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An Assessment of the Ability of Maintenance and Logistic Models to Support Research on Early Estimation

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for

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Abstract

This ~~research note~~ describes an assessment of several existing logistic and maintenance estimation techniques and modeling approaches was conducted to evaluate their suitability for supporting exploratory research into the development of tools for assisting in the minimization of maintenance burden for existing and future material systems.

A conceptual model of factors influencing maintenance demand was used as a baseline against which to evaluate the selected modeling approaches. The existing approaches evaluated were determined to be highly resource and time-intensive, which may make them less than optimum for near-term payoff research. An approach involving development and utilization of reduced-scale maintenance system models for exploratory research was described, and this approach was recommended for research support in maintenance demand minimization.

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AN ASSESSMENT OF THE ABILITY OF MAINTENANCE AND LOGISTIC MODELS TO SUPPORT RESEARCH ON EARLY ESTIMATION

CONTENTS

LIST OF TABLES

AN ASSESSMENT OF THE ABILITY OF MAINTENANCE AND LOGISTIC MODELS TO SUPPORT RESEARCH ON EARLY ESTIMATION

INTRODUCTION

One goal of the MANPRINT program is to develop methods and techniques to assist in designing supportable materiel systems. The abilities and characteristics of the maintenance function supporting a materiel system are acknowledged to be a key issue in system supportability. Therefore, the ability to optimize the characteristics of the maintenance function can function as both a force multiplier (by supporting higher levels of readiness and sustainability) and in minimizing life cycle costs.

The Army Research Institute (ARI) supports the MANPRINT program by developing tools and methods that can be used to extrapolate the consequences of materiel and support system designs upon manpower, personnel, and training (MPT) demands once a system is fielded. Maintenance has been identified as a significant consumer of MPT resources, and is receiving attention as part of this process. One goal of work in this area is to find ways to reduce skill demands in the maintenance workforce, as well as the overall maintenance burden.

A conceptual model of factors influencing the Army maintenance function has been developed (Evans and Roth, 1988). This model identifies approximately 50 variables and factors (see Table 1) that can contribute to the performance of maintenance and the MPT demands of the maintenance function. For convenience, these variables are segregated by acquisition versus operations issues, in four major domains: policy, MPT, system design, and logistics (an extensive discussion of the variables is provided in Evans and Roth, 1988). Future work may explore the discrete and joint influences of these factors, to develop methods for maintenance optimization.

It is infeasible to design and implement alternative maintenance functions on an experimental basis to develop optimization methods. This approach would have a low likelihood of acceptance, and very high cost implications. An alternate approach is to develop or adapt, and exercise, models that reflect important characteristics of maintenance functions. Models of this general type exist and are used for logistic and maintenance estimation by the military services (DoD, 1987).

The goal of this effort was to identify candidate models or estimation approaches, and evaluate their potential use as tools to explore means of optimizing maintenance. This required the conceptual model referred to above, since it was necessary to know which variables might need to be accommodated by modeling approaches under evaluation.

Table 1

Maintenance Demand Factors Model

Type of Issue	System Life Cycle Issues		
	Acquisition Issues	Operational Issues	
		Potential Compensatory Factors	Givens
Policy Issues	Levels of Repair Allocation of Tasks Maintenance Concept Maintenance Strategy Maintenance Perspective Force Structure (TOE) O&O Plan	Promotion Flow	Extended Storage of Equipment Distractors OPTEMPO
MPT Issues	Planned Manpower Training Personnel KSAs Force Structure (TOE) Personnel Mix Publications	Actual Manpower Actual Personnel KSAs Training Motivation Diagnosis TMDE Use Management & Supervision Formal Training OJT Tool Control Preventive Maintenance Retention Publications Use	System Operation System Status Reporting Crew Preventive Maintenance Migration into CMF

Table 1 (Concluded)

Maintenance Demand Factors Model

Type of Issue	System Life Cycle Issues		
	Acquisition Issues	Operational Issues: Potential Compensatory Factors	Operational Issues: Givens
Design Issues	Maintainability Design Automatic Fault Diagnostics (BIT, BITE, ATE) Parts Commonality Planned RAM Acquisition Strategy Testibility Design		Achieved RAM
Logistics Issues	Facilities Publications Spare Parts and Expendables Provisioning	Tool Control	Spare Parts Availability

METHODS

This effort was carried out in three sequential steps. The first step was to identify candidate models for evaluation. This was accomplished by examining the DoD Catalog of Logistic Models (DoD, 1987), and by telephone with points of contact in agencies responsible for performing maintenance and logistic estimation for new and existing materiel systems. The agencies contacted were:

1. U.S. Army Logistics Center, Fort Lee, Virginia.
2. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.
3. Air Force Human Resources Laboratory, Logistics and Technical Training Division, Wright-Patterson Air Force Base, Ohio.
4. ARI.

Also, it was decided to examine a class of modeling approaches using tools that tend to be more straightforward and less data- and resource-intensive to use than large-scale models. This decision resulted from the fact that logistic estimation models in general are very data-intensive and usually require mainframe computers for efficient execution. Given the likelihood of limited resources for future work in this area, it seemed logical to identify tools that might fit more readily into resource constraints than the more traditional logistic modeling approaches. This class of approaches is typified by models developed using a software product known as MicroSAINT(TM). This tool is an outgrowth of large-scale modeling techniques and shares many of the strengths of such techniques, but can be used on personal computers. MicroSAINT(TM) is essentially a high-level programming language developed specifically for building models.

As a result of the identification effort, more than 200 different models were identified. In view of the limited resources available for the evaluation effort, a decision was made to select no more than 10 models or modeling approaches on which to gather data. The following criteria were used in selecting approaches and models:

1. The models or approaches should be operational rather than developmental. This is desirable, since an operational model will typically be validated and debugged, and there should be a reasonable idea of its flexibility and ability to accommodate variables of interest.
2. The models chosen should be accepted and routinely used for estimation in the communities where they are used. This

reflects some confidence in the predictive validity, as well as face validity, of the models.

3. The models should accommodate a significant proportion of the variables and factors identified as acquisition-impacted factors in the Evans and Roth (1988) conceptual model of maintenance. Single-variable or restricted domain models will clearly not be suitable for analyses that wish to accommodate flexible exploration of the consequences of factors and decisions upon maintenance demand.

As a result of applying these criteria to the initial list of models, a total of five modeling approaches, used in logistic or maintenance estimation during systems acquisition, were selected for further study. These are:

1. The Logistics Composite Model (LCOM), developed by the Air Force Human Resources Laboratory (AFHRL) and widely used among Air Force planners and logisticians.

2. The Optimum Supply and Maintenance Model (OSAMM; Department of the Army, 1985), developed by the Army Communications-Electronics Command (CECOM) and used for logistics estimation.

3. The Logistics Analysis Model (LOGAM; Department of the Army, 1984), developed and used by the Army Missile Command (MICOM) for maintenance and logistic estimation.

4. The MAnpower Requirements Criteria (MARC) development models developed and used by the Army Logistics Center (LOGC) for developing maintenance manning criteria. Currently, only one of the three projected MARC models (for aviation systems) is operational (Price, 1988). The tracked vehicle model is due to come on line within the next year, and a wheeled vehicle model is under development.

5. HARDMAN II (formerly MIST)--a computerized tool developed by ARI to support manpower and personnel estimation for developing materiel systems (Herlihy, Iceton, Oneal, & Guptill, 1985).

To this list of five models was added a class of smaller-scale modeling approaches, exemplified by MicroSAINT(TM), which was developed under the auspices of the U.S. Army Air Defense Center and School at Fort Bliss, and currently marketed as off-the-shelf software. While MicroSAINT(TM) is not a logistic or maintenance estimation model, it is a model development approach that can potentially support the creation of more tractable sorts of models than the larger-scale logistic models. This particular tool requires only a modest amount of computer capability (it executes on personal computers), and is capable of both discrete event and stochastic modeling, considered in this effort to be a useful attribute.

The MANpower CAPability (MANCAP) model developed by ARI as part of MANPRINT efforts for the Light Helicopter Experimental (LHX) program was not considered in this effort, although it was originally included in the candidate list of models. A parallel effort to define a more global, flexible modeling capability based on the original MANCAP model was being performed during the period when this work was conducted. It was decided that an additional evaluation of MANCAP would represent a duplication of effort. Therefore, MANCAP was not considered in the work reported here.

Model Characteristics Assessment

The second step involved obtaining documentation on each of the approaches selected for attention. Study of the documentation was expected to support the process of characterizing each model or technique on a number of dimensions that are considered important for evaluating their applicability in future work in this area. The dimensions that were defined as of importance are:

1. Input data requirements. Ideally, a model for exploratory use should have minimal requirements for input data or the development of descriptive algorithms to model input data characteristics. Specific domains of input data that are needed to prepare for a model execution were identified. These are:

    a. Mission models. Characterization of the specific or generic missions to be performed by the type of unit being modeled. This includes mission resources needed (how many of what types of systems), frequency of each type of mission, expected mission durations, mission conditions, and criteria for conducting missions under limited resource conditions (e.g., what are the minimum resources required to conduct a specific type of mission).

    b. Organization. The numbers and relationships of assets in the unit or other organizational structure that is being modeled. This includes unit identification, association of equipment with units, organizational structures, command and control relationships, and other organizational data. It may include some manpower data, but does not include personnel data (e.g., MOS and skill levels).

    c. Logistic variables. Number and placement of spare parts, transport times, availability and number of maintenance organizational contact teams, various sorts of delay time assumptions and doctrine, etc.

d. Manpower and Personnel (M&P) variables. Numbers of people and personnel characteristics at each organizational level of the maintenance, operations, and support functions. Includes distributions and numbers of MOSs by skill level in most cases. These variables are sometimes embedded in task factors (see below).

e. Battle damage (BD) factors. The impact of battle damage on systems, including various sorts of consequences of weapons effects and target aspects. These data are generally supplied by the Ballistic Research Laboratory when needed.

f. Use. Use rate factors for each type of system; also known as operational tempo factors.

g. Task factors. The identification, distribution across maintenance levels, and resource requirements (manpower and spare parts) for each maintenance task. Conditions that require task performance (condition or time) are also commonly included in task data.

2. Preparation time for one run of the model. Time and associated level of effort are scarce resources. Therefore, it is in the interest of future research involving the use of models to minimize the amount of time needed to prepare and format data to control model execution.

3. Execution time for one run of the model. Computer resources are also valuable. Some models are known to take between hours and days to execute, especially those that must iterate processes many times. Minimizing the amount of time required to perform modeling research will be beneficial.

4. Level of effort for model and data preparation. The amount of effort required to develop and execute a model through one run, including all necessary input data. This includes coordination with other agencies to obtain data. The level of effort ideally should be as small as possible.

5. Model capability for stochastic and event modeling. Since there are no predictive algorithms known to exist that link many of the factors in the Evans and Roth (1988) conceptual model, both statistical (stochastic) and event-based (deterministic) representations will have to be used to simulate the effects of such relationships. Therefore, it

is important that the models be able to handle both kinds of representations of events or phenomena.

6. Sensitivity analysis capability. This refers to the ability to manipulate one or more input variables across discrete values or ranges and examine the related effects on output quantities or variables. This capability is important to developing predictive relationships regarding the consequences of various factors on maintenance demand.

7. Sensitivity analysis level of effort requirements. In some cases, many different variable values may be explored in one execution through a model, while in others, it may be necessary to alter the input data sets and completely re-execute the model to conduct a sensitivity analysis. The former case is desirable, since it minimizes the amount of redundant work to be performed in using a model.

8. Ability to incorporate or manipulate the variables of interest from the Evans and Roth (1988) conceptual model. The more variables that can be accommodated and later varied, the higher the value of a model to future efforts in this area.

9. Phenomena coverage (domains). The capability of a model to represent and manipulate variables pertaining to the four major variable categories in the Evans and Roth (1988) conceptual model (policy; MPT; logistics; and system design). This was of interest because it is expected that some domains (e.g., system design) may be more important in influencing maintenance demand and skills than others (e.g., logistics).

10. Output data characteristics. This refers to the sorts of data that are produced as a result of model execution against an input database. These are in general categories (e.g., availability, MPT, etc.), rather than specifics, since, in some cases, it was not possible to examine the output of a model execution.

11. Availability. Whether a model or approach is Government-owned and available for use by researchers, and the model's users or custodians.

12. Usage cost factors. All of the identifiable factors that may contribute to the cost of use of the modeling approach or model.

The available documentation on each model was reviewed to identify the range of each of the 12 characteristics associated with the model. Document reviews were supplemented with interviews with personnel with working knowledge of each approach, when necessary. In some cases, gross estimates of some characteristics were made based on implications in the documentation that either were unsupported, or could not be confirmed.

Suitability Assessment and Recommendations

After the characterization of each model was completed, the data were tabulated and examined in the aggregate. This examination led to an overall assessment of each of the six approaches individually to support exploratory research into optimizing maintenance. Further scrutiny of the literature was supplemented by contact with developing organizations and users for some of the modeling approaches that were evaluated. Comments on the suitability of each approach were added to the tabulation of model characteristics. Based on the composite outcome of the model evaluation process, the various models were roughly rank-ordered as to their relative suitability for research purposes. This does not imply an assessment of suitability for the primary purposes for which the models were developed. Each of the models evaluated is considered to be a useful tool in the domain for which the model was developed.

RESULTS

The characteristics of each of the six models or approaches that were examined are summarized in Table 2. The remainder of this section contains a discussion of findings on each characteristic for each of the six models or approaches, and a summary discussion of the suitability of the models for research purposes.

LCOM Characteristics

LCOM, developed by the Air Force Human Resources Laboratory in the early 1970's, is the "grand-daddy" of comprehensive maintenance manpower estimation models. Since the general functionality of this model is representative of the way some of the other models (specifically the MARC models) operate, a brief summary is in order at this point. The basic approach embodied in LCOM is to "play out the war" from a logistic perspective, to evaluate the sufficiency of logistic resources (including maintenance manpower) to support a unit in sustained combat operations. Mission requirements (sorties) and mission resources (aircraft or other systems by type and combat load) are supplied to the model as input, as are the characteristics and limitations of logistic and manpower resources to support operations. Various other parameters, such as battle damage probabilities, munitions shot lines, availability of manpower (or personnel) or spare parts, etc. are defined, also as part of input data. These parameters are defined by the LCOM analysts, as part of input data development. The comprehensive input database controls model execution during a run. The model run simulates the performance of the assigned missions, on a user-specifiable time resolution scale (one day's resolution is a commonly used scale). Losses, battle damage, and scheduled and unscheduled maintenance tasks are simulated as part of the model functionality. Maintenance resource demands and consumption are tracked as part of the model's output database, as are system availability, mission accomplishment, numbers of systems available, and logistic system performance (in terms of supporting maintenance and sortie capability).

The model can be executed over as many simulated "days" as desired by the user, to examine maintenance system performance in both brief and protracted simulated combat. A common scenario used in LCOM simulations is a scenario modeling a Warsaw Pact-NATO non-nuclear major force conflict in central Europe. Maintenance performance in LCOM is based on task description data, including tasks to be performed, manpower requirements, and spare parts requirements, both specified by

Table 2

Assessment of Modeling Approaches

EVALUATION CHARACTERISTICS	MODELING APPROACHES LCOM	OSAMM
Input Data Requirements	Mission, M&P, BD, Organization, Task	Task, Use, Logistic, Organization, M&P
Preparation Time	Months	Months
Execution Time	Hours (variable)	Hours (variable)
Level of Effort for Preparation	Moderate	Moderate
Stochastic versus Event Modeling	Both	Both
Sensitivity Analysis?	Yes	Yes
Level of Effort for Sensitivity Analysis	Large	Moderate
Incorporate Variables of Interest?	Most variables (not compensatory)	Most, but not M&P or compensatory
Phenomena Coverage (Domains)	Policy, MPT, logistics, some design (indirect)	Policy, logistics, design (indirect)
Output Data Characteristics	Availability, M&P, resource demand and consumption, events, input	Maint. policy, availability, task distributions, costs, input, manpower
Availability	Yes--Air Force (ASD)	Yes--Army (CECOM)
Cost of Use Factors	Preparation, data, CPU time, output interpretation	Preparation, data, CPU time, output interpretation
Comments	Very comprehensive, but also very resource-intensive	Linear optimization approach (somewhat limiting)

Table 2 (Continued)

Assessment of Modeling Approaches

EVALUATION CHARACTERISTICS	MODELING APPROACHES LOGAM	Aviation MARC
Input Data Requirements	Logistic, manpower, use, task, organization	Mission, org., use, BD, M&P, logistic
Preparation Time	Months	Months
Execution Time	Minutes	8 - 40+ hours
Level of Effort for Preparation	Moderate	Large
Stochastic versus Event Modeling	Both	Both
Sensitivity Analysis?	Yes	Yes
Level of Effort for Sensitivity Analysis	Large	Very Large
Incorporate Variables of Interest?	Some variables (not compensatory)	Most variables (not compensatory)
Phenomena Coverage (Domains)	Policy, manpower, logistics, some design (indirect)	Policy, some MPT, logistics, some design (indirect)
Output Data Characteristics	Availability, maint. and ops. demand, LRU supportability	Availability, events, resource use, summaries, input
Availability	Yes--Army (MICOM)	Yes--Army (LOGC)
Cost of Use Factors	Preparation, data, output interpretation	Preparation, data, CPU time, output interpretation
Comments	Poor domain coverage, restricted linear optimization	Very comprehensive, resource intensive, large input data requirements

Table 2 (Concluded)

Assessment of Modeling Approaches

EVALUATION CHARACTERISTICS	MODELING APPROACHES HARDMAN II	Reduced-scale Modeling Approach
Input Data Requirements	Task, FEA decisions, assumptions	Organization, logistics, use, M&P
Preparation Time	Months	Weeks
Execution Time	Highly variable	Hours (uses PC)
Level of Effort for Preparation	Moderate	Small to moderate
Stochastic versus Event Modeling	Neither	Both
Sensitivity Analysis?	Yes	Yes
Level of Effort for Sensitivity Analysis	Moderate	Small (theoretically)
Incorporate Variables of Interest?	Some (not compensatory)	Potentially most (including compensatory)
Phenomena Coverage (Domains)	Policy, MPT, some design (indirect) - not compensatory	Potentially all (some probably indirect)
Output Data Characteristics	M&P, training, FEA data, input	To be determined (all data of interest)
Availability	Yes--ARI	Software--yes Model--not yet
Cost of Use Factors	Data preparation, FEA, output interpretation	Model and data preparation, output interpretation
Comments	Not a modeling approach; useful for sensitivity analysis	See text for discussion of this approach.

task. Realistic nonproductive time ratios are used in developing maintenance manpower availability. The capability to represent task performance degradation due to sustained or continuous operations, or to Mission Oriented Protective Posture (MOPP), can be achieved through manipulation of maintenance task time estimates. Nonproductive time and performance degradation parameters can be based on analysis of real-world data, or can be simply estimates provided by analysts. Both approaches are reported to have been used.

LCOM Characteristics Summary

The data below expand on the presentation in Table 2 with respect to characteristics of LCOM.

1. Input data requirements. LCOM requires input of all classes of data considered as potential input data in this report. This includes mission data (required mission types and assets); organizational data (characteristics of the maintenance organization, including levels and task assignments to levels); logistic data (availability of spare parts, logistic delay factors, and cannibalization rules); maintenance task characteristics data (task identification, time distributions by task, manpower requirements by task, and contingency factors); manpower and personnel data (some embedded in maintenance task data-manpower requirements and assumptions about personnel characteristics and other data that is explicitly provided, including career field cross-utilization matrices); battle damage probability and severity data; and system usage factors data (embedded in mission data--assumptions about sortie rates, durations, and frequencies, by type). It should be noted that in LCOM version 4.1 (Richards, 1983) all data preparation is accomplished off-line, on special formatting forms, and is then translated to card input for database development.

2. Preparation time for one run of the model. Depending on the scope of the scenario and the depth to which the maintenance system is simulated, preparing an LCOM database can require several months. One available estimate is 10 - 12 calendar weeks for a relatively small-scale simulation (Richards, 1983). Each calendar week probably represents one professional staff-month of effort.

3. Execution time for one run of the model. Model execution requires several Central Processing Unit (CPU) hours on a Control Data Corporation mainframe computer. Execution time is variable, and increases in an approximately linear manner with the number of conflict "days" simulated and the complexity of the mission scenario defined for a run.

4. Level of effort for model and data preparation. Preparation of an LCOM model requires several person-months of time by the primary analyst team (typical is six to eight person-months), plus consultation time from logistics, mission scenario, and maintenance Subject Matter Experts (SMEs).

5. Model capability for stochastic and event modeling. Both stochastic and event modeling are supported for model nodes. Several types of standard probability distributions are provided by the support software for stochastic simulation, or user-defined distributions and parameters can be input for special purposes.

6. Sensitivity analysis capability. LCOM can support sensitivity analysis. Sensitivity analysis is accomplished by providing alternate versions of input data, varying on the parameters of interest, and examining the differences in output parameters that result.

7. Sensitivity analysis effort required. A large amount of effort is required to accomplish sensitivity analysis using LCOM. Since each point on a sensitivity curve would require an entirely separate run of the software, the level of effort increases linearly for one sensitivity variable, and by the cross-product of the number of sensitivity curve points for two or more variables. This could be mitigated somewhat by using common data for non-manipulated variables in the input databases, or by using central-composite sampling designs rather than full-model designs, for sensitivity analysis explorations.

8. Ability to incorporate or manipulate the variables of interest. Most of the major variables associated with acquisition policy, manpower and personnel, logistics, and some system design characteristics could theoretically be accommodated by careful development of an LCOM database. Many of the specific variables would have to manipulated indirectly through the development of LCOM task networks and other input data.

9. Phenomena coverage (domains). Generally, LCOM appears able to deal with factors related to acquisition policy, manpower and personnel, logistics, and some system design factors. Variables manipulated with respect to each of these would have to be carefully defined and correlated to characteristics of the LCOM database. Acquisition policy issues could be dealt with by varying the maintenance concept and maintenance strategy adopted for system support, as well as some ultimate task variables that would

be impacted by these two major factors. Manpower and personnel variables could be manipulated by varying task and organizational characteristics. Logistical variables' effects could be explored by varying capabilities of the logistical support system such as spare parts availability, delay time characteristics, or task characteristics for maintenance tasks. System design factors could be addressed through varying maintenance task demands and characteristics.

10. Output data characteristics. LCOM provides output data that deal with achieved sortie or mission generation, simulated event sequences that occurred during the model run, manpower and logistics shortfalls that were encountered (and their association with simulated time and events), the input data and assumptions used, and manpower utilization information (Richards, 1983).

11. Availability. LCOM is available for use, and can be obtained from the Air Force (ASD/ENESA) on request. Richards (1983) recommends a trained, experienced modeler and logistician make up a part of the LCOM user team.

12. Usage cost factors. Four major use cost factors will be associated with using LCOM. They are: data gathering to develop scenarios, organizations, and other needed input; actual development of the database for LCOM runs; CPU time expenditures; and time required for output interpretation and developing conclusions. No quantitative values can be associated with the use of LCOM without further study. It is expected, based on implications from LCOM documentation (Richards, 1983), that a total level of effort for an LCOM analysis could consume as much as 3 - 4 person-years of labor and as much as several hundred CPU hours.

LCOM Observations

LCOM has a great deal of potential for use in exploring optimized maintenance concepts, organizations, and strategies. The Air Force requires LCOM be used to model and estimate the manpower and availability factors associated with using proposed new major systems, and continued use of LCOM to re-assess supportability throughout the system life cycle (Air Force Regulation 25-8, 1978). From available documentation, LCOM appears to be quite capable of dealing with most of the major variables that might be addressed in maintenance optimization efforts. However, the large level of effort required to use LCOM, and the amounts of data and CPU time needed to exercise this model, suggest that it may not be ideal for exploratory analyses. This is particularly true if a single system exemplar is being considered. The Air Force reportedly tends to use LCOM only after a significant commitment to a new system has been made. This may reflect the cost-benefit associated with using LCOM. Also, LCOM would require a large amount of adaptation to be suitable for use with other than aviation systems. For Army research and methods development purposes, this may represent an unacceptable level of investment.

OSAMM Characteristics

The Optimum Support and Maintenance Model (OSAMM) is described by its developers (CECOM) as:

> "... designed to simultaneously optimize support and maintenance policies for new equipment while achieving a given operationability target at least cost." (Department of the Army, 1985)

OSAMM uses input data available early in the system acquisition process, while the maintenance concept is under development. It describes organization locales for Line Replaceable Unit (LRU) removal and replacement; parts stockage locations; inventory variables, and manpower and Test, Measurement, and Diagnostic Equipment (TMDE) requirements (by task). Outputs include a summary of the maintenance policy modeled, achieved system operational availability (A_O) under the maintenance policy, distributions of maintenance and replacement tasks over the maintenance organization (by task), logistic system costs (based on input assumptions), and the relative cost of each maintenance concept modeled. OSAMM is also capable of supporting level of repair analyses (LORA) to define different maintenance concepts and philosophies. It is not clear from the available documentation whether this capability is achieved by sensitivity analyses in a single execution of the model or whether different input data sets are required to examine alternative candidates. An evaluation of OSAMM (Department of the Army, 1985) indicates that this model is adequate to support several subtasks of each of Logistical Support Analysis (LSA) tasks 203, 204, 205, 302, 303, and 501. OSAMM is not a scenario-based model like LCOM. It is described as a linear programming-based optimization model, that operates to optimize on a cost basis.

OSAMM Characteristics Summary

The data given below expand on the summary data on OSAMM provided in Table 2.

1. Input data requirements. OSAMM requires data on maintenance tasks and task distributions over the levels of the maintenance system, logistic system data (including parts identification and linkage to tasks, logistic delay and

transport time assumptions, manpower and parts cost data), organizational assumptions (TOE and manpower distributions), system use rates (to derive scheduled maintenance frequencies), and maintenance manpower data (by task).

2. Preparation time for one run of the model. Several months are required to compile data and prepare for an execution of OSAMM. Estimates from CECOM users range from three months for a relatively uncomplicated system, to over six months for a relatively complex system.

3. Execution time for one run of the model. Execution time for OSAMM is from one to several CPU hours on the mainframe computer types (IBM and CDC) on which it is implemented.

4. Level of effort for model and data preparation. Discussions with OSAMM users at CECOM indicate that between one-half and one and one-half person-years are required to prepare an OSAMM model for use.

5. Model capability for stochastic and event modeling. OSAMM can accommodate both stochastic and deterministic elements in models that are executed. No information was found on the manner in which the nature of particular elements is established in model input. The OSAMM program itself uses a number of parameter-based deterministic algorithms. It is assumed that these are based on empirical experience within the logistic modeling community.

6. Sensitivity analysis capability. OSAMM is capable of performing sensitivity analyses. Sensitivity analysis is possible during a single run for certain variables, most notably level of repair analysis and maintenance policy (the OSAMM software generates and explores alternate maintenance policies based on input parameters). Sensitivity analysis is also possible by using alternate data sets or models.

7. Sensitivity analysis effort required. For variables that can be explored for sensitivity in a single model execution, sensitivity analysis effort is trivial. The level of effort required to develop alternate data sets for sensitivity analysis on other variables can vary widely, depending on the amount of additional data that must be prepared. Conversations with OSAMM users at CECOM indicate that alternate data sets are seldom used, but that the effort required is a small fraction of that needed to develop an original OSAMM data set.

8. Ability to incorporate or manipulate the variables of interest. OSAMM appears to be able accommodate most of the

general acquisition related variables of interest in the Evans and Roth (1988) conceptual model, with the exception of manpower and personnel variables. These appear to be manipulated in OSAMM through association of manpower demand values with specific tasks. No evidence of personnel variables (e.g., occupational specialties, skill levels, etc.) appears in the documentation examined on OSAMM. OSAMM does not appear to be able to accommodate any of the compensatory category variables that reflect reality in maintenance operations.

9. Phenomena coverage (domains). OSAMM appears able to accommodate primarily variables associated with the policy and logistics domains in the Evans and Roth (1988) model. There is a possibility that some system design factors could be accommodated indirectly, through manipulation of the characteristics and demands of maintenance tasks provided as input to OSAMM.

10. Output data characteristics. OSAMM outputs describe the maintenance policies associated with the maintenance organization and task data input, achieved availability of the modeled system given input data assumptions, task distributions over maintenance levels (i.e., a LORA analysis), logistics costs, maintenance concept costs, and a summary of input data and assumptions used in a model run. Absolute manpower requirements for both support and maintenance are included in outputs.

11. Availability. OSAMM is available for use, since it is a Government developed model. It is available in IBM and CDC mainframe versions. Interactive access to OSAMM is reported to be impossible due to the nature of the software and the machine-specific features incorporated. CECOM (AMSEL-PL-E) is the custodian of OSAMM. Assistance in OSAMM use is also available from MRSA (Mr. Karenbauer, AMXMD-EL).

12. Usage cost factors. Cost factors in using OSAMM include preparation and input data gathering time, runtime costs, and time to interpret the output of a model run and draw conclusions. No quantitative estimates of the cost of conducting an OSAMM analysis are available. Based on the level of effort for model data preparation, one and one-half to two person-years' equivalent appears realistic for exercising OSAMM.

OSAMM Observations

OSAMM can generally be considered a restricted-domain model that is principally used for the exploration of and attempts at optimizing maintenance and support costs for a system. This modeling technique appears to have less overall value for assessing factors that impact maintenance than does LCOM. The reason for this observation is that OSAMM does not deal with manpower and personnel variables as discrete elements, other than as manpower resource requirements associated with maintenance tasks. Personnel characteristics do not appear to be treated at all in OSAMM. There may also be some difficulty in manipulating variables of interest to general maintenance topics, using OSAMM. While maintenance policy and maintenance concept (two important driver factors for the maintenance burden) are manipulable in OSAMM, and the model is capable of LORA analyses, manpower requirements associated with maintenance tasks must be provided as input data. Since OSAMM is principally designed to examine logistic cost factors for systems, it may be of some use as a secondary model in exploring maintenance factors, once operational factors and issues have been explored by other means.

LOGAM Characteristics

The Logistics Analysis Model (LOGAM) is characterized as:

> "...[for] evaluating alternate logistic postures for system and equipment [items] on the basis of cost and availability." (Department of the Army, 1984)

LOGAM examines maintenance policies, stockage locations for spare parts, test equipment capability, and manpower mixtures for their combined impact on system availability and logistic system cost factors. LOGAM was designed for use in early, exploratory LSA investigations of new systems, to assist in determining feasible, cost-effective approaches to logistic support for new systems. This model was developed by the U.S. Army Missile Command (MICOM), and has been subsequently used by MICOM and other Army commodity commands for early logistic estimation for a number of systems. LOGAM is reported (Department of the Army, 1984) to provide data that support various subtasks of LSA tasks 203, 204, 205, 302, and 303. Like OSAMM, LOGAM is a linear programming-based optimization model, rather than a scenario-based model such as LCOM. Cost is used as the principal optimization factor.

LOGAM Characteristics Summary

LOGAM characteristics, expanding on the summary in Table 2, are as follows:

1. Input data requirements. Input data for LOGAM consist of a description of logistic-oriented Tables of Organization and Equipment (TOE) projected to support the system, and data associated with system (LRUs), including failure rates and repair times, logistic waiting and delay times, use rates, and associated test equipment for task performance. Also required are several types of cost data, including labor costs, technical documentation costs, and transportation costs (from one maintenance level to another, and for spare parts transport).

2. Preparation time for one run of the model. Discussions with MICOM users of LOGAM indicate that three to six months' calendar time is typical for preparing a LOGAM model and data set for execution.

3. Execution time for one run of the model. LOGAM is reported (Department of the Army, 1985) to require approximately one to five minutes of CPU time to execute on the mainframe computers on which it is implemented (IBM 43XX series and CDC 6XXX series).

4. Level of effort for model and data preparation. Approximately one to two person-years' level of effort is needed to develop a LOGAM model and input data, according to conversations with MICOM personnel.

5. Model capability for stochastic and event modeling. LOGAM appears to be able to accommodate stochastic events or nodes, but explicit use of stochastic estimation is not reported in the available documentation (Department of the Army, 1985). Event modeling, based on the linear optimization approach used in LOGAM development, is possible through manipulation of time parameters and failure rates.

6. Sensitivity analysis capability. Sensitivity analysis is possible with LOGAM, through the use of alternate input data sets. In general, LOGAM will develop a cost-optimized output solution based on input data. Thus, sensitivity analysis within one run of the model is not considered possible.

7. Sensitivity analysis effort required. Since alternate input data sets are required for sensitivity analysis with LOGAM, the level of effort associated should vary ap-

proximately linearly with the number of sensitivity points explored in an analysis. However, generation of a total data set is not required for each sensitivity point to be explored. Deviations from a baseline data set accommodate many sensitivity analysis requirements.

8. Ability to incorporate or manipulate the variables of interest. LOGAM appears to be restricted somewhat in its ability to accommodate variables described in the Evans and Roth (1988) conceptual model. LOGAM should have some sensitivity to some policy issues (levels of repair, task allocation, maintenance strategy and concept, and force structure). It should also be sensitive to manpower demand (by task) and design issues (repair times), as well as use rates. General MPT issues, and some design issues, probably are not suitable for exploration using LOGAM.

9. Phenomena coverage (domains). In general, LOGAM should be usable to explore policy issues, manpower demands, and some design issues, as well as logistics issues. Since LOGAM's approach centers around exploration of the demand associated with various LRUs, there may be some value in exploring impacts of "high driver"-associated equipment items or LRUs on maintenance demand and associated costs.

10. Output data characteristics. LOGAM provides the following categories of output: operational and inherent availability (A_o and A_i) of each LRU in the system; maintenance support demand (manhours); operations support demand (also by manhours); and a support requirements summary for each LRU in the system. Aggregated summaries are also provided above the LRU level.

11. Availability. LOGAM is Army-developed and owned, and is therefore available for potential use. It can only be accessed interactively, however. Also, the computer programs presently require large-scale mainframe computer support. MICOM (Systems Analysis Directorate, DRSMI-DS) is the custodian and maintainer of LOGAM. Assistance in LOGAM use is also available from MRSA (Mr. Atkinson, AMXMD-EL).

12. Usage cost factors. Using LOGAM requires investment in data and preparation time, and interpretation of model output. Given the relatively small amount of CPU time required for LOGAM runs, this is not considered to be a major factor.

LOGAM Observations

Since LOGAM, like OSAMM, is a restricted linear optimization approach to examining system support requirements, it appears less suitable for programmatic exploration of factors impacting maintenance than a scenario-based model. Some of LOGAM's limitations include an inability to deal with personnel factors (occupational specialties and skill levels), and an orientation toward micro, rather than macro, system elements (e.g., concentration on LRUs as the element of analysis). While LOGAM's data requirements and computational time requirements are modest compared to some models, its suitability for exploring the total range of issues in the Evans and Roth (1988) model is restricted. LOGAM appears to one of the less suitable estimation approaches examined for supporting exploratory work in maintenance system optimization.

MARC Models Characteristics

Three models to support the Manpower Requirements Criteria (MARC; Army Regulation 570-2) development process are under development by the Army Logistics Center (LOGC). The models are specific to unit equipment types: aviation, tracked vehicle, and wheeled vehicle models are being developed. Of the three models, only the aviation model is currently operational. The tracked vehicle model is scheduled to be available for use sometime in the next calendar year. The wheeled vehicle model is under development, with no projected availability date as of March, 1988. All characteristics reported below are therefore based on the known attributes of the aviation MARC model. Data reported below are based on an interview with LOGC personnel conducted on 8 February 1988 (Fisher, 1988; Blair, 1988; Price, 1988).

The aviation MARC model is a scenario-driven model with many functional similarities to LCOM. This model portrays a brigade and associated unit support "slice" up through the Corps level. Of particular note in this model is the attention devoted to modeling the maintenance process. Detailed operational maintenance models, that use realistic derived criteria, are used in "playing out" the scenarios specified for the model. This represents a potentially valuable approach to exploring organizational, manpower, and personnel aspects of maintenance. However (see below), the aviation MARC model uses large amounts of resources in its execution. This may represent a significant tradeoff factor if this model is further considered for use.

Aviation MARC Model Characteristics Summary

The following data expands on the Aviation MARC model summary presented in Table 2.

1. Input data requirements. This model requires several classes of data as input, including: available resources (number of personnel, number of systems, and spare parts amounts and locations); predicted equipment failure rates for all systems and support equipment to be modeled; desired readiness rates for systems; threat and weapons-effects models; spare parts availability factors; indirect productivity factors for maintenance; equipment usage rates; organizational structure supporting the systems (i.e., how the unit and support "slice" are organized); and the mission scenario to be played out (including sortie rates and equipment criteria for sorties, etc.). Data are derived from a number of Army sources, including MRSA, the Ballistics Research Laboratory (BRL), Training and Doctrine Command (TRADOC) schools; Army Materiel Command (AMC) laboratories, and data maintained by LOGC. Maintenance task data are provided by estimates from prior systems (e.g., a Baseline Comparison System or BCS), and validated by SMEs. Most data are provided on magnetic tape, in formats established by Headquarters AMC, in cooperation with other agencies that supply data to LOGC for the analyses.

2. Preparation time for one run of the model. Data collection, preparation, and validation requires several months for the Aviation MARC model (Price, 1988).

3. Execution time for one run of the model. For a simple case, the Aviation MARC model requires up to eight (8) hours of dedicated CPU time on a Digital Equipment Corporation (DEC) VAX 11/785 minicomputer. Complex cases are reported (Price, 1988) to require up to 40 dedicated CPU hours for execution.

4. Level of effort for model and data preparation. No direct information was available via the LOGC interviews to address this issue. It is projected that, given the number of involved agencies and the time required for data preparation, that between one-half and one and one-half person-years is a reasonable estimate for the level of effort required.

5. Model capability for stochastic and event modeling. The Aviation MARC model can handle both stochastic and event modeling. Both types of representation are routinely used in various parts of the model.

6. Sensitivity analysis capability. The Aviation MARC model is capable of sensitivity analysis. Some parameters can be manipulated within a single model execution (specifics were not determined during the interviews); other parameters must be manipulated for sensitivity analysis purposes by altering the input data sets and re-executing the model.

7. Sensitivity analysis effort required. For those parameters that can be manipulated during a single model execution, the effort associated with sensitivity analysis is almost totally associated with designing the sensitivity analysis model and interpreting outputs from model execution. Thus, the level of effort will be relatively small compared with the overall cost of using this model. For parameters that require alteration of input data sets to achieve sensitivity analysis, significantly more effort will be required. Even a close estimate of the level of effort for this process is unavailable, since there has been relatively little experience with performing sensitivity analysis in this fashion using the Aviation MARC model (Price, 1988).

8. Ability to incorporate or manipulate the variables of interest. While limited to consideration of units operating primarily aviation systems, the Aviation MARC model appears to be able to accommodate essentially all of the acquisition-related issues described in the Evans and Roth (1988) conceptual model. The issues associated with maintenance operations (particularly compensatory issues) in Evans and Roth (1988) probably cannot be dealt with by this model.

9. Phenomena coverage (domains). Most issues in each of the domains described in the Evans and Roth (1988) conceptual model of maintenance demand factors (limited to acquisition issues) can be handled by the Aviation MARC model.

10. Output data characteristics. The principal output of the Aviation MARC model is the system operational availability (A_o) associated with the input data set and scenario. Supplementary outputs include a detailed event summary, manpower utilization and requirements by MOS, maintenance task performance by level of maintenance, sortie rates achieved (and equipment profile by sortie), spare parts demand and use rates, accumulated logistic and maintenance delays, and operational and support performance summaries.

11. Availability. The Aviation MARC model is Army-developed and -owned, and is therefore available for use. Its proponent and maintainer is LOGC. The model cannot be accessed by remote means.

12. Usage cost factors. Usage cost factors associated with the Aviation MARC model include specification of data requirements and scenario characteristics, data preparation and data gathering, CPU time, and interpretation of outputs.

MARC Models Observations

The Aviation MARC model, and in concept the two developmental MARC models, is an extremely powerful means of examining the consequences of a given support and maintenance organization on mission readiness and capability. Based on the available information, it appears that this model is at least hypothetically capable of dealing with the majority of significant acquisition-related maintenance issues of potential interest to ARI. There are three present arguments that suggest that this model not be used for exploratory research, however. The first is the amount and variety of data required to prepare a data set for execution against the model software. The efforts of several different agencies (and associated Memoranda of Agreement, etc.) are required to develop a data set for the MARC models. This could prove a significant deterrent to the use of this model, since large amounts of time and resources are required to gather and validate input data. A second, rather obvious, problem is that the only one of the MARC models available for current use is limited to aviation systems and units. Since the Army has only one major aviation-related system under consideration (the Light Helicopter, LHX), this may be more limiting for research purposes than is desirable. Finally, this model requires a very large amount of dedicated CPU time to execute. In a complex model case with any significant degree of sensitivity analysis being performed, using this model could occupy a major computing resource exclusively for several days. Unless such a resource were to be made available, this model would probably prove unsuitable for ARI's immediate purposes.

HARDMAN II (MIST) Characteristics

HARDMAN II (formerly known as Man Integrated Systems Technology, or MIST) is a computer support system developed by ARI in the mid-1980's in an attempt to simplify and rationalize a significant portion of the data maintenance, and some analytic, functions associated with conducting HARDMAN (HARDware versus MANpower) analyses. The HARDMAN technique, adapted for Army use (Mannle and Guptill, 1985), provides a structured approach to developing BCS and conducting exploratory analyses of probable MPT characteristics for new systems very early in the acquisition process. Since there are a great many redundant data elements in the documentation that results from a HARDMAN application, HARDMAN II provides a database system that, in essence, rationalizes data utilization resulting from HARDMAN analysis, and ensures consistent utilization of data across the various forms of documentation. HARDMAN II also provides some analytic aiding to the HARDMAN analyst, in the form of databases for consultation (principally for MOS decisions, some personnel pipeline determinations, and training cost estimation and media selection), decision guidance, and suggested decision criteria. However, most of the decisions required of the analyst in the HARDMAN process must be made off-line when using HARDMAN II.

Although it is not a modeling approach per se, HARDMAN II was included in this analysis because of a demonstrated utility in exploring some aspects of maintenance demand factors. Recent work by Shvern and Stewart (1988) and Stewart and Shvern (1988) utilized HARDMAN II in exploratory investigations of some maintenance manpower requirements related to two components of the Forward Area Air Defense (FAAD) system under development, with significant success. While development of a HARDMAN consolidated database and performing appropriate Front-End Analyses (FEA) is known to be a time-consuming and laborious process, it is presently the principal means of early exploration of MPT characteristics of proposed new systems within MANPRINT. Therefore, HARDMAN II was examined on the same basis as the other estimation approaches, to determine its relative utility. An additional reason for examining HARDMAN II is that it is an ARI-maintained asset, and thus readily available for use in future investigations.

HARDMAN II Characteristics Summary

The following information elaborates on the characteristics of HARDMAN II as summarized in Table 2.

1. Input data requirements. Input data requirements for HARDMAN II are based on the results of conduct of the HARDMAN FEA methodology. A full listing of the data elements input into HARDMAN II may be found in Herlihy, et. al. (1985). The categories of data include system requirements analysis data, mission analysis data, functional requirements and engineering analysis data, manpower and reliability and maintainability determinations, personnel analysis results, training analysis results, MOS selections and determinations, manpower determinations, personnel determinations, and training resource and cost determinations.

2. Preparation time for one run of the model. Approximately 10 months (Shvern and Stewart, 1988) is required to develop a HARDMAN II consolidated database, including performing the requisite HARDMAN analyses in conjunction with HARDMAN II support.

3. Execution time for one run of the model. Execution time equates to preparation time, since preparation time includes all off-line analyses. No modeling is conducted by HARDMAN II.

4. Level of effort for model and data preparation. Anecdotally, a HARDMAN II analysis with development of a full

consolidated database is reported to require approximately two person-years of effort as a typical figure.

5. Model capability for stochastic and event modeling. None. No modeling is accomplished in HARDMAN II.

6. Sensitivity analysis capability. Sensitivity analysis is possible with HARDMAN II, by altering the assumptions used and determinations made as part of the HARDMAN process. The capability to explore alternate consequences of automated test equipment capability on manpower requirements using HARDMAN II was demonstrated by Shvern and Stewart (1988) and Stewart and Shvern (1988). Hypothetically, other types of sensitivity analysis can be performed by knowledgeable users of HARDMAN II.

7. Sensitivity analysis effort required. Using a full data set, HARDMAN II has required on the order of 15 person-months (in about six calendar months) to accomplish a sensitivity analysis (Stewart and Shvern, 1988). Using a more restricted data set, approximately four person-months (in two calendar months) were required for a related sensitivity analysis effort (Shvern and Stewart, 1988).

8. Ability to incorporate or manipulate the variables of interest. HARDMAN II is potentially able to deal with most acquisition-related policy and MPT issues in the Evans and Roth (1988) conceptual maintenance demands model. It also has a demonstrated ability to deal with at least some of the design issues. However, HARDMAN II probably cannot deal with logistics-related acquisition issues. It also appears unable to deal with any of the operational issues in the Evans and Roth (1988) conceptual model, since no process modeling can be performed in HARDMAN II.

9. Phenomena coverage (domains). As mentioned above, three of the four acquisition-related domains are potentially addressable through HARDMAN analyses and HARDMAN II support: policy, MPT, and design.

10. Output data characteristics. HARDMAN II output data are presented as any of a variety of formatted reports summarizing input data and determinations made by the HARDMAN analysts. Some aggregation and summarization of FEA and MPT data items is made for these reports, to render them useful for various classes of users and different purposes.

11. Availability. HARDMAN II is maintained by ARI, and is available for use in future investigations of maintenance, within the domain and variable coverage limitations described above.

12. Usage cost factors. The cost of using HARDMAN II is basically driven by database development and output interpretation. No "modeling" CPU costs are involved, although some costs will be associated with using the HARDMAN II software, and computer system resource use charges will be encountered. These should be relatively minor compared to the costs of data development.

HARDMAN II Observations

HARDMAN II appears to have significant potential for exploring acquisition-related issues, particularly in investigating the impact of policy and design issues on manpower demand factors. It is, however, a laborious and somewhat cumbersome technique to use for these purposes. Experienced HARDMAN II users should participate heavily in planning future utilization of HARDMAN II for exploratory research.

The development of HARDMAN II databases solely for research purposes may not be a cost-effective approach to exploring maintenance impacts within the MANPRINT context. However, the use of sensitivity analysis on existing HARDMAN II databases would be a much more parsimonious approach. This capability has been demonstrated by Shvern and Stewart (1988) and Stewart and Shvern (1988). Again, experienced HARDMAN II users should play a major role in planning such investigations, since appropriate selection of the input parameters to be altered in sensitivity analysis will have a profound impact on the value of the results.

Reduced-Scale Modeling Approaches

One common characteristic of the five approaches just reviewed is that they all require large-scale computational resources and large amounts of highly specific input data in order to support their respective estimation procedures. From a MANPRINT-oriented exploratory research standpoint, the use of such resource-intensive tools is less than ideal. While use of such large-scale tools may contribute to an understanding of the manner in which maintenance demand-influencing factors operate and, ultimately, to principles and techniques to minimize the maintenance burdens of new systems, the costs of using such tools may be prohibitive.

In the last two years, at least one significant smaller-scale tool for conducting modeling investigations of task-type processes has emerged. This tool is MicroSAINT(TM). MicroSAINT(TM) has the advantage, for exploratory purposes, of executing on personal computer systems, which are generally able to be dedicated to such investigations. Also, MicroSAINT(TM) can represent a task performance model, such as developed for maintenance by Evans and Roth (1988), quite adequately. Further, MicroSAINT(TM)-based models can, when properly developed, account for resource demands and expenditures of the kinds that are associated with maintenance performance (e.g., personnel and manpower, spare parts, etc.).

What is envisioned is the development of one or more models of maintenance process systems, including the capability to track resource demand, availability, and use. Such models could represent alternate maintenance systems for an operational materiel system based on various maintenance strategies, philosophies, or organizational concepts, and reacting to varying levels of demand factors. Specific maintenance tasks and conditions under which each task is performed would be represented in the models, and the resources required to accomplish each task would be specified in terms of manpower, personnel, and other resources. An LCOM-like, iterative, approach to exercising the model over many time periods would be used, examining maintenance system performance and demand factors on a periodic basis.

This approach has several advantages over use of existing large-scale models. First, system operations (that lead to maintenance needs) need not be explicitly modeled. These factors can be represented by parameters describing maintenance task performance frequency. For example, scheduled and unscheduled maintenance demands by particular task type, or battle damage (based on some probabilistic function) can be represented as either periodic, scheduled, or probabilistic events. The LSA process and other FEA techniques commonly describe many types of maintenance tasks on a task requirement per operating hour (or other operational parameter) basis, or on a frequency (x occurrences of the task per day, week, month, etc.) basis. Thus, data descriptive of raw maintenance demands for systems will be compatible with their representation in such models.

Second, the operational nodes in the maintenance system can be represented as queues, against which task performance demands accumulate as maintenance tasks are scheduled. This enables both monitoring of resource demand and consumption (e.g., personnel, spare parts, etc.) by particular activity nodes (e.g., diagnosis of faults, particular types of repair actions) and tracking of total resource demand during each cycle of execution. In turn, tracking resource demand and consumption enables pinpointing over-demand for particular resources. This can be particularly important in identifying where there are suspected bottlenecks, or high demand drivers, in a system. In some cases, modifying or eliminating such high demand drivers can lead to measurable improvement in the performance of a system.

Third, this modeling approach supports continuous monitoring of maintenance system output, and related but derived variables such as mission capability or availability of the "fleet" of systems to be maintained. Since maintenance is an operations support activity, this is an extremely important parameter to be monitored. Operations cannot suc eed if sufficient systems are not available.

Finally, this approach supports a parsimonious representation of any maintenance concept and maintenance strategy, over all levels of maintenance. Each level of maintenance can be modeled separately, as a sub-model, and the relationships and flows between them easily defined, in such a model. And, the performance of each level of maintenance can be monitored both individually and in the aggregate. Within the type of model envisioned, any organizational structure that can be defined by TOE can theoretically be accommodated.

Such an approach is projected to be highly valuable in exploratory investigations of maintenance strategies and concepts for both existing and new systems. Since relatively few resources would be required to develop and execute such models, sensitivity analysis of alternate maintenance resource configurations (e.g., personnel; manpower availability) and assessment of the performance of many alternate candidate maintenance structures for projected new systems would be simple and straightforward. And, model outputs could be developed to be easily understandable by decision-makers, reflecting tradeoffs between alternate maintenance resource configurations and systems availability.

Since models based on such an approach are not yet generally available, no evaluation against the 12 factors discussed for other modeling approaches above is made. However, it is projected that the desirable features on each factor described in the previous section could be satisfied by the general modeling approach described.

CONCLUSIONS

Of the six modeling approaches discussed in the previous section, four have characteristics that are desirable to support exploratory research into minimization of the maintenance burden (LCOM, Aviation MARC, HARDMAN II, and the reduced-scale modeling approach). OSAMM and LOGAM, because they have been developed to optimize on specific variables, are less desirable from an exploratory standpoint. While these models are perfectly adequate for the purposes and in the domains for which they have been developed (Department of the Army, 1984, 1985), they are less well suited for a programmatic exploration of the impact of individual variables on maintenance demand. In particular, these models seek to optimize the values of all important variables (with cost as the principal optimization criterion) for a particular input data case, rather than a more deliberate controlled exploration of the individual and joint influences of specific variables on the maintenance burden and related resources. It is the latter sort of approach which is believed to have the most value in developing methods and techniques to support the implementation of MANPRINT with regard to the maintenance function.

Among the four modeling approaches with particularly desirable general characteristics, sensitivity analysis with HARDMAN II and the reduced-scale modeling approach offer the most parsimonious approaches to supporting programmatic research into minimizing the maintenance burden and related resource demands. Although LCOM and the MARC models can conceptually support such explorations, the use of these models is time- and resource-intensive. A related shortcoming of both these models for general research purposes is that they are restricted by their nature to explorations involving aviation systems. Also, the amounts of data required to exercise these models could lead to some confusion as to what to manipulate in the input data to bring about a change in some parameter believed to influence the maintenance burden.

A good deal of familiarity with HARDMAN II is apparently required to perform effective sensitivity analyses. Also, the level of effort required in analyses to develop new databases for HARDMAN II is quite high. Therefore, it is recommended that the development of a reduced-scale modeling approach for exploring the influences of the variables in the Evans and Roth (1988) conceptual model be pursued as the first step in future maintenance research by ARI. Two person-years of effort is estimated to be adequate for the initial development and evaluation of such a model, using MicroSAINT(TM) as a development tool. This would include development of a base-case maintenance system model. Concurrent with initial development of the model, sensitivity analyses using HARDMAN II could be pursued to reduce the initial variable set to be explored.

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APPENDIX A

LIST OF ABBREVIATIONS AND ACRONYMS

AFHRL	Air Force Human Resources Laboratory
AMC	U.S. Army Materiel Command
ARI	U.S. Army Research Institute for the Behavioral and Social Sciences
BCS	Baseline Comparison System(s)
BRL	U.S. Army Ballistics Research Laboratory
CECOM	U.S. Communications-Electronics Command
FAAD	Forward Area Air Defense
FEA	Front-End Analyses
HARDMAN	HARDware versus MANpower Analysis
HARDMAN II	A computer support system for HARDMAN analysis
LCOM	Logistics Composite Model
LOGAM	Logistics Analysis Model
LOGC	U.S. Army Logistics Center
LORA	Level of Repair Analysis
LRU	Lowest Replaceable Unit
MANCAP	MANpower CAPability Model
MARC	MAnpower Requirements Criteria
MICOM	U.S. Army Missile Command
MIST	Man Integrated Systems Technology
MOS	Military Occupational Specialty(ies)
MPT	Manpower, Personnel, and Training
MRSA	U.S. Army Materiel Readiness Support Activity

OSAMM	Optimum Supply and Maintenance Model
SME(s)	Subject Matter Expert(s)
TRADOC	U.S. Army Training and Doctrine Command