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A R M S T R O N G L A B O R A T O R Y

CRITICAL EXPERIMENTS OF HARDMAN III UTILITY FOR USE BY AIR FORCE ANALYSTS

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13. ABSTRACT *(Maximum 200 words)*
This paper documents a software modification and validation effort targeted at providing a manpower requirements analyses tool for the Air Force's Integrated Manpower, Personnel, and Comprehensive Training and Safety (IMPACTS) program. Described are development and testing of the Air Force-MANpower CAPability model (AF-MANCAP) which was derived from the Army's HARDware vs. MANpower (HARD MAN III) suite of manpower, personnel, and training analysis tools. The paper also provides results of field product reviews and a convergent validation test using the Logistics Composite Model (LCOM).

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PREFACE

This paper describes the development and testing of the Air Force-MANpower CAPability model, or AF-MANCAP. The focus of this paper is to provide a top level review of the AF-MANCAP model. Also, the paper provides the results of a user survey and a convergent validation test. The convergent validation testing model was the Logistics Composite Model (LCOM).

The Army's HARDware vs. MANpower (HARDMAN III) suite of manpower, personnel, and training analysis tools was the steppingstone for the development of AF-MANCAP. The authors appreciate the support of Dr. Jonathan D. Kaplan and Mr. Rich Maisano from the U.S. Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue, Alexandria Virginia who provided support to transition the Army's manpower analytical concepts into an Air Force analytical approach. Also, thanks to Mr. Edward Boyle for the use of his paper LCOM Explained.

During September 1991 HAY Systems, Inc. demonstrated the AF-MANCAP software and obtained comments from potential analysts. We thank the following personnel who contributed to this effort:

- Headquarters Air Force Logistics Command participants (3 September 1991) - - Captain Steven Andrasz, Mr. Keven Cooksey, Major Greg Grice, Mr. Harold Hixson, Mr. John Madden, Mr. Max Mohr, and Mr. Dave White.

- Aeronautical Systems Division participants (4 September 1991) - - Captain Steve Bean, Lieutenant Colonel Ken Binzer, Mr. Billy Bishnow, Captain Bob Boeshart, Mr. Fred Conway, Mr. Dick Cronk, Lieutenant Colonel Paul Cunningham, Mr. Don Dyer, Lieutenant Chase McCown, Mr. John Magnone, Captain Jack Mohney, Mr. Ray Moore, Mr. Richard Schiffler, Captain Pat Vincent, Mr. Allan Wallace, and Lieutenant Cheryl Zeek.

- Headquarters Tactical Air Command participants (23 September 1991) - - Technical Sergeant Bussy Bolster, Major Steve Cooper, Mr. Karl Fulnecky, Mr. Ed Merry, and Senior Master Sergeant Jim Schoeppel.

Comments and suggestions to a draft, received from several sources, have improved the paper's technical accuracy. These were: Hay Systems Inc: Mr. Ken Johnson and Mr. Terry Garrett. Also, Ms. Robin Walthour assisted in the edit and document preparation.

This volume is the final report of the Critical Experiment to modify HARDMAN III software for Air Force use. This effort included the development of the AF-MANCAP software and seven additional technical reports. The work was performed under Contract No F49642-88-D0003, Delivery Order 5027.

SUMMARY

The Air Force-MANpower CAPabilities (AF-MANCAP) analysis aid is designed to assist Air Force acquisition managers in developing a Baseline Comparison System (BCS). Using AF-MANCAP an analyst creates a task level database from current operational system data. The task level database closely represents the design, operational, and support characteristics of a new system under development. Linked to the BCS function is a stochastic simulation process. The model supports simulations at the component level and task level for an individual system. The outputs include reports of component repair manhours and associated data. These data include: Air Force Specialty Code (AFSC), number of personnel performing the task, maintenance task time, and mean time between component failure.

Using the AF-MANCAP model, an analyst has a personal computer-based tool to assess the impacts of proposed hardware trade-offs for resource requirements (manhour increases or decreases). Also, the model includes the capability to assess the impact of trade-offs at the system level in terms of availability measures. The availability measures are: inherent, achieved, and operational.

The current study is a proof-of-concept project. The first phase of the effort involved a top-down review of software and documentation from the United States Army HARDware vs. MANpower (HARDMAN) project. The changes for converting the Army's maintenance and skill concepts as well as types of activity for adding Air Force data were detailed in a testing plan. The second phase of the project added new task level databases and covered the modification/debugging of the simulation software. Concurrent with the software modifications, a structured demonstration was developed for the critical experiment task of the statement of work. The Laboratory Contract Monitor and 16 potential users participated in the critical experiments. Their reactions to the product are detailed in this report. The third phase of the project implemented a convergent validation analysis strategy. The results of AF-MANCAP simulation scenarios were compared to the results from Logistics Composite Model (LCOM) simulations using the same input data and assumptions.

The users participating in the second phase, or critical experiments, were personnel familiar with the Air Force's Integrated Manpower, Personnel, And Comprehensive Training and Safety (IMPACTS) program. After viewing the software and the available documentation the personnel

commented on the ability of the product to fulfill their customer needs. Four rating levels were used:

- Excellent - the product equals or exceeds the requirements on every aspect, and can be used as specified - - the product is very satisfactory.

- Good - the product equals or exceeds the requirements on most aspects. It can be used as specified, or with minor limitations -- the product is satisfactory.

- Fair - the product doesn't meet the requirements on some aspects. It can however be used, but with major limitations - - the product is almost satisfactory.

- Poor - the product does not meet the requirements. It cannot be used - - the product is not satisfactory.

Using the above rating level, we assessed customer satisfaction in five areas. The five areas were: functionality, reliability, usability, efficiency, and maintainability. The customer ratings, for the 16 participants were:

- functionality <u>Good</u> - the product performs user required functions, with only minor limitation in some of them.

- reliability <u>Good</u> - the product performs its intended functions under all conditions. However, infrequent conditions such as extreme load out of specification input data sets or function parameter might result in incorrect output.

- usability <u>Good</u>- minimal prior training is necessary. This training can be done with a "tutorial" type of software package, included in the main delivery. On-line itemized "help"is available. Full user documentation is provided.

- efficiency — Good - response time remains acceptable under all conditions; however, performance degradation under simulation conditions is noticeable. The software indicated when products will be available.

- maintainability — Good- some documentation is available to the user.

Since the 1960s the Air Force has used the main frame based Logistics Composite Model (LCOM) as a manpower analysis tool. This tool relates base-level logistics resources with each other and with sortie generating capability. The four LCOM users assessing AF-MANCAP, during the critical experiment, quickly recognized that the personal computer based AF-MANCAP is not a one-for-one replacement. Their AF-MANCAP product assessment ratings were lower than the 12 personnel who were not LCOM experts.

The third phase, or evaluation phase, was a cooperative effort with contractors and Armstrong Laboratory personnel. Hay Systems, Inc. personnel conducted over 80 hours of AF-MANCAP software testing. Armstrong Laboratory personnel accomplished the LCOM testing for the convergent validation. A common task level database representative of a notional new fighter aircraft was used for the convergent validation.

Based on the convergent validation effort we conclude that the AF-MANCAP analysis aid provides reliable manhour requirements. We thought the model would provide manpower requirements; however, this determination could not be evaluated due to overall model size constraints. This was a proof-of-concept demonstration. We identified several areas where changes will improve the accuracy, efficiency, and effectiveness of the analysis aid. The changes for example: increase the task capability from 300 to 3,000 tasks, modify the sortie sequencing screens, add task sequencing, and add life cycle cost features. With such enhancements, the AF-MANCAP analysis aid can support the early phases of an acquisition, when the using command is striving to identify manpower constraints for preparation of the Mission Need Statement or Operational Requirements Document. Also, the AF-MANCAP analytical approach is supportive of activities conducted by the acquisition activity during the concept development phase and later acquisition phases. In the later acquisition phases the tool could be used for trade-off study evaluation.

AIR FORCE-MANPOWER CAPABILITY ANALYSIS AID: CRITICAL EXPERIMENTS

I. INTRODUCTION

The Air Force's new Integrated Manpower, Personnel, and Comprehensive Training and Safety (IMPACTS) program integrates, during the acquisition cycle, six human systems disciplines. The human systems disciplines are: manpower, personnel, training, safety, health hazards, and human factors engineering. The goal is to support the development of mission-capable systems that can be operated, maintained, and supported effectively at the lowest life-cycle costs.

The existing human systems integration tools and databases typically provide independent answers addressing manpower, personnel, and training, etc. The existing tools, also, do not work in concert and do not support the retention of historical or current operational data. Usually, the major effort to analyze the impacts of the disciplines occurs after the manufacturing and Engineering Development phase. In these situations the major design decisions have been made and most life-cycle costs already fixed. One of the reasons for the lateness is the lack of sufficient data and analysis tools. (Rossmeissl, et al, 1990)

Prior Research

United States Air Force Research - - In support of IMPACTS, several research efforts are underway at the Armstrong Laboratory to develop the necessary tools and databases for timely analysis of acquisition programs. A front-end analysis tool called Weapons System Optimization Model (SYSMOD) is under development. This tool supports the Mission Need Statement plus the concept exploration and definition phases of the acquisition process. Another effort at the Armstrong Laboratory is the Manpower, Personnel and Training Decision Support System (DSS). This tool supports the demonstration and validation phase plus later phases of the acquisition process. The development of the DSS may require four to five years of research and development.

Once through development, SYSMOD and the DSS tools must be tested and distributed. Moreover, analysts must be trained. SYSMOD and DSS may not come into accepted use within the Air Force for several years. Yet the need for new tools exists today. (Rossmeissl, et al, 1990)

United States Army Research - - This report addresses the potential of adopting off-the-shelf technology from the Army for the creation of a tool for the immediate use by the IMPACTS program. Foremost among the tools are the HARDware vs. MANpower (HARDMAN) tools developed by the Army Research Institute (ARI). There are two software tools within the HARDMAN approach. These tools are HARDMAN II.2 and HARDMAN III. We provide a brief overview and discussion of the current use of the two tools in the following paragraphs:

- The HARDMAN II.2 tool: HARDMAN II.2 requires a Vax-11 computer to host the suite of analytical processes. The HARDMAN II.2 software provides an analytical approach for early estimation of manpower, personnel, and training on Army systems in the early phases of the acquisition process. The software was available for use after 1985 and has undergone some degree of operational testing and validation. An upgraded version became available during 1990.

  The cost of applying the HARDMAN II.2 method is approximately two and one-half person-years for a large system, but varies with such factors as system size, system complexity, accessibility of data and experienced analysts. A fairly large (ten plus) team of interdisciplinary analysts must conduct an analysis. (Bogner, Kibbe, Laine, and Hewitt, 1990)

- The HARDMAN III tools. Since 1986, the Army conducted additional research and development for the creation of a new set of Personal Computer (PC) based tools known as HARDMAN III. These tools require the use of an IBM PC-AT or compatible computer. The software consists of six components. Each component can be used either singly or in combination for a determination of the number, attributes, availability, and training needs of the manpower required to operate and maintain the system. This methodology is appropriate for use in evaluating system designs before the decision to develop a prototype. Also, the methodology provides trade-offs when data are available from breadboard or prototype hardware. (Bogner, Kibbe, Laine, and Hewitt, 1990)

  The cost of applying the HARDMAN III methods can be one-half person-year for a large system. The cost varies with such factors as system size, system complexity, accessibility of data and experienced analysts. The library of historical data and user friendly software eliminates the need for the large team of interdisciplinary analysts. (Bogner, Kibbe, Laine, and Hewitt, 1990)

Origin of Air Force-MANpower CAPabilities Analysis Aid

During 1990, Air Force researchers noted that the HARDMAN III personal computer (PC) or compatible computer features and user friendly screen technology had the potential for immediate applications within the Air Force. Additionally, the Army's manpower evaluation component of the software may be adaptable for Air Force use. Figure 1 shows that the off-the-shelf technology was lifted from the MANpower-based System EVALuation (MANSEVAL) and MANpower CAPabilities (MANCAP) components. The output of this effort was the Air Force-MANpower CAPabilities (AF-MANCAP) model.

Influencing the Weapons System Design

Human resources (manpower, personnel and training) account for nearly 50 percent of the yearly operations and support cost of weapon systems. Therefore, any policy, design concept, or technology that affect the human resources, should be evaluated for trade-offs and appropriate input made to the acquisition decision process. AF-MANCAP supports trade-off analyses at the task level and serves two key purposes: influence design(s) and provide information.

First, an AF-MANCAP analysis aid can identify and limit requirements for manpower, particularly for tasks that demand support from more than one individual. Also, the analysis aid tracks support needs for different Air Force Specialties (AFS). The focus of this analysis is to *influence design*. Design influence trade-off studies can identify *high driver* tasks and thereby help to specify mission need goals or constraints.

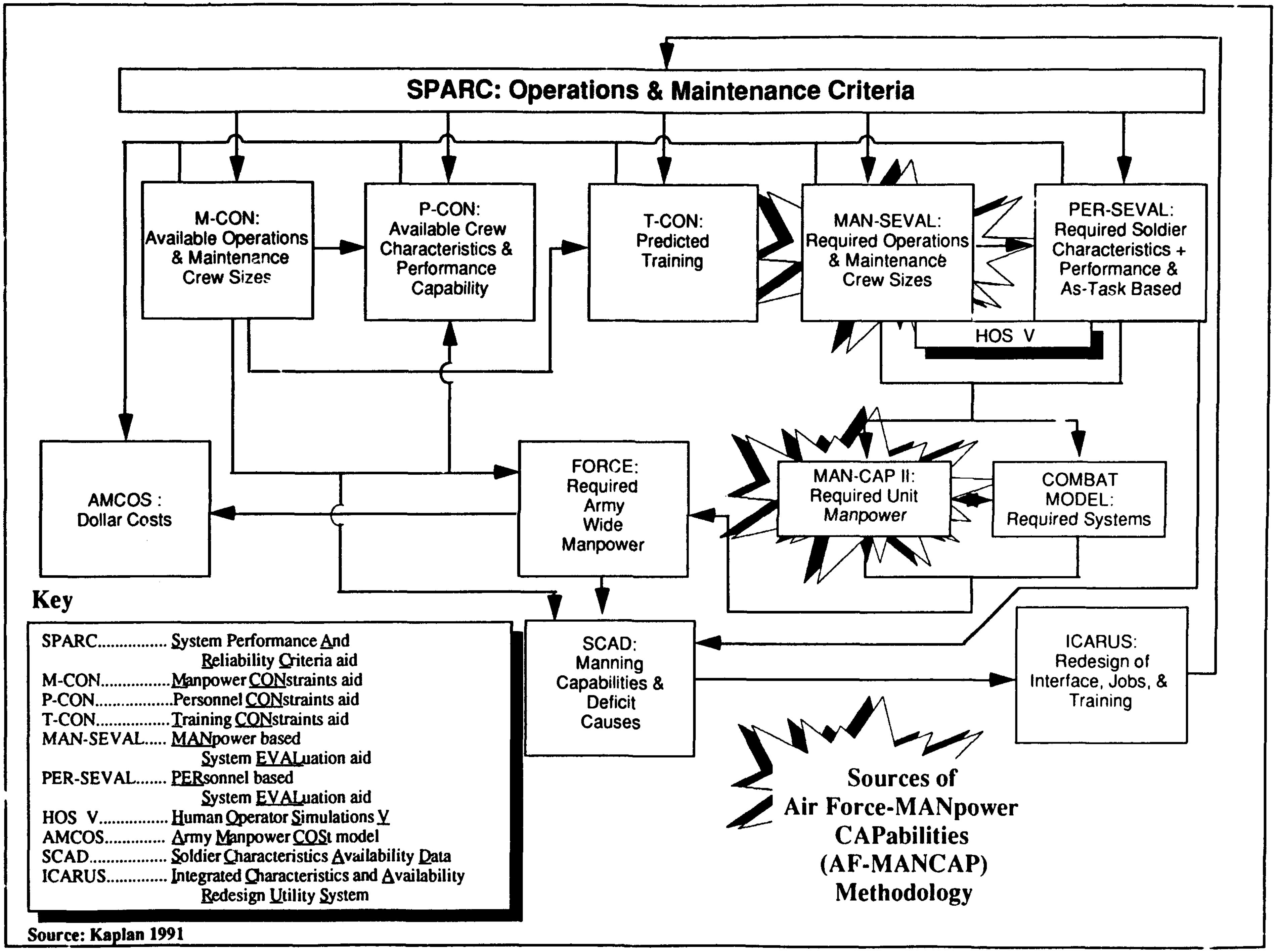


Figure 1. Origin of Air Force-MANpower CAPabilities analysis aid.

Second, an AF-MANCAP analysis aid supports work force planning. Planning in this context addresses: the structure of the AFS and the numbers of personnel. The focus of this analysis is to *provide information* about the work force. However, trade-off studies of the type supported by AF-MANCAP cannot be easily quantified in isolation from other factors. In this instance, AF-MANCAP provides information on work force requirements with the overall requirements evaluated against system level measures of availability (e.g., inherent, achieved, operational, and sortie).

Need for Manpower Analysis

According to Boyle (1991) "requirements documents from users (e.g., statement of need, system operational requirements document) will often state manpower targets for direct maintenance manhours per operating hour or manpower spaces per unit. In practice, this is typically all that is meant by design influence for human resources. In effect, manpower, personnel and training (MPT) analysis means manpower analysis."

In the late 1960s early 1970s the Air Force demonstrated the need for responsive methods for predicting maintenance manpower requirements during weapons system development (Tetmeyer and Moody 1974). Evolving from this early research was a maintenance manpower simulation named the Logistics Composite Model (LCOM). Through simulation, the impact of availability of all types of support resources on the operational status can be assessed. This approach was applied to the A-10 weapon system, using early estimates of maintenance task data for the new aircraft coupled with detailed operational scenarios and maintenance concepts. The A-10 model reflected Air Force experience with comparable subsystems and equipment on existing aircraft, factored for the new design and environment (Tetmeyer and Moody 1974).

The early LCOM efforts grew into a composite of individual programs written in SIMSCRIPT II.5. These communicate directly with each other and function as a unit. The LCOM software provides simulation support to studies concerning Air Force base level functions, e.g., operations, maintenance, and supply. The LCOM software, together with the data representing a weapons system's environment, form either peacetime or wartime base level study models. The model permits the analysis of weapons system support requirements (Dengler 1981).

LCOM modeling support is often extensive and the development time lengthy. Past model development for the validation of Major Command manpower requirements can consume six or more person-months of analytical support. The activities include: collection of the maintenance task data, validation of the data, development of the operational scenario, creation/testing of the simulation networks and report production. Modeling of this magnitude during new weapon system development is usually accomplished during the later stages of the acquisition process.

Some reduction in the LCOM modeling support requirements and development times are possible through top level modeling of existing networks. Analysts from the Directorate of Manpower, Personnel, and Training, Aeronautical Systems Division (ASD/ALH), in report some success in providing early estimates support. Finished reports were produced in weeks, and supported decisions in the early stages of the acquisition cycle

AF-MANCAP does not replace the LCOM model. However, the AF-MANCAP analysis aid, with recommended refinements, can satisfy a requirement for a PC-based comparability manpower tool.[1]

Section II of this report focuses on the methods, assumptions and procedures for the conversion of the manpower evaluation components of HARDMAN III for Air Force use. Included is a structured interview process for soliciting potential users' reactions to the AF-MANCAP software. Lastly, this section includes the critical experiment - comparison of AF-MANCAP results to LCOM. Section III addresses the results of the potential user reactions and the critical experiment. Sections IV and V of this report address the conclusions and recommendations.

SECTION II. METHODS, ASSUMPTIONS AND PROCEDURES

Overview of Key Analytical Methods

The AF-MANCAP analysis aid applies two key analytical methods. The methods are baseline comparison analysis and simulation modeling. Some background information associated with each analytical method is provided to acquaint the layman reader with the applications within AF-MANCAP.

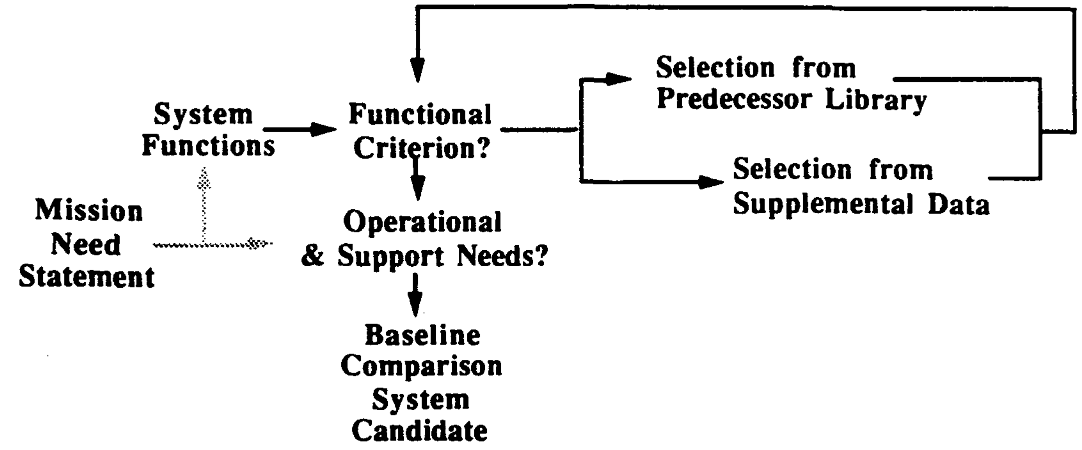
[1] The requirement for a PC based manpower tool is documented in the AL/HRMM Manpower, Personnel, and Training Needs Statement reference material. Headquarters Military Airlift Command provided the need statement in 1989.

Baseline Comparison System Construct Development - -AF-MANCAP is based on the comparability analysis process. This process derives systematic estimates of the human resource requirements of emerging weapon systems by extrapolating from the known requirements of similar operational systems and subsystems. The mission need determination phase of an acquisition program ends in the Air Force's assessment of its mission need(s). The needs are documented in the Mission Need Statement (MNS). (DoDD 5000.1) If a need for a new system emerges from the process, it results from validated deficiencies in the predecessor system, a system currently in the inventory. By definition, the predecessor system is unable to satisfy the functional requirements of the new system. However, the functional requirements information in the MNS usually focuses on predecessor deficiencies. Missing from the MNS is a full set of functional requirements associated with the new system.

The process of identification of the functional requirements (e.g., two crew members, and short field landing capability) and mapping those requirements to specific equipment configurations is a construct process. This process is facilitated by the AF-MANCAP tool. In theory, the AF-MANCAP library would contain construct data from operational systems and subsystems. Based on a full set of functional requirements, the analysts would link the functional requirements to specific equipment configurations from predecessor systems or subsystem. In this process, the analyst identifies the functional requirements - knowing what the system must do - and links these to equipment configurations - the hardware that will perform the mission. Ideally, the identified components should meet the design, operational, and support needs implicit in the overall functional requirements. The system level construct created from this process is called a Baseline Comparison System (BCS).

As defined in MIL-STD 1388-1A (March 1991) the BCS is "a current operational system, or a composite of current operational subsystems, which most closely represents the design, operational, and support characteristics of the new system under development." Components of the BCS may be drawn from the predecessor system and other comparable existing systems in the Department of Defense or the North Atlantic Treaty Organization inventory. The BCS should closely approximate the design, operational, and support characteristics. This concept is illustrated in the AF-MANCAP demonstration library. The library contains the representative subsystems that may satisfy a notional new tactical fighter requirement. Individual data entries in the BCS came from data files associated with current predecessor systems. Examples of the data are: landing gear of the F-15, radar of the F-16, and flight control system of the F-18.

Figure 2 illustrates the BCS process. To qualify for inclusion in the BCS, a candidate component must have mature data available. Such data are used to demonstrate the likely human resource considerations under fielded conditions. The data are found in the Core Automated Maintenance System (CAMS) or Logistics Composite Model networks. Information can also be obtained from subject matter experts and from the maintenance tasks described in the predecessor technical orders.



Source: Department of Army: HARDMAN comparability analysis methodology guide (Volume I) Alexandria, VA: Army Research Institute. (Modified for DoD 5000.1 changes)

Figure 2. Baseline Comparison System Construct Development.

<u>Proposed System Construct Development</u> - - Another feature of AF-MANCAP is the capability to create a construct of the Proposed System (PS). The data associated with the PS is defined as less technologically mature. As such, the PS can include data from test or engineering estimates. Or the PS contains data from individual contractor designs (e.g., engineering estimates). Typically, such data are found in the Logistic Support Analysis Record (LSAR). Differences between the BCS and PS can be analyzed with the AF-MANCAP analysis aid.

<u>Modeling Database Content and Simulation</u> - - The main function of the BCS, described above, is to create a database that reflects the rate of scheduled and unscheduled maintenance. Included are supporting data: Air Force Specialty Code, task time, task frequency, and crew size. The BCS database should be developed according to the work unit code structure (TO 00-20-2). Each 3-digit work unit code that satisfies a functional requirement is shown. The 3-

digit level is recommended because the troubleshooting, remove and replace, inspect, or adjust maintenance tasks are normally reported at this level. Within each system, significant line replaceable units at the 4- or 5- digit work unit code level should be identified, if at all possible. However, this level of information is not normally available. Very early analysis is limited to the 3-digit level of detail.[2]

Simulation modeling is applied within AF-MANCAP to address variables such as unit size or availability of different specialists. Simulation modeling is used to answer complex questions about the manning and mix to support a new system under a range of different operational conditions. The simulation approach adopted under AF-MANCAP was to allow the user the freedom to sequence up to five events over a 24-hour period. The event sequencing features of AF-MANCAP can address the duration of a sortie and the frequency of a turnaround. Compared to the LCOM networking simulation features, the AF-MANCAP networking simulation features are simplistic. As an example, AF-MANCAP currently does not allow identification of the takeoff pattern and sequencing of tasks by dependencies.

The AF-MANCAP is a simplistic approach using PC hardware and operating systems. The software design has some current limits, e.g., only 300 tasks can be held in memory during a simulation. While some proponents of large-scale simulation development may argue that this is a weakness of AF-MANCAP, it can be a strength. Complex scenarios and detailed databases are not normally available early in the requirements development phase of an acquisition. Therefore, the strength of AF-MANCAP rests in the simplistic approach to scenario and database development. For example, the entire scenario development process for AF-MANCAP takes approximately 15 minutes.

Air Force-MANpower CAPability Tool Methodology

The Air Force-MANpower CAPability (AF-MANCAP) tool is a stochastic probability process. The process meets the definition of a strong stationary stochastic process (Pritsker and Pedgen 1990) or a set of ordered random variables.

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[2] AF-MANCAP supports alternative database file arrangements. We used the Logistic Support Analysis control number; however, any task description can be used. The current file allows up to 50 alphanumeric characters for the task description.

AF-MANCAP features user-friendly inputs, use of a personal computer, and standard screens. An analyst develops scenarios that are sufficiently simple that significant amounts of user training are not needed for modeling. The model invokes three major activities: development of a baseline comparison system, simulation of one system, and simulations at various levels. The analytical efforts address the same model, design, and series system. Refer to Figure 3 for an overview of the AF-MANCAP analysis aid.

First Activity - Baseline Comparison System (BCS) Development - - For this activity, data come from task level databases within the software. The task level databases are called the library. The library includes task level information on Army systems such as helicopters, tanks, and vehicles. Under this contract a demonstration notional new fighter task level database was added to the existing library files. The library contains the maintenance parameters of each component. This information includes:

- a task description (this is user definable within a range of 50 alpha/numeric characters. For this development a Logistic Support Analysis Record format was used);

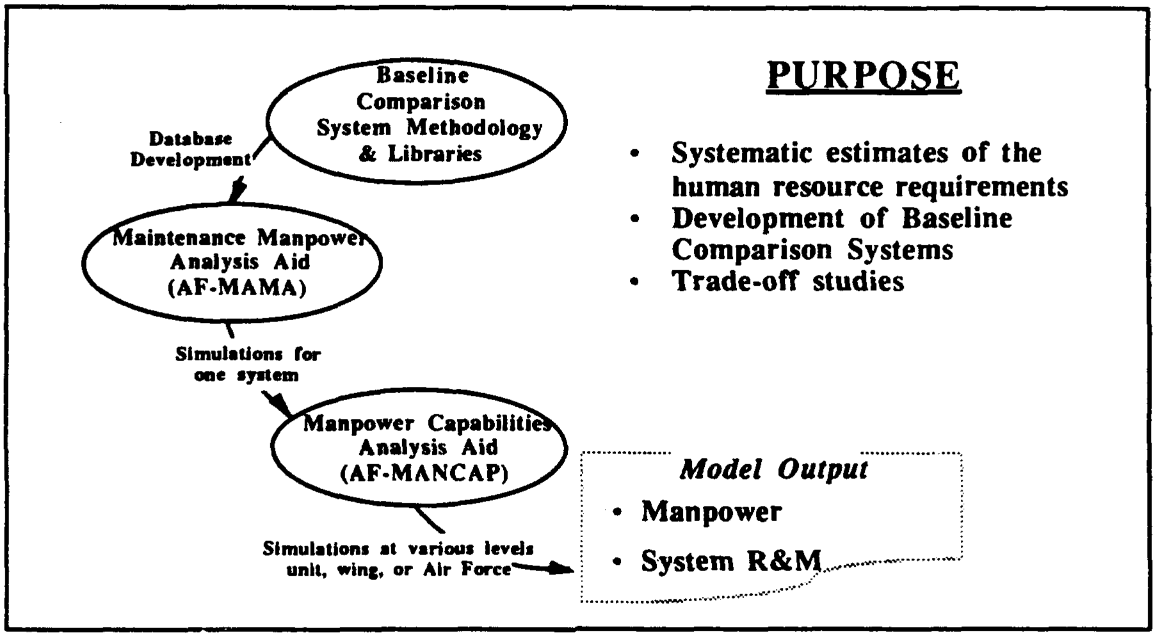

Figure 3. Overview the AF-MANCAP analysis aid.

- how often the component needs maintenance;
- what type of maintenance is needed (troubleshoot, remove & replace, inspect, adjust & repair, or test & check);
- what category of maintenance is needed (scheduled or unscheduled);
- what level of maintenance is associated with the maintenance (on-equipment, off-equipment, or depot level);
- who will do the maintenance (the specific AFSC) and the number of personnel associated with the maintenance (team size);
- how long the maintenance action will take; and
- whether the need for this maintenance will interrupt the current mission.

Using the BCS model features allows the analyst to use the library database and select or rearrange the tasks between system and subsystem level. Also, the BCS feature allows for refinement of the task data or the creation of new task level databases. The new BCS can be named, saved, or exported to other users. After development the BCS is automatically linked to the simulation activities described below.[3]

<u>Second Activity - Simulation of one system</u> - - For this activity, stochastic network simulations are run at the component level or task level. Only one system operates. The simulation generates a table of component and subsystem failure probabilities plus associated data per component for one system. These data include the Air Force Specialty Code (AFSC), number of personnel performing the task, maintenance task time, and mean operational time between component failure. Scenario development and model execution follow the data entry. A standard series of reports is retrievable to the screen, and options are available for printing output reports. A key report example is manhour predictions. The reports include the identification of the tasks associated with each AFSC and the manhours for tasks at various maintenance levels. The

[3] Currently, only 300 task descriptions can be retrieved from a library for BCS modeling. This limit is a constraint of the disk operating system (DOS) and hardware. Recommended conversion of AF-MANCAP to WINDOWS will remove the BCS constraint.

maintenance levels are: on-equipment, off-equipment, or depot maintenance. The interface between this activity and the next activity is simplified with an automatic transfer of data.

Third Activity - Simulation for several systems of the same model, design, and series - - For the third activity, the above components and associated task level data support the analysis of support requirements for a range of systems of the same model, design, and series. Under the first function of this activity, the user develops a scenario for major activities over a 24 hour period. For example, the analyst enters an aircraft sortie generating sequence of maintenance, alert, fly, and recovery. This simple sequencing of events creates the stochastic network. Component failures occur as sorties accumulate during the flying sequence. After the flight sequence, the available maintenance resources are committed for the duration of the repair time for the failed component. Repair times and maintenance actions are accumulated by AFSC and component over the duration of the simulation. The second major function of this activity is the input of key scenario variables. The variables and associated ranges are shown in Table 1 below.

Table 1. KEY SCENARIO VARIABLES

Variables	Range
Duration	1 to 180 days
Systems	1 to 500 systems
Activity levels	Number rounds fired, sorties flown, and operating hours
AFSC Constraints	1 to 999

A standard series of reports is retrievable to the screen and options are available for printing output reports. Readers may refer to Appendix A for additional AF-MANCAP details.

The overall research effort was driven by the statement of work that specified three phases for the project. These were: Phase I - orientation; Phase II - database interfaces, software modifications, and demonstrations; Phase III - convergent validation. A summary is provided for each phase of the project.

Phase I - Orientation

The general strategy for developing AF-MANCAP focused first on understanding the Army's approach to the database design and the simulation network. During January and February 1991, the research team collected information about the Army's MAintenance MANpower (MAMA) analysis aid and MANpower CAPabilities, second version (MANCAP II) analysis aid. The Army Research Institute provided software demonstrations, documentation, and supported two meetings. Based on the information gathered and demonstrations of the HARDMAN III products, a plan of attack was developed for software modification.[4] In March of 1991, the following software modification were approved for prototype testing (Flint and Rossmeissl, 1991):

Add Air Force symbols to the start up screen and change the product name from MANCAP II to AF-MANCAP.

- Convert the Army's Military Occupational Specialty (MOS) to Air Force Specialty Code (AFSC) and increase the characters in the AFSC field from five to six.

- Convert the Army's maintenance level terms (Organization, Direct Support, General Support, and Contact Teams) to Air Force maintenance terms (On-equipment, Off-equipment, Depot, and Aircraft Battle Damage Repair).

- Modify the mobility equipment group from the term "miles" to read "miles/sorties."

- Change the terms" preventative" maintenance to read "scheduled" maintenance, and change the term "corrective" maintenance to read "unscheduled" maintenance.

The above changes were required before demonstration of the product to Air Force analysts. Other product improvements were noted during the Phase I orientation but were deferred for later implementation. For example, the Army software tools accept only 300 maintenance tasks for simulations. Under typical conditions, the Air Force may require over 3,000 maintenance tasks. A list of the recommended changes may be found in Section V of this report.

Phase II - Database interfaces, software modifications, and demonstrations

Database Interfaces - -We used a maintenance task database representative of a notional new fighter. This database supports other research at Armstrong Laboratory (Boyle, Plassenthal,

[4] The contract effort also included a review of the PERSEVAL tool for potential Air Force utilization. During the Phase I effort we found that the PERSEVAL taxon structure was not adaptable to the Air Force's classification structure.

Weaver, 1991). The notional new fighter database includes subsystems from existing fighter aircraft arranged by work unit code. The maintenance task database was used for experiment design. We used known data to compare the AF-MANCAP results to LCOM results. Also, the fighter database provided information to build a Logistic Support Analysis Record (LSAR). We used the LSAR format to show a proposed system construct capability. The overall contents of the notional new fighter task database are summarized in Table 2.

Table 2. NOTIONAL NEW FIGHTER DATABASE

Work Unit Code	Subsystem	Work Unit Code	Subsystem
11 Airframe	F-16, F-15, F/A-18	49 Misc Utilities	F/A-18
12 Cockpit	F-16, F-15, F/A-18	51 Instruments	F/A-18
13 Landing Gear	F-15	62 VHF[1]	F/A-18
14 Flight Controls	F-16, F-15, F/A-18	63 UHF[2]	F/A-18
24 Auxiliary Power	F-16, F-15, F/A-18	64 Interphone	F/A-18
27 Propulsion	F-15	65 IFF[3]	F/A-18
29 Power Plant	F/A-18	66 Radio Beacon	F/A-18
41 Environmental	F-16	67 Comm. Nav/IFF	F/A-18
42 Electrical	F-15	71 Radio Nav.	F/A-18
44 Lighting	F-15	72 Radar/Bomb Nav.	F/A-18
45 Hydraulics	F/A-18	74 Fire Control	F/A-18, F-15
46 Fuel	F-15	75 Weapons	F/A-18
47 Oxygen	F-16	76 ECM[4]	F/A-18

1. Very High Frequency (Radio)
2. Ultra High Frequency (Radio)
3. Identification Friend or Foe
4. Electronic Counter measures

We modified the task nomenclature associated with the maintainability and reliability data before uploading in AF-MANCAP. The first position of the new task database included the identification of Logistic Control Numbers associated with a typical LSAR. The data associated with the rest of the fields may be found in Table 3 below. The Table 3 database was prepared in American Standards for Communications Information Interchange (ASCII) format. Wherever possible we linked AF-MANCAP data fields with data representative of the LSAR file.

Table 3. DATA ELEMENT DEFINITION (DED) USED

AF-MANCAP Title	Position	Field Type	DED Number	DED Name
Task	1	50 a/n	197	Logistic Control Number
			467	Task Code
			181	Item Name
Comptype	2	1n	n/a	See note[4]
Organization Code	3	1n	n/a	See note[5]
Corrective Code	4	1n	n/a	See note[6]
AFSC 1[1]	5	6a/n	316	Person Identifier
Nr AFSC 1	6	3n	269	Nr. of Persons Per Skill Specialty Code
AFSC 2	7	6/an	n/a	Not provided by LSAR
Nr AFSC 2	8	7n	n/a	Not provided by LSAR
Unit Metric	9		244	Measurement Base
MOUBF[2]	10		236	Mean Time Between Maint Actions
MTTR[3]	11		222	Mean Man-Hours Per Skill Specialty

1. Air Force Specialty Code
2. Mean Operational Units Between Failure
3. Mean Time To Repair
4. AF-MANCAP task code developed from 1st position of the LSAR task code
5. AF-MANCAP organization code developed from 3rd position of the LSAR task code
6. AF-MANCAP Corrective or Preventative Maintenance code developed from 1st and 2nd position of the LSAR task code

During March of 1991, the preliminary integrated AF-MANCAP software was delivered by Micro Analysis and Design, Inc. This AF-MANCAP software and its database management system (R:BASE System V) provides the technology for the transfer of ASCII format task database into AF-MANCAP. The FileGateway options of the R:BASE System V software allow conversion of data from all the most popular software formats (Taylor 87).

We could not make a direct FileGateway transfer of the notional new fighter task database into the AF-MANCAP file structure. First, we created mapping methods to convert the Logistic Support Analysis (LSA) task function codes into one of five possible AF-MANCAP maintenance codes. Examples of the AF-MANCAP codes are: inspect, test/check, adjust/repair, remove/replace, and troubleshoot. The key mapping assumptions came from a program that extracts Logistic Support Analysis Records data and reformats it into LCOM input data (Cronk

1989). The reformatting procedures were mapped to equivalent AF-MANCAP code. Since LSA task function codes vary between on-equipment and off-equipment tasks, we developed unique conversion tables for on-equipment and off-equipment. The results of this effort are shown in Figures 4 and 5.

LOGISTIC SUPPORT ANALYSIS TASK FUNCTION CODE	LOGISTICS COMPOSITE MODEL ACTION TAKEN CODE	MAINTENANCE DATA COLLECTION ACTION TAKEN CODE	AF-MAMA MAINTENANCE TASKS
A - inspect	V - operational check	X - test, inspect, serviceinspect	
B - test	V - operational check	X - test, inspect, servicetest & check	
C - service	V - operator al check	X - test, inspect, servicetest & check	
D - adjust	M - repair inplace/minor maint	L - adjust	adjust & repair
E - align	M - repair inplace/minor maint	not applicable	adjust & repair
F - calibrate	M - repair inplace/minor maint	J - calibrated (no adjust)	adjust & repair
		K - calibrated (adjust req)	adjust & repair
G - install	R - unsch remove replace	Q - installed	remove & replace
H - remove replace	R - unsch remove replace	R - remove replace	remove & replace
J - repair	M - repair inplace/minor maint	F - repair	adjust & repair
K - overhaul	not applicable	not applicable	
L - rebuild	not applicable	not applicable	
M - mission profile change	not applicable	not applicable	
N - fault locate	T - troubleshoot	Y - troubleshoot	troubleshoot
O - operate	V- operational check	not applicable	test & check
P - lubricate	M - repair inplace/minor maint	not applicable	
not applicable	H - cannot duplicate	H - check, no repair	test & check
R - remove	R - unsch remove replace	P - removed	remove & replace
W - access	X - remove for access	S - remove + reinstall	remove & replace
S - disassemble/assemble	not applicable	not applicable	
T - transportation prep	not applicable	not applicable	
U - package/unpackage	not applicable	not applicable	
V - preserve	not applicable	not applicable	adjust & repair
Y - transport	not applicable	not applicable	
Z - end of runway	not applicable	not applicable	
X - can not duplicate (CND) (See Note 1)			
Q - not reparable this station (See Note 1)			

Note 1 Codes added to typical LSAR to track LCOM events Also, CND treated as AF-MAMA troubleshoot maintenance task.

Figure 4. On-equipment matrix.

LOGISTIC SUPPORT ANLYSIS RECORD TASK FUNC CODE	LOGISTICS COMPOSITE MODEL ACTION TAKEN CODES	MAINTENANCE DATA COLLECTION ACTION TAKEN CODES	AF-MAMA MAINTENANCE TASKS
A - inspect	K - bench check, no repair	X - test, inspect, service	inspect
B - test	K - bench check, no repair	X - test, inspect, service	test & check
C - service	K - bench check, no repair	X - test, inspect, service	test & check
D - adjust	W - bench check repaired	L - adjust	adjust & repair
E - align	W - bench check repaired	not applicable	adjust & repair
F - calibrate	W - bench check repaired	J - calibrated (no adjust)	adjust & repair
		K - calibrated (adjust req.)	adjust & repair
G - install	not applicable	not applicable	
H - remove replace	not applicable	not applicable	
J - repair	W - bench check repaired	F - repair	adjust & repair
K - overhaul	not applicable	not applicable	inspect
L - rebuild	not applicable	not applicable	
M - mission profile change	not applicable	not applicable	
N - fault locate	not applicable	not applicable	
O - operate	not applicable	not applicable	
P - lubricate	W - bench check repaired	not applicable	
R - remove	not applicable	not applicable	
(See Note 2)	N - not reparable this station	1 thru 9 - NRTS	inspect
S - disassemble/assemble	D - disassemble/assemble	M,N - disassemble/assemble	remove & replace
T - transportation prep	not applicable	not applicable	
U - package/unpackage	not applicable	not applicable	
V - preserve	not applicable	not applicable	
Y - transport	not applicable	not applicable	
Z - end of runway	not applicable	not applicable	
X - can not duplicate (See note 1)			
O - not reparable this station (See note 2)			

Note 1 See maintenance (level) code D, task function code K or L
Note 2 Codes added to typical LSAR to track LCOM events

Figure 5. Off-equipment matrix.

Our next database preparation action covered the subdivision of the 1,655 notional new fighter tasks descriptions. We decomposed most of the library files into groups of 300 or less tasks. This was done to work within the 300 tasks limits of AF-MANCAP. The results of this effort are shown in Table 4.

Table 4. NEW FIGHTER DATABASE RESTRUCTURE

Task Name AF-MANCAP Librar	Number of Subsystems	Number of Tasks
F-15 On-Equipment	9	165
F-16 On-Equipment	9	204
F-18 On-Equipment	19	427[1]
Engine On-Equipment	1	74
Armament On-Equipment	1	34
F-15 Off-Equipment	7	129
F-16 Off-Equipment	8	68
F-18 Off-Equipment	18	283
Engine Off-equipment	2	190
Armament Off-Equipment	1	30
Support General	1	51
	Total	1655

1. Currently only 300 tasks can be retrieved from a library for modeling.

Software Modifications - - Once we entered the notional new fighter aircraft databases into the AF-MANCAP library function, we started preliminary testing. Also, we changed the software to improve the model performance. As an example, initially the model would abort simulation scenarios of 180 days. In our final version of the software, the model run time for the 180 day scenario was 72 minutes. We identified the need for product changes from April through December 1991. Appendix E contains a summary of the software development effort.

We conducted over 80 hours of simulations and 34 tests of the AF-MANCAP software. We tested AF-MANCAP in unconstrained and the constrained mode. The results are summarized in Table 5.

Demonstrations - - Concurrent with the software testing, we developed an AF-MANCAP demonstration using the notional new fighter aircraft database. We used a briefing format to introduce potential users to the AF-MANCAP product. This required about one-half hour with questions and answers. Following the briefing potential users saw all of the AF-MANCAP features. We provided a step-by-step viewing of the AF-MANCAP computer generated images. A high-resolution liquid crystal display was placed on top of an overhead projector. This required about one and one half hours with questions and answers.

A standard presentation scenario was used for each demonstration (Flint and Dahl, August 1991). The demonstration scenario was approved by the Laboratory Contract Monitor during July 1991. During August 1991, we made two presentations at Wright-Patterson Air Force Base, Ohio, and one presentation at Langley Air Force Base, Virginia.

We developed a three part survey: Part I - collected background information about the participant, Part II - contained questions to assess if the software products fulfill the potential user needs, and Part III - contained questions about requirements for a production version of the software. With each presentation, potential users were provided the survey questions to capture user reactions to the analytical tools and the manpower analysis process.

Part II of the survey addresses user system interface issues. We developed the questions after an extensive literature survey and interviews with software standards experts at Headquarters, Air Force Systems Command. We eliminated methods of assessing the AF-MANCAP software that address features such as design consistency, design flexibility, and design context (Goodwin 1988, Shneiderman 1987, and Boehm 1989). According to Goodwin under design context "the user should always know how they reached a certain point, what data are being display, the date and time of data updates, and other contextual information that will help them accomplish their task." It was our conclusion that the software demonstrated such design features. Also, the above methods applied to the development of software or realization of a software product and not to the assessment of a product once it is realized.

The International Standards Organization guide (ISO 1991) provides metrics for software quality measurements, ratings, and assessments of existing software products. Key to their metrics approach is a customer focus. The customer is defined as a functional entity who looks at the software with a quality view and has the technical abilities. Four rated levels are stated for customer satisfaction (ISO 1991). The rating levels are:

- Excellent - the product equals or exceeds the requirements on every aspect, and can be used as specified - - the product is very satisfactory

- Good - the product equals or exceeds the requirements on most aspects. It can be used as specified, or with minor limitations -- the product is satisfactory.

- Fair - the product doesn't meet the requirements on some aspects. It can, however, be used, but with major limitations - - the product is almost satisfactory.

- Poor - the product does not meet the requirements. It cannot be used - - the product is not satisfactory.

We enhanced the features of the ISO matrix with the addition of contingency questions if the product was rated Fair or Poor. Babbie (1979) defines contingency questions as questions in a series and whether they are to be answered is contingent on responses to the first question.

Table 5. AF-MANCAP TESTING SUMMARY

Test		Expected Results	Test Results[1]	Minutes
1.	Time for 10 day MAMA simulation	Unknown	Initial test Final test	2.3 2.3
2.	Time for 30 day MAMA simulation[1]	Unknown	Initial test Final test	5.6 5.6
3.	Time for 10 day MANCAP simulation	Unknown	Initial test Final test	9.45 4.63
4.	Time for 30 day MANCAP simulation	Unknown	Initial test Final test	76.43 13.1
5.	Time for 60 day MANCAP simulation	Unknown	Initial test Final test	282.0 25.23
6.	Time for 180 day MANCAP simulation	Unknown	Initial test Final test	Abort 72.53
7.	Effect when one AFSC is constrained[2]	Lower system availability	Confirmed	n/a
8	Effect when three AFSCs are constrained[2]	Lower system availability	Confirmed	n/a
9.	Effect when all AFSCs are constrained[2]	Lower system availability	Confirmed	n/a
10.	Effect when spare parts are constrained[3]	Availability will be lower	Confirmed	n/a
11.	Effect when on-equipment tasks are transferred[4]	All workload transfers to the next level	Confirmed	n/a
12.	Effect of random number seed changes	Results should vary by one standard deviation	Confirmed	n/a
13.	Repeatability of model with same assumptions	Same results should be provided	Confirmed	n/a

1. Test time shown in minutes. Testing confirmed that simulations greater than 30 days did not change the overall results of the model.

2. In initial simulations, the AFSCs were unconstrained - value of 999. In a later test, three AFSCs were reduced to the maximum demand level. For example, with the constraint set at 21 there should be no change in the model availability results. Then the manpower constraint was lowered. For example, 6 for the peak demands or 2 for the lowest possible demands. At these levels there should be a change in the model availability results.

3. For initial simulations, the spares were unconstrained - value of 100 percent. For this test, the spares availability was lowered to 85 percent.

4. All on-equipment tasks were changed to off-equipment tasks.

Using the above rating levels, the overall AF-MANCAP product assessments were developed for customer satisfaction in five areas: functionality, reliability, usability, efficiency, and maintainability. Appendix C contains an example of the survey. The customers ratings are covered under results section of this report.

Phase III - Convergent Validation

The final task in this effort is the validation of AF-MANCAP. We used a convergent validation approach. We compared the results from a proven model with the results of a new model. This is a predictive method to see if the new model outputs match the output of an existing model. The Logistics Composite Model was the proven model (Boyle, 1990). The AF-MANCAP analysis aid was the new model. The same database was used for each model. That database focused on the F-16 on-equipment listings, containing 204 maintenance tasks associated with eleven AFSCs. Next, a series of common assumptions was developed for each model. Table 6 contains a list of the common convergent validation assumptions.

Table 6. CONVERGENT VALIDATION SCENARIO ASSUMPTIONS

Variable	Range
Number of systems	24
Number of simulation days	30
Spare parts availability	unconstrained
AFSC availability	unconstrained
Average sortie duration	2 hours
Turnaround time between sorties	6 hours
Probability of an abort occurrence	no abort

Cascio (1982) discusses that convergent validation studies attempt to answer two questions: (1) what is the construct being measured by the simulation, and (2) how well does the experiment measure this construct? Table 7 lists the construct measurements, or what is being measured, under this experimental design for convergent validation.

Table 7. EXPERIMENTAL DESIGN

Construct Ref Nr.	AF-MANCAP Measure (Source)	LCOM Measure (Source)
1	Maintenance Headcount (MANCAP Headcount Histograms)	Max/Constrained Manpower[1] (Matrix Post Processor Reports)
2.	Average number needed & Maximum number needed (MANCAP Maintenance AFSC Requirements Report)	Average, Max Manpower[2] (Matrix Post Processor Reports)
3.	Mean Daily Maintenance Hours by AFSC (MANCAP Maintenanc. Manhour Requirements - Daily Ranges Report)	Daily Manhour Requirements[2] (Matrix Post Processor Reports)
4.	Percent Utilization by AFSC (Maintenance Workload Report)	Average AFSC Hours (Performance Summary Report)
5.	Percent System Availability (System Availability Report)	Mission data (Mission Post Processor Reports)

1. Maximum manpower and average manpower were taken from the LCOM manpower matrix reports and associated data. These runs were unconstrained on manpower positions but constrained to the target sortie rates.

2. Total maintenance hours are available in the LCOM performance summary report and mean daily maintenance hours was computed by dividing the total by the simulated days.

SECTION III - RESULTS

Demonstrations

Sixteen officers, enlisted and civilian personnel participated in the demonstrations and completed surveys. The military/civilian breakout was: 44 percent civilians, 12 percent field grade officers, 32 percent company grade officers, and 12 percent enlisted. The participants' background included: 25 percent from Headquarters, Air Force Logistics Command, 56 percent from the Air Force Acquisition Logistics Division, and 19 percent from Headquarters, Tactical Air Command. Additionally, the participants were familiar with disk operating systems, and their backgrounds typically included experience with human resource activities (e.g., preparation of Manpower Estimate Reports, LCOM, System Training Plans, and baseline comparison system analytical efforts).

Our metrics approach was a customer focus. The customer is defined as a functional entity who looks at the software with a quality view and has the technical abilities. Four rating levels are were used: excellent, good, fair, or poor (ISO 1991). The definitions linked to each rating level are:

- excellent — the product equals or exceeds the requirements on every aspect, and can be used as specified - - the product is very satisfactory.

- good — the product equals or exceeds the requirements on most aspects. It can be used as specified, or with minor limitations - - the product is satisfactory.

- fair — the product doesn't meet the requirements on some aspects. It can, however, be used, but with major limitations - - the product is almost satisfactory.

- poor — *the product does not meet the requirements.* It cannot be used - - the product is not satisfactory.

Using the above overall rating levels, 16 experts rated the product in five areas: functionality, reliability, usability, efficiency, and maintainability. Overall, the product received a good rating. Table 8 is a summary of the rating levels. Also, the table provides a breakout of responses by three categories of users (e.g., all users, non-LCOM users and LCOM users). The non-LCOM users provided the highest overall product ratings.

Table 8. SURVEY RESULTS: CUSTOMER SATISFACTION

		Excellent	Good	Fair	Poor
Functionality	All Users	0%	60%	20%	20%
	Non-LCOM Users	*0%*	*82%*	*18%*	*0%*
	LCOM Users	*0%*	*0%*	*25%*	*75%*
Reliability	All Users	8%	77%	15%	0%
	Non-LCOM Users	*9%*	*91%*	*0%*	*0%*
	LCOM Users	*0%*	*0%*	*100%*	*0%*
Useability	All Users	7%	57%	36%	0%
	Non-LCOM Users	*9%*	*64%*	*27%*	*0%*
	LCOM Users	*0%*	*33%*	*67%*	*0%*
Efficiency	All Users	0%	69%	15%	15%
	Non-LCOM Users	*0%*	*82%*	*18%*	*0%*
	LCOM Users	*0%*	*0%*	*0%*	*100%*
Maintainability	All Users	27%	64%	9%	0%
	Non-LCOM Users	*33%*	*67%*	*0%*	*0%*
	LCOM Users	*0%*	*50%*	*50%*	*0%*

Our survey tool included questions on requirements for a production version of the product. We provided a statement and then asked each participant if they: strongly agree, agree, undecided, disagree, or strongly disagree with the statement. We found strong agreement that the Air Force needs a baseline comparison development system, that depot level tasks should be added to the library, and that the product should be modified for operations under WINDOWS which would provide more tasks for simulation.

Our survey shows indecision concerning other product enhancements. Some support was shown for the following features: fuel use linked to the terrain scenario, fuel transportation, and ammunition transportation. Overall agreement was lacking for the following areas: implementation of K-Kill computations[5], and use of operational crew modeling feature of the prototype. Refer to Appendix D for additional details of the survey and the assessments for the next update of the AF-MANCAP analysis aid.

[5] To implement this feature requires the addition of new library data for the notional new fighter. The model provides the capability to identify the percent probability that each component will be damaged during combat. The probabilities would be modeled and subsequently generate repair actions for Aircraft Battle Damage Repair teams.

Convergent Validation

The objective of this task was first, to determine if AF-MANCAP accurately predicts the outcomes of manpower simulations and second, to increase the users' confidence in the AF-MANCAP model. Due to the 300 task limitations, whole manpower requirements could not be accomplished. The following results reflect manhour comparisons of the maximum or minimum task demands. Key to the experimental design is the accepted use of LCOM as a measure of the real-world outcome. Since LCOM is the Air Force standard (AFM 26-1) the results of AF-MANCAP can be compared and any discrepancies that occur should be explainable. Table 9 illustrates the results of the experimental design. The left column shows the convergent validation measures, the second column shows the AF-MANCAP measurement, and the third column the LCOM measurement. The right column shows the plus or minus difference between AF-MANCAP and LCO M.

Table 9. CONVERGENT VALIDATION MEASUREMENTS

Ref. Nr.	Measure	AF-MANCAP Measure	LCOM Measure	Difference Measure
1.	Maintenance Headcount	65	54	-11
2.	Average Nr. Needed/ Maximum Nr. Needed/	18/65	19/54	+1/-11
	452X1	2/8	2/8	0/0
	454X3	6/20	6/16	+0/-4
	452X5	4/18	5/15	+1/-3
	458X2	2/5	2/5	0/0
	452X4H	4/14	4/10	0/-4
3.	Mean Daily Maint Hrs. by AFSC	139.78	145.05	+5.27
	452X1	15.14	16.22	+1.08
	454X3	54.39	55.51	+1.12
	452X5	35.62	36.88	+1.26
	458X2	6.34	7.22	+0.88
	452X4H	28.29	29.22	+0.97
4.	Percent Utilization by AFSC	n/a	n/a	n/a
	452X1	0.10	0.067	-.033
	454X3	0.26	0.24	-.02
	452X5	0.18	0.17	-.01
	458X2	0.04	0.03	-.01
	452X4H	0.13	0.13	0
5.	Percent Operational Availability	88.81	90.58	+1.77

SECTION IV - CONCLUSIONS

Demonstrations

Sixteen experts looked at the AF-MANCAP product with a view on customer quality. These individuals possessed technical abilities and the decision power to influence the potential use of the product. The overall ratings were:

- functionality — Good - the product performs user required functions, with only minor limitation in some of them.
- reliability — Good - the product performs its intended functions under all conditions. However, infrequent conditions such as extreme load out of specification input data sets or function parameter might result in incorrect output.
- useability — Good - Minimal prior training is necessary. Training can be done with a "tutorial" type of software package, included in the main delivery. On-line itemized "help" is available. Full user documentation is provided.
- efficiency — Good - response time remains acceptable under all conditions, however, performance degradation under simulation conditions is noticeable. The software indicated when products will be available.
- maintainability — Good- some documentation is available to the user.

Overall the participants were undecided about the use of the prototype now. Also, they were undecided about the retention of other features in the model (e.g., operational crew modeling, fuel consumption, and the logistics report features). Several wanted more "hands on time" and additional technical documentation about the simulation network.

Convergent Validation

Once the model was tested and the convergent validation results obtained, the meaning must be interpreted back into the real world. Based on these results, AF-MANCAP nearly mirrored the manhour requirements predictions from LCOM, but, due to software constraints, AF-MANCAP could not predict LCOM's whole manpower requirements.

AF-MANCAP's prediction success for Mean Daily Maintenance Hours (Table 9, Ref. Nr. 3) shows that the underlying simulation generates maintenance and accounts for task manhour requirements accurately. The Average Number Needed (Table 9, Ref Nr. 2) and Percent Utilization by AFSC (Table 9, Ref. Nr. 4) are likewise derived from the manhour requirements and are also favorable. The Percent Operational Availability data (Table 9, Ref. Nr. 5) also compared favorably since it is task length dependent. However, the favorable comparison is not true for the Maintenance Headcount (Table 9, Ref. Nr. 1).

The Maintenance Headcount or manpower prediction capabilities of AF-MANCAP require evaluation of peak whole manpower requirements supporting a targeted mission rate. Each AFSC would have to be constrained (numbers of positions available raised or lowered) until each AFSC proportionally contributed to the targeted mission rate. This could not be accomplished using the present AF-MANCAP software due to the limitation of 300 tasks per BCS and the inherent differences between AF-MANCAP and LCOM mission processing (See SECTION V). Some peak manpower differences showed in the Maintenance Headcount (Table 9, Ref. Nr. 1). Had constraining been possible, differences would have also shown in the Maximum Number Needed (Table 9, Ref. Nr. 2). As illustrated, the AFSC specific elements from (Table 9, Ref. Nr. 2) are all that is shown. Even that data shows different peak demand relationship.

Applicability of AF-MANCAP to the Acquisition Process

Tetmeyer and Moody (1974) indicate that the following characteristics apply to manpower tools:

- √ Should provide early estimates for use in trade-offs and evaluation
- √ Should be sensitive to the way in which the new system will be employed

The AF-MANCAP analysis aid supports some early phases of an acquisition when the using command is striving to identify manpower drivers and manpower constraints. The analysis aid can provide inputs for the preparation of the Mission Need Statement and Operational Requirements

Document. Also, the AF-MANCAP analytical approach supports manhour estimation activities conducted by an acquisition activity during the concept development phase.

The AF-MANCAP analysis aid is not as sensitive as LCOM to the way a system will be employed. The AF-MANCAP simulation scenario does not permit the development of staggered launch or varying sortie lengths. All systems fly and all systems enter maintenance at specified times. The lack of a staggered or variable sortie length currently reduces the utility of the product for detailed on-equipment comparability analytical efforts.

With enhancements, the AF-MANCAP analysis aid could be used for baseline comparison system development during the early acquisition phase. The analysis tool provides the flexibility to transition from the baseline comparison system to a proposed system construct development. In this form of use it supports early trade-off studies where manhours or systems availability factors are the measures of merit.

SECTION V - RECOMMENDATIONS

In our demonstrations and discussions, we found potential users for the tool in the present configuration. First, the tool could be used to support two levels of maintenance studies on avionics systems for Air Force Logistics Command. Second, Manpower, Personnel, and Training program managers could use the analysis aid for trade-off evaluations associated with common avionics developments. We recommend that the current model be provided to the above activities for utilization with small (300 task) databases. The model can provide top level trade-off support.

Throughout our demonstrations, we noted other features that should be added. For example, personnel at Headquarters, Tactical Air Command expressed an interest in the model if it included life cycle cost trade-off computations. Another critical improvement is needed in the number of components model. The task capability of the model should be expanded from 300 to 3,000 tasks, and the model should be modified to allow sortie scheduling sequences plus mission specific sortie lengths. During the demonstrations and testing we noted other product limitations. These are discussed in Appendix A: AF-MANCAP Explained.

This study assessed the feasibility of adapting part of the Army's HARDMAN III technology for Air Force use. Our software modifications were successful. We achieved the objective of completing a convergent validation of the AF-MANCAP model with LCOM. This evaluation produced a working prototype. The working prototype and extensive documentation reduce the risk of future product developments. We believe the prototype is robust enough to serve as a low-risk baseline for future product evolution. Table 10 provides a list of our recommended features for a production version of the AF-MANCAP analysis aid. We believe these are low-risk changes and we recommend a succeeding cycle of product development.

Table 10. LISTING OF FEATURES FOR THE PRODUCTION ANALYSIS AID

Ref Nr	Feature
1.	Convert from DOS to WINDOWS which will allow for the expansion of task capabilities from 300 to 3,000
2.	Expand the library to include depot level tasks
3.	Conduct further review of the need to retain such features as: fuel consumption and transportation vehicle use, ammunition consumption and transportation, probability of kill, and probability of abort.
4.	Allow the user to define pre- and post-sortie maintenance tasks.
5.	Allow the user to specify the sortie scheduling sequences and mission specific sortie lengths.
6.	Provide variance capability for the mean time to repair data.
7.	Provide a report of the sorties flown and the flying hours.
8.	Add a new utilities function that would provide the capability to read ASCII[1] formatted files and query the user regarding where the data would be placed in the library file structure.
9.	Add new utilities functions to provide for the export of data to the Logistics Support Cost Model.
10.	Allow the user to enter the percentage of indirect time per shift.
11.	Provide for pre-screening of histograms to preclude the printing of all histograms when no data were generated during the simulation.
12.	Eliminate the SPARC[2] interfaces by allowing the user to enter R&M 2000[3] like goals.
13.	Link the product to a life cycle cost (examples are SABLE[4] or CORE[5]).
14.	Provide recommended changes to adjust the mean operational units between failure (MOUBF) when the operational environment changes.

1 American Standards for Communications Information Interchange
2 System Performance And Reliability Criteria
3 Reliability and Maintainability 2000
4 Systematic Approach to Better Long-range Estimating
5 Cost Oriented Resource

In summary, the customer-focused product survey proved to be a good customer feedback device. This survey was combined with a demonstration of the product with the use of a liquid crystal display placed on top of an overhead projection. Through these techniques we increase our ability to illustrate the feature of the product during a fast-paced two hour demonstration. In addition the *AF-MANCAP Demonstration Handbook* (Flint and Dahl, August 1991) provides the user key "how to" examples.

In retrospect, we could have improved the demonstration phase of the project with the use of a background paper describing the model. Providing the paper to the participants before the demonstration could have reduced the number of questions. After the demonstration, we created a technical paper that responds to the typical questions (Flint and Dahl, December 1991).

The prototype of the AF-MANCAP analysis aid has undergone an extensive review. To our knowledge this was the first time that the Armstrong Laboratory (AL/HRMM) has applied a convergent validation strategy to a manpower model. The results were encouraging. With modification, the AF-MANCAP analysis aid will be a powerful PC-based simulation tool for the acquisition community. The enhanced tool would support the development of Baseline Comparison Systems and the subsequent trade-off studies. As an example, the trade-off capability would support the evaluation of changes in system parameters such as mean time to repair or mean time between failure. Each parameter could be reviewed independently in terms of effects on each other. AF-MANCAP provides the added feature of integrating the elements with a user-defined scenario. The mathematical and simulation features of the model make it possible to deal with the variables of the problem on a simultaneous bases and provide relative measures of merit indicators in terms of higher-order system parameters such as system availability.

SECTION VI - LIST OF REFERENCES

Babbie, E. (1979). The practice of social research. Belmont IL: Wadsworth Publishing Company.

Boehm, B. (1989). Software risk management. Washington, DC: The Institute of Electrical and Electronic Engineers, Computer Society Press.

Bogner, M., Kibbe, M., Laine, R. & Hewitt, G. (November 1990). Directory of Design Support Methods. Alexandria, VA: MANPRINT Directorate, Department of the Army.

Boyle, E. (July 1990). LCOM explained. (AFHRL-TP-90-58). Wright-Patterson Air Force Base, OH: Logistics and Human Factors Division, Human Resources Laboratory.

Boyle, E., Plassenthal, J. & Weaver, W. (June 1991). Manpower impacts of job aiding technology. (AFHRL-TP-1991-0027). Wright-Patterson Air Force Base, OH: Logistics Research Division, Armstrong Laboratory.

Cascio, W. (1982). Applied psychology in personnel management. Reston, VA: Reston Publishing Company.

Cronk, R. (August 1989). A program to extract MIL-STD-1388 2A logistic support analysis record (LSAR) data to feed the logistics composite model (LCOM). Wright-Patterson AFB, OH: Deputy for Engineering, Aeronautical Systems Division.

Dahl, S. & Flint, R. (December 1991). Air Force MANpower CAPabilities (AF-MANCAP) analysis aid- software documentation. Unpublished manuscript. Provided to AL/HRMM and provides a detailed description of the software.

Dengler, D. (December 1981). LCOM II student training guide. (AFMSMMET Report 81-2). San Antonio, TX: Air Force Management Engineering Agency.

Department of the Army (Undated). HARDMAN comparability analysis methodology guide. (Volume I). Alexandria, VA: U.S. Army Research Institute.

Department of Air Force. (October 1991). The maintenance data collection system. (TO 00-20-2)

Department of the Army (Undated). HARDMAN comparability analysis methodology guide. (Volume I). Alexandria, VA: U.S. Army Research Institute .

Department of Defense. (February 1991). Defense acquisition. (DoDD 5000.1)

Department of Defense. (March 91). Logistic support analysis. (MIL-STD-1388-1A, includes notice 3).

Department of Defense. (April 1991). DoD requirements for a logistic support analysis record. (MIL-STD-1388-2).

Flint, R. & Rossmeissl, P. (March 1991) Inventory of MAN-SEVAL, MANCAP and PER -SEVAL changes. Unpublished manuscript. Outlines the Phase I orientation observations and ranked the software modifications.

Flint, R. & Dahl S. (August 1991). AF-MANCAP demonstration handbook. Unpublished manuscript. The handbook provides a scenario for product demonstrations. Potential analysts within Air Force Systems Command, Air Force Logistics Command, and Tactical Air Command attended the product demonstrations.

Flint, R. (November 1991). AF-MANCAP test results. Unpublished manuscript. Used in the development of the comparative analysis of the outcomes of AF-MANCAP to LCOM.

Flint, R. & Palmer C. (December 1991). AF-MANCAP data conversion procedures. Unpublished manuscript. Provided to AL/HRMM and covers the step by step process used to add Logistic Support Analysis Records into the AF-MANCAP Library.

Flint, R. & Dahl S. (December 1991). AF-MANCAP explained. Unpublished manuscript. Provided to AL/HRMM and covers the analytical details of the analysis aid. This was updated and included as Appendix A in this technical report.

Kaplan J. (June 1991) Synthesizing the effects of manpower, personnel, training, and human engineering. (AL-TP-1991-0010). Wright-Patterson Air Force Base, OH: Logistics Research Division, Armstrong Laboratory.

Goodwin, N. (December 1988). User-system interface: designing for usability. (M88-54). Bedford, MA: The MITRE Corporation.

International Standards Organization. (March 1991 working document). Evaluation and metrics framework. New York, NY: Guide for Measurement, Rating and Assessment Working Group.

Pritsker, A and Pegder, C. (1979). Introduction to simulation and SLAM. West Lafayette, IN: Systems Publishing Company.

Rossmeissl, P., Akman, A., Kerchner, R., Faucheux, G., Shields, J. & Waldrop, G. (October 1990). Analysis of manpower, personnel, training and safety during the acquisition of Air Force systems. Requirements and capabilities. (HSD-TR-90-022). Brooks Air Force Base, TX: Human Systems Division, Air Force Systems Command.

Rossmeissl, P. & Flint, R. *(March 1991)* HARDMAN III,II MAN-SEVAL - MANCAP II library/database structure & critical experiment. Unpublished briefing. Outlines the overall approach to the development of an Air Force task library, software modifications, and test program strategy.

Rossmeissl, P. & Flint, R. (August 1991). Survey for manpower, personnel, and training analysts. Unpublished manuscript. Sixteen potential analysts completed the survey after receiving a two hour demonstration of the AF-MANCAP products.

Rossemissl, P. (October 1991). Interim survey results. Unpublished briefing charts. Provided to AL/HRMM as an interim summary of analysts comments.

Shneiderman, B. (1989). Designing the user interface, strategies for effective human-computer interaction. Reading, PA: Addison-Wesley Publishing Company.

Tetmeyer, D. & Moody, W. (December 1974). Simulating maintenance manning for new weapon systems: Building and operating a simulation model. (AFHRL-TR-74-97(II)). Wright-Patterson Air Force Base, OH: Advanced Systems Division, Air Force Human Resources Laboratory.

SECTION VII - GLOSSARY

Achieved Availability Achieved availability, within AF-MANCAP, is calculated as the percentage of time the system was able to go out on its scheduled missions. If the system missed a mission because the maintenance actions were not complete, then the Achieved Availability percentage will be reduced. If the system has an Achieved Availability of 100%, then it never missed a mission.

Inherent Availability Inherent availability, within AF-MANCAP, is calculated as shown in the following algorithm:

Ai = MTBF / (MTBF + MTTR)

where:

MTBF = Mean time between failure for the system

MTTR = mean time to repair the system

IMPACTS **Integrated Manpower, Personnel and Comprehensive Training & Safety** - An acquisition management program that directly implements the specific human systems integration, manpower, personnel, training, health hazards, safety, and human factors engineering policy outlined in DoDD 5000.1, DoDI 5000.2, AFR 57-1, and AFR 57-4 into the Air Force Acquisition process and functional managers.

LCOM **Logistics Composite Model** - a highly flexible and versatile model used to simulate the work of a maintenance organization. It may be applied to support widely varying study objectives, but is most often applied to identify the optimal mix of logistics resources to support a given weapon system under given operating conditions. Logistics resources considered can include: spare parts, support equipment, facilities, or human resources.

Operational Availability Operational availability, within AF-MANCAP, is defined as follows:

$$Ao = (OT + ST) / (OT + ST + TCM + TPM + TALDT)$$

where:

OT =	Operating time during a given calendar time period
ST =	Standby time (Not operating but assumed operable)
TCM =	Total corrective maintenance downtime in clock hours during the given time period
TPM =	Total preventative maintenance downtime in clock hours during the stated OT period
TALDT =	Total administrative and logistics downtime spent waiting for parts, maintenance personnel, or transportation per given calendar time period

APPENDIX A

AF - MANCAP EXPLAINED

APPENDIX A: AF-MANCAP EXPLAINED[1]

Introduction

The purpose of the Air Force MANpower CAPabilities Tool (AF-MANCAP) is to allow Air Force analysts to evaluate maintenance and supply/support personnel requirements for proposed new weapon systems at a variety of unit levels. The AF-MANCAP modeling tool enables analysts to model units and determine the requirements for manpower based on equipment reliability and maintainability (R & M) characteristics, maintenance concept, and supply concept.

AF-MANCAP is the Air Force's version of the MANCAP II tool that is part of the Army Research Institute's HARDware vs. MANpower (HARDMAN III) project. The MANCAP approach was originally inspired by the Air Force's Logistics Composite Model (LCOM), currently managed by the Air Force Management Engineering Agency (AFMEA) and used throughout the Air Force. AF-MANCAP is intended to analyze a subset of the issues encompassed by LCOM, and to provide a PC-based tool for logistics and manpower analysts to perform an evaluation in a timely manner. It is not intended to replace LCOM, rather it provides a unique feature that enables MPT analysts to develop a Baseline Comparison System (BCS) for beginning manpower analysis prior to development of full LCOM capability.

AF-MANCAP helps analysts determine manpower requirements for a system at a variety of unit levels. AF-MANCAP takes into consideration maintenance requirements for scheduled maintenance, unscheduled maintenance, and battle damage repair at different levels of combat activity. These requirements are represented in AF-MANCAP in terms of:

1) the Operational, Achieved, Inherent, and Sortie availability of the systems in the unit given the configuration of unit personnel

2) the total number of maintenance manhours and headcount required for each AFSC at each maintenance level

[1] Authors: Dahl, S & Flint, R. (December 1991). This paper introduces a general audience to AF-MANCAP.

3) the utilization or workload of maintenance personnel at each level

The methodology that AF-MANCAP uses to estimate personnel requirements is stochastic network simulation modeling. At the heart of the AF-MANCAP tool is a generic maintenance simulation model that can represent any new weapon system. Analysts can supply and modify model parameters as input for the simulation model. Data can be obtained from AF-MANCAP libraries of various system types or from other U.S. Air Force sources.

The current version of AF-MANCAP has retained much of the original functionality developed for the Army Research Institute's version. As an example, maintenance data for 21 Army systems are included in the AF-MANCAP library.

The Three Parts of the Analytical Tool

This tool consists of three parts. The first part is used to develop a Baseline Comparison System (BCS). The second part is used to model a single system's maintenance requirements. The third part is used to model multiple systems' maintenance requirements. Each of these parts is briefly discussed in this section.

Part 1 : The Baseline Comparison System Developer - - In this part, users develop a description of the tasks required to maintain each component in their new system, how frequently each task needs to be performed, and what kinds of maintainers are needed to perform those tasks. The tool also helps users define mission scenarios that include the amount that each subsystem is used and the amount of time that is available for maintenance given system availability requirements

This part is designed to enable users to "cut and paste" all of this information from a database of existing system data into the description of a new system. Users can mix data from several different existing systems, at either the subsystem or component level. In addition, users can enter completely new data into the description.

The output of the BCS Developer provides the other two parts of the tool with component maintenance parameters. These component maintenance parameters include:

- MOUBF (Mean Operational Units Between Failure) for each maintenance action[2]
- MTTR (Mean Time to Repair)
- Who does the maintenance action (up to two different Air Force Specialty Codes)
- The organizational level at which the maintenance action is performed
- The probability that the need for the maintenance action will cause a mission abort

Part 2 : The Single System Model - AF-MAMA - - The second part of the tool is a version of the Army's MAintenance MAnpower Analysis Aid (MAMA). This was renamed Air Force MAintenance MAnpower Analysis Aid (AF-MAMA) and is a stochastic model that is used to predict the maintenance requirements of a single system. AF-MAMA is a pre-processor and must be performed prior to use of Part 3 of the analysis aid.

For all maintenance actions that do not lead to mission aborts, the occurrences are generated from the MOUBF parameter entered in the BCS Developer and passed through to AF-MAMA. For maintenance actions that do lead to mission abort the occurrences are generated using data pre-processed by AF-MAMA. For those data, AF-MAMA generates the mean time between failure for each subsystem and the probability of each possible maintenance action given a subsystem failure. These calculated failure rates are then passed on to the multiple systems model.

A detailed discussion of AF-MAMA is available in Dahl, Adkins, and Bravo (1990). The remainder of this paper only addresses the multiple systems modeling tool.

Part 3 : The Multiple Systems Model - AF-MANCAP - - This final part of the tool includes a task network model that represents multiple systems performing missions and undergoing maintenance. This part is discussed in detail in the following pages.

AF-MANCAP Simulation Overview

AF-MANCAP Inputs - - The AF-MANCAP model is driven by data entered using a series of pop-up screens. The user can supply and modify model parameters as input for the simulation model. These parameters include:

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[2] A maintenance action is a maintenance task/component pair (e.g., remove & replace engine).

- System usage rates - These are specified in rounds fired by each gun per hour, distance traveled per hour, and amount the system was operated each hour. These values are used to accrue usage on the components in the system. This ultimately drives the frequency of failure for each component.

- Number of available maintainers - This is specified by AFSC and by maintenance organization level. The number of available maintainers will affect the availability of the systems.

- Combat activity levels - The user enters a mission profile by specifying different activity levels, and sequencing those levels throughout the simulation. The model accrues usage on the components at different rates for each activity level.

- Number of systems to be modeled - The maximum number of systems AF-MANCAP can model in each simulation run is 500.

Users are also asked to enter the number of days that they want the simulation to run, the travel time between different levels of maintenance, and the probability that spare parts will be available when needed.

How AF-MANCAP Works

AF-MANCAP is a fairly sophisticated tool that includes a task network simulation model. This model is quite complicated and is fully documented in the AF-MANCAP Software Documentation Technical Report. In this appendix, we attempt to simplify the discussion of how the model works and how the factors in the model play together to predict maintenance requirements.

AF-MANCAP is essentially a limited resources model that is designed to simulate maintenance organizations. AF-MANCAP is based on a task network model. The model sends systems out to perform missions, and accrues usage on all components at a rate appropriate for the equipment type and the activity level.

For maintenance actions that do not cause the current mission to abort when they fail, AF-MANCAP uses the MOUBFs and an exponential distribution to predict when the failure will occur. For maintenance actions that do cause the current mission to abort, AF-MANCAP uses probabilistic distributions compiled in the AF-MAMA pre-processor to predict failures. At the end of each mission, each system that experienced failures is sent to maintenance.

In maintenance, the systems are sorted such that those that can be repaired in the shortest time are placed in maintenance first. Then, the maintenance is modeled by applying the user-entered limitations of maintenance crew size by AFSC. When each system exits from maintenance, it is inserted back into the mission schedule.

More Details - - The AF-MANCAP model takes preprocessed information from the AF-MAMA model and new user input scenario and combat level information as input and simulates maintenance requirements across multiple systems. Figure 1 illustrates the top level of the AF-MANCAP model. The model is composed of five main parts that are discussed in detail below (NOTE: Rectangles in the diagram denote networks of tasks, ovals denote tasks. The numbers inside each symbol are used to identify the task or network and roughly correlate to processing order.):

1) The **start** task initializes all model counters and synchronously starts four of the five main parts.

2) The **increment periods** task updates the 24-hour day counter and calculates the daily availability measurements at the end of each 24 hours.

3) The **increment intervals** task changes the combat level based on the clock duration.

4) The **manpower pool** network refreshes the available hours for each AFSC at the shift change. At the end of the simulation, the mean maintenance hours per AFSC per day and the standard deviation are calculated.

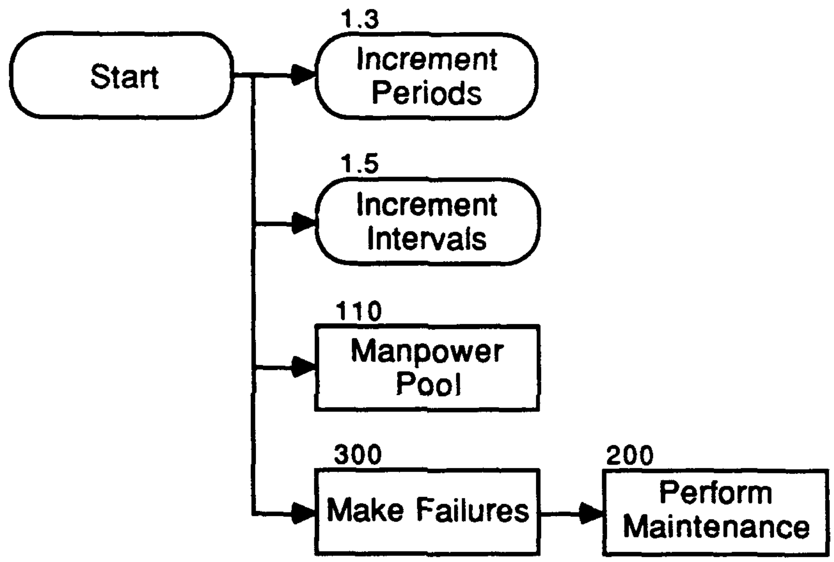

Figure 1. AF-MANCAP top level network diagram.

5) The **make failures** network feeds the systems into the scheduled missions. Systems then begin missions that last until the next failure time scheduled for that individual system. When a system finishes a mission, maintenance tasks are generated and routed to maintenance. If a system is killed, a replacement system is introduced after a user-specified length of time.

6) The **perform maintenance** network routes tasks to the Aircraft Battle Damage Repair (ABDR) team, On-Equipment, Off-Equipment, or Depot. Travel times to

maintenance and between maintenance levels as well as parts delay times are calculated. Maintenance takes place based on which system can be repaired most quickly with off-line tasks as lowest priority. Systems are returned to the current mission as soon as they are repaired.

Figures 2 through 4 show the expanded views of the three main networks. The following discussion briefly explains the activities that are performed in these tasks.

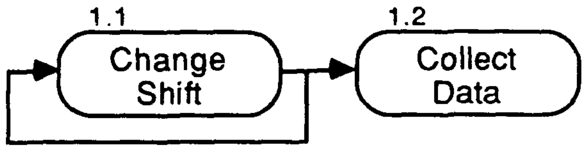

Figure 2. Manpower pool network.

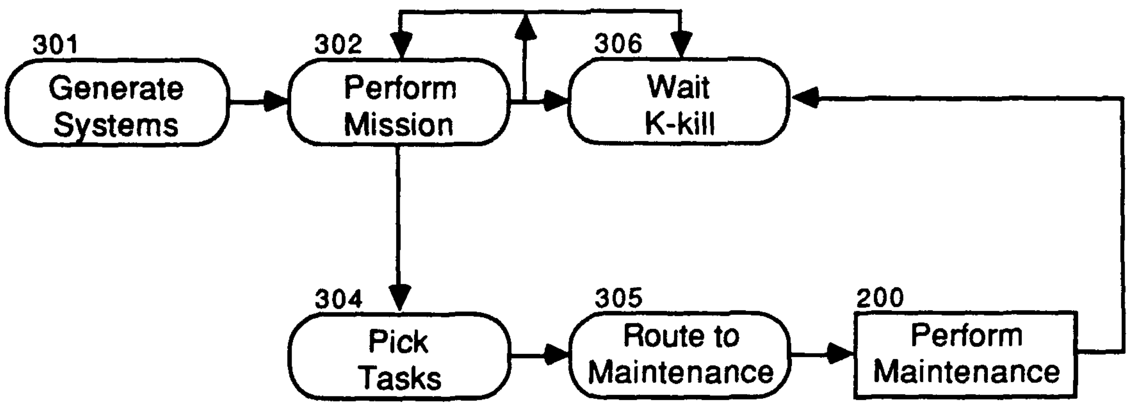

Figure 3. Make failures network.

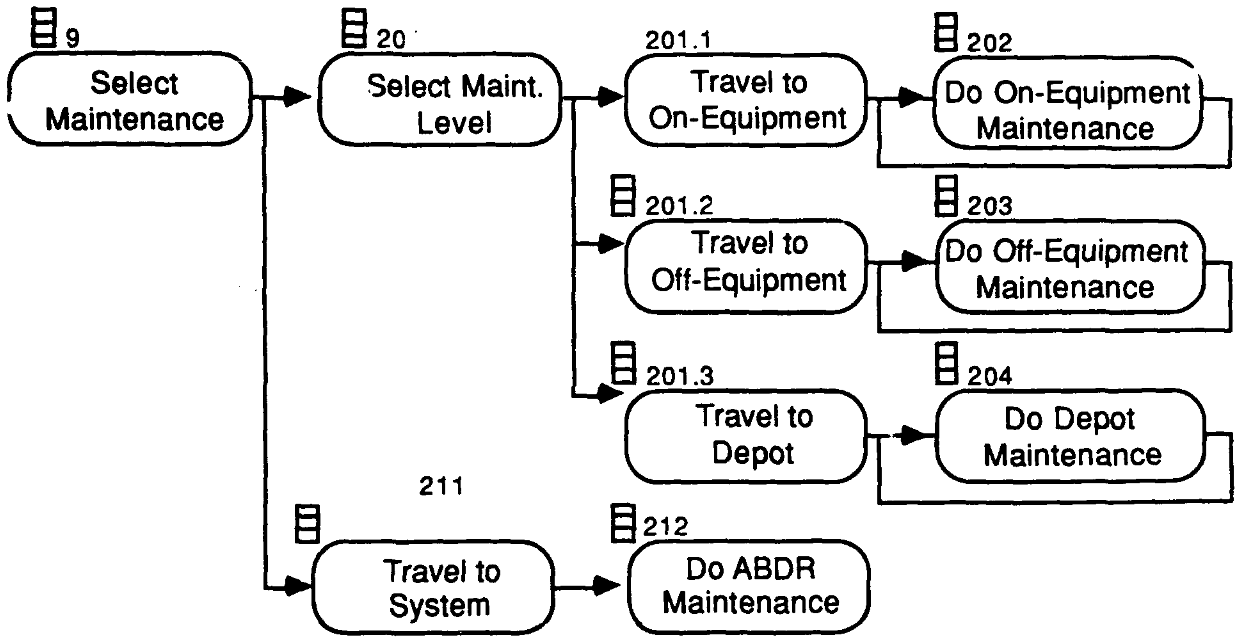

Figure 4. Perform maintenance network.

Task Start - - This task initialize all model counters and synchronously starts four of the five main parts. This task does not require the model clock to increment. Initialization events are "zero time" task. This task is followed by two tasks, 1.3 (increment periods) and 1.5 (increment intervals) and by two networks, 110 (Manpower Pool) and 300 (Make Failures).

Task 1.3 - Increment Periods - - This task counts the number of full days simulated and completes the daily calculations. The task cycle time is one full day. In this task, AF-MANCAP increments the overall mission time by the mission time accrued in this period by all the systems, calculates the daily operational availability and increments the daily maintenance hours and the sum of the squares of the maintenance hours for each AFSC at each level. This task is followed only by itself. The period counter just keeps cycling every day until the end of the simulation time.

Task 1.5 - Increment Intervals - - An interval is the amount of time missions are held at a single combat activity level. In AF-MANCAP, there are only two combat activity levels currently being used[3]. The two levels currently being used are "Maintenance" and "Fly." For example, this task increments the interval counter at the end of the Maintenance interval and starts the next Fly interval. If the interval is changing from Maintenance to Fly, AF-MANCAP calculates the sortie rate availability. This task cycles back to itself for the duration of the simulation.

Network 110 - Manpower Pool - - The manpower pool network refreshes the available hours for each AFSC at the shift change. At the end of the simulation, the mean maintenance hours per AFSC per day and the standard deviation are calculated. Tasks 1.1 (Change Shift) and 1.2 (Collect Data) are contained in this network.

Task 1.1 - Change Shift - - This task refreshes the manpower pool by reallocating hours to each AFSC at each level at the shift change. The length of a shift is 24 hours divided by the number of shifts specified. This task cycles back to itself until the end of the simulation at which time 1.2 (Collect Data) is called.

Task 1.2 - Collect Data - - This is a zero time task. For each AFSC at each level the mean maintenance hours and standard deviation are calculated from the sum and sum of the squares. This is the final task executed. None follow it.

Network 300 - Make Failures - - This network initially generates all the systems. Systems then begin to perform their mission. When a system finishes a mission, maintenance tasks are generated and routed to maintenance. If a system is killed, a replacement system is introduced after a specified length of time. There are five tasks in this network: 301 (Generate Systems), 302 (Perform Mission), 304 (Pick Tasks), 305 (Route to Maintenance), and 306 (Wait Kill Time).

Task 301 - Generate Systems - - System tags are created and sent into the first mission. All the systems begin the first mission at the same time. This task returns to itself until all the systems are generated. The schedule for operational requirements is obtained from the Sequence Combat Activities screen that is input by the analyst. Currently, the scheduling sequence is limited to hourly increments over a 24 hour period. Generated systems fly at the start of the

[3] Users can enter and up to five different activity levels. Users have the opportunity to enter names for each activity level (e.g., alert, recovery).

hour and recover at the end of the hourly increment specified by the analyst. The generated systems are sent to 302 (Perform Mission).

Task 302 - Perform Mission - - All available systems begin the first mission at the same time. If abort data or K-Kill data are not used, all systems end the first mission at that same time. The software also models each system independently.

This task involves "looking ahead" to determine what the next failure will be for each system. There are two types of failures:

1) Abort failures are generated by using failure probabilities that were generated during execution of the single system model (AF-MAMA). AF-MAMA drew failure rates for each component from an exponential distribution and, over the length of the simulation, calculated the failure rate of each subsystem. AF-MAMA then calculated the probability that each component in the subsystem caused the failure.

2) Nonabort failures are generated at the component level by drawing from each individual component's failure distribution (i.e., an exponential distribution with the component's MOUBF as the mean).

After the next failure is identified, there are three possibilities:

1) If the user specified (during the development of the mission profile) that nonaborts are to be repaired on occurrence during the Fly activity level, then the next failure is generated. This failure can be either an abort or nonabort. This mission is advanced to that failure time and then the system is pulled into maintenance when failure time is reached.

2) If the user specified (during the development of the mission profile) that nonaborts are to be repaired only when the system is in maintenance, the mission is completed and then the system is pulled into maintenance at the end of the mission or other operational activity levels.

3) If the user specified abort or K-kill data (during the database development) and aborts are turned "on" (during the development of the simulation parameters) then

aborts are to be repaired on occurrence during the Fly activity or other operational levels specified by the analyst. Also, combat damage repairs are generated on occurrence during the Fly or other operational activity levels. The system is pulled into maintenance when the failure time is reach for the abort or combat damage repair.[4]

Once the new failure is generated, the system can be routed to one of the following nodes:

1) If the survivability parameters dictate, the system can be killed and then sent to 306 (Wait K-Kill).

2) If the system is not killed and needs maintenance, it is sent to 304 (Pick Tasks).

3) If no failures were generated during the mission and the system was not killed, the system is returned to 302 (Perform Missions) and waits there until the Fly or operational segment is scheduled.

All "in commission systems" wait until the next operational period (defined by the analyst through the Sequence Combat Activities and Define Operational Mode Summary/Mission Profile windows). They also complete missions as a group (unless some of them have experienced failures, combat damage, or K-kill).

Task 304 - Pick Tasks - - Specific tasks are generated here and sent into the maintenance network. There are two different kinds of tasks that can be generated, those that do not lead to mission abort ("nonaborts") and those that lead to the interruption of the current mission ("aborts"). In addition, tasks can either be caused by component reliability parameters or by combat damage. Therefore, there are four different types of maintenance tasks. These are described below:

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[4] A system attrition (input during the development of the system survivability parameters) can occur if the probability of a K-kill is greater that 0.0%. Attrition is pulled from a uniform distribution. Once the attrition is generated the system is no longer available. Replacements can be added (input during the development of the system replacement lag time, specified in hours). The replacements are not available until the lag time has accumulated after the K-kill.

1) Nonabort failures caused by reliability parameters - AF-MANCAP predicts these failures by comparing the system usage since the last time each nonabort component failure was generated to failure times picked from exponential distributions whose means are the component MOUBFs. These are the same MOUBFs that are input data for the AF-MAMA.

   The Notional Tactical Fighter aircraft components in the AF-MANCAP library do not include any components failure data that will generate mission aborts. Also, they do not include any combat damage probabilities or K-kill probabilities. For this reason, the remaining three types of task generation do not apply to the current Air Force databases.

2) Nonabort failures caused by combat damage - AF-MANCAP predicts these failures by comparing random number picks against the joint probability that a component will experience a combat hit and that a component will not cause an abort.

3) Abort failures caused by reliability parameters - These failures are predicted using data pre-processed by the AF-MAMA model. AF-MAMA generates probabilities that each subsystem will experience a failure that causes a mission to abort.

4) Abort failures caused by combat damage - These failures are predicted by comparing random number picks against the probability that a component will experience a combat hit and the probability that the component will cause an abort.

If no tasks are generated, the system is returned to 302 (Perform Mission). Otherwise, the system waits until repairs are complete.

Task 306 - Wait kill time - - If a system is killed, another system is reintroduced after a user-defined length of time. The new system is sent to 302 (Perform Mission).

Network 200 - Perform Maintenance - The routing of tasks is done by 9 (Select ABDR maintenance) and 201 (Select Maintenance Level). The travel time takes place in 201.1 (Travel to On-Equipment), 201.2 (Travel to Off-Equipment), 201.3 (Travel to Depot), and 211

(Travel to system). Maintenance is completed at 202 (Do On-Equipment Maintenance), 203 (Do Off-Equipment Maintenance), 204 (Do Depot Maintenance) and 212 (Do ABDR Maintenance).

Task 9 - Select ABDR Maintenance - - This task determines if the ABDR team is appropriate for the repairs for this system and, if so, sends the ABDR team to the system. Otherwise, the system is sent to the other three maintenance levels. This is a zero time task. If the number of systems waiting for the ABDR team is less than the user-defined maximum, and all the repairs needed for this system are repairable by the ABDR team, then the system waits for the ABDR team. If the system is waiting for the ABDR team, 211 (Travel to System Location) is initiated. Otherwise, the system is sent to 201 (Select Maintenance Level).

Task 211 - Travel to System Location - - This task determines the time the ABDR team will take to get to the system based on travel time and waiting for any necessary parts.[5]

Task 201 - Select Maintenance Level - - Repair tasks are routed to their appropriate maintenance levels. Since the system can only be in one place at any one time, level one repairs must complete before level two repairs begin and level two repairs must complete before level three repairs begin.[6] This is a zero time task.

Tasks 201.1, 201.2, 201.3 - Travel to Maintenance Level - - Determine the time the system will take to get to the maintenance level based on travel time and waiting for any necessary parts.

Tasks 202, 203, 204 - Do Maintenance - - Tasks are released into maintenance based on a priority scheme that favors the system with the least cumulative repair hours needed. When all the repairs on a system are complete, the system returns to mission ready status.

Each maintenance task requires a specific number of airmen assigned to specific AFSCs, all of them working for the time set forth in the MTTR. Before we begin a task, we check to ensure that

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[5] The scenarios that were developed and validated for the Air Force overrode this feature by specifying zero travel times between maintenance levels.

[6] The Air Force version assigns On-Equipment, Off-Equipment, and Depot maintenance to the three separate levels. For that reason, it is not strictly true that level 1 and level 2 maintenance cannot be performed concurrently. This is discussed further in the "Limitations of this Version" section of this paper.

the manpower pool has at least a portion of the required resources left in the current shift. Maintenance cannot begin unless there are manhours available in the necessary AFSCs.

Maintenance tasks take as long as either the MTTR or the number of manhours left in the current shift for the needed AFSCs, whichever is smaller. If two different AFSCs are required to perform the task, they are each checked to ensure there are enough manhours left in the current shift to perform the maintenance. If there are not enough manhours left, the task uses the available manhours, then waits until the next shift (and the required remaining manhours are available) before it is finished.

AF-MANCAP also calculates the maximum number of AFSCs used and ensures that the number of airmen that are busy at any one time does not exceed the crew size for that AFSC.

When any maintenance action is completed, the queue of tasks awaiting for maintenance is re-sorted to ensure that the shortest task that uses the available combination of AFSCs, organization level, and maintenance hours is placed in maintenance.

Finally, data are recorded in this task. It sets variables that are recorded into an ASCII data file (system *identification number, repair time*, AFSCs, task identification number). Manpower measures and daily achieved and inherent availability are post-processed from this file following the termination of the model.

If the task was not fully completed, it is returned to the queue in front of the maintenance level to wait for manhours to become available. Otherwise, if the repair was online and this was the last repair task scheduled for a system, the system is returned to 302 (Perform Mission).

AF-MANCAP Outputs - -After executing the simulation, AF-MANCAP produces a number of reports that include the amount of maintenance that was performed by each type of maintainer and the resulting reliability, availability, and maintainability of the systems modeled. AF-MANCAP also includes a limited capability to estimate supply/support requirements.[7]

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[7] This capability was not validated. The current version includes tables of Army data for truck capacities, etc. In order to implement this capability for the Air Force, new data tables would need to be created.

The AF-MANCAP output consists of several reports that compile and summarize the results of the simulation run. These reports are summarized below.

Execution Summary - The execution summary lists the number of total direct and indirect maintenance manhours at each organizational level throughout the simulation. In addition, it specifies the total number of maintenance tasks and the total number of offline maintenance tasks that were performed. The execution summary also lists the maximum maintenance headcount used at each organizational level.

Maintenance Headcount Requirements - The Maintenance Headcount Requirements Report consists of a number of frequency histograms that specify how often different crew sizes were used to perform maintenance at each maintenance level, for each AFSC.

Maintenance AFSC Requirements - This report specifies the total number of maintenance hours required for each AFSC at each organizational level. It also contains the maximum number of airmen needed for that AFSC and organizational level for the simulated period.

Maintenance Manpower Requirements - This provides an exhaustive report of each maintenance action that could have happened to the systems being simulated. In addition, this report lists the number of times that maintenance action was performed, and the total maintenance manhours spent performing that action. This report can be sorted in order to enable the user to reorder the information in the report. The report can be sorted by subsystem, component, maintenance task, AFSC, or organizational level.

Maintenance Manhour Requirements Daily Ranges - This report contains the total number of maintenance manhours required by AFSC. In addition, it contains the average number of manhours used per day as well as a standard deviation.

Maintenance Workload - The maintenance workload report contains a calculation of the percent utilization of each AFSC. It calculates this utilization by dividing the number of maintenance manhours required by the maintenance hours available for each AFSC.

System Availability - This report contains four measures of system availability, calculated and reported on a daily basis. The four measures of availability are inherent, achieved, operational[8], and sortie. Inherent availability is calculated by dividing the operational time by the sum of the operational time and the unscheduled maintenance time. Achieved availability is calculated by dividing the operational time by the sum of operational time, scheduled maintenance time, and unscheduled maintenance time.

System Maintainability - The system maintainability report contains the maintenance ratio (maintenance manhours per operational hour) for each subsystem. In AF-MANCAP, operational hours are defined as the total time the system was operationally ready (either performing a mission or out of maintenance and waiting to begin a mission). This report is useful for identifying the "high driver" subsystems of your system (i.e., those subsystems that require more maintenance than the others).

Limitations of the Version

The current version of AF-MANCAP (Version 2.6) was developed for the purpose of demonstrating whether AF-MANCAP provided a viable method of estimating manpower requirements. Since this version was developed directly from the Army's version with a minimum effort, there are several areas in which the functionality does not adequately represent the manner in which Air Force maintenance organizations operate. These areas are discussed below.

Launch windows - The current version of AF-MANCAP sends all the systems out to perform a scheduled mission. Then, they return to the base together. While this represents the way in which most Army systems operate as a unit, it is not representative of Air Force sortie generation. The Air Force typically launches "cells" of aircraft (e.g., four aircraft launch, then 15 minutes later another four aircraft launch), thereby resulting in staggered requirements for launch, recovery, and maintenance tasks.[9]

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[8] Operational availability is calculated by dividing operational time by the sum of operation time, all maintenance time, indirect maintenance time and administrative logistics down time (including travel to and from maintenance organizations, waiting for spare parts, etc). The sortie availability is the percentage of systems that completed maintenance and were operationally ready when a mission was scheduled.

[9] Due to this inconsistency, AF-MANCAP will tend to overestimate the crew sizes required to maintain the systems, since the peak manning requirements are not accurately modeled. However, the AF-MANCAP prediction for maintenance manhours are not affected by this problem.

Mean time to repair variability - AF-MANCAP does not currently model any variability in the performance times for each maintenance action. The Army did not implement this feature due to a lack of reliable historical data. While it would require a fairly minor change to AF-MANCAP to implement this variability as well as a selective distribution parameter, it is not implemented in this version. With fairly long runs of AF-MANCAP, the effect of this limitation on fidelity will be fairly minor, particularly with respect to the output of maintenance manhours. It is more likely to produce an effect on the crew size output.

Off-line maintenance processing - The current version of AF-MANCAP assumes that all maintenance assigned to either the off-equipment or depot organizational levels will be performed "off-line". In other words, the system will not be held in maintenance until the action is complete. Rather, the model assumes the component will be removed from the system, replaced with a spare, and the system will be returned to operational status. NOTE: This implementation of off-line capability is not consistent with the current implementation in the Army version of MANCAP.

Indirect maintenance time - This version of AF-MANCAP computes indirect maintenance time at the rate of 2.5 hours per shift for each maintainer. This calculated value is displayed on the Execution Summary Report. The indirect maintenance time does not affect the model. The amount of indirect maintenance time does not affect the maintenance manhour report, nor does it affect the maintenance headcount reports.

Spare parts processing - The AF-MANCAP tool does provide for the unavailability of spare parts. The model assumes that spare parts are only needed for 'remove & replace' tasks. Each maintenance organization level (i.e., on-equipment, off-equipment, depot) has a user-entered probability that any spare part will be available when it is needed. If the part is not available, the length of the delay until it becomes available is based on a series of rectangular distributions.

Run time - AF-MANCAP has succeeded in that it provides a fairly high fidelity unit-level maintenance model on a personal computer. The user interface consists of pop-up windows with fairly simplistic data entry schemes. Due to the model's power and the limited processing environment, model execution time can be quite long. This can be improved dramatically with a math co-processor.

AF-MANCAP Software and Data

Software Modules - - AF-MANCAP is a Disk Operating System (DOS) application. It is written and compiled using MicroSoft C. It consists of eighteen separate modules, and over 60,000 lines of source code. The executables are distributed on nine 5 1/4" 1.2 mega byte (MB) floppy diskettes, and the total program requires approximately 5.5 MB of hard disk storage.

Since AF-MANCAP is hosted on a 640K Random Access Memory personal computer, it does have limitations regarding the number of maintenance actions that can be modeled. This limitation is currently 300. This number of maintenance actions can be distributed in any way among up to 300 subsystems. NOTE: A maintenance action is a component paired with a maintenance task. In addition, AF-MANCAP models are limited to 500 systems and 180 days of simulation.

Utilities - - AF-MANCAP does include context-specific help screens. These help screens also include access to a glossary of terms and a facility through which the user can examine data sources for library data.

AF-MANCAP does include an extensive set of utilities. The utility programs enable users to share data, generate backups, and update databases. The utilities also allow the user to personalize the set-up of AF-MANCAP to access different storage devices (i.e., bernoulli boxes).

Data Libraries - - AF-MANCAP contains data libraries that are stored in a relational database. These libraries enable users to "cut and paste" from existing system maintenance data. This can significantly decrease the amount of data entry required to perform an analysis.

The current AF-MANCAP libraries contain Air Force maintenance data that are representative of a notional advanced tactical fighter design. The data were developed from Logistic Support Analysis Records and Logistics Composite Model (LCOM) networks associated with the F-15, F-16, and F-18. The AF-MANCAP libraries also contain systems data from 22 Army systems (e.g., M1A1 Tank, Scout Helicopter).

The libraries are in R:BASE format, and were designed to be easy to update as more data become available.

SUMMARY

AF-MANCAP is a desktop tool that can be used to aid decision makers in assessing maintenance requirements for new or proposed systems. The tool includes embedded stochastic simulation models that increase the fidelity of the maintenance requirement predictions. The tool is fairly easy to use, with help screens and a user's manual. Further information can be found in Archer et. al. (1990) and in the AF-MANCAP Software Documentation technical report.

REFERENCES

Archer, R., Griffith, W., Laughery, R., Maisano, R., & Kaplan, J. (1990). Tools for predicting manpower requirements and system availability: the maintenance manpower (MAMA) analysis and the manpower capabilities (MANCAP) predictor. Proceedings, 58th MORS Symposium. Annapolis, MD: United States Naval Academy.

Dahl, S., Adkins, R., and Bravo, T. (1990). Final Report on Concepts on MPT Estimation (Development of MANPRINT Methods). Report Number E-17611U. Boulder, CO: Micro Analysis and Design and Dynamics Research Corporation.

GLOSSARY

HARDMAN III - HARDMAN III is a collection of personnel computer-based software tools that were developed to support the Army's MANPRINT initiative. This project was sponsored by the Army Research Institute in Alexandria, VA. The ARI point of contact is Dr. Laurel Allender, (703) 274-9046.

Maintenance Action - A *maintenance action is a component and maintenance* task pair. Examples include: inspect engine, troubleshoot landing gear.

MOUBF - Mean operational unit between failure. For components belonging to armaments subsystems, this is measured in mean rounds between failure. For components belonging to mobility subsystems, this is measured in mean distance between failure. For all other components, the measure is mean time between failure. For unscheduled maintenance actions, the MOUBF is interpreted as the mean of an exponential distribution and failures are predicted stochastically. For scheduled maintenance actions, the MOUBF is applied as a constant failure rate.

MTTR - Mean time to repair. The MTTR is modeled as a constant repair time.

APPENDIX B

LCOM EXPLAINED[1]

[1] This appendix is reproduced from Boyle, E. LCOM explained. (AFHRL-TP-90-58). Wright-Patterson Air Force Base, OH: Logistics and Human Factors Division. Reproduction approval provided 16 December 1991.

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LCOM EXPLAINED

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Reproduction approval provided by Mr. Edward Boyle
16 December 1991

APPENDIX B: LCOM EXPLAINED

SUMMARY

This paper introduces a general audience to the Air Forces's Logistics Composite Model. LCOM is a MonteCarlo simulation of a maintenance organization used to identify optimal base-level resources. An important LCOM application is to determine maintenance manpower requirements. This paper describes the motives and some of the processes of LCOM. For LCOM practitioners, this overview is not need. This paper is included in the Critical Experiments of Hardman III Utility report, for lay people, who wish to understand the basics of the model used for the convergent validation of AF-MANCAP.

APPENDIX B: LCOM EXPLAINED

Introduction

The Logistics Composite Model (LCOM) was created in the late 1960's through a joint effort of The Rand Corporation and the Air Force Logistics Command. The original purpose of LCOM was to provide a policy analysis tool to relate base-level logistics resources with each other and with sortie generating capability. Logistics resources modeled in LCOM include maintenance people, spare parts, and aerospace ground equipment (AGE). LCOM is a flexible and versatile model. The interaction of any of the factors can be studied in virtually any level of detail the analyst requires.

Though intended to examine the interaction of multiple logistics resource factors, LCOM's most important use has been in establishing maintenance manpower requirements. A large portion of the Air Force maintenance workforce is justified through LCOM simulation. These people are said to be "LCOM-earned." LCOM is connected by Air Force Regulation 25-7 to the manpower standards process, and through this to the Air Force budget.

LCOM software documentation is abundant (e.g., Drake & Wieland, 1982; Aeronautical Systems Division, 1990; Air Force Manual 171-605). And several LCOM training guides have been written (e.g., Dengler, 1981; Keller, 1977). But there has been surprisingly little published focusing on the LCOM manpower estimation process itself. LCOM modeling is often cited as a basis for organizing certain kinds of manpower, personnel, and training (MPT) analysis, but since few people understand LCOM, few understand why this connection with MPT is so apt. Because of its complexity, understanding of this simulation has always been limited to a very small group of specialists. This essay provides a concise explanation of LCOM for the non-specialist who wants to understand the general manpower estimation process without having to learn LCOM's myriad details. The objective is to promote LCOM understanding, not LCOM mastery.

LCOM Simulation Overview

LCOM simulates the work of a maintenance organization. LCOM study objectives may differ widely, but the usual one is to locate the best - or optimal - mix of logistics resources to support a given weapon system under given operating conditions. These logistics resources can be spare parts, support equipment, facilities, or human resources (i.e., maintenance people). An LCOM simulation is analogous to an experiment in which variations in input resources are related to variations in output. In LCOM, the most important output measure is usually the number of sorties flown. In manpower studies using LCOM, the idea is to find, for each defined Air Force Specialty (AFS), the lowest manpower input that just achieves the desired sortie rate. We don't want manpower to be too high, because then people would be idle, or, in LCOM jargon, underutilized. But we don't want manpower to be too low, because then people would be too busy, or overutilized. We would lose sorties as aircraft needing servicing or repair wait for maintenance crews to become available. LCOM simulation for manpower amounts to a search for a satisfactory balance between these two manpower considerations and sortie generation potential.

The details of LCOM modeling may seem daunting but the core ideas are few and easy to understand.[1] LCOM can be thought of as a simple counting device. The simulation logs sorties and other performance variables from manpower levels and other resource information supplied to it by the analyst. From this perspective, to say that LCOM "determines" manpower is to speak very imprecisely. In fact, the analyst supplies the manpower. LCOM simply counts the sorties corresponding to that manpower level. The manpower versus sortie trade-off is evaluated as a queuing problem. If repair waiting lines are too long, more servers will be added to reduce waiting times and thereby meet the sortie demand.

The analyst describes the maintenance environment through task networks and resource definitions. Air Force Specialties (AFS), with corresponding manpower levels, are one of these resources. These can be described in any manner, but they must be declared. The analyst also describes the number of aircraft, mission types, spare part levels, configuration requirements, and other information. These data are used as input to the simulation. The simulation calls for aircraft with specified configurations to be launched at particular times. If aircraft are available, they are launched. LCOM forgets about them after they're launched but remembers them when they return. If they are "broke" they are repaired. If they are not "broke" they are serviced and returned to a launch pool. LCOM counts and summarizes all such simulated events. The rest is detail.

Why Simulation?

The Air Force has long favored a simulation approach to aircraft maintenance manpower requirements. The main reason is that mathematical work measurement methods, which are based on expected or average long run workload, do not accurately reflect aircraft maintenance realities or mission imperatives day by day. The volume of maintenance work fluctuates over time. Equipment breaks randomly, and peaks in sortie generation demand may arise suddenly.

[1] The person who quipped "God is in the details" was surely referring to LCOM.

Consequently, maintenance work and maintenance manpower cannot be entirely preprogrammed in expectation of an orderly and uniform production rate.

Much of aircraft maintenance work is "unscheduled" repair of equipment that breaks in a stochastic - or random - manner. Though we may be sure that aircraft components will break in the long run, we cannot be certain when they will break in the short run. Hence, to man work centers according to the long run average workload would sometimes mean inadequate sortie production in the short run. A simulation approach deals with random variations in workload by establishing a statistical basis for estimating the sortie risk of different manpower levels. If randomness in maintenance workload and spikes in sortie demands were removed, there would be little reason to simulate. A deterministic formula or other "management engineering" approach might be used instead. In LCOM, manpower is wrapped with a statistical confidence band.

LCOM is called a Monte Carlo simulation because the model uses random draws from equipment failure parameters to introduce demands for unscheduled maintenance work. Similar random draws determine how long a particular repair will take. The analyst specifies the mean, variance, and distribution types for failures rates and repair times. The model allows chance to play a role in failure occurrences in any given simulation trial. As a consequence, simulation trials must be run repeatedly to determine the "just right" manning level for each work center. After a satisfactory manning level is found, the model is run again using new random number seeds to determine the statistical robustness of a given manpower level. Variance reduction and other techniques can make the simulation process more efficient, but the LCOM iteration process will usually be more time consuming than a deterministic mathematical approach applied to the same modeled environment.

The interested reader will find illuminating literature on military manpower requirements particularly in Rand's work in the late 1950's and early 1960's. The work of Houston (1960, 1962) on the "personnel subsystem" concept and of Levine & Rainey (1959) on the Base Maintenance Operations Model describe the use of systems analysis tools much like the current LCOM model for manpower planning to support Air Force systems. The technical issues surrounding maintenance manpower estimation are quite old and, for the most part, quite well studied. Newer logistics analysis methods, such as SAMSOM (Bell & Stucker, 1971) and TSAR (Emerson & Wegner, 1985) in the Air Force, and manpower tools such as MANCAP in the Army (Archer, Griffith, Laughery, Maisano, & Kaplan, 1990), attest to the enduring value of the simulation approach to logistics trade-off analysis. See also an early description of LCOM by Fisher, Drake, Delfausse, Clark, and Buchanan (1968).

LCOM Model Description

A simplified view of how LCOM can model the aircraft maintenance world is shown in Figure B-1. Aircraft are flown, serviced, repaired, and returned to flying status according to rules defined by the analyst. The aircraft are processed through task networks that describe what the work is and what it requires. For this reason LCOM is also called a network processing model.

Maintenance resource levels in Figure B-1 (i.e., spare parts, people, and equipment) are defined by the analyst, not by LCOM. The model will call upon these resources, human and otherwise, in supplying aircraft to meet the flying demand. Generally speaking, if too few resources are provided, the aircraft will wait. Missions will be cancelled as maintenance queues or backlogs prevent aircraft from flying. If too many resources are provided, they will be under-utilized; in effect, wasted. The statistics gathered by the LCOM simulation provide clues about how the resource levels should be changed to improve either resource utilization or sortie generation potential. For a manpower study, this usually means adding manpower to reduce maintenance waiting time, or reducing manpower to improve human resource utilization. Normally, many simulation runs are needed to measure the effects of these adjustments.

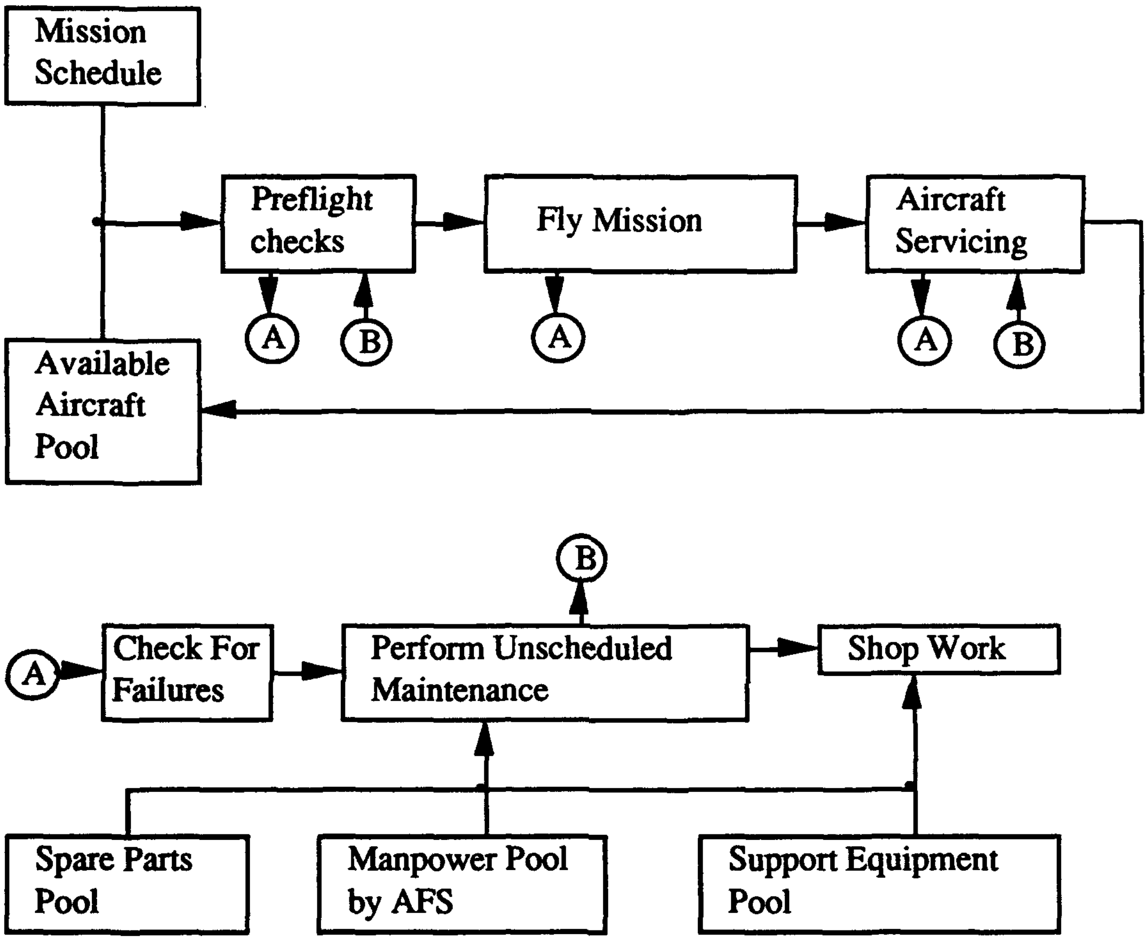


Figure 1. LCOM Simulation Logic. (Adapted from Dengler, 1981)

Figure B-1. LCOM Simulation Logic. (Adapted from Dengler, 1981)

LCOM Software

The overall structure of the LCOM software, which is written primarily in Simscript II.5, is shown in Figure B-2. LCOM consists of a preprocessor program (Input Module), a simulation program (Main Module), and Post Processor Modules. In addition, a number of supporting programs are available to aid the data build-up process of LCOM. This Data Preparation Subsystem extracts and formats Air Force maintenance information from deployed aircraft to help create the LCOM task networks.

The various LCOM forms (Table B-1) constitute the LCOM data base. After error checking, an LCOM preprocessor converts the data into two files: the initialization ("init", in LCOM jargon) and the exogenous events (or "exog") files. The init file describes the maintenance environment to be simulated and provides starting values for the prescribed variables. The exog file contains flying schedule and related scenario data created from the mission data supplied by the user. This is what creates demand for sorties and maintenance work.

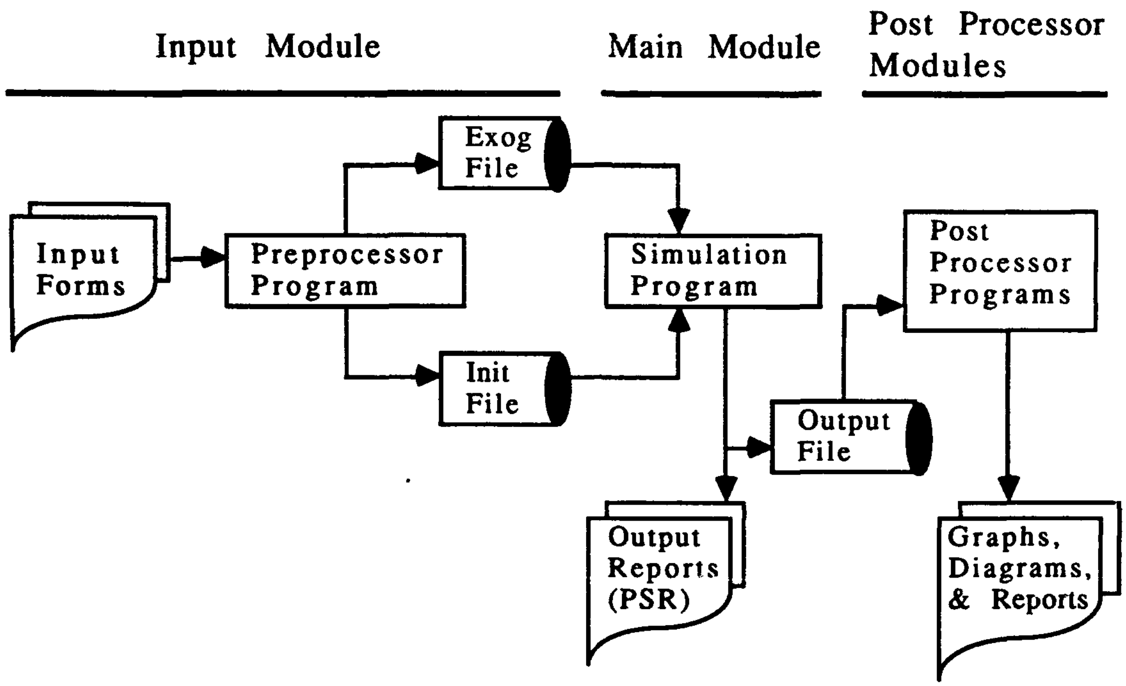


Figure B-2. LCOM Software Structure (adapted from Dengler, 1981)

The Performance Summary Report (PSR) is LCOM's principal output. Aeronautical Systems Division's LCOM Version 89.D lists 109 PSR statistics in eight categories:

- operations (e.g., sorties flown)
- activities (e.g., average time to get resource)
- personnel (e.g., manhours used, manhours per flying hour)
- supply (e.g., number of items back ordered)
- shop repair (e.g., number of items repaired)
- AGE (e.g., aerospace ground equipments used)
- aircraft (e.g., number of aircraft days available)
- facilities (e.g., facilities used)

The Post Processor Modules produce summary statistics for the entire simulated period. These include manpower matrices showing demands for manpower by Air Force Specialty (AFS) by time of day, and usage and availability of spare parts, among others. The manpower matrix and parts reports are particularly important in manpower modeling with LCOM.

The simulated work environment includes scheduled maintenance needed to fuel, arm, service, and inspect aircraft. This is described in the main servicing network. It also includes work needed to fix airplanes that have broken in some way. This is described in the unscheduled maintenance network. The modeled work may also include phase (periodic) maintenance. Both organizational (flightline) and intermediate (shop) tasks are described. These are also called "on-equipment" and "off-equipment" tasks, respectively.

The analyst may define so-called maintenance action clocks for each aircraft subsystem, component, or part. The maintenance action clock "decrement" governs the rate at which equipment fails, and this, in turn, governs the volume of unscheduled maintenance manhours. Often, these clocks are set in mean sorties between failures, but other metrics can be used. The reliability of equipment is estimated from maintenance experience with fielded systems or from engineering data for new systems.

A common LCOM modeling scenario is to cycle aircraft in and out of the main servicing network until a maintenance action clock has breached, whence it passes the aircraft through the unscheduled maintenance (repair) networks corresponding to the failed equipment item. When repaired, the aircraft returns to a mission-ready pool for assignment.

A large array of options and related "instrumentation" have been added to LCOM over the years. These allow the maintenance environment to be modeled with greater detail, flexibility, and realism. Even the PSR can be tailored. While these doubtless make LCOM difficult to master, they do not alter the model's "fly, fix, and figure" logic in any fundamental way. They do make it difficult to describe LCOM briefly without misleading through oversimplification.

LCOM Data Base

The LCOM input forms are listed in Table B-1.

TABLE B-1. LCOM INPUT FORMS

Form Name	Purpose
Task Network	Every task's name, sequence node, and selection mode,
Task Definitions	Every task's name, time (mean & variance) and resource ID and quantity (AFS, crew size, spare part, AGE)
Resource Definitions	AFS, spare parts, aircraft, AGE, and failure clocks are identified
Clock Decrements	Equates equipment failure probabilities to sorties
Shift Change Policy	Defines shift length and how resources are to be allocated to shifts
Mission/Activity Entry Points	Defines resources entering the network and the required aircraft configuration allowing tracking and assignment of aircraft to missions
Priority Specifications	Describes how to handle task conflicts when using resources through preempting, expediting, and restarting rules
Sortie Generation Data	Defines mission types and other scenario data
Performance Summary Reports	Defines PSR reporting structure
Statistical Distributions	Specifies distribution types (normal, log normal, exponential, etc.)
Aircraft Assignment Search Patterns	Defines aircraft external and internal configuration search selection sequence
Internal Equipment Authorization Changes	Defines internal equipment, its authorization, and the network location effecting its quantities
Internal Equipment Group Definitions	Defines internal equipment groupings or combinations by aircraft
Attribute Definitions	Defines an input format for combining data on separate LCOM forms

Notes: (1) LCOM form numbers are not listed
(2) AFS = Air Force Specialty
(3) AGE = Aerospace Ground Equipment

LCOM Task Language

In LCOM, most maintenance tasks are described as actions taken on a piece of hardware. These tasks require resources (people, parts, and AGE) and time. The actions applicable to people are:

On-equipment (Flightline)

X = Access (Use AGE)
T = Troubleshoot
R = Remove and replace
H = Inspect
M = Minor repair
V = Verify system works
J = Aircraft handling
B = Loading/downloading munitions

Off-equipment (Shop)

L = Component identification
W = Check/repair component
K = Component checks OK
N = Check and condemn
Y = Disassemble/reassemble

When these action codes are paired with equipment Work Unit Codes, a concise task descriptive language is created. For example, "T74AB0" in LCOM means "troubleshoot the (F-16) radar low power RF." The entire LCOM language for unscheduled maintenance is spoken in this "action taken/work unit code" manner. For general aircraft servicing tasks and other work that cannot be tied precisely to specific equipments, words like FUEL, LAUNCH, and TOW are also used.

The task descriptive vocabulary used by LCOM is exact but it is also rather limited. There is no implication in LCOM maintenance networks of what military psychologists would call task analysis. That is, the only things LCOM knows about a task is who does it, how many people are needed, who may substitute, what support equipment is needed, and how long the task takes. Through the maintenance action clocks, LCOM also knows how often a task is apt to occur. It knows nothing else about the qualitative aspects of the work. Task difficulty, personnel skills, safety considerations, and so on are not considered by LCOM.

LCOM Task Networks

Maintenance tasks are described in networks that define their logical flow. These networks can be defined in many different ways and in any level of detail. The task in Figure B-3, for example, begins when a failure clock for Part X has breached. The network section applicable to Part X is then activated. The aircraft will halt processing through the main servicing network while maintenance is performed.

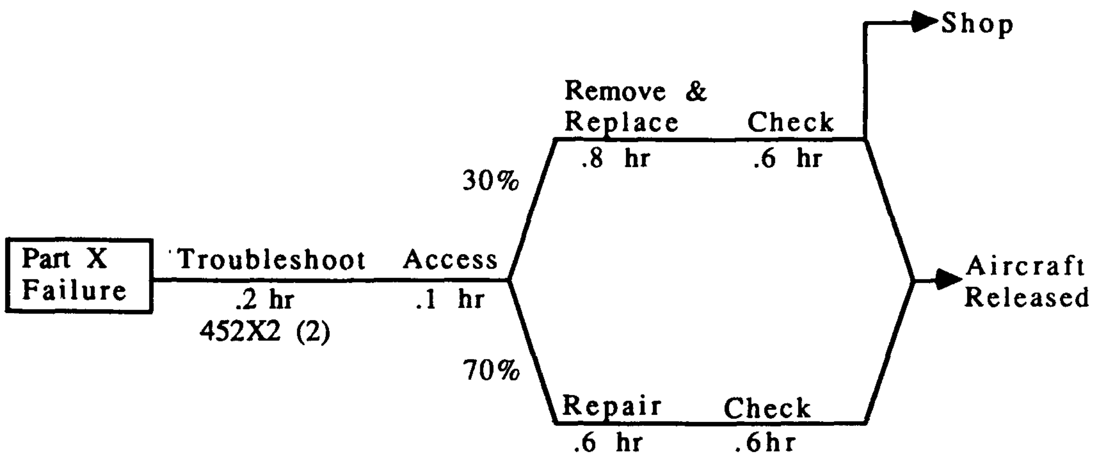


Figure B-3. LCOM Network Example

The diagram shows that it takes a crew of two specialists with AFS 454X2 three tenths of an hour to identify and access the problem. A repair action taking .6 hours will result 70 percent of the time, a remove and replace action taking .8 hours 30 percent of the time. After a check, the aircraft continues processing toward mission-ready status. Shop manhours are also generated when the failed part arrives for repair. The frequency with which this network section is activated is governed by the maintenance action clock describing the equipment's expected reliability. The manhours consumed by this maintenance over the simulated period are summed. Eventually, these manhours will contribute to an LCOM manpower estimate.

One of LCOM's distinctive features is the wide array of task networking controls it provides. These can be used, for example, to:

- "call" other tasks or networks,
- create probabilistic branching (Figure 3)
- skip over or accomplish tasks in parts
- define sequential and parallel task strings
- consume and generate parts
- change the location of resources
- decrement failure clocks
- model parts cannibalization (i.e., taking parts from another aircraft)

An LCOM data base (i.e., the assembled forms) can run to several thousand lines of code for a detailed weapon system study. The bulk of this code consists of task networks, resource definitions, and task definitions. A special input coding device, the Extended Form 11, can be used to consolidate the information contained on separate LCOM forms.

Deriving Maintenance Manpower With LCOM

LCOM models are typically run for debugging purposes with resources unconstrained. This means that essentially unlimited quantities of people, parts, and equipment are made available. Initial wide-open simulation permits the analyst to confirm that sorties are being demanded, that maintenance is occurring, and that the modeled environment conforms with the data base and operational logic prescribed for it. An unconstrained LCOM simulation can be used to determine the maximum achieveable theoretical performance.

But, typically, we don't want the theoretical maximum sortie rate. We want a sortie rate that reflects real-world flying requirements. And, in any case, we don't have unlimited resources to work with.[2] Hence, resource optimization in LCOM is a process of systematically adjusting resources until the LCOM sortie rate settles around the desired sortie rate and other criteria, such as manpower utilization limits, are not violated. This process is called constraining. It is through constraining that the analyst eventually finds the "just right" manpower level for each work center.

Since resources interact in complex ways, it is common to constrain their levels one at a time. For example, it would make little sense to try to optimize manpower if scarcity of spare parts and equipment prevented people from doing work. Hence, in manpower studies, attention falls first on constraining spare parts and equipment down to levels which, upon simulation, restrict performance to some pre-defined criterion.

Often, this criterion is the "Not Mission Capable - Supply" (or NMCS) rate, a statistic produced by the PSR. If the LCOM scenario specifies a NMCS rate of, say, 10 percent, the objective of parts constraining simulation trials is to establish parts levels that produce an average aircraft availability factor of 90 percent. The Post Processor Modules can produce reports useful for finding appropriate spare parts levels. Similar procedures can be used for equipment constraining, though AGE is less often at issue in LCOM manpower studies.

[2] Of course, without resource scarcity there would be no economics. And LCOM would be superfluous.

Manpower Factors

The relationship of manpower factors to sortie rate is shown in Figure B-4.

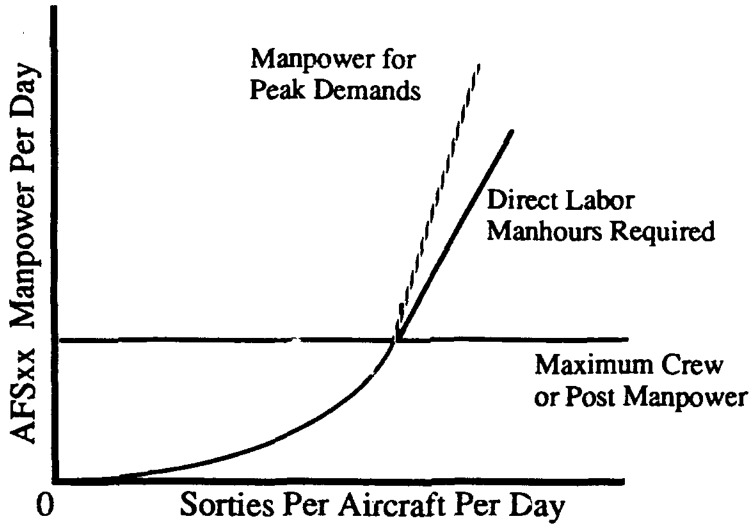


Figure 4. Manning Factors (Adapted from Dengler, 1981)

During manpower constraining, the LCOM analyst must consider which of these factors is driving the manpower requirement for each AFS. Other things equal, the sortie rate will govern the manpower factors. These are:

Post Manpower: Crews dedicated to a fixed post (e.g., end of runway checks) for a fixed period and who cannot be reassigned during the work shift.

Crew Size: Each LCOM task has a defined minimum crew size. Imagine an AFS with 20 tasks in all, 19 of which require two people, and one of which requires three people. A charming LCOM locution identifies this latter task as the "maximum minimum crew size." As a general rule, manpower on each shift should not be lower than this number.

Direct Labor: The manpower level needed to accomplish the direct manhours of work generated by the simulation. It is shown as a near linear increasing function of sorties flown.

Peak Demand: Sortie demand may have an irregular pattern through the day. Massed fights or surge conditions may require many people to be working at the same time for brief periods. More people may be needed to cover these peak demands than might be provided by applying the other manning factors alone.

Manpower Constraining

When spare parts constraining is done, manpower constraining starts. The required manning levels for each work center (or AFS) are determined through a progressive and systematic process of manpower constraining over many simulation runs. This process of allocating and reallocating manpower calls upon LCOM statistical reports as well as the analyst's judgment.

Dengler (1981) describes the following method. In the equation,

$$M(s) = \frac{\text{AFS Manhours Used (from PSR Statistic 29)}}{\text{(Utilization Factor) x (Number of Days) x (Shift Length)}}$$

manhours used by each AFS are converted to average daily number of people required for a shift [M (s)] by taking shift length, days simulated, and manpower utilization or availability factors into account. Utilization factors are specified as the percent of available manhours that can be allocated for direct work. The upper limits vary by AFS, but average about 80 percent. The availability factors, by current Air Force policy, are 144.5 hours per person per month in peacetime and 244 hours per month in wartime. The analyst must decide which policy is applicable to his simulation problem. The shift manning levels so derived become starting values for manpower constraining runs. AFS manning should not be lower than the maximum minimum crew size if no AFS substitution rules have been defined.

LCOM simulations are performed using so-called "change cards" which list authorized resource levels for the run. The number of days to be simulated, the simulation run time, must be large enough to ensure that random effects do not unduly distort the overall results. The sortie rate target and the number of PAA (Primary Authorized Aircraft) for the simulation must be taken into account. Dengler (1981) recommends 112 days for a 24-PAA unit and 38 days for a 72-PAA unit; both yield 2,000 sorties.

The analyst is guided in setting manning levels for subsequent LCOM runs by monitoring the sortie rate and manpower utilization statistics associated with a given manning level. AFSs that may need additional manpower can often be identified by examining the Manpower Matrix Post Processor, which shows AFS "backorder" statistics. The analyst must determine whether repair delays in particular work centers are constraining the sortie rate. Such delays might be tolerated if they are not. Work center manning might be reduced if the average utilization rate falls below established standards.

Finally, the actual manpower - the bottom line. After the analyst has completed all AFS manning adjustments and satisfied himself through confirmatory LCOM runs that he has reached the optimal manpower levels for each AFS, he has one final calculation to make. The number of authorizations (i.e., the number of whole people to be listed on manning documents) for each AFS depends on the total daily LCOM requirement for all shifts, the monthly manpower availability factor, the work days per month, and the shift length. The equation below shows how this calculation is made.

$$M = \frac{\text{Average Daily LCOM Derived Manpower} \times \text{Work Days Per Month} \times \text{Shift Length}}{\text{Manpower Availability Factor}}$$

The term "whole people" above is used advisedly. Division with fractional availability factors (e.g., 244.8 hours per month for wartime) will produce fractional manpower requirements. Since we can authorize people only in whole (integer) units, tables for rounding these fractions into whole-person equivalents have been developed.

Certain Matters

Manpower Availability and Utilization. Availability is the number of hours per month a person can be allocated to a duty post. For peacetime, 144.5 hours is used; for wartime, 244.8 hours. Utilization is the percentage of a person's duty time that can be allocated to direct work. There are published standards for utilization. Manpower requirements computed from LCOM - and from other methods - take both factors in account since both influence manpower requirements.

AFS Task Inventory. LCOM describes only direct maintenance work. The indirect work maintenance people do is accounted for through the manpower utilization factors, but the work itself is not described. Hence, LCOM data bases will not normally contain a complete inventory of the work of each specialty.

LCOM vs. Standard Manning. In general, only those work centers whose manning levels directly constrain sorties are modeled in LCOM. Shop overhead, maintenance management, and certain off-equipment AFSs are excluded. Depot manpower is likewise excluded. About half of unit-level maintenance manpower is derived with LCOM across the Air Force. (See Furry, Bloomberg, Lu, Roach, & Schank, 1979.) The rest of the manpower requirement is determined by application of manpower standards or by other means.

LCOM Data Base Support. LCOM data bases are created in part from the Air Force Maintenance Data Collection System (MDC). A number of computer programs have been created to process these data into LCOM format. These programs are not actually part of LCOM but they are important for LCOM modeling. The Common Data Extraction Programs (CDEP) and other software aids - the Data Preparation Subsystem - could be called LCOM's front porch.

LCOM Audit. A so-called "Operational Audit" is conducted to verify the simulated maintenance world. LCOM technicians will visit operating bases for the weapon system under study to check the accuracy of MDC data, verify AFS-task assignments and crew sizes, determine maintenance procedures and task times, and so on.

LCOM Software Vintage. LCOM is basically a 1960's style "batch" system. It is not very user-friendly, not user-interactive. Until recently, LCOM was confined to mainframe computers. Many Air Force users now run LCOM on IBM 9370 super mini's. Some run LCOM on VAX 11/780 series machines. We are not likely to see LCOM software running on personal computers any time soon, although proposals for rewriting, compressing, and updating the LCOM code to make this possible are sometimes heard. See the "LCOM 2000" study (Dymond, et al., 1987) for proposed enhancements to the LCOM software.

LCOM Substitutes. The basic queueing processes and simulation logic of LCOM can be easily replicated by any number of competing methods. SLAM (Simulation Language for Alternative Modeling) and Micro-SAINT are well known examples. The Army Research Institute's MANCAP (Manpower Capabilities Predictor), one of the new HARDMAN III tools, was inspired by LCOM. But LCOM remains unique. Its flexibility, detail, range of application, and data base support far exceed those of any potential substitute within its domain. For a given study, equivalence of model criteria might mean equivalence in model credibility, but LCOM findings still tend to be used as the standard for comparing manpower results.

An LCOM Sampler

The LCOM process lends itself to innovative applications. LCOM has been used with other models and it has been extended to systems other than aircraft and to the other Services. The applications discussed below convey some idea of LCOM's use within the MPT domain.

LCOM in Acquisition. LCOM has been paired with comparability analysis to produce early estimates of maintenance manpower for new systems. The work of Tetmeyer (1974) and his colleagues at the Air Force Human Resources Laboratory and at Aeronautical Systems Division is the best known example. The comparability approach pioneered by Tetmeyer is now prescribed by Logistics Support Analysis (MIL-STD 1388-1A). The basic idea is to create a baseline equipment configuration for a new system by using subject- matter experts to identify existing systems that are most like the projected new system. Tetmeyer's approach emphasizes the development of equipment reliability "deltas" which are used to adjust LCOM failure clocks. The notion of baseline comparison systems so prominent in MPT analysis for new systems is rooted in this LCOM-oriented work. (See also Maher & York, 1974; Tetmeyer & Moody, 1974; and Tetmeyer, Nichols & Deem, 1976)

The "Skill Level Problem." LCOM modeling assumes that all people within an AFS will perform a task in the same way. Every person is assumed to be task qualified and to take the same amount of time to do a task. Howell (1981) showed what could happen if "three-levels" (inexperienced people) predominated the workforce. He adjusted the LCOM task times using subject-matter expert judgments comparing "three-levels" against "five-levels" (experienced people). LCOM projected much larger manpower requirements with the "three-level" workforce since inexperienced people were judged to require more time to do the same work as "five-level" technicians. Garcia & Racher (1981) attempted to incorporate Air Force occupational survey data on task difficulty and time spent on maintenance tasks identified in LCOM and obtained similar results.

MPT Integration. The LCOM process has been expanded by the SUMMA (Small Unit Maintenance Manpower Analyses) model to serve as an integrating mechanism for manpower, personnel, and training analysis. The SUMMA model (Boyle, 1990) uses LCOM task data supplemented with subject-matter expert judgment to identify improved AFS-task alignments. The objective is to limit manpower requirements, especially for small unit deployments by, in effect, enlarging maintenance jobs. An MPT projection model informs the analyst of potential aptitude, training, and cost impacts of job merger options, and an analytic manpower forecast is provided. LCOM upload and download software is also included in the SUMMA package. The SUMMA model attempts to tie MPT analysis to altered AFS policies and to tie these, in turn, to LCOM.

REFERENCES

Archer, R., Griffith, W., Laughery, R., Maisano, R., & Kaplan, J. (1990). Tools for predicting manpower requirements and system availability: the maintenance manpower analysis (MMAA) and the manpower capabilities predictor (MANCAP). Proceedings, 58th MORS Symposium. Annapolis, MD: United States Naval Academy.

Bell, C., & Stucker, J. (1971, May). A technique for determining maintenance manpower requirements for aircraft units. (R-770-PR, AD 733561). Santa Monica, CA: The Rand Corporation

Boyle, E. (1990, April). SUMMA Summary. (AFHRL-TP-90-XX). Wright-Patterson Air Force Base, OH: Logistics and Human Factors Division, Air Force Human Resources Laboratory.

Dengler, D. (1981, December). LCOM II student training guide. (AFMSMMET Report 81-2). Wright-Patterson Air Force Base, OH: Air Force Management Engineering Agency.

Drake, W., & Wieland, B. (1982, March). LCOM simulation software users reference guide. (AFMSMMET Report 81-1.1). Wright-Patterson Air Force Base, OH: Air Force Management Engineering Agency.

Dymond, L., Hinds, B., Hopple, G., Gunkel, R., Schadle, W., & Bergeron, P. (1987, May). Analysis of LCOM capabilities final report. Washington, DC: Synergy, Inc. (AF Contract F49642-85-D0035).

Fisher, R., Drake, W., Delfausse, J., Clark, A., & Buchanan, A. (1968, May). The Logistics Composite Model: an overall view. (RM-5544-PR). Santa Monica, CA: The Rand Corporation.

Furry, W., Bloomberg, K., Lu, J., Roach, C., & Schank, J. (1979, April). MANPOWER: A model of tactical aircraft maintenance personnel requirements. (R-2358/1-PA&E). Santa Monica, CA: The Rand Corporation.

Garcia, R., & Racher, J. (1981). An investigation into a methodology to incorporate skill level effects into the Logistics Composite Model. (LSSR 29-81, AD A105131). Wright-Patterson Air Force Base, OH: Air Force Institute of Technology.

Houston, M. (1960, December). Concepts for estimating Air Force manpower requirements for planning purposes. (RM-2611, AD 250725). Santa Monica, CA: The Rand Corporation.

Houston, M. (1962, February). Manpower planning factors for Air Force systems in the conceptual stages of development. (RM-2823-PR). Santa Monica, CA: The Rand Corporation.

Howell, L. (1981, August). Manpower forecasts and planned maintenance personnel skill level changes. (ASD-TR-81-5018). Wright-Patterson Air Force Base, OH: Aeronautical Systems Division.

Keller, K. (1977, July). Logistics Composite Model student training text. Langley Air Force Base, VA: 4400 MES/LC.

Levine, R, & Rainey, R. (1959). The base operations model used in Rand logistics research. (RM-2374, AD 220605). Santa Monica, CA: The Rand Corporation.

Maher, F., & York, M. (1974, December). Simulating maintenance manning for new weapon systems: maintenance manpower management during weapon system development. (AFHRL-TR-74-97, AD A011986). Wright-Patterson Air Force Base, OH: Advanced Systems Division, Air Force Human Resources Laboratory.

Richards, F (1982, July). Building and operating the Logistics Composite Model for new weapon systems. (ASD-TR-82-5033). Wright-Patterson Air Force Base, OH: Aeronautical Systems Division.

Tetmeyer, D., & Moody, W. (1974, December). Simulating maintenance manning for new weapon systems: building and operating a simulation model. (AFHRL-TR-74-97 (II), AD A011987). Wright-Patterson Air Force Base, OH: Advanced Systems Division, Air Force Human Resources Laboratory.

Tetmeyer, D. (1974, April). Estimating and controlling manpower requirements for new systems: a concept and approach. (AFHRL-TR-74-31, AD 778838). Wright-Patterson Air Force Base, OH: Advanced Systems Division, Air Force Human Resources Laboratory.

Tetmeyer, D., Nichols, S., & Deem, R. (1976, May). Simulating maintenance manning for new weapon systems: maintenance data analysis programs. (AFHRL-TR-74-97 (III), AD

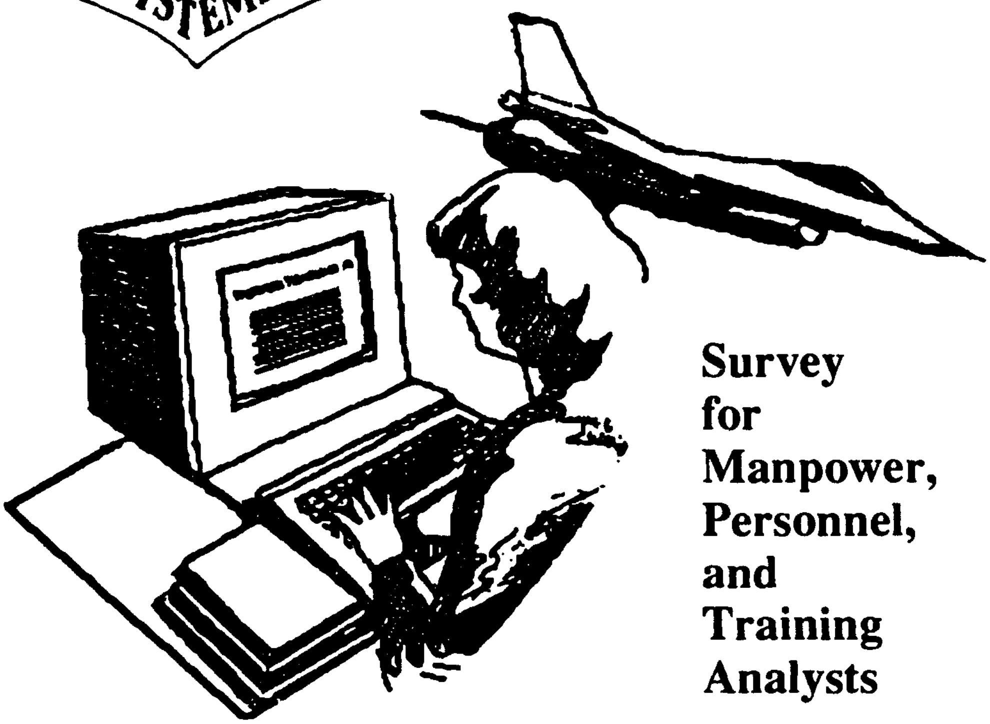
A025342). Wright-Patterson Air Force Base, OH: Advanced Systems Division, Air Force Human Resources Laboratory.

APPENDIX C

SURVEY

Critical Experiments of HARDMAN III.II Utility for Use by Air Force Analysts

Contract F49642-88-D0003
Delivery Order 5027



Survey for Manpower, Personnel, and Training Analysts

Developed by
HAY Systems Inc.
2000 M Street, N.W.
Washington, DC 20036

12 August 1991

Critical Experiments of HARDMAN III Utility for Use by Air Force Analysts

1. INTRODUCTION:

This project addresses the utility of a suite of analysis tools for evaluating the manpower, personnel, and training (MPT) impacts and trade-offs of emerging Air Force weapon systems. The technologies addressed in the software products are based on components of the HARDMAN III.II analysis tools: Manpower-Based System Evaluation (MAN-SEVAL) and Manpower Capabilities Model (MANCAP II). During the summer of 1991 the original HARDMAN III.II software products were modified for Air Force use. The new tool was called AF-MANCAP. Also, a test library of components from the F-18, F-15 and F-16 was created from historical Logistic Support Analysis Records and Logistics Composite Model networks. The prototype software products were developed by HAY Systems, Inc., Washington D.C. and Micro Analysis and Design, Inc., Boulder, Colorado for the Air Force Armstrong Laboratory, Brooks Air Force Base, Texas.

2. SCOPE AND FIELD OF APPLICATION:

2.1 SCOPE:

The AF-MANCP products were developed to obtain user reactions to the analytical tools and manpower analysis process. Your assessment will provide information for the determination of the characteristics and requirements for a production version of the software products.

2.2 EVALUATION AUDIENCE AND FIELD OF APPLICATION:

Subject matter experts (SME) who prepare manpower, personnel, and training inputs for Manpower Estimate Reports (MER) and Integrated Manpower, Personnel, and Comprehensive Training & Safety (IMPACTS) Program Plans.

3. REFERENCES:

- Statement of Work, Critical Experiments of HARDMAN III Utility for Use by Air Force Analysts F49642-88-D0003, Delivery Orders 5023 and 5027.

- Acquisition Guide for Measurement (draft), Rating and Assessment, International Standards Organization, 2 March 1991.

4. AIR FORCE POINT OF CONTACT:

- Dr. Bruce Gould, AL/HRMM, Brooks AFB, TX 78235-5601, (512) 536-3648.

Please note that all information provided is considered confidential and will only be used by the development team for the purpose of improving the software products.

Background Information

1. Your job title is: ______________________________

2. Your Primary AFSC or Occupational Series is: __________

3. Your Duty AFSC or Occupational Series is: __________

4. Military [ ] yes [ ] no
   If military your grade is: ________ and your TAFMS is: ________

5. Civilian [ ] yes [ ] no
   If civilian your grade is: ________ and your Govt. Service Time is: ________

6. Your civilian education background is:
   Highest degree: ____________ field of study: ____________

7. Have you developed: (If "yes" is checked provide program name(s)

   a. Manpower Estimate Report? [ ] yes [ ] no
      Program(s)? ______________________________

   b. IMPACTS Program Plan? [ ] yes [ ] no
      Program(s)? ______________________________

   c. LCOM Model? [ ] yes [ ] no
      Program(s)? ______________________________

   d. System Training Plan? [ ] yes [ ] no
      Program(s)? ______________________________

   e Predecessor/Comparability Analysis? [ ] yes [ ] no
      Program(s)? ______________________________

   f. Baseline Comparison System? [ ] yes [ ] no
      Program(s)? ______________________________

   g. Other: Describe any other examples of manpower, personnel, and training analyses that you may have accomplished? ______________________________
      ____
      ____
      ____

8. Do you have Disk Operating System (DOS) Experience? [ ] yes [ ] no

   a. If "yes" provide the years of experience: ______ (years)

   b. If "yes" list programs you have used in the last year: ______________________________
      ____

Background Information (cont)

9. Have you used any of the following databases or tools for manpower, personnel, or training analyses:

a. Operational Research Data Bank (ORDB) at Brooks Air Force Base? [ ] yes [ ] no

b. Lesson Learned database at Wright-Patterson Air Force Base? [ ] yes [ ] no

c. Crosswalk or Footprint databases provided by the Training and Performance Data Center (TPDC), Orlando, Florida? [ ] yes [ ] no

d. Logistic Support Analysis Records (LSAR)? [ ] yes [ ] no

e. Logistics Composite Model (LCOM) Networks? [ ] yes [ ] no

f. Training System for Maintenance (TRANSFORM)? [ ] yes [ ] no

g. Small Unit Maintenance Manpower Analysis (SUMMA)? [ ] yes [ ] no

h. Manpower Standards Development System (MSDS)? [ ] yes [ ] no

i. Maintenance Operational Data Access System (MODAS)? [ ] yes [ ] no

j. Core Automated Maintenance System (CAMS)? [ ] yes [ ] no

k. Occupational Survey Report Data from Randolph AFB? [ ] yes [ ] no

l. Cost Oriented Resource Estimating (CORE) model? [ ] yes [ ] no

m. CREWCHIEF model? [ ] yes [ ] no

n. Other databases or models? [ ] yes [ ] no

____

____

____

Instructions

This part of the survey contains questions on five characteristics of software products. The characteristics are: functionality, reliability, usability, efficiency, and maintainability. For each of the characteristics select one response (A, B, C, or D by marking the [ ] that represents your observations about the prototype software product. Please evaluate each characteristic. Please provide comments for any "C" or "D" ratings. If you have an questions regarding these instructions or the survey please ask the consultant.

Explanation of Rating Scales

The survey questions are designed to assess if the software products will fulfill the needs of a manpower, personnel, and training analyst. Four rating levels are used. From an analyst point of view the rating levels are to be linked with customer satisfaction:

A. Excellent - the product equals or exceeds the requirements on every aspect, and can be used as specified - - the product is very satisfactory.

B. Good - the product equals or exceeds the requirements on most aspects. It can be used as specified, or with minor limitations - - the product is satisfactory.

C. Fair - the product doesn't meet the requirements on some aspects. It can however be used, but with major limitations - - the product is almost satisfactory.

D. Poor - the product does not meet the requirements. It cannot be used - - the product is not satisfactory.

Please turn to the next page.

Customer Survey

Characteristic	Degree of Satisfaction	Rating
Functionality	Performs user required functions with no limitations.	[ ] A: excellent
	Performs user required functions, with only minor limitations in some of them.	[ ] B: good
	Performs user required functions except for some limitations in some of the functions. These limitations can generally be overcome by manual procedures.	[ ] C: fair
	Provided functions do not meet user's requirements.	[ ] D: poor

Briefly describe limitations
in the space below
if either of these blocks are "X"

Comments:______________________________

Customer Survey (cont)

Characteristic	Degree of Satisfaction	Rating
Reliability	Performs its intended functions under all foreseeable conditions.	[ ] A: excellent
	Performs its intended functions under all conditions. However, infrequent conditions such as extreme load, out of specification input data sets or function parameter might result in incorrect output.	[ ] B: good
	Performs its intended functions. However, load conditions and input data set and functions parameters should be kept within specification, so as to reduce data loss or prevent program interruptions.	[ ] C: fair
	Produces incorrect results, data losses, and/or the program quits even on correct input data sets and normal load conditions.	[ ] D: poor

Briefly describe limitations
in the space below
if either of these blocks are "X"

Comments:

Customer Survey (cont)

Characteristic	Degree of Satisfaction	Rating
Usability	The software can be used with no prior training. On-line itemized "help" is available. Full user documentation is provided.	[ ] A: excellent
	Minimal prior training is necessary. This training can be done with a "tutorial" type of software package, included in the main delivery. On-line itemized "help" is available. Full user documentation is provided.	[ ] B: good
	Training is required prior to the use of the software. On-line "help" is available, but requires prior knowledge of software to be used Documentation requires some prior knowledge of software to be used.	[ ] C: fair
	Extensive training is required before use. No documentation, nor help is available.	[ ] D: poor

Briefly describe limitations
in the space below
if either of these blocks are "X"

Comments:____

Customer Survey (cont)

Characteristic	Degree of Satisfaction	Rating
Efficiency	Response time remains acceptable under all conditions.	[ ] A: excellent
	Response time remains acceptable under all conditions, however, performance degradation under simulation conditions is noticeable. The software indicates when products will be available.	[ ] B: good
	Severe performance degradation under simulation conditions. The software indicates to the user requirements to initiate manual or alternative procedures to save data and continue work.	[ ] C: fair
	Unacceptable performance even under moderate load. When short of resources (file space, memory, etc.) the software will quit with no prior notice.	[ ] D: poor

Briefly describe limitations
in the space below
if either of these blocks are "X"

Comments:____

Customer Survey (cont)

Characteristic	Degree of Satisfaction	Rating
Maintainability	All user documentation is available to the user.	[ ] A: excellent
	Some documentation is available to the user.	[ ] B: good
	Documentation is limited but an Air Force point of contact will be provided.	[ ] C: fair
	No documentation is provided and no Air Force point of contact is provided.	[ ] D: poor

Briefly describe limitations
in the space below
if either of these blocks are "X"

Comments:

Customer Survey (cont)

This part of the survey contains questions about your requirements for a production version of the software product. The prototype product can be used on computer systems that meet the following minimum configuration requirements:

- 80286 processor
- Enhanced graphics display
- Hard disk with a minimum of 20M bytes of storage
- One floppy drive that can read and write floppy diskettes
- Dot matrix printer capable of printing 80 characters per line. This printer must be capable of outputting IBM graphics
- IBM AT-compatible keyboard
- DOS 3.0 or higher
- 640 K bytes of RAM (minimum of 571 K bytes free)
- 80287 coprocessor (optional)

1. Do you have access to the above computer system, printer, disk storage, etc.? [ ] yes [ ] no

2. Should the software provide for use of laser printers? [ ] yes [ ] no [ ] undecided

   if "yes" what type of laser printer?____________________________

   ____

3. The current system is limited to simulations of 300 tasks. What do you consider to be the <u>maximum</u> number of tasks?

   [ ] 500
   [ ] 1,000
   [ ] 1,500
   [ ] 2,000
   [ ] 2,500
   [ ] 3,000
   [ ] 3,001 or more tasks
   [ ] undecided
   [ ] limit of 300 is acceptable

Customer Survey (cont)

4. I agree that the AF-MANCAP tool should included features for recommending a new MTBF when the operating environment changes (e.g. when avionics systems from a fighter are moved to a cargo aircraft the MTBF will be adjusted from 2,000 hours to 8,000 hours)? [ ] yes [ ] no [ ] undecided

5. If an operational product is developed would you require:

   a. Source code for day-to-day use? [ ] yes [ ] no [ ] undecided

   b. Hot line technical support? [ ] yes [ ] no [ ] undecided

6. I could use the prototype product to support any past or ongoing manpower or personnel analytical efforts?

   [ ] Strongly Agree
   [ ] Agree
   [ ] Undecided
   [ ] Disagree
   [ ] Strongly Disagree

If you agree discuss the applications and any savings____________________

7. I agree with the concept of developing a baseline comparison system from a large library that users can access?

   [ ] Strongly Agree
   [ ] Agree
   [ ] Undecided
   [ ] Disagree
   [ ] Strongly Disagree

Comments:____

8. I agree with the AF-MANCAP simulation concepts?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

9. I agree that the next update to AF-MANCAP should included the data for implementation of the Probability of K-Kill computations for the components?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

10. I agree that the next update to the AF-MANCAP tool should included an implementation of aircraft fuel utilization and fuel truck/operator support requirements?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

Customer Survey (cont)

11. I agree that the Terrain substep should be retained in AF-MANCAP for potential vehicle modeling applications in the Air Force?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

12. I agree that the next update to the AF-MANCAP tool should include a rework of the Fuel Transportation functions of the Support Model for Air Force applications?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

13. I agree that the next update to the AF-MANCAP tool should include a rework of the Ammunition Transportation functions of the Support Model for Air Force applications?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

Customer Survey (cont)

14. I agree that the next update to the AF-MANCAP tool should implement depot level tasks data?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

15. I agree that the Operational Crew modeling feature should be retained in the AF-MANCAP tool?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

16. I agree that the AF-MANCAP tool should be modified for use with "WINDOWS"?

[ ] Strongly Agree
[ ] Agree
[ ] Undecided
[ ] Disagree
[ ] Strongly Disagree

Comments:____

Customer Survey (cont)

17. Please use this space for any other comments or suggestions about the AF-MANCAP software products

Comments:____

18. Please use this space for comments or suggestions about the AF-MANCAP Overview Briefing and Walk Through Handbook materials?

Comments:____

Additional References:

The following additional reference material was reviewed during the development of this survey:

1. Babbie, Earl R. The Practice of Social Research, Belmont: Wadsworth Publishing Company, Inc. 1979. Chapter 12: Survey Research (Concept of Contingency Questions, Answer Formats, and Instructions)

2. Boehm, Barry W. Software Risk Management, Washington: IEEE Computer Society Press, 1989

3. Shneiderman, Ben. Designing the User Interface, Strategies for Effective Human-Computer Interaction, Reading: Addison-Wesley Publishing Company, 1987.

4. U.S. Army Research Institute for the Behavioral and Social Sciences. Final Report for Concepts on MPT Estimation (Development of MANPRINT Methods), Alexandria, VA, September 1990.

APPENDIX D

SURVEY RESULTS

APPENDIX D: SURVEY RESULTS

		Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Could Use Prototype Now	All Users	6%	13%	56%	13%	13%
	Non-LCOM Users	*8%*	*17%*	*67%*	*8%*	*0%*
	LCOM Users	*0%*	*0%*	*25%*	*25%*	*50%*
Need A Baseline Development System	All Users	43%	36%	7%	7%	7%
	Non-LCOM Users	*40%*	*40%*	*10%*	*10%*	*0%*
	LCOM Users	*50%*	*25%*	*0%*	*0%*	*25%*
Agree with AF-MANCAP Concepts	All Users	0%	43%	21%	14%	24%
	Non-LCOM Users	*0%*	*60%*	*30%*	*10%*	*0%*
	LCOM Users	*0%*	*0%*	*0%*	*25%*	*75%*
Should Implement K-Kill Computations	All Users	0%	21%	64%	7%	7%
	Non-LCOM Users	*0%*	*30%*	*60%*	*10%*	*0%*
	LCOM Users	*0%*	*0%*	*75%*	*0%*	*25%*
Should Implement Fuel Considerations	All Users	7%	29%	43%	14%	7%
	Non-LCOM Users	*10%*	*40%*	*50%*	*0%*	*0%*
	LCOM Users	*0%*	*0%*	*25%*	*50%*	*25%*
Should Retain Terrain Substep	All Users	0%	36%	29%	29%	7%
	Non-LCOM Users	*0%*	*40%*	*40%*	*20%*	*0%*
	LCOM Users	*0%*	*25%*	*0%*	*50%*	*25%*
Should Rework Fuel Transportation	All Users	7%	36%	29%	21%	7%
	Non-LCOM Users	*10%*	*50%*	*30%*	*10%*	*0%*
	LCOM Users	*0%*	*0%*	*25%*	*50%*	*25%*
Should Rework Ammunition Transportation	All Users	7%	36%	50%	0%	7%
	Non-LCOM Users	*10%*	*40%*	*50%*	*0%*	*0%*
	LCOM Users	*0%*	*25%*	*50%*	*0%*	*25%*
Should Implement Depot Level Tasks	All Users	21%	64%	0%	7%	7%
	Non-LCOM Users	*20%*	*80%*	*0%*	*0%*	*0%*
	LCOM Users	*25%*	*25%*	*0%*	*25%*	*25%*
Should Include Operational Crew Modeling	All Users	0%	43%	36%	14%	7%
	Non-LCOM Users	*0%*	*50%*	*40%*	*10%*	*0%*
	LCOM Users	*0%*	*25%*	*25%*	*25%*	*25%*
Should Modify to Run Under Windows	All Users	36%	36%	21%	0%	7%
	Non-LCOM Users	*40%*	*40%*	*20%*	*0%*	*0%*
	LCOM Users	*25%*	*25%*	*25%*	*0%*	*25%*

APPENDIX E

AF-MANCAP Software Development Log

APPENDIX E: AF-MANCAP SOFTWARE DEVELOPMENT LOG

Version Nr.	Product Purpose	Key Date	Remarks
1.0	Working shell for upload of notional tactical fighter database	8-Jun-91	Working tool for Hay Systems Inc. (HSI). Not provided to the AL/HRMM
		18-Jul-91	Working prototype available but limited Library features. Expanded Subsystem capability to accept 50 subsystems.
2.0	Working demo of product	9-Aug-91	Received software with intial Phase I conversions.
			• Included new front screen
			• Addition of glossary, and help screens
			• Notional Fighter Aircraft Library
			• Conversion of MOS to AFSC
			• Conversion of DS,GS,and CT to on-equip, off-equip, and depot
			• Changed mobility equipment group from miles to miles/sorties
			• Changed the terms preventative to read scheduled and corrective to read unscheduled
		12-Aug-91	Provided Demonstration to AL/HRMM and AF/MOR. Also copies of product provided to AL/HRMM for inital testing.
2.1	Expected Value Change	23-Aug-91	Version 2.1 received. Not sent to AL/HRMM
			• Expenditure rate logic change
			Noted error in the Support General and Weapons Libraries. The wrong group code (other) was used. Micro Analysis & Design (MAD) provided new library with mobility group codes.
2.2	Baseline product for demonstration to AFLC/ASD/ and HQ TAC	26-Aug	Version 2.2 software received, copied by HSI and sent to AL/HRMM. Included Army concurrent efforts:
			• Multiple Guns
			• Faster HELP screens
			• Probablistic Aborts
			• 300 components per subsystem
			• MTTR unit conversions days/hrs
		4-Sep-91	Demonstrations at HQ AFLC
		5-Sep-91	Demonstrations at ADS/ALH
		23-Sep-91	Demonstrations at HQ TAC

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Version Nr.	Product Purpose	Key Date	Remarks
2.3	Off-Line Implementation	16-Oct-91	Version 2.3 software received, installed product, duplicated disks, and sent HSI copies to AL/HRMM.
			• Army HARDMAN III functions included for off-line maintenance.
		18-Oct-91	Encounter software error for simulations of 84 days or more. Also advised that AL/HRMM could not install the software. Traced problem to defective disk duplication by HSI.
		30-Oct-91	New disks received from MAD. HSI found that working files could not be deleted.
		5-Nov-91	Replacement disks received, installed and tested on HSI computer. Sent MAD original disks to AL/HRMM. Also, included correction of the following defects noted during HSI testing:
			• Fixed simulation limit of 68 days. Goal of 180 days established for MANCAP.
			• Added form feed at the end of the manpower analysis print routine.
			• Revised the "Identify Maintenance Manpower Resources" edit routines.
			• Software changed to allow deletion of working files.
		8-Nov-91	HSI noted that product aborted the 180 day simulation after 88.7% and a run time of 1342 minutes.
2.4	Off-line Army	19-Nov-91	Version 2.4 software ready to ship to AL/HRMM. Advised AL/HRMM that we would not ship the product. Army off-line features did not work. Only Remove & Replace tasks counted for off-line
			HSI conducted testing to verify that simulation run times of 180 days could be finished.
2.4	Off-line Air Force	27-Nov-91	Version 2.4 software shipped to AL/HRMM. Disks were installed and tested and installed by HSI.
			• Included modification of the off-line to consider: troubleshoot, remove & replace, inspect, adjust/repair, and test/check.
			• Included fix to the reduce simulation run time by half.

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Version Nr.	Product Purpose	Key Date	Remarks
		5-Dec-91	Notifed by AL/HRMM that front screen was missing. Also, could not complete simulations for 30 days. Suspected defective disk.
2.5	Off-line Air Force	6-Dec-91	Replacement disks provided to AL/HRMM direct from MAD.
			• Corrected version numbering.
			• Repackaged the front screen.
		11-Dec-91	AL/HRMM indicated that product would not complete a 30 day simulation. Tried installation on two 386 computers and one 286 computer.
		11-Dec-91	Successful simulations initiated by HSI and MAD from duplicate software on WYSE computer. Also front screen was missing.
		12-Dec-91	Notified by AL/HRMM that front screen was missing.
		12-Dec-91	Conference call (AL/HRMM, HSI, & MAD) - found software error in the sequence software activity entry screen.
2.6	Off-line Air Force	17-Dec-91	Replacement disks provided to AL/HRMM direct
		18-Dec-91	AL/HRMM found error in the total entry for System Availability Report.
		20-Dec-91	HSI & MAD unable to duplicate the error. Requested AL/HRMM download the model and send disk to HSI for analysis.