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ANALYSIS OF AIR FORCE LOGISTICS CAPABILITY ASSESSMENT MODELS

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The Air Force is using a number of simulation models to perform logistics capability assessment. This paper describes the results of a review of these models, the ultimate goal of which was to develop improved combat operations and logistics capability evaluations. The effort involved investigating the views of current model users and analysts, consulting with subject-matter experts, and reviewing relevant literature and support documentation. From these sources, a set of model evaluation criteria were derived. A methodology based on utility theory is described that can be used to select an optimal modeling system from among several candidate logistics capability assessment modeling systems. Keywords:

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ANALYSIS OF AIR FORCE LOGISTICS CAPABILITY ASSESSMENT MODELS

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SUMMARY

This paper describes the results of a review of Air Force logistics capability assessment modeling undertaken by the Logistics and Human Factors Division of the Air Force Human Resources Laboratory. The goal of this effort was to determine ways to apply technology advances in computer hardware and software to improve combat operations and logistics capability evaluations. This paper concentrates upon the initial findings of the study with respect to current computer-based models, and the criteria that one can use to evaluate these models. Multiple sources were used to collect data. Information was collected through a combination of written surveys, interviews with users, and a literature review. Users of models were interviewed at organizations within HQ USAF, major commands, various other military agencies, and the RAND Corporation. The paper then provides a set of shortfalls identified by users regarding current models' capabilities. Following this, a set of model evaluation criteria is proposed, dealing with such features as: mission effectiveness, cost effectiveness, realism, documentation, and design features. Examples are used to illustrate a model evaluation technique and to illustrate tradeoffs between the proposed criteria. The evaluation method can be used to help judge the relative merits of alternative modeling systems.

PREFACE

This paper describes the results of a review of Air Force logistics capability assessment modeling undertaken by the Logistics and Human Factors Division of the Air Force Human Resources Laboratory (AFHRL). This study is part of a larger effort whose ultimate goal is to develop improved combat operations and logistics capability evaluations. The approach is based on the premise that technological advances in computer hardware and software could be applied to address widespread perceived deficiencies in current logistics capability assessment modeling techniques. The initial study described here involved investigating the views of current model users, consulting with subject-matter experts, and reviewing relevant literature. The focus of this paper is on describing findings and model evaluation techniques. A separate paper, The Productivity Improvements in Simulation Modeling (PRISM) Project: Concepts and Motivations (Popken, 1988), discusses the specific technical approach AFHRL is taking to address the identified modeling deficiencies.

The authors would like to acknowledge the contributions of Captains Tom King and Maureen Harrington. These individuals were instrumental in establishing the requirements for and initial direction to the user needs study. They logged many miles to ensure that the project received this vital user input.

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I. INTRODUCTION

In 1987, the Air Force Human Resources Laboratory (AFHRL) initiated an effort to determine the simulation modeling needs of Air Force organizations which conduct logistics capability assessment. The major focus was on discrete-event simulation models of logistics support systems. Several simulation models of air combat were also investigated for relevant information on modeling practices and needs. In addition, information was gathered on computer hardware and software technologies that could prove useful in meeting user-identified needs. AFHRL was assisted in this effort by Systems Exploration Incorporated (SEI).

The findings of the user needs study indicated the need for substantial improvement in the types of models and modeling support available for logistics capability assessment. In general, the existing models were found to be difficult to use, insufficiently documented, and difficult to modify, and to require inordinate amounts of data preparation.

The purpose of this paper is to present the logistics modeling community with a comprehensive discussion of the advantages, disadvantages, and tradeoffs present in the simulation models currently used for logistics capability assessment. The paper begins with a discussion of the data collection method. User-identified model deficiencies are then provided. The paper then defines a set of model evaluation criteria. A method is described for using the criteria to prioritize model selection or improvements in terms of organizational priorities, resource requirements, and the current models' capabilities. The intent is for organizations to apply or adapt the evaluation methodology to their own situations. Those intending to use or improve logistics capability assessment models will have a framework by which to judge the appropriateness of candidate models.

II. DATA COLLECTION

Identification of modeling deficiencies was accomplished through a combination of written surveys, interviews with users, and literature review. To begin, an initial survey was designed to identify United States Air Force (USAF) and other personnel who used military models or the output of military models. A brief survey form was designed and a mailing list was compiled from attendance rosters of recent meetings and conferences on the subjects of capability assessment, military modeling, and wargaming. This survey was limited to the following questions:

1. Do you currently use simulation models? Which ones?
2. Name, address, phone number?
3. Planned upgrades or changes?
4. Category of use? (See the three categories given below)

This survey was useful in identifying the scope of modeling efforts and in establishing points of contact for the interviews.

By far the most effective of the data collection approaches was the interview process. Those interviewed can be grouped into three major categories: (a) those who develop and modify logistics capability assessment models for various research and analysis purposes, (b) those who use established logistics capability asssessment models to obtain specified outputs, and (c) those involved with technologies similar to that used in modeling logistics capability assessment (for example, computer-assisted wargaming). The interviewees included analysts and modelers in the following organizations:

Office of the Joint Chiefs of Staff, Joint Analysis Directorate	(OJCS/JAD)
HQ US Transportation Command, Analysis and Studies Division	(TC/J5-E)
HQ US European Command, Analysis Division	(TC/J5-E)
National Defense University, Simulation Wargaming Center	(NDU/SWGC)
HQ USAF, Readiness Assessment Group	(AF/XOOOC)
Air Force Center for Studies and Analysis	(AFCSA):
Tactical Support Division	(/SAGP)
Fighter Division	(/SAGF)
HQ Military Airlift Command	(HQ MAC):
Commander in Chief, MAC (CINCMAC) Analysis Group	(/AGR)
Directorate of Manpower and Organization	(/XPM)
War Readiness Material (WRM) Systems Support Section	(/LGSWR)
HQ Tactical Air Command	(HQ TAC):
Tactical Resources Analysis Office	(/LGY)
Manpower Studies and Analysis Team	(/XPMS)
Joint Studies Group	(/XPJSG)
HQ US Air Forces in Europe	(HQ USAFE):
Directorate of Operations Analysis	(/DOA)
Directorate of Manpower and Organization	(/XPM)
Weapons Systems Support Division	(/LGSW)
Air Force Logistics Management Center: Directorate of Logistics Analysis	(AFLMC/LGY)
Center for Aerospace Doctrine Research, Development, and Evaluation	(AU CADRE):
Exercise Operations Division	(/WGOO)
Operations Analysis Division	(/WGTA)
RAND Corporation	

The literature review was very useful in developing a broader context for the problems of simulation model users. The references discussed the original purposes behind the development of the models, provided a history of model development and uses, and demonstrated that some of the problems associated with logistics capability assessment models are common to other types of simulation modeling. Other sources were useful in describing general theoretical and practical issues relative to developing simulation models. Several of the references warrant further discussion here.

An excellent reference for a general discussion of logistics capability assessment is Nolte (1980). It describes basic concepts, discusses each of the then-current (several are still in use) capability assessment models, and provides recommendations for improving logistics capability assessments.

Rich, Cohen, and Pyles (1987) trace the evolution of RAND's research on the resource management issues involved in assessing combat readiness and sustainability. The report discusses some of RAND's previous modeling efforts, a new concept known as Coupling Logistics to Operations to meet Uncertainties and the Threat (CLOUT), and the need to incorporate realistic assumptions about combat operations. In particular it states:

> Current analytic techniques do not adequately reflect the likelihood that actual flying patterns may differ sharply from the assumptions in our planning scenarios, that future component removal rates (the frequency at which parts need maintenance attention, often relative to flying hours or sorties) will probably vary (especially during wartime), and that airbase damage and disruption will probably shatter our assumptions about repair and stock resource availability. (p. 9)

Law and Kelton (1982) provide a comprehensive discussion of simulation modeling and analysis. Their emphasis is on the theoretical statistical issues involved with probabilistic simulation models.

Balci (1986) discusses current problems with simulation modeling. The problems described are very similar to concerns raised in the interviews; for example, inadequate documentation, inadequate management, high model development costs, and lack of full life-cycle support. Balci provides a set of requirements for a model development environment. The proposed environment would provide an integrated and comprehensive set of tools for cost-effective and automated support of a model throughout its life cycle.

III. USER-IDENTIFIED SHORTFALLS OF CURRENT MODELS

This section summarizes the data collected during the user interviews and describes a set of "shortfalls" identified by various users of capability assessment models. All shortfalls cannot be attributed to all models; however, there was significant commonality in the opinions expressed by users of different models as well as by different organizations using the same model.

The users surveyed were primarily involved with one of four major capability assessment models -- the Theatre Simulation of Airbase Resources (TSAR), the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC), the Logistics Composite Model (LCOM), and the Tactical Air Command (TAC) Thunder -- and were using them for a variety of management, planning, and analysis purposes. For example, the WRM Systems Support groups at all commands were using the Weapon System Management Information System - System Assessment Module (WSMIS-SAM) reporting capability, based on the Dyna-METRIC model. Dyna-METRIC forecasts demand rate per flying hour of repairable spare parts; however, it is currently an analytical model rather than a true simulation. The manpower community is universally using LCOM to assess maintenance manpower issues; however, LCOM was originally designed for investigating numerous functional areas within logistics capability assessment. The Air Staff is using a general purpose model, the TSAR/TSAR Input Using Airbase Damage Assessment (TSARINA) to perform a variety of special studies and to perform the Air Force Capability Assessment Program (AFCAP) evaluation of unit capability. The Fighter Division in the AFCSA is using TAC Thunder for a large group of operations studies and the model is also being developed for wargaming exercises at various locations. RAND is continuing research and development on new versions of TSAR and Dyna-METRIC. A number of other models were also encountered that were not used frequently enough by the Air Force to warrant inclusion in this study.

The interview results were organized into a set of basic categories. In general, the categories below describe features that a majority of users felt were handled poorly by their particular model or by its operating environment.

Data Set Repository

Data sets do not belong to a central repository, causing redundancy and obsolescence. Although large amounts of resources have been employed in creating data sets for various models, there is no single repository where these expensive data sets reside. Rather, each organization that creates or has created a data set maintains that data set at its own site.

Data Set Currency

Data sets are often not current. When models are used to assess the combat capability of Air Force units, the data sets fed into the model must reflect the actual state of the organizational unit being modeled. Automated data extraction and management systems could alleviate this problem. Without effective data base management, the effort required in maintaining current data will remain overly demanding, both of time and resources.

Documentation

Because of poorly written, insufficient, or outdated documentation, almost all the model users interviewed found it necessary to learn to use the model from the original developer or one of his disciples. In some cases, the models had been originally developed for use in a particular study or a single organization; consequently, the developer had not prepared comprehensive documentation for the model. An even greater problem identified was the failure to provide adequate documentation updates. The documentation for these often large models becomes increasingly outdated and unreliable as the models evolve.

Focusing Capability

Models do not easily permit users to track special areas of interest throughout the simulation. This requirement might include limiting input or output to only the areas of concern, or tracking a given variable such as a high value spare or a particular aircraft tail number throughout the simulation. The ability to focus on the area of interest affects not only the structure of the models themselves, but also the data bases upon which the models operate.

Network Development

Model activity networks are difficult to change. Each of the four major capability assessment models makes extensive use of networks to establish the time sequences and relationships among simulated activities. In these models, the networks are exceedingly complex but subject to change as a result of the dynamic nature of logistics support operations. Consequently, the operator frequently has to redefine many of the networks which constitute the heart of the model. This redefinition currently requires labor-intensive programming and data preparation.

OPFOR Operations

Logistics models do not effectively examine the impact of Opposition Force (OPFOR) operations on the logistics support posture of USAF forces. For example, an OPFOR employment of a "Follow-on-Forces Attack" that concentrates on ensuring no aerial resupply by strategic airlift within 200 miles of the Forward Edge of the Battle Area (FEBA) would have a significant effect on the availability of logistics support. Current models only allow these effects to be modeled implicitly through fixed input parameters (e.g., attrition rates and supply rates).

Aircraft Battle Damage Repair

Most model users felt that logistics capability assessment models do not treat Aircraft Battle Damage Repair (ABDR) problems effectively. Frequently, aircraft attrition simulations result in an aircraft which does not return to base. When this occurs, the models assume that none of the damaged aircraft return to base. As a result, two untoward effects occur. First, those aircraft which should have been modeled as returning to base damaged do not enter the maintenance queue; therefore, the maintenance effort which would be devoted to returning those aircraft to serviceable condition is not modeled. In addition, the maintenance effort required to support the aircraft once returned to the flying schedule is not accounted for. Secondly, the models fail to consider as cannibalization sources those battle-damaged aircraft which are in a non-flyable condition.

Electronic Combat

Existing models cannot distinguish between missions which differ as to their requirements levied upon the aircraft's electronic combat equipment. For example, not one of the models examined provides the ability to tailor EF-111A sorties to any of the three very different sortie profiles which might be demanded and which place enormously different stresses upon the aircraft's mission equipment. Mission profiles that vary in this respect would have differing equipment failure rates, and would thus place differing requirements upon maintenance and repair capabilities.

Electronic Countermeasures (ECM) Equipment

Spares requirements are not accurately calculated for electronic countermeasures equipment. Both TSAR and WSMIS-SAM (Dyna-METRIC) calculate spares requirements based upon failure rates loaded into the model. In today's models the failure history of the components identified in the model is based upon peacetime failure rates. In the case of passive ECM equipment, these failure rates are probably adequate predictors of wartime failure rates. For active ECM equipment, however, peacetime failure rates (per flying hour) do not approximate wartime use sufficiently to justify their use for wartime scenarios.

Operations Models

Current models do not accurately reflect rapidly changing, realistic air operations. The operations assumptions built into logistics assessment models are drivers of the logistics workload; however, the wartime air operations which the operations community envisions as a future possibility are not built into the logistics models. Consequently, the logistics problems associated with rapidly changing operational scenarios are not encountered. Rapid changes of munitions loads, fuel loads, tactics, electronic demands, or enemy tactics are all areas which cause demands on logistics to fluctuate wildly, yet they are not explicitly modeled in the logistics models.

Training

No systematic training on model construction, modification, or use exists. In that most of the models examined are large and use specially constructed data bases, the knowledge required to run them -- let alone modify them -- is extensive. Further, the documentation is often weak at best; so, new operators have little opportunity for self-paced learning. A model expert or trainer has to be on hand virtually all the time if new people are to have an opportunity to learn to construct and run the models effectively. For example, the LCOM community stated almost unanimously that most new analysts need at least 6 months of training on the model before they can be considered effective.

Support Operations

Aircraft missions which include support operations are not well modeled. For instance, neither the tanker nor the receiver aircraft is well modeled for air-to-air refueling efforts. In addition, the effects of critical component failures on tanker aircraft are not accounted for.

Mission Packages

All three of the major logistics capability assessment models examined assume that any aircraft that maintenance can deliver can be used immediately to satisfy unfulfilled mission requirements. This is incorrect. Frequently, operations must have several aircraft available simultaneously in order to launch. In general, tactical aircraft must be launched in pairs, and mission requirements could dictate flights of four to twenty as the minimum required, in addition to any support aircraft.

Attrition Modeling

Attrition is currently modeled as some predetermined loss rate, and all attritted aircraft are treated as "non-returners." This is an unrealistic approach to a very real operational and maintenance-related problem. As discussed under ABDR, returning battle-damaged aircraft create maintenance workloads, yet they also provide a source of cannibalized parts.

Pre- and Post-Processors

The models examined require extensive manipulation of data, both on the input and the output sides of the model. This task could be better automated through statistics processing routines, graphics interface programs, or graphics display packages. This requirement is especially severe with the LCOM model, where each major manpower study requires almost a complete rewrite of the data base.

Level of Aggregation/Granularity

It is often the case that the level of detail represented in the model or its outputs renders the model inappropriate or cumbersome for use in a particular study. (This does not necessarily imply that the model will not be used.) The presence of economies or diseconomies of scale implies that, for example, a wing-level model is not simply a squadron-level problem increased by a factor of three or four. Thus, the ability to easily select the level of aggregation in the model, with a concomitant adjustment of data base requirements, would be highly desirable. This capability is thwarted in current models by a lack of modularity, coupled with fixed data base requirements and standard output products.

Treatment of Partially Mission Capable/Dual-Role Aircraft

Current models do not allow the analyst to examine the increased Operational Plan supportability which can be obtained from proper use of Partially Mission Capable or Dual-Role Aircraft. If an aircraft is incapable of performing even one of many possible mission types, today's models consider it incapable of performing any mission. Yet, for example, an F-16 which is not capable of an air-to-air role might be fully capable in an air-to-ground role.

Multiple Base Operations

None of the models examined has the ability to effectively examine the capability to support air operations from multiple bases. The problems associated with command, control, communications, lateral resupply of critical parts, and reallocation of previously allotted critical parts are crucial to the successful conduct of wartime operations at a theater level.

Institutionalization

Some users were very concerned by the lack of any formal institutionalization of their model. By definition, an institutionalized model is one that is widely used and formally acknowledged by the Air Force as performing certain analysis functions. It has an Office of Primary Responsibility (OPR), standardized documentation procedures, training classes, standard input and output formats, and formalized updating procedures (configuration control).

Configuration Control

This is a subset of the institutionalization category, and refers to the control exercised in maintaining an "official version" of model code. Comparability of results among different user organizations can be assured only if they use the official version of a model. Normally, the OPR would establish formal procedures for implementing model modifications and releasing only object code versions of the model.

IV. MODEL EVALUATION CRITERIA

This section defines a set of criteria for the evaluation of existing or proposed capability assessment models. The criteria defined are based on interviews with model users and developers, and study of the literature and model documentation relevant to this area.

The criteria described below will affect the cost effectiveness of a model, the mission effectiveness of a model, or both. Therefore, we may think of these two measures as "global criteria" that provide an ultimate measure of the importance or relevance of other evaluation criteria described below. Both measures are first discussed to provide their meaning in the context of logistics capability assessment.

Cost Effectiveness

The cost effectiveness of a model, while important to consider in an evaluation, is difficult to assess. At the highest level, the cost effectiveness of a model is ultimately derived from the value of the information that the model provides. One could ask: "Does the contribution to defense posture provided by the information justify the resources necessary to provide that information?" This judgment is necessarily subjective; the value of the information is a function of not only the model, but also the mission of the using organization, the people using the model, the accuracy of the input data, and other factors often beyond the control of the user. A measure of cost effectiveness that is more relevant to the model's using organization could be given by determining whether the information provided by a model could be provided more cheaply through some alternative means. Examples of these alternatives would include empirical studies, analytical techniques, expert opinion, or other simulation models. Under this conceptual framework, cost effectiveness could be derived primarily from comparisons of cost-benefit analyses that considered development, training, data preparation, software maintenance, and hardware acquisition costs.

Mission Effectiveness

Considerations of mission effectiveness provide a separate measure of how effective the model is in providing information that contributes to the mission of the user's particular organizational unit, independent of the model's cost effectiveness. By "mission," we imply a narrow definition that refers to the process of providing specified forms of information (forecasts, raw data, analyses, etc.) to other organizational units. Any improvement to a model's information-providing capabilities must be measured against its effects on mission effectiveness; otherwise, we are merely modeling for modeling's sake.

Operating Efficiency

The efficiency of a model can be evaluated with regard to: (a) the time required to prepare, process, and analyze its input and output; or (b) the model execution time. The criterion described here refers to the first. The total time involved here is a function of both model-dependent features and features that arise independently in the model's operating environment. An example of a model-dependent feature might be a model that requires the user to enter the data in a very precise, inflexible format. The model could be made more efficient by removing some of the burden placed on the user, thereby reducing time required for data entry. On the other hand, the time required to pre-process input data is often a function of factors that are independent of the model but still affect its operating efficiency.

Realism

An evaluation of simulation models should include validation of the simulation results as an important factor contributing to the realism and credibility of the models. However, it is extremely difficult and costly to validate military simulation models. One might also argue that it is inappropriate to evaluate a simulation model's credibility out of context; that is, apart from its users, its particular application, and its input data. Furthermore, validation is an ongoing process, in that the systems being modeled will change continually. Practically speaking then, evaluation of a model's realism by knowledgeable users ("face validity") may have to suffice as validation. Of course this assumes that the user is sufficiently knowledgeable in those functional areas to render such a judgment.

Models are constructed to provide information in specific subject domains, at given levels of detail, and under assumptions either specified or implied. Judicious exclusion of features perhaps only marginally related to the issue at hand is an essential part of sound modeling practices. Thus, in evaluating realism the evaluator must do so only in terms of the specific information desired from a model. For example, many of the "shortfalls" listed in the previous section of this paper do not apply to every situation; for particular cases, some may be irrelevant. The following list provides some of the functional areas for which "realism" within a logistics capability assessment model could be evaluated:

- Multiple base operations
- Treatment of dual-role aircraft
- ECM and Electronic Combat
- OPFOR Operations
- Aircraft Battle Damage Repair
- Support Operations
- Attrition
- Mission Packages
- Maintenance Networks
- Repairable Spares
- Cannibalization in Peacetime
- Cannibalization in Wartime
- Tactics (response to threat)
- Air Base Operability (under attack)
- Consumable supplies

Documentation

The importance of good documentation to support a simulation model cannot be overstated. An idea has value only if the idea can be communicated. Similarly, a model will have value to its potential users only if they can understand how to use it. If the documentation does not communicate the information that the user needs, the model may be misused, unused, or rejected by the user in favor of a more user-friendly but perhaps less appropriate tool. An evaluation of the model documentation, therefore, is an important part of model evaluation. It should include an evaluation of the operational system documentation, the support system documentation, and the documentation control plans and procedures.

Data Procedures

The effectiveness of logistics capability assessment models is contingent upon large quantities of real-world data which are both valid and consistent. Many classified and unclassified data bases are maintained by the Air Force for planning and reporting purposes. Simulation developers face some major obstacles, however, when they attempt to use these data bases. For example, they often receive data in the form of record-oriented flat files which in some cases must be subsequently reorganized into a relational data base and loaded into a data base management system (DBMS).

Usually the external data bases and their simulation-specific counterparts are not at all isomorphic. For one thing, generally the external data bases generally contain much more information than is needed for a particular simulation. The user must therefore extract a subset of the data bases in preparing the input for a specific simulation model. The data must then be transformed again to meet the requirements of the model, and then be reformatted to meet the format requirements of the input data sets.

During the selection of the appropriate data from the external data base or from a relational data base, the semantics of the data play a major role in the integration and abstraction operations performed by the model user. The documentation of the model is critical at this stage of input preparation because in the course of integrating the data to obtain required parameter values, errors can be made that are very difficult to detect upon review of the input data sets.

Most simulation models reviewed in this study were found to be executed exclusively in batch mode. As an alternative to batch mode, simulation in interactive mode with on-line access to external data bases shows promise of alleviating the problem of preparing input data sets. A common problem with reusing data files is that some of the data may not be current at the time the file is reused. By having access to external data bases, however, the data can be frequently updated and saved. Having this on-line capability can greatly reduce the burden on the user to update the input data bases and can also increase the credibility of the simulation by ensuring the currency of the data.

There is no single criterion for evaluating data input procedures, but there are several related criteria. Clearly, the existence of an established data set repository (discussed in the previous section) is directly related, and would alleviate a number of the problems discussed above. The value of a data repository can be further enhanced through residence within a DBMS. One of the features of a DBMS, however, is that it must be upgraded whenever the simulation is upgraded. Its usefulness is greatly reduced if it is not upgraded concurrently with the model, since its value lies in controlling error and inconsistency.

Power

Discrete-event simulations are extremely limited in the kinds of questions they can answer. Typically users define the initial conditions, run the simulation, and see what happens. After obtaining the results, they ask a "what-if" question, redefine the initial conditions, run the simulation, and examine the output again. Running the simulation and drawing a conclusion is, in effect, drawing an inference from an explicit representation of the model. Inference can be defined in general terms as "the ability to draw implicit information from explicit information." The power of the model lies in the ability of the user to draw an implicit conclusion based on the explicit discrete-state representation of the problem.

There are limitations, however, in the kinds of questions that discrete-state simulations can answer. Although these simulations can answer what-if questions, there are other kinds of questions that are equally important, such as "Why?" "When?" "How?" "Can X ever be Y?" "What is the highest/lowest value X will reach?" or "What initial conditions will produce the maximum value of X?" Because of the what-if limitations, the conclusions that can be drawn are also generally limited to statements of the form "Events a, b, and c will occur under initial conditions x, y, and z."

Consequently, the power of a model may be limited by its inability to answer various types of questions. It may also be limited in its ability to represent goals and intentions, plans and beliefs. Generally, these are encoded in procedures, making it difficult to answer questions about them without understanding the code. As a measure of the power of currently used models, users can rate their satisfaction as to the flexibility the model provides in choosing an aggregation level, and its capability to focus on an area of interest.

Output

In logistics capability assessment, the output will reveal resource utilization rates and the number of sorties generated. In the case of wargaming simulations, the output may indicate relationships between players at given points in time, or measures of effectiveness such as miss distance or probability of kill. Some models store a history of the events which occur in the simulation, providing a continuous record of the simulation. Whereas a single record at a given point in time is referred to as a snapshot, a continuous record is, in effect, a data base created during the simulation that can be used to provide input to graphical or analytical routines. These routines can be provided by a post-processor which, like the simulation model, is run in batch mode. In other cases, the graphics processor may run concurrently with the simulation model or may be driven by the simulation.

Emerging graphics technologies go beyond batch mode processing, however, to allow the user to explore interactively not only <u>what</u> occurred in the simulation, and <u>when</u> it occurred, but also <u>why</u> and <u>how</u> these events occurred. Although the technologies are available, the degree to which they have been incorporated into existing simulation models varies greatly from model to model.

Output Format

A simulation model can be evaluated in terms of how well its output conveys information to a user. Data should be arranged in meaningful patterns, with clear descriptions and easy readability. Dense columns of numbers with cryptically coded header descriptions should be avoided.

Graphics

Graphics can be applied to allow greater comprehensibility of simulation input, output, and state during the model execution. Many simulation models have no graphics at all, whereas others have some graphical representation of the simulation output. A more advanced use of graphics is found in the development of the interactive graphical interface.

Graphical interfaces to simulations make possible new types of interactions by allowing one to control, manipulate, and monitor simulations of dynamic systems at many different hierarchical levels. In a maintenance support system simulation, such an interface could, for example, allow one to inspect the status of a key component as it traverses the maintenance network from flightline to depot.

Output Analysis

A model is of little value unless it provides output which is comprehensible and meaningful. Raw output data will usually require some form of analysis to derive a meaningful result. In particular, stochastic models necessitate such analyses to avoid drawing improper conclusions from the relatively small statistical information available in the output. The computer can help alleviate some of the burden of performing this analysis. For example, analytical post-processors can apply a series of standard statistical procedures to collections of output data. Users can evaluate their modeling environment with regard to its current ability to perform and facilitate output analysis.

Design Features

The design of a model is important because of its direct effects upon model comprehensibility, ease of model modification, and model performance and efficiency. A properly maintained model is not static but is continually modified to avoid premature obsolescence. The architectural design is also changing as a result, and must be carefully monitored and balanced to ensure that a good overall design is maintained. As discussed below, this task may not be straightforward. Tradeoffs are often unavoidable. For example, to make a model more efficient, one might be forced to reduce its modularity. However, the increased speed of available computer hardware now allows a greater emphasis on model comprehensibility over efficient source code.

Run-Time Efficiency

Architectural features that affect the speed of execution are important to note in an evaluation of a model because of the strong relationship between run-time efficiency and total costs. Data structures should be designed for efficient data handling during model execution. Previous software development techniques emphasized control structures as opposed to the organization of the data structures (Booch, 1983). Less attention was paid to the handling of global variables and module interface design (Dickinson & Steenrod, 1984). Good architectural design requires a balanced treatment of control structures and data structures. Criteria for model evaluation should therefore include criteria for well-designed data structures, good handling of shared data, efficient control structures, and well-designed module interfaces.

Modularity

Modularity is of particular importance because of its effects on the comprehensibility and flexibility of the source code. This principle can be applied in different ways according to different design methodologies, resulting in differing degrees of flexibility in design. For example, top-down structured design, as described by Yourdon and Constantine (1979), suggests that a system be decomposed by making each step in the process a module. This leads to modules that are highly functional and focuses on operations rather than data, leaving the data structure to be defined later. This concept is best exemplified in object-oriented programming languages. At the other end of the spectrum, there are alternative design methodologies that define data structures first, and then structure the program units based on the data structure. Using this technique, one can clearly define the implementation of the objects in the solution space, and then make their structure visible to the necessary functional units that provide the operations of the objects.

A simulation model can be evaluated for its degree of modularity by examining the length of the subroutines, and the design of the module interfaces. Long subroutines imply a need to further decompose the code into smaller modules. The interfaces should have a standard format, and their preambles should be accurate and consistent with the source code.

Ease of Modification

Models may require modification for one of three reasons: (a) to respond to a change in requirements for the modeled system, (b) to add enhanced modeling capabilities or levels of detail, or (c) to correct errors that have been introduced earlier in the development process. A model that is modular in its design is more easily modified because changes can be introduced without increasing the complexity of the system. The effects of changes tend to be localized within the module where the change occurs. If the module is small in size, it is easier to predict where these effects will occur. Hence, it is easier to control any undesirable effects of introducing a change.

Enhancements of the software must be designed within the existing structure of the model. Because earlier languages such as Fortran are not self-documenting, the programmer must rely on external documentation to represent the structure. Capability assessment models have tended to be written in either Fortran or Simscript; thus, an evaluation of the documentation is important to understand how well the structure is conveyed and to estimate the labor that would be required to enhance the model or to correct errors. If the structure is not modular and the documentation is incomplete, a major upgrade in the existing model may be required before any real enhancements can be designed by anyone other than the original model developers.

Size of the Program

Models can be evaluated in terms of the number of executable statements. The size of a program is one factor in determining the difficulty of upgrading or modifying the program; however, this problem can be reduced with increased modularity of design. On the other hand, the ability to verify, validate, or fully comprehend a model will certainly decrease as a function of increased model size.

Implementation Language

The choice of language will affect the degree of modularity, the number of lines of source code, the comprehensibility of the code, and training and maintenance costs. An organization must be able to locate analysts who are fluent in the language of the model, or provide training. Initial learning or retraining can be costly. Simulation models may be written in general purpose programming languages such as Fortran, Pascal, Basic, or Ada. The advantages of using one of these languages are the relatively large number of analysts who know these languages, and the easy portability between computer systems due to the fact that compilers for these languages are fairly common. Specialized simulation and modeling languages also exist (SLAM, GASP, GPSS, Simscript). Fluency in these languages is less common; however, model development time can be significantly reduced in that each statement in a higher level simulation language can replace numerous statements in a general purpose programming language. In fact, most simulation languages are constructed from a general purpose language.

Treatment of Randomness

Simulation models often assume that physical functions can be modeled as stochastic processes. This allows the incorporation of elements of natural randomness. On the other hand, it entails building implicit assumptions into the model regarding the form and parameters of numerous probability distributions. Verifying the statistical validity of these distributions and maintaining this validity over time are arduous tasks. At the same time, some types of desired model outputs may be rather insensitive to the accuracy of internal probability distributions. In such cases, an expected value treatment may be more appropriate. This is especially true if only a rough first-order type of analysis is needed for a given system.

Institutionalization

Institutionalization of a model carries with it two very important attributes. First and foremost is the recognition that a particular model is the preferred vehicle for performing a particular task. From this recognition flows widespread use of the model and acceptance of model results as being authoritative representations of the modeled scenario. Secondly, institutionalization requires that some agency be designated as Office of Primary Responsibility (OPR) for the model. From this OPR designation stems the responsibility for configuration management of the model including documentation, currency, and the other activities that responsibility entails.

Configuration Management

Configuration management is the application of technical and administrative direction (a) to identify the configuration items that comprise the model baseline; (b) to control the changes made to the baseline; and (c) to record and report change processing and implementation status. The technical and administrative direction is carried out according to a Configuration Management Plan, which specifies controls that are required for maintainability and provides a system for recording errors identified, errors corrected, and enhancements made. Upgrades made by users in different locations need to be coordinated and controlled to conserve resources. This coordination necessitates the establishment of a baseline for the model and a plan for maintaining configuration control. Configuration Management may also have the effect of opening up to a larger number of contractors the opportunity to work on the model, encouraging competition for the opportunity to participate. Involving a larger number of contractors makes the need for the standards more critical and more obvious to model developers.

Criteria for model evaluation should therefore include an examination of the way in which the model is maintained, whether it is under configuration control, whether its modifications are designed to meet existing software standards, and whether it has a User's Group and other organized support groups.

V. EVALUATION METHODOLOGY

This section illustrates how to use the criteria in a model evaluation. The purpose of the evaluation methodology described is to provide using organizations with a means of making an intelligent choice between two or more candidate models or modeling systems, either proposed or already in existence.

This evaluation is inherently subjective. There is no absolute scale for measuring, say, the quality of the output format or the efficiency of the data procedures. Furthermore, we must establish some unified basis for making tradeoffs among different and difficult-to-quantify attributes. Rather than relying on intuition alone, however, we do have some recourse in quantitative techniques having firm theoretical foundations. We refer specifically to the techniques of utility or preference functions (Keeney & Raiffa, 1976).

The strong point of utility theory is its reliance on the preferences of the decision-makers themselves in assessing values for the components of an evaluation. If we assume that the decision-maker will make "rational" assessments, the identified course of action will be "optimal" for the decision-maker. This rationality will depend on the consistency of the decision-maker's stated preferences.

Problem Structure

We shall structure our problem such that a utility is to be determined for each candidate model/system. The model/system with the highest overall utility is then the optimal choice from the decision-maker's point of view. (The utility of each model is to be calculated as a weighted function of the evaluation criteria and the estimated life-cycle costs of using the model/system.) To simplify the discussion, we will assume that the decisions are to be made under certainty; that is, that outcomes are known in advance.

We propose that each model/system under consideration be provided with two relevant attributes that must be determined: mission effectiveness and cost (negatively oriented). These attributes are derived from the two "global criteria," cost effectiveness and mission effectiveness, discussed in the previous section. Mission effectiveness was defined as a measure of how well a model assists a user organization in its mission of providing specified forms of information (forecasts, raw data, analyses, etc.) to other Air Force organizations. The cost attribute refers to the organization's estimated life-cycle costs of using a particular model/system. Reducing the problem to these two attributes focuses the analysis on their inevitable tradeoff.

The mission effectiveness of a model/system will be constructed as a weighted linear combination of its mission effectiveness when measured against each individual criterion. For clarity in this discussion, we define the following parameters:

K_i - the estimated life-cycle cost for model i,
M_i - the overall mission effectiveness of model i,
r_{ij} - the mission rating of model i when measured against criterion j,
w_j - the relative importance of criterion j in relation to the mission of the using organization.

The relationship between mission effectiveness parameters is defined here as:

$$M_i = \Sigma_j w_j r_{ij} \qquad (1)$$

The range of allowable values for the parameters can be set arbitrarily, as long as it is consistent across the criteria and between models. Here we assign r_{ij} to the interval $1 \leq r_{ij} \leq 5$ and w_j to the interval $0 \leq w_j \leq 1$. In the case of r_{ij}, a value of 1 would indicate that model i has poor performance for criterion j, whereas a value of 5 would indicate superior performance. In the case of w_j, a value of 0 would indicate that criterion j is irrelevant to the mission of the using organization; a value of 1 would indicate that the model's performance for criterion j must be maximized.

The other attribute of the utility function is total life-cycle cost. Estimation of this cost should be done as accurately as possible, acknowledging that some costs can be only roughly approximated. A complete discussion of costing techniques is beyond the scope of this paper. For further information see, for example, Grant, Ireson, and Leavenworth (1982), Air Force Systems Command (1985), or Electronic Systems Division (1984).

Recall that K_i is the estimated life-cycle cost for model i. Our utility function can then be expressed as:

$$U_i = u(M_i, K_i) \qquad (2)$$

where u is an increasing function of the independent variables M_i and K_i. The precise form of the function will depend on the preferences expressed by the decision-maker regarding the rates of substitution between the two variables. For example, under certain conditions the function u may be additive, such that $U_i = m(M_i) + k(K_i)$, where m and k are both increasing functions.

Establishing the form of the function u is accomplished by having the decision-maker answer questions of the following form: If M_i is increased by some number of units, by how many units does K_i have to decrease (costs increase) for you to be indifferent? (That is, at what point would you feel that increased costs make a given increase in mission effectiveness of neutral value.) In most cases, the answer depends on the current levels of M_i and K_i. If at level (M, K) of M_i and K_i the decision-maker is willing to give up $\mu\epsilon$ units of K_i for M_i , then the "marginal rate of substitution" of K_i for M_i at (M, K) is μ. The marginal rate of substitution is defined as the negative reciprocal of the slope of the "indifference curve" at (M, K). (See Figure 1.)

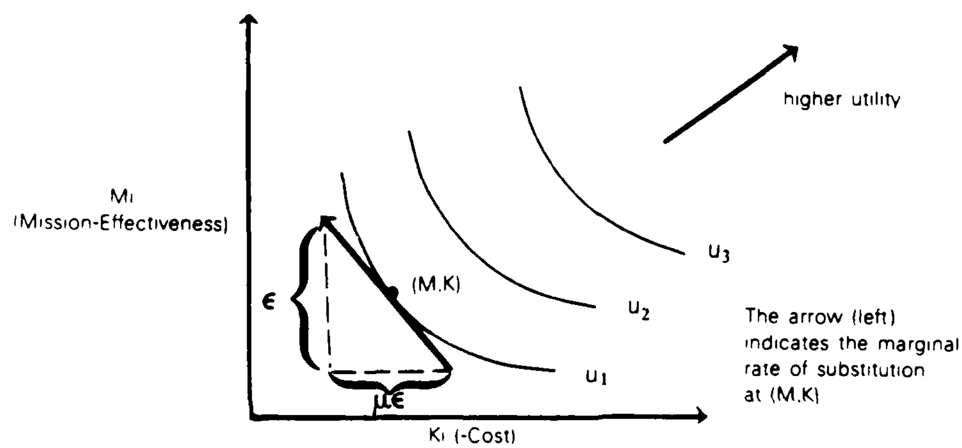

Figure 1. Indifference Curves.

The decision-maker is indifferent between any combination of M_i and K_i on a given indifference curve. Moving outward from the origin, the curves represent higher levels of satisfaction (utility) for the decision-maker. The curves are constructed by plotting data corresponding to the decision-maker's marginal rates of substitution. (See Keeney and Raiffa for examples and further discussion of how one might structure an interview to obtain these data.) For each model i, the points M_i and K_i are plotted on the same graph. The model corresponding to the point on the highest indifference curve is selected as optimal for the decision-maker.

Example

Table 1 presents a list of model evaluation criteria and sample mission importance ratings (w_j values) assigned by a hypothetical decision-maker. The criteria are divided into two categories: "general criteria" and "domain criteria." General criteria apply to most large discrete-event simulation models. The domain criteria are those that might be applied to models in the functional area of logistics capability assessment. The relevance of each of the criteria to our hypothetical decision-maker is reflected by its w_j value.

Table 1. Sample Mission Importance Ratings

General criteria		Domain criteria	
Power	0.83	Multiple Base Operations	0.92
Output Analysis	0.83	Attrition	0.92
Ease of Modification	0.75	Mission Packages	0.92
Operating Efficiency	0.75	Aircraft Battle Damage Repair	0.83
Documentation	0.75	Repairable Spares	0.83
Data Procedures	0.75	Airbase Operability	0.83
Modularity	0.75	Consumables	0.75
Configuration Management	0.75	Cannibalization - Wartime	0.75
Run-Time Efficiency	0.75	Dual-Role Aircraft	0.75
Output Format	0.67	ECM and Electronic Combat	0.67
Treatment of Randomness	0.58	Support Operations	0.67
Implementation Language	0.42	OPFOR Operations	0.58
Output Graphics	0.42	Maintenance and C2 Networks	0.50
Size of Program	0.17	Cannibalization - Peacetime	0.13
		Tactics	0.10

Table 2 provides model criteria ratings (r_{ij} values) for three hypothetical candidate models/systems, denoted here as A, B, and C. When the criteria ratings are multiplied by the mission importance ratings from Table 1, and summed for each model, we arrive at the mission effectiveness attributes listed at the bottom of Table 2.

Table 2. Model Criteria Ratings

Criterion	Criteria ratings (r_{ij}) Model A	Model B	Model C	(w_j)
Data Procedures	1.33	3.33	3.00	0.75
ECM and Electronic Combat	2.00	3.00	4.00	0.67
Configuration Management	1.67	4.17	2.25	0.75
Output Analysis	2.33	3.54	2.75	0.83
Output Graphics	1.33	4.00	1.00	0.42
Ease of Modification	1.25	4.33	3.00	0.75
Output Format	3.00	4.00	3.00	0.67
Modularity	1.50	4.33	4.00	0.75
Cannibalization - Peacetime	3.67	4.33	4.00	0.13
Size of Program	1.33	4.50	1.50	0.17
Documentation	2.50	3.50	2.75	0.75
Operating Efficiency	2.00	5.00	3.75	0.75
Tactics	1.00	1.33	1.00	0.10
Attrition	3.00	3.33	4.50	0.92
Aircraft Battle Damage Repair	3.00	1.00	3.50	0.83
Mission Packages	3.33	2.67	1.00	0.92
Cannibalization - Wartime	3.67	4.33	4.00	0.75
Dual-Role Aircraft	4.00	2.00	3.00	0.75
Treatment of Randomness	4.00	4.67	3.50	0.58
OPFOR Operations	3.00	1.00	1.00	0.58
Implementation Language	3.33	4.50	1.25	0.42
Maintenance and C2 Networks	4.67	2.33	5.00	0.50
Consumables	4.00	3.33	4.00	0.75
Power	3.50	4.17	4.12	0.83
Multiple Base Operations	3.00	3.00	3.25	0.92
Run-Time Efficiency	4.00	5.00	3.75	0.75
Support Operations	5.00	3.00	4.75	0.67
Airbase Operability	4.33	1.33	2.00	0.83
Repairable Spares	4.67	5.00	5.00	0.83

Mission Effectiveness Ratings: $M_A = 58.58$, $M_B = 66.44$, $M_C = 62.39$ $\quad (M_i = \Sigma_j w_j r_{ij})$

Based on the mission effectiveness ratings alone, model/system B is the best, followed by C and then A. Before making a selection, however, life-cycle costs need to be considered. Assume that the following costs have been calculated:

Model/System A - $2,000K
Model/System B - $3,000K
Model/System C - $2,500K

The (M_i, K_i) points can now be plotted. (See Figure 2 - Note that the cost axis is negatively oriented.) Clearly, the optimal choice will depend on the form of the indifference curves, since no point "dominates" the others. That is, no model/system is both highest in mission effectiveness and lowest in cost.

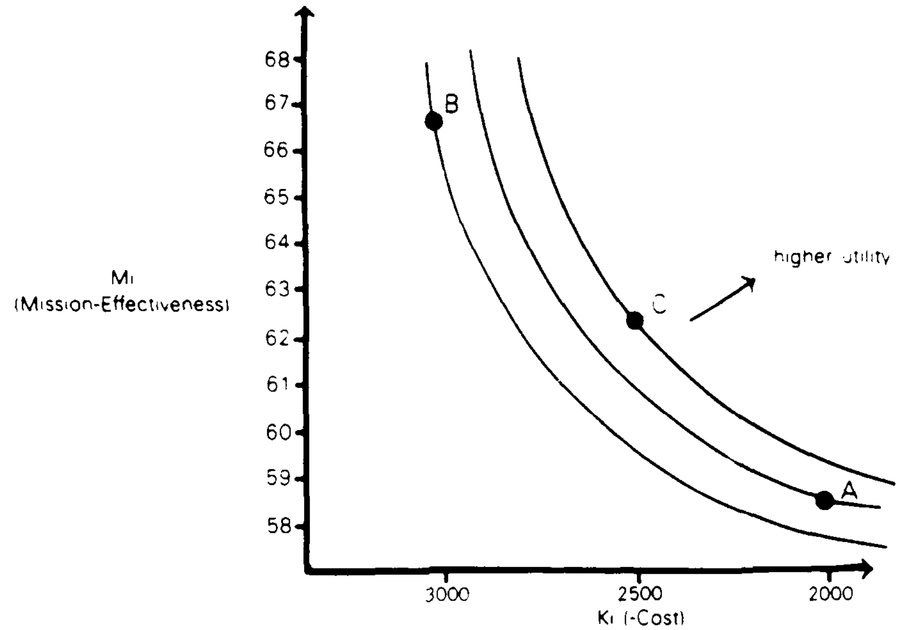

Figure 2. **Results of Example.**

In this example, the indifference curves have been plotted such that model C achieves highest overall utility. This occurred despite the fact that it was neither the most mission effective nor lowest in cost. Different preferences by the decision-maker on the rates of substitution between K_i and M_i could have produced other results, however.

Limitations

There are possible limitations to the literal application of the evaluation methodology. First, in an attempt to be comprehensive, the method focuses attention on distinct categories of model evaluation criteria. The astute reader has probably recognized that these categories are neither necessarily distinct nor independent; in fact, some are highly related. This may introduce an element of bias into the evaluation in that model deficiencies may get "double-counting" if they affect more than one criterion. For example, a very large program could receive a poor rating in "size of program." It might also get poor ratings in "run-time efficiency" or "ease of modification," simply because it is a large program. On the other hand, large programs are not necessarily inefficient or difficult to modify; thus, the problem may not be significant.

Second, it may be difficult for a decision-maker to determine substitution rates between dollar costs and an arbitrarily scaled mission effectiveness rating. This problem can be ameliorated by allowing the decision-maker to first develop an intuitive notion of the value of "a unit" of mission effectiveness. In addition, it may be that critical values can be established for the marginal rate of substitution such that, for example, $\mu^{\circ} \leq \mu \leq \mu'$ implies model/system A is optimal, $\mu' \leq \mu \leq \mu^2$ implies model/system B is optimal, etc. In this way, the decision-maker need not determine precise values for substitution rates, but need determine only within which of several broad ranges the values fall.

It seems clear that sensitivity analysis can play a major role in the model evaluation. This is true not only in the case of marginal rates of substitution above, but also in assigning values to the model criteria and relative mission importance ratings. Sensitivity analysis may also provide relief to those attempting precise calculations of life-cycle costs. A general rule of thumb is to first determine the sensitivity of the solution to small changes in parameter values before expending a great deal of effort in deriving precise values for the parameters.

VI. CONCLUSIONS

This paper illustrated that evaluating any simulation model requires consideration of numerous criteria. However, not all criteria are equally relevant in all situations or to all organizations. The proposed evaluation methodology takes this fact into account through the use of mission importance ratings. These ratings also provide a convenient vehicle for the expression of a decision-maker's preferences, a necessary element in deriving utility functions.

A corollary to the notion of evaluation criteria having differing degrees of relevance or importance among organizations is the fact that the importance ratings will change over time within a single organization. Such changes stem from the highly dynamic nature of Air Force operations and procedures, as well as the availability of new modeling technologies. Ultimately, any model will eventually become obsolete. Organizations must therefore continually monitor and evaluate models to ensure that the models' performance (mission effectiveness) and cost effectiveness justify continued usage. It is hoped that this paper will provide a basis for such evaluations.

We have also illustrated the inevitable tradeoff between model costs and model performance that must be faced by decision-makers. Not as apparent, however, are the tradeoffs among performance criteria. However, such tradeoffs must be made, as no model can be all things to all people. For example, attempts to continually incorporate additional "realism" and detail into a model will eventually make the model too cumbersome and difficult to use. In terms of the criteria given here, run-time efficiency, operating efficiency, and ease of modification would eventually deteriorate in the face of repeated program modifications. A more effective strategy would be to develop models that would provide for a high degree of flexibility. Thus, models could be altered or extended without necessarily making them more complicated or less efficient.

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