the MTOE.)

The model does not contain any feedback from the identified excess demand for combat capability or from later logistic demands and cannot handle uncertainties. With one exception, that the model makes little use of detailed skill and task breakdown, it has a structure very much like that in Fig. 3. Without a feedback loop, there can be no assessment of the marginal product of the various bottleneck resources. The model, therefore, cannot be used very effectively to conduct trade-off analyses.[15]

FORCEM/VIC

FORCEM and VIC are, respectively, theater and ground-level models that are used to analyze the activities of forces for an extended

[15]Our summary was obtained from a briefing provided by the U.S. Army Logistics Evaluation Agency.

period of time. Performance on the battlefield can be assessed by examining force ratios and the movement of units.[16]

Both of these models contain combat service support (CSS) units, which include the maintenance activities of the theater or corps. Also, as equipment is repaired, it can be returned to combat units. Maintenance activities, therefore, have an effect on the performance of combat units; there is a feedback from the excess demand for maintenance to the possible level of military activity of the type described in Fig. 4.

The detailed structure of maintenance by specialty area, however, is not modeled. Rather, a maintenance unit operates with a sort of composite individual possessing the mix of specified maintenance skills. As a result, FORCEM and VIC are not very useful for answering detailed questions about the demand for specific types of maintenance personnel. Although one may add more "generic" maintenance personnel to a maintenance unit and obtain some of the impact of such a TOE change on combat, detailed questions relating to the composition of skills, crew size, and CUT cannot be addressed. It would, however, be possible to address force structure questions with these models. One may add and subtract maintenance units containing these composite maintenance individuals and measure the implications of such force structure changes on combat performance.

AURA

The Army Unit Readiness/Sustainability Assessor is a ground-force model that was developed by RAND for the DoD. The model is based on the TSAR framework, and can, in principle, be used to assess the detailed structure of maintenance activities. The model uses a precisely defined sortie-like measure of capability called the specific operational capability (SOC). This measure has been defined for both attack and active defense missions of a combined arms brigade of armored and mechanized infantry forces with relevant artillery and combat and service support. By comparing the SOCs supplied with those demanded, one can obtain a measure of the readiness and sustainability of the brigade.[17]

Like TSAR, there is a feedback from the excess demand for maintenance activities to a possible level of military activity. If one accepts the SOC measure of military capability as being analogous to the sortie

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[16]A summary of FORCEM is provided in U.S. Army Concepts Analysis Agency (March 1985). For a discussion of the relevant portion of VIC, see U.S. Army TRADOC Analysis Center (November 1986).

[17]This model is discussed in Shishko and Kamins (January 1985).

as a measure of capability, then AURA, like the aircraft maintenance models discussed, might be used to analyze the effect of the detailed structure of maintenance activities on military capability.

Additional work would be needed to link the SOC to measures of capability at higher organizational levels, such as those used in FORCEM or VIC. Ultimately, detailed maintenance activities might be related to broader measures of capability than the SOC through the hierarchical linkage of the models that have been developed at different organizational levels. This type of linkage is needed if one is to be able to analyze the trade-offs among the maintenance activities of a variety of ground-force units.

IV. OBSERVATIONS AND RECOMMENDATIONS

Our comments will focus primarily on the aircraft maintenance models. These models have a sufficiently detailed skill and task breakdown so that they can play an enlarged role in the manpower requirements process. Additional work is needed on ground-force models before they can be used to address skill composition, CUT, and minimum crew size.

Let us first review how the models linking aircraft maintenance manpower to sorties generated can be used more effectively in analyzing these three interrelated areas. Our discussion also addresses doctrine versus practice and how different purposes may need to be considered when analyzing manpower requirements.

SKILL COMPOSITION, CUT, AND MINIMUM CREW SIZE

We have indicated in Sec. III that a significant increase in flying hours is obtained by the U.S. Army when the mix of skills is changed from that specified by the TOE. We also indicated that the Air Force typically uses the mandated personnel skills in its LCOM applications. On the other hand, the Naval Air Development Center has used SPECTRUM to analyze maintenance manpower questions with the actual primary and secondary skills held by individuals who are assigned to a specific carrier or naval air station.

This raises the important issue of doctrine versus practice. Military doctrine, as embodied in the TOE and in the set of skills possessed by an individual with a particular specialty area, plays an important role in the military planning and assignment process. It is necessary to be able to do force planning with well-defined units, and the military assignment process must be able to function routinely.

However, the requirements specified by the TOE may not be achievable for a variety of reasons. There may be personnel constraints, equipment constraints, or other considerations that preclude the achievement of a TOE. The Army, therefore, employs a notion called the Modified TOE (MTOE) that codifies the personnel and equipment authorizations.

There may also be methods of practice that are, in part, influenced by the gap between the TOE and the MTOE. Certain repair activities may occur in a manner not prescribed by doctrine. For example, the Army, in the aviation support example described above, may have been able to obtain a significant increase in helicopter flying hours because many peacetime jobs were not being conducted in accordance with doctrine. Thus, if windows are not being replaced in peacetime by the primary repairer MOS for the UH1H as specified by doctrine, or the technical inspection MOS formed a bottleneck constraint because this function was not being performed in accordance with doctrine, these features of practice may need to be taken into account in certain types of analysis.

When analyzing skill composition changes, it is important, therefore, that the purpose of the analysis be clear. If the analysis is to be used to specify requirements as part of, say, the process of unit design, then one would probably use the TOE as the starting point in the analysis. On the other hand, if one is concerned about actual manpower authorizations, then something analogous to the MTOE and actual practice is relevant. And, of course, the experience gained assessing practice may, in turn, shed some light on the appropriate doctrine.

The Navy's use, with SPECTRUM, of actual primary and secondary skills at the base and their use of actual base data in the analysis of air operations, therefore, deserve to be noted. This is the appropriate basis for evaluating actual readiness and sustainability questions and for evaluating changes in the composition of actual skills.

In addition to a bias toward the use of the TOE as the basis for analysis, we have also noted some institutional resistance to analyzing certain issues with these models. We have indicated, as an example, that there is line responsibility within the Air Force for using LCOM during the manpower requirements process. This responsibility is, however, circumscribed by directives. For example, CUT issues may not be considered during the analysis unless explicitly permitted by directives. As a result, even if certain types of CUT are required by the TOE, they may not be taken into account in the analysis unless the directives permit it. However, as we have indicated above, changes in CUT can have a significant effect on the number of sorties that can be generated with a specified number of people.

In Sec. III, we noted that changes in the minimum manning requirement can also have a significant effect on military capability. These minimum manning requirements, however, should not be determined exclusively by management engineering considerations. It is not appropriate, therefore, simply to set the minimum requirements of a maintenance shop equal to two shifts of the number of people required to do the job that requires the greatest number of people. Other simple assignment rules are not appropriate either.

These minimum manning requirements need to be evaluated from the standpoint of the entire maintenance system, that is, with the aid of a Monte-Carlo simulation model. This is because a decrease in manning (below the minimum manning requirement) that prevents a particular aircraft maintenance task from being accomplished does not necessarily result in a reduction of one aircraft sortie that day. When priorities are assigned in aircraft maintenance, preference is given to those maintenance tasks that can increase the number of sorties flown. If one aircraft cannot be flown because a change in the minimum manning requirements eliminates the people needed to do the task in the current shift, other aircraft would be assigned a higher priority and processed through the maintenance system. In addition, if the manpower saved by decreasing or eliminating the minimum manning requirement were used where it was needed most, or if there were a parallel effort directed toward increased CUT, the sorties generated might even increase. The point is that because of the interpendencies that exist among the maintenance tasks and decision rules, the effect of such a change in policy on military output can only be evaluated by analyzing the maintenance system as an entity.

We conclude, therefore, that the capabilities models that we have been considering can play a more significant role in the evaluation of CUT and minimum manning. When skill mix questions are being considered, it is appropriate to understand whether the analysis is being accomplished to specify doctrine or being used to improve current practice.

COST AND CAPABILITY

The next step would be to relate the estimated trade-offs to relative cost. There are differential manpower costs associated with each specialty area. This type of analysis will aid the determination of a cost-effective allocation of resources in the generation of sorties.

We have also identified the significant benefits from CUT. As we have indicated above, one needs to carefully analyze CUT's cost dimension.

UNCERTAINTY

As we make analysis coverage more comprehensive and realistic, it is appropriate that the models be made more realistic in their treatment of uncertainty. The way uncertainty is typically handled is to specify the probability of failure of each aircraft part on a particular mission. Then, during a specified mission, a part will either fail or not fail given a roll of the appropriately sided die.

We argued above in Sec. III that because so many different types of parts can fail, each random drawing can be expected to place a similar aggregate set of demands for unscheduled maintenance. As long as the maintenance force, with its skill-associated repair times, is reasonably well matched to the specified failure rates and resulting demands for maintenance, one would not expect a great deal of variation in the number of sorties that can be achieved from a given number of maintenance personnel. We conclude, therefore, that the resulting relationship between manpower and sorties may be nearly deterministic even though the part failure rates are random. This would continue to be applicable when repair times are also assumed to be random.

One may question whether this approach captures the real uncertainty associated with combat operations. Although there are many types of uncertainties to consider, one type that might be dealt with directly is the uncertainty associated with the specified failure rates and mean repair times. Consider then what might happen if the probability is significant that the failure rates for some set of parts are higher than expected and the repair rates are lower than expected. A specialized maintenance force would not be able to effectively deal with this "worst case" type of planning situation, and substantial bottlenecks would emerge. Also, in this situation, one would begin to encounter a very large randomness in the number of sorties generated by each trial with a given number of maintenance personnel.[1]

It is in this situation that manpower flexibility, as measured by the extent of cross-training, would show substantial returns. The effect would be to both increase the expected number and reduce the variance of the total number of sorties. We suggest, therefore, that the existing models be extended to handle this additional level of uncertainty. In this manner one can begin to assess the value of flexible forces.[2]

MODEL VALIDATION

Greater efforts are needed in the area of model validation, including sensitivity analyses. One needs to ensure that the models accurately portray the operational environments. As a minimum, this suggests more use of actual base-specific data so that the model output can be compared with the results actually obtained during surge training activities.

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[1]This issue has been discussed in Gotz and Stanton (January 1986). For a discussion of the role of uncertainty in modeling, see Emerson (February 1969).

[2]This capability does exist in TSAR, but it has not been used in actual analyses.

On the other hand, the validation process can only proceed so far. The most interesting model applications may be in an environment where there is aircraft battle damage and attrition as well as airbase attack. In fact, TSAR was actually designed to deal with these types of war fighting issues. These realistic features of air operations need to be more extensively incorporated in analysis. And when account is taken of them, the magnitude of the uncertainties is revealed to be even larger, and an additional argument for flexible resources emerges.

ADDRESSING BROADER POLICY QUESTIONS

To effectively use manpower models to address broader policy questions, several key factors must be dealt with. First, the organization directly responsible for conducting the analysis must have responsibility for all the policy factors to be included in the analysis. Second, the model must be appropriate to the questions being addressed. Third, the model must be flexible and the underlying computer code must be accessible and changeable so it can be used over a period of time. Fourth, the assumptions used with the model must be appropriate and balanced. Fifth, the time and cost of running the model must be small enough to allow a reasonably thorough exploration of the policy questions. The broader and more general the policy questions, the more factors there will be that need to be varied and, thus, the more important a quick and efficient program will be. Finally, the cost of developing the computer program must be small enough for the benefit from its use to exceed the cost of development.

Organizational Responsibility

A broad analysis of manpower policy might have to include the interactions with spare parts and test equipment. We have already noted that when LCOM was originally developed, it was set up to optimize the total manpower *and* logistics resources; it is not used that way now. Rather, manpower analyses typically hold logistics resources constant and vice versa. As an example of the importance of this constraint, the manpower analysis group at Hq TAC was asked to estimate how much additional manpower would be needed to compensate for a possible higher-than-previously-expected failure rate for a key piece of test equipment. Under the stipulation that logistics resources would be held constant, it was determined that no amount of manpower could do the job. In order to complete their task, the group was required to formally justify an increase in some of the logistics resources in their analysis.

This suggests that any manpower analysis that includes the trade-offs with other logistic resources needs to be done by an organization with both manpower and logistics responsibility. Similarly, to fully analyze a manpower mix with substantially increased skills, training and accession policy would need to be examined. Other policy questions might have an impact on force structure or procurement questions. Clearly, a comprehensive view needs to be taken.

Methods for Model Development and Maintenance

Obviously the capabilities of a computer model are determined in part by the way in which it was developed and maintained. Heretofore, we have been concerned with the results of these efforts but not with how they were achieved. However, in the following discussion, we will explicitly consider the possibility of developing a new computer model. Therefore, alternative development methods must be considered. Similarly, the feasibility of modifying an existing computer model will depend on how it was developed and maintained.

Basically, there are two distinct methods by which large computer software projects are developed. The first method is characterized by one key individual who understands all aspects of the software as well as the problem it is designed to solve. This individual has overall responsibility for developing and maintaining the software, is responsible for coding and debugging and maintenance, and is also a principal user of the software. We label such individuals "honchos." A good honcho's knowledge of the problem and of the software reinforce each other. Frequently honchos write software entirely alone. When they do have additional programmers working for them, these subordinates are few in number, and the honcho works closely with them, integrating all the codes together and understanding all the codes.

The alternative method for large software development is the team approach. The team approach is based on subdividing the overall problem into smaller pieces, each of which is the responsibility of one individual. The overall programming approach is selected so that the pieces fit together with an interface that is as simple and standard as possible. Unfortunately, the problem generally must be structured, the pieces defined, and the interfaces chosen before any experience in attempting to develop the computer code can enlighten these decisions. Compromises to meet these standards are then incorporated in the resulting code. These compromises tend to produce an inefficient, inflexible code that is very hard to modify. Furthermore, the software will be very structured and may be written in specialized computer languages chosen for their suitability to such structuring rather than for efficiency, interpretability, flexibility, or modifiability.

The team approach is the appropriate choice primarily in situations where the problem is too complex for any honcho to handle or where no one with the appropriate knowledge and skills is available to be a honcho. Because of the highly structured code that results, the team approach is also indicated in situations where fail-safe testing is needed (for instance, flight control software for the space shuttle).

In situations where either method could be used, the honcho method has many advantages. Initial development is relatively rapid and costs generally much lower (because both less time and much less manpower are involved). A honcho generally uses well-known, general-purpose, portable computer languages and produces efficient and functional code. A good honcho understands the code well enough to make modifications relatively quickly. Furthermore, code produced by the honcho method will be such that it is feasible for a new individual to learn all of the software and, if needed, to replace the honcho or to honcho a separate version. The team approach tends to produce inefficient, hard-to-modify code that is too complex to allow any individual to comprehend the overall software completely.

Monte-Carlo simulation models for manpower analysis are well adapted to the honcho approach. The scale is small enough for a honcho to understand the overall problem. A comprehensive view of the software and knowledge of the underlying problem can reinforce each other effectively, and good potential honchos with an interest in the problem exist. The honcho method has worked well for TSAR, SPECTRUM, and ALOM. The importance of the honcho role will be mentioned below when it is relevant.

Model Appropriateness

Selecting an appropriate model (or modeling paradigm, if a new model is to be developed) is the simplest of the tasks addressed here. TSAR, SPECTRUM, and ALOM each has a honcho who has had overall responsibility for developing, coding, and using the specific model. In each case this primary individual is aware in great detail of the capabilities and limits of the model.

Frequently, teams responsible for using a model are interested in addressing broader policy questions than is the honcho, questions the models can handle, but they are frustrated by organizational constraints. For many potential additional policy questions, TSAR or SPECTRUM could be modified to handle the analysis. (Possibly ALOM as well, though this model is a bit more specialized, newer, and not quite as fully developed.) In each case, the modified program would need an individual in the honcho role, either the current honcho or a new one. Development of a new model would require selecting an extremely competent honcho to work with current experts to determine the desired capabilities for the model.

Model Flexibility

The four major manpower models all include in their structure the degree of needed flexibility (though, in the case of LCOM, the time and expense to utilize this flexibility can easily become prohibitive). However, some policy questions inevitably arise that require modifying the computer code if they are to be practically addressed by the model. Because of the inherent complexities of these models, it is here that a honcho is absolutely essential. Furthermore, the program should be written in a simple general-purpose computer language, such as FORTRAN.

In discussing the modifiability of the various models with their respective groups, we used a couple of sample modifications. The first test modification was: "If not enough people of the needed MOS were available, allow substitutions of anyone with the right broad skill (e.g., electronics or hydraulics), so long as at least one person of the right MOS was available." In each case, the first response was (as expected) that a set of input data could be generated to do this "in effect." However, in each case it was agreed that unless the problem was otherwise oversimplified, such an approach would result in an unduly slow and costly estimation. It was also determined that adding an elaboration such as "on-the-job learning" (a reduction in the time penalty each time the same person substituted for the same MOS) would make the approach of changing only the data input clearly impractical. While we have described the test modification in detail here, this is not to suggest that this particular modification is important; rather it is to demonstrate that the "test" was reasonably simple but nontrivial and fairly representative of the kind of modification that might be desired. The interesting result was that the programs (TSAR, SPECTRUM and ALOM) written entirely or mostly in FORTRAN could be so modified in less than a month by one person, whereas LCOM (written in SIMSCRIPT, a complex specialized language *designed* for writing Monte-Carlo simulation programs) might require six or more months.[3]

[3]We also discussed the cost of modification with the Force Evaluation Model (FORCEM) group. While FORCEM is a somewhat different kind of program, no nontrivial modification could be expected to require less than a man-year of effort (FORCEM is also written in SIMSCRIPT and is being coded by a large team with each person having responsibility for a different piece of code).

In a second test example, we obtained similar answers. We considered a possible analysis of the general advantages attainable by increasing the number of cross-trained individuals. LCOM has attempted to address this issue by running cases with groups of skills combined (i.e., allow *all* individuals with skill A to be cross-trained for skill B and vice versa, then consider AB a single skill). This approach is obviously easy to implement in these Monte-Carlo simulation models. However, this approach assumes an inflexible skill structure compared with the case where one person knows skills A and B, another A and C, etc. Therefore, it does not fairly represent the practical possibilities of CUT.

A more flexible cross-trained skill structure may have even greater overall capability with fewer cross-trained individuals and will be much more robust to alternative failure probabilities. While either TSAR or LCOM could address this question as currently designed, the current code could not do so efficiently and an inconveniently large amount of input data would be needed. (In the case of LCOM, the only practical approach would be to write a program to generate the data!) Again, the modification of TSAR, but not LCOM, would be practicable.

The important point here is that a policy issue was framed in an undesirably limited way for analysis by LCOM, not because LCOM could not handle the more general formulation, but because of the "mere" manhours, computer time, and cost involved in so doing. Both a flexible program structure and accessible and easily modifiable code are necessary for a Monte-Carlo simulation model to be a good policy analytic tool for a broad range of policies. We note that while TSAR and SPECTRUM have been modified from time to time, LCOM has rarely, if ever, been modified in the recent past.[4]

Model Assumptions

The selection of appropriate and balanced assumptions for a given policy analysis is similar to the problem of selecting an appropriate model. It is important to understand, however, that the data inputs are so voluminous that external testing of the assumptions they embody is rarely feasible. Thus, just as the organization conducting the analysis must have responsibility for all the policy factors included, it also must have incentives to produce an accurate, unbiased answer. Even with the best of intentions an organization with an interest in a particular policy outcome may tend to subtly bias elements.

[4]ALOM is too new to have a substantial history of modifications.

It is also important to recognize that different questions can require very different levels of input detail and complexity of assumptions. For instance, PROLOGUE is run with relatively simple assumptions. These are, however, entirely appropriate for PROLOGUE's primary use, which is to check quickly whether a given plan incorporates an appropriate balance of maintenance units vis-à-vis combat units. On the other hand, PROLOGUE's simple assumptions would not be adequate for, say, a policy study of the benefits resulting from additional CUT.

Addressing broad policy questions using simulation models inherently involves comparing numerous runs. There are many reasons the number of runs tends to grow significantly beyond that initially anticipated. First, obvious policy questions involve inherent comparisons. Second, major changes in one area usually require adjusting other policies to obtain the optimal effect. For example, if one is analyzing the issue of basing some aircraft in small units nearer the front in shelters off highways, with less maintenance resources, it is appropriate to consider the option of procuring a different aircraft. In this situation, more reliable aircraft would be at a particular premium, smaller aircraft would be better, and those that currently exist in inventory might not be the most cost effective.

Third, the optimizing parts of simulation models have the unfortunate tendency to produce implied behaviors that are impossible or implausible when faced with assumptions qualitatively different from those envisioned when the optimizing mechanisms were chosen. This inevitably produces results that are difficult to interpret, resulting in a need to modify the assumptions and compute new results.

Fourth, initial simulations may suggest that a given policy outcome depends critically on other assumptions in the model. If the foundation of these assumptions is not firm, it is necessary to vary them to determine if the policy prescription is robust. Finally, many interesting policy questions involve not just comparing a few discrete alternatives, but instead requiring optimization over entirely new dimensions. These considerations imply that many simulations are required for a typical broad policy question to be investigated.

Time and Cost of Model Operation

As we discussed earlier, the ability to do multiple and complete analyses is frequently determined in practice partially by the time and cost of model operation. Many of the problems with using models in practice would require more complex model runs to be eliminated. Thus, fast and efficient model runs are important generally. Some of the models currently use two factors that are keys to obtaining the fast and efficient simulation runs necessary for detailed policy analyses. First, as we have indicated, the program must be developed with a honcho. When programs are developed by large groups with an extensive division of labor and no honcho, a slow and laborious code will inevitably result. Second, the program should be written entirely or primarily in FORTRAN or some other well-known, general-purpose, reasonably efficient programming language.

There is also a third factor that is not employed in any of the models surveyed here. The models should be designed to utilize modern techniques for efficient Monte-Carlo estimation of the *difference* in results between two sets of inputs. Most policy studies depend specifically on estimating such differences. Such a capability is best incorporated in the design of the program.[5]

The two most important techniques in this context are (1) reusing random numbers and (2) reusing antithetic random numbers. To reuse random numbers, the random numbers chosen are divided into streams, each stream having its own unique use and unique sequence of random numbers. Each of these streams is then used once for each policy alternative considered. Thus, if flying hours between failure by tail number are determined in a Monte-Carlo fashion, the sequence of intra-failure times (and type of failure) can be the same for each policy considered. Thus, no policy can happen to benefit relative to the others due to randomly less frequent failures. This reduces the number of Monte-Carlo iterations necessary to make reliable policy comparisons.

Antithetic random numbers can be illustrated using this same example. Suppose that failures occur at a constant rate per unit time. Then the time between failures is minus a constant times the log of a zero-one uniform random variable. Note that if R is a zero-one uniform random variable, $1 - R$ is as well. To use antithetic random numbers for failure times, a program would, after running each policy with one stream of random numbers for failures, replace each uniform random number with one minus the old value and run each policy with this new stream. Thus, if the first set of runs obtains unusually frequent failures, they would be equally unusually infrequent in the second. Therefore, fewer runs would be required to ensure that the policies have been tested in a representative set of environments.[6]

[5]TSAR or SPECTRUM could be modified to incorporate such a capability.

[6]Another technique is to compute the compound probability of a complex but frequent event once and, at appropriate points, make a test against a single random number. Thus, only infrequent complex events would require multiple tests. A similar technique is to save the policy invariant results of Monte-Carlo draws for reuse in multiple scenarios.

Model Development Costs and Benefits

By following the above prescriptions, a new Monte-Carlo simulation model for detailed broad policy analyses could be developed. A well-functioning development effort using a honcho should succeed in about a year. Alternatively, with one to three man-years of effort, TSAR, SPECTRUM, or perhaps ALOM could be modified at less cost to be almost as good as a policy analysis tool. The best strategy would seem to be to select a set of policy questions that would be addressed by such models and then consult extensively with the honchos of the existing models. Whether a new development effort would be worth the cost (and risk of misjudgment and failure to produce a tool of the desired capability) would depend on how well-fitted current models are to the policy questions to be considered.

V. CONCLUSIONS

Our survey identifies a wide variety of models currently in use that link manpower to military capability. Some models include only a limited representation of manpower while others include a detailed representation. The most detailed models link skilled maintenance manpower to aircraft sorties. Generally, the level of detail was selected to be appropriate to the analyses for which the model was intended.

In accordance with the focus of this project on manpower, our study emphasizes the four models with the most elaborate manpower representation. All four are Monte-Carlo simulation models that link maintenance manpower to aircraft sorties and that are being used effectively in current manpower analyses. Further, each model is very flexible in principle and capable of performing a much broader class of analyses than those currently being performed. Of course, any new analysis would require substantial work in developing appropriate data and formulating the analysis.

We determined two critical requirements necessary for such models to be used to perform broader policy analyses effectively. The first requirement is that the organization requesting the analysis must have the authority to consider all the factors that need to be included in the analysis. The person performing the analysis must be solely responsible for its accuracy and must be disinterested in the impact of the results on any particular factor in the analysis. The second requirement is that the model must be developed by the honcho method and must be maintained by a current honcho who is capable of modifying the code in a reasonable time. This honcho must be either the person performing the analysis or available to aid that person.

Of particular interest are the possibilities for model-based broad policy analyses. The currently available models were not developed with this type of analyses in mind. Their performance in this area could be improved by adopting some modern Monte-Carlo techniques designed for such situations. For example, individual analyses could be greatly facilitated by appropriately targeted modifications of the computer code. Three of the current large-scale Monte-Carlo simulation programs are written primarily or entirely in FORTRAN and maintained by the honcho who developed them; any of these could be so modified. Alternatively, a new Monte-Carlo simulation model could be developed by the honcho method using a general-purpose computer language. We believe that either approach should result in a powerful policy analysis tool.

REFERENCES

Abell, J. B., T. F. Kirkwood, R. L. Petruschell, and G. K. Smith, *The Cost and Performance Implications of Reliability Improvements in the F-16AB*, The RAND Corporation, N-2499-AF, March 1988.

Bell, C. F., Jr., and J. P. Stucker, *A Technique for Determining Maintenance Manpower Requirements for Aircraft Units*, The RAND Corporation, R-770-PR, May 1971.

Berman, M. B., J. Holliday, T. F. Kirkwood, W. E. Mooz, E. D. Phillips, R. J. Kaplan, and C. L. Batten, *Integrating Basing, Support, and Air Vehicle Requirements: An Approach for Increasing the Effectiveness of Future Fighter Weapon Systems*, The RAND Corporation, R-3304/1-AF, August 1985.

Emerson, D. E., *A Note on Handling Uncertainty in Force-Structure Studies*, The RAND Corporation, P-4017, February 1969.

Emerson, D. E., *An Introduction to the TSAR Simulation Program: Model Features and Logic*, The RAND Corporation, R-2584-AF, February 1982.

Emerson, D. E., and L. H. Wegner, *TSAR User's Manual—A Program for Assessing the Effects of Conventional and Chemical Attacks on Sortie Generation, Vol. 1, Program Features, Logic, and Interactions*, The RAND Corporation, N-2241-AF, August 1985.

The First Japan-U.S. Operations Research Seminar, abstracts and papers, September 16–29, 1986, Camp Ichigaya, Tokyo, October 1986.

Fisher, R. R., W. W. Drake, J. J. Delfausse, A. J. Clark, and A. L. Buchanan, *The Logistics Composite Model: An Overall View*, The RAND Corporation, RM-5544-PR, May 1968.

Gotz, G., and R. E. Stanton, *Modeling the Contribution of Maintenance Manpower to Readiness and Sustainability*, The RAND Corporation, R-3200-FMP, January 1986.

Joint Chiefs of Staff, *Department of Defense Dictionary of Military and Associated Terms*, JCS, Pub. 1, Washington, D.C., April 1984.

Lanagan, T., "Applications of Model Based Aviation Manpower Requirements Criteria (MARC) to Aviation Unit Design Issues," presented at The U.S. Army Operations Research Symposium, Ft. Lee, Virginia, October 1986.

Miller, T., "Modeling for Manpower Requirements," *The First Japan-U.S. Operations Research Seminar*, September 16–29, 1986, Camp Ichigaya, Tokyo, October 1986.

Moore, S. C., et al., *Exploratory Analysis of Aircraft Maintenance Task Allocation Alternatives*, Advanced Technology, Inc., Reston, Virginia, and Universal Energy Systems, Inc., Dayton, Ohio, December 1985.

Perraza, J., and G. Temkin, *Aviation Resources, Readiness and Combat Sustainability: SPECTRUM System Level Documentation*, Naval Air Development Center, Warminster, Pennsylvania, November 15, 1986.

Shishko, R., and Kamins, M., *AURA Applications: Division-Level Transportation and Selected Spares Issues*, The RAND Corporation, R-3156-MIL, January 1985.

U.S. Air Force, *Logistics Composite Modeling (LCOM) System User Manual*, AF Manual 171-605, May 15, 1984.

U.S. Army Concepts Analysis Agency, *Force Evaluation Model: FORCEM Briefing*, Washington, D.C., March 1985.

U.S. Army TRADOC Analysis Center, *Combat Service Support Representation in VIC*, briefing, White Sands, New Mexico, November 1986.