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Decision Support for the Wartime Theater Ammunition Distribution System

Research Accomplishments and Future Directions

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Flexible and responsive management systems can allocate limited logistic resources in ways that maximize combat capability. This research identified uncertainty and complexity as the key problems facing the management of the wartime theater ammunition distribution system. Early in the study, three research areas were identified: a system data model should be developed, a quantitative evaluation mechanism was required, and narrow-purpose expert systems could improve decision support. A prototype knowledge-based simulation creates models of material management centers, movement control centers, and other ammunition managers. A method was developed to identify decisionmaking problems appropriate for expert system solutions. Questions concern whether a problem is appropriate, whether the development of an expert system is feasible, and whether expert system developments can be justified. The authors noted a need for developing expert systems in domains where knowledge is scarce and building a portable and extensible laboratory environment for training and evaluation purposes.

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John F. Schank, Brian Leverich
with Jody Paul

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PREFACE

This report addresses completed and continuing Arroyo Center work on problems in ammunition distribution management that are related to information management and decisionmaking within a wartime theater of operations. The objective of the project, "Decision Support Systems for Combat Service Support," is to improve combat service support (CSS) performance and thereby to increase the combat capability of supported forces by identifying and evaluating applications of decision support technology that could improve the quality or timeliness of CSS management decisionmaking. The research falls within the Arroyo Center's Readiness and Sustainability Program, and is part of a larger effort to improve the Army's warfighting capabilities by increasing the effectiveness of logistics resource management. The project is sponsored by the Commanding General, U.S. Army Logistics Center, Fort Lee, Virginia.

The report provides an overview of the initial stages of the research and describes research directions and objectives. It should be of interest to organizations and individuals concerned with developing doctrine for ammunition distribution or with designing and evaluating information management and decision support software. Individuals involved with operations research—especially simulation modeling, expert systems, and decision support systems—may also be interested in the analysis techniques described here.

THE ARROYO CENTER

The Arroyo Center is the U.S. Army's federally funded research and development center for studies and analysis operated by The RAND Corporation. The Arroyo Center provides the Army with objective, independent analytic research on major policy and management concerns, emphasizing mid- to long-range problems. Its research is carried out in five programs: Policy and Strategy; Force Deployment and Employment; Readiness and Sustainability; Manpower, Training, and Performance; and Applied Technology.

Army Regulation 5-21 contains basic policy for the conduct of the Arroyo Center. The Army provides continuing guidance and oversight through the Arroyo Center Policy Committee, which is co-chaired by the Vice Chief of Staff and by the Assistant Secretary for Research, Development, and Acquisition. Arroyo Center work is performed under contract MDA903-86-C-0059.

The Arroyo Center is housed in RAND's Army Research Division. The RAND Corporation is a private, non-profit institution that conducts analytic research on a wide range of public policy matters affecting the nation's security and welfare.

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SUMMARY

Future wars will be characterized by highly dynamic battlefields complicated by much uncertainty concerning enemy intentions and actions, required operations and missions to counter enemy actions, and weapon system reliability, effectiveness, and survivability. Logisticians must face the uncertainties of war and the variabilities of demands when addressing questions concerning the quantity of various logistic assets required at different locations and the capabilities needed to move, store, and maintain those assets. Constrained defense budgets exacerbate the problems faced by logisticians and eliminate the alternative of "buying out" part of the uncertainty and variability.

The uncertainty and variability of wartime, coupled with constraints on the availability of logistic assets, will require flexible and responsive management systems that can allocate the limited logistic resources in ways that maximize combat capability. This report describes the research for an Arroyo Center project entitled "Decision Support Systems for Combat Service Support." The objective of the project is to investigate ways of increasing combat capability by improving the effectiveness of logistic resource management. Focusing on the wartime theater ammunition distribution system (WTADS), we are developing methods to identify and evaluate decision support enhancements that can improve the quality and timeliness of management decisions.

PHASE I RESEARCH RESULTS

The initial phase of the research identified *uncertainty* and *complexity* as the key problems facing the management of the WTADS. The general solutions to these problems include:

- Better information and short time horizon forecasts
- Better decision support
- Increased system responsiveness.

The various technologies of operations research, artificial intelligence, computer science, and decision support systems were examined to identify and evaluate potential applications that could help provide solutions to the overall management problems. Three high priority research areas were identified during the first phase of this research. First, a system data

model should be developed to understand the information flows and availabilities within the WTADS. Second, a quantitative evaluation mechanism was required to measure the impact of potential decision support enhancements. Third, the development of narrow-purpose expert systems offered the potential for improving decision support within the WTADS and warranted further investigation.

PHASE II RESEARCH RESULTS

The second phase of the research evolved into two parallel, but related paths to pursue the recommendations made during the first research phase.[1]

The objective of the first path was the development of a prototype model to help evaluate the combat effects of proposed decision support tools. The resulting knowledge-based simulation model, written in an object-oriented language, represents not only the physical distribution aspects of the WTADS, but also the information flows and decisionmaking capabilities of the WTADS managers. The simulation explicitly models materiel management centers, movement control centers, and various other ammunition managers. Furthermore, the WTADS simulation models the complete ammunition system from CONUS manufacturing plants to the ultimate combat users (although the model concentrates on the theater distribution of ammunition).

The WTADS model captures the variability and uncertainty of wartime by allowing planned postures and target sets to be altered on a random basis and by allowing the enemy to interdict and destroy logistics resources. Finally, the model provides not only standard logistics measures of effectiveness, but also *combat-oriented* measures so that the overall effects on system performance can be measured along with the local effects of decisionmaking enhancements.

The objective of the second path of the research was the development of a method to identify decisionmaking problems appropriate for expert system solutions. A number of aspects of the WTADS suggest that expert systems should prove beneficial to the decisionmakers—several decisions involve the consideration of a large number of factors and alternatives, decisions are made in limited time frames, the dynamic and stressful environment contribute to human error, and there are a limited number of trained and experienced WTADS

[1]Formal development and specification of a system data model were not undertaken based on the assumption that the Army, or another contractor, could adequately accomplish that objective. Understanding and representing information flows were critical aspects, however, of developing the quantitative evaluation model.

managers. The problem lies in identifying those applications where expert system technology would have large payoffs.

The resulting expert system screening mechanism involves a wide range of questions concerning whether a problem is *appropriate*, whether the development of an expert system is *feasible*, and whether expert system development efforts can be *justified*. Through the interactions of a knowledge engineer and an ammunition system domain expert, a number of WTADS problems were identified and subjected to the screening criteria. The result was the identification of several problems that were applicable to expert system solutions, but a major hurdle to the development of expert systems was the lack of domain experts with relevant wartime experience.

PHASE III RESEARCH OBJECTIVES

The current phase of our research is pursuing the two paths initiated under Phase II plus examining some new research objectives. Now that the prototype WTADS model has been developed, we are using it to examine the combat effects of a number of policy and structural changes to the WTADS. Specific changes being evaluated include the:

- Introduction of the palletized load system (PLS)
- Implementation of aspects of the manuever-oriented ammunition distribution system (MOADS)
- Examination of increased management of high-lethality munitions.

The expert system research is continuing by developing a prototype expert system for one of the appropriate problems identified by the screening mechanism. We are also addressing the shortage of relevant expertise by examining methods to *cultivate* new knowledge and by investigating the potential of *adaptive* expert systems that learn from actual experience.

The new research questions we are addressing during Phase III include:

- Predevelopment evaluation of decision tools in order to quantify the value of a decision aid before development efforts begin. The ability to evaluate at this stage of the development cycle permits the relative ranking of several potential decision aids and can be used to help justify funding for development efforts.

- Postdevelopment evaluation of decision tools in order to understand whether a decision aid actually improves system performance and whether further development efforts or fielding is justified.
- Implementation of decision aids in order to determine the best strategy for interfacing the human decisionmaker with the decision tool. Implementation alternatives would include what data are provided by the decision aid, how that data are displayed to the decisionmaker, and what mechanisms are available for manipulating data.

A number of the research issues we are addressing during the current phase of our research require interfacing a human decisionmaker with the WTADS simulation model. The structure of the object-oriented language used to develop the WTADS simulation model provides a ready and effective mechanism for such human interfaces. Any of the objects programmed in the model can be replaced by interactive inputs in terms of responses to messages directed to that object. Therefore, a human can be seated at a terminal receiving model output and provide corresponding input representing an object's behaviors.

To provide this human/model interface, we plan to build a laboratory environment that can graphically present various logistics data and battlefield information to the decisionmaker, allow him to make decisions, and, based on the results of the simulation model, see the combat effects of his decisions. This type of capability will help us to cultivate new expertise, examine the effects of various implementation strategies, and make postdevelopment evaluations of decision support tools. Furthermore, this initial laboratory capability can be extended to include other functional areas in addition to ammunition, provide an effective training device for WTADS managers, and be adapted for use as a logistics wargaming capability.

It is important to note that our research does not have a narrow goal of developing a single expert system for WTADS or of building a laboratory for limited use in this research environment. Rather, we are striving to evolve a general approach for developing expert systems in domains where knowledge is scarce, and we are building a laboratory environment that is portable and extensible by the Army for training and evaluation purposes.

Given shrinking defense budgets, improved information and decisionmaking capabilities are an important way to achieve greater responsiveness and support from finite logistic resources. The development of decision support tools and enhancements has been difficult to fund because of limited research and development budgets and problems with quantifying the potential benefits of the resulting management tools. The techniques and models developed in this project should help the Army quantitatively evaluate the impact of proposed decision support systems and thus more objectively justify their development.

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Many people have contributed to our understanding of the wartime theater ammunition distribution system. We are indebted to the staff of the U.S. Army Ordnance Missile and Munitions Center and School, especially Michael Belt and Timothy Brady, for their generous assistance. Richard Camden, Carolyn Dunmire, and John Stephens of the Army's Human Engineering Laboratory have helped us understand the ammunition distribution system and how artificial intelligence tools can assist in the management of that system. Our initial understanding of the ammunition distribution system was further enhanced by the knowledge and experience of LTC Samuel Cantey and LTC James Price, Army Fellows assigned to The RAND Corporation. Their interactions with the overall research were invaluable.

Several members of the RAND staff, have made substantial contributions. Morton Berman first laid out the problem of determining the value of decision support systems in the combat service support domain. Steven Bankes and Louis Miller contributed to the initial work and provided continuing useful insights and suggestions. Finally, Chris Tsai and David Taylor provided a number of comments and suggestions that improved the overall quality of the report.

Particular thanks go to our project sponsor, LTG William Tuttle, commanding general of the Logistics Center, and Charles Correia, our project point of contact.

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FIGURES

I. INTRODUCTION

One of the few things certain about war is that unexpected things happen. The deliberate planning process in peacetime cannot fully anticipate enemy intentions or actions, the specific operations and missions that will be required to counter enemy actions, or the degree of support that will be provided by allies. This uncertainty in wartime operations, coupled with the uncertainties in weapon system effectiveness, reliability, and survivability, result in difficult problems for logistic support planners. Logisticians must confront these uncertainties when faced with decisions concerning not only the required quantities of various assets such as repair, repair parts, and munitions, but also how to provide the storage and distribution of those assets to ensure that operational plans can be supported.

Requirements decisions (how much is needed) are addressed by logisticians in peacetime using available data and knowledge, supplemented by assumptions concerning wartime operations and weapon system characteristics. Regardless of whether these decisions are correct or incorrect, the result is a fixed set of logistic assets available at the outbreak of war. Because of the uncertainties about how much will actually be required and where and when it will be needed, it is particularly important that logisticians effectively allocate the limited resources in conjunction with current operational plans and priorities. To do this, flexible and responsive management and distribution systems are necessary. If distribution systems can be developed that are more responsive, i.e., that are able to recognize and adapt quickly to unanticipated events, then more responsive supply of key commodities, such as spare parts and munitions, or functions, such as transportation or repair, may overcome the problems caused by the wrong mix or quantities of those commodities.

Based on the premise that wartime variabilities and uncertainties will require flexible and responsive management systems, the Arroyo Center's Readiness and Sustainability Program is conducting a project entitled *Decision Support Systems for Combat Service Support.* The objective of the research is to increase *combat capability* by improving the effectiveness of logistics resource *management.* Specifically, we are identifying and evaluating decision support tools and technologies that can improve the quality and timeliness of management decisions. The initial focus for the study is the wartime theater ammunition distribution system (WTADS).

PHASE I RESEARCH

The first phase of the study identified key problems related to information management and decisionmaking within the WTADS, proposed general solutions to those problems, and considered the potential contributions the technologies of artificial intelligence (AI), computer science (CS), and operations research (OR) could make in supporting general solutions.

The two key problems faced by the managers of the wartime theater ammunition distribution system were identified as *uncertainty* and *complexity*. Uncertainty, as described above, arises from numerous sources—uncertainty about enemy actions, about our own plans and objectives, about demands for ammunition and the supplies of not only ammunition, but also the trucks, material handling equipment, and personnel required to move, store, and handle ammunition, and uncertainty about uncontrollable random factors such as the weather. The problems associated with complexity are due to the sheer size of the WTADS plus the amount of inter-player and inter-temporal coordination required for many actions within the system.[1]

Three general solutions were identified to help WTADS managers address these key management problems:

- Better information and short-term forecasts
- Better decision support
- Increased system responsiveness.

Better information and short-term forecasts can help to reduce the uncertainty inherent in wartime operations. Increased decision support capabilities can assist WTADS managers in dealing with the complexities of the overall distribution system. Finally, increasing the responsiveness of the WTADS will allow decisionmakers to recognize problems and identify inconsistencies earlier and will assist in selecting and implementing solutions to those problems more quickly.

Within these three general solution areas, a number of specific applications of AI, OR, and CS technologies were identified as high leverage research objectives. Two of these research objectives, the development of a prototype WTADS model and evaluation mechanism and the development of an enumeration and screening mechanism for expert system applications, formed the basis for the second phase of the project.

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[1]Using standard Army firing rates, the ammunition distribution system during a major war will move across the theater almost an aircraft carrier's tonnage in munitions *every day*. Also, even relatively simple operations such as making a single shipment of ammunition between two locations require 38 separate steps to be taken in sequence by seven different individuals or organizations (see Ref. 1, p. 88).

OBJECTIVE OF THE DOCUMENT

This report reviews the research accomplishments of the second phase of the project and describes the progress and objectives of the current research phase. During Phase II of the research, we developed a prototype model for use in evaluating enhancements to the ammunition distribution system. This knowledge-based simulation model, written in an object-oriented language, captures not only the physical distribution aspects of the WTADS, but also the information flows and management decisionmaking aspects. The model incorporates the uncertainty of wartime and provides combat-oriented measures in addition to logistics-oriented measures of effectiveness.

A second output of the Phase II research is an expert system screening mechanism for identifying decision problems that are appropriate for expert system solutions. Various screening criteria were applied to a range of WTADS decision problems, with several identified as warranting the development of expert systems. A major problem, however, is the apparent lack of experts with relevant wartime experience.

In Phase III, we are extending the two paths of our current research by using the WTADS model to evaluate several specific structural changes to the ammunition distribution system and by investigating methods to develop and cultivate management expertise. The existence of an evaluation mechanism and the potential for the development and application of expert decision aids presents new research questions and opportunities. These include the post-development evaluation of specific decision tools (does a decision tool really improve combat performance?), the identification of ways to interface expert systems with WTADS decisionmakers (how can expert systems be implemented to optimize their use by and benefit to decisionmakers?), and the predevelopment evaluation of potential decision aids (how can the potential impact on combat performance of a decision tool be estimated before the tool is ever developed?).

ORGANIZATION OF THE DOCUMENT

Section II reviews the development of the WTADS model—a knowledge-based simulation model of both the physical distribution system—and the management command and control aspects of the ammunition distribution system, and describes how this model is being used to evaluate three specific structural changes currently being considered by the Army. Section III provides a similar description of the expert system research, reviewing the development and application of a problem enumeration and screening mechanism. This section also outlines potential methods for addressing the lack of meaningful wartime expertise that we are pursuing in the current research phase of the study. Section IV describes the new research objectives we are undertaking and summarizes the concepts and operations of a logistics laboratory—an environment to interface human decisionmakers with the WTADS model that is essential to our research.

II. DEVELOPMENT OF A WTADS MODEL

The size and complexity of the WTADS suggest that an overall system model is required to evaluate the effects of alternative strategies, policies, and structural changes, and the effects of better information and decision support tools. This section describes the development of a prototype system model. We discuss the rationale for developing a new model of the ammunition distribution system, the philosophy we adopted in developing the model, and, in a brief overview, the composition of the WTADS model. We conclude the section by giving an example of how the WTADS model can be used to evaluate the effects of improved decision support and discuss several specific possible structural changes to the ammunition distribution system.

RATIONALE FOR DEVELOPING THE WTADS MODEL

The first phase of our research identified numerous decision support tools that could potentially improve the management of the ammunition distribution system. The Army is also considering several structural and doctrinal changes to the overall distribution system. Identifying changes and enhancements is only the first step; what is ultimately needed is an assessment of the impact on overall system performance.

Quantitative evaluation of proposed changes is required for a number of reasons. First, there is the obvious need to know if a proposed change will actually improve the performance of the overall system. Within a complex system such as WTADS, instituting a change in one area, or for one decisionmaker, may have positive local effects, but may not in fact improve overall system performance because of other constraints or bottlenecks within the system. Evaluation is also necessary when several potential enhancements are being considered and the overall effectiveness of the individual changes must be ranked or the interrelationships of several simultaneous changes understood. Finally, the quantitative evaluation of proposed changes is often necessary to justify the development costs associated with decision support tools.

Evaluating the effect of changes on the combat capability of supported units is difficult for several reasons. The presence of variability and uncertainty in a dynamic wartime environment complicates any evaluation. Understanding and representing the variability and uncertainty, combined with the overall complexity of the ammunition distribution system, makes subjective evaluation almost impossible. The alternative of using field tests or exercises to evaluate changes has numerous shortcomings. Again, the uncertainty and complexity complicate such field tests, making realistic exercises difficult to design and expensive to conduct. When field tests are used, the resulting evaluations are often limited because of the need to constrain or structure various aspects of the overall exercise. Typically, the only viable alternative for evaluating potential changes is to develop simulation models of the overall environment.

There are a number of simulation models that treat all or part of the WTADS. These models share the following shortcomings in terms of evaluating the combat impact of proposed changes to the WTADS:

- The models are "rigid" in the sense that they are incapable of modeling changes that are much different from current doctrine.
- The interaction of management and communication with the physical system cannot be studied because materiel management and movement control centers are not played.
- The impact on combat capability cannot be assessed because combat performance measures are either entirely missing or are of marginal relevance.
- The impact of uncertainty cannot be evaluated because the models are deterministic.
- Several of the models run so slowly that studies of more than a handful of changes would be prohibitively expensive.

The shortcomings of existing models and the objectives of our research suggested that a new evaluation tool should be developed.

PHILOSOPHY USED IN DEVELOPING THE MODEL

From the perspective of evaluating the impact of improved information and decision support tools, it is imperative that the model of the ammunition distribution system emphasize the *information flows* within the overall system and the *decisionmaking* characteristics of WTADS managers. In constructing the WTADS simulation, we explicitly model Materiel Management Centers (MMCs), Movement Control Centers (MCCs), and various other ammunition managers, such as the Division Ammunition Officer (DAO). This inclusion of the management aspects and interrelationships within the overall system is one characteristic that makes the WTADS simulation model different from other available system models.

We model within the WTADS simulation aspects of the *entire* ammunition distribution system by representing the flow of ammunition from CONUS production plants to the actual combat user. At this stage of model development, we are focusing primarily on the *theater* distribution system with only a rudimentary representation of the ammunition flow from the plants to the theater. This structure is contained within the WTADS model, however, to enhance the first leg of the overall distribution system during a later model iteration.

An important issue in the development of the WTADS simulation was the representation of the variability and uncertainty that will exist in wartime. Wartime variability and uncertainty are incorporated within the model in a number of ways. The model generates daily postures for the combat units included in the simulation. These postures include offensive and defensive engagements at various levels of intensity.[1] Each posture relates to an assumed enemy action and has associated with it a set of enemy targets. The model incorporates the uncertainty and variability of war by generating *actual* enemy actions and target sets that may differ from the *planned* postures and target sets. This allows the model to measure how robust the overall system and proposed enhancements are with respect to unpredictable enemy intentions. The model also incorporates uncertainty by allowing the enemy to interdict and destroy various elements of the distribution system such as storage sites, material handling equipment, trucks, and personnel.

Two final characteristics included in our modeling philosophy are the measures of performance calculated by the model and the user-related aspects of the overall modeling environment. Although the model generates the standard types of logistics-oriented metrics such as tons delivered or equipment utilization, we felt that it was also important to include *combat-oriented* measures of effectiveness. The model evaluates the impact of proposed system changes on combat capability by calculating the number and type of targets killed.

To provide a suitable modeling environment from a user perspective, we developed the WTADS simulation using an object-oriented language. The use of this construct, described in more detail below, facilitated the overall modeling effort and results in a simulation that is easy for a user to understand and modify.

Incorporating the above mentioned points provides a model that can address the evaluation of both structural changes to the WTADS and enhancements in the information flow and decisionmaking capabilities within the WTADS. It can also perform these evaluations using both

[1]Altogether there are nine postures that a particular unit can assume, including the various permutations of protracted attack and defense in combination with intensities of light, medium, and heavy.

logistics and combat-oriented measures of effectiveness. An overview of the WTADS model is given next.

OVERVIEW OF THE WTADS MODEL

The WTADS model is a simulation written in the ROSS language.[2] ROSS is a language that uses interacting *objects* to represent an overall system. A simulation of a military engagement might include objects representing Red and Blue maneuver units, physical resources, such as trucks or weapon systems, and command and control organizations. Each object has various *attributes* that describe it, plus a set of *behaviors* that enumerate *messages* the object may receive from other objects and messages that an object may send in response. ROSS provides a powerful and flexible environment in which to build and modify simulation models. Its English-like syntax permits fairly rapid understanding of the interactions contained within the simulation model, even by individuals not familiar with the language.

The WTADS model is composed of four modules as shown in Fig. 1. The heart of the model is the combination of the *physical distribution* module and the *management decision* module. These modules contain the attributes, behaviors, and messages for the numerous objects contained in the overall simulation. These objects, or actors, include combat and support units, storage locations, trucks, roads, and various decisionmaking managers or organizations from the division to the theater Army level. The physical distribution module passes resource status information to the management decision module, which in turn passes back courses of actions (e.g., what ammunition to ship where, at what time, and using which resources) based on the behaviors and rules representing the managers' decision strategies. The physical distribution module then executes the directives and passes back the resulting resource status information.

Interacting with these two modules are the *scenario generator* and the *combat evaluator* modules. The scenario generator develops postures (operational orders) for the various units, targets associated with these postures, and data on losses due to enemy actions. The physical distribution module incorporates the damage reports into the resource status information, and the management decision module uses the operational orders implied by the postures when determining courses of action. The last module, the combat evaluator, combines the target array faced by combat units and the ammunition delivered from the

[2]The ROSS language is described in Ref. 2; previous applications of ROSS simulation models are described in Refs. 3 and 4.

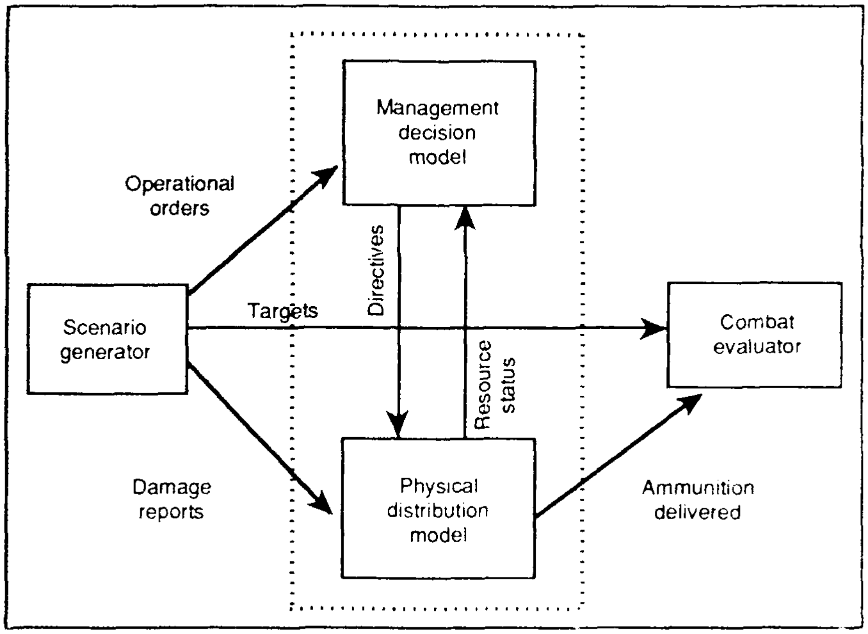

Fig. 1—WTADS model components

distribution module into a combat-oriented performance measure (such as targets killed or percent of "correct" ammunition delivered).

EXAMPLE OF USING THE WTADS MODEL

As an initial demonstration of the WTADS model, we considered the problem of scheduling trucks for ammunition pickup at ammunition transfer points (ATPs). Trailers from the corps storage areas deliver ammunition to the ATPs where they are picked up by trucks from the combat units. Currently, the unit trucks arrive randomly to pick up their loads from the ATP, although some DAOs attempt to schedule truck arrivals to minimize waiting times and congestion.

The WTADS model was first exercised using random arrivals for the unit trucks. This assumes that the DAO either has no visibility of when corp trailers will resupply the ATPs or, if he does have trailer arrival information, does not attempt to schedule unit trucks into the ATP. At the other extreme, we assume that the DAO has perfect forecasts of trailer arrivals and schedules the unit trucks to minimize their waiting times at the ATP. Since perfect forecasts are highly unlikely, a more reasonable assumption of plus or minus two hours of scheduling accuracy was used for a third model run. Each of the three model runs involved fairly simple modifications of the appropriate parts of the WTADS model logic to reflect the scheduling rules.

The results of the three WTADS runs examining the effect of scheduling accuracy are shown in Figs. 2 and 3. In Fig. 2, the measure of interest was the number of trucks waiting at the ATP. The model indicates that with perfect information and scheduling, the number of waiting trucks can be reduced by two-thirds over the completely random scheduling alternative. Even if trucks can be scheduled within a two hour window, the number of waiting trucks can be reduced by a third over the random scheduling alternative. The advantages of fewer trucks waiting at the ATP include the availability of more trucks for other missions, reduction in congestion, and reduction of target signature.

Figure 3 shows the effects of scheduling accuracy on the average number of tank equivalents killed. Perfectly coordinated scheduling of

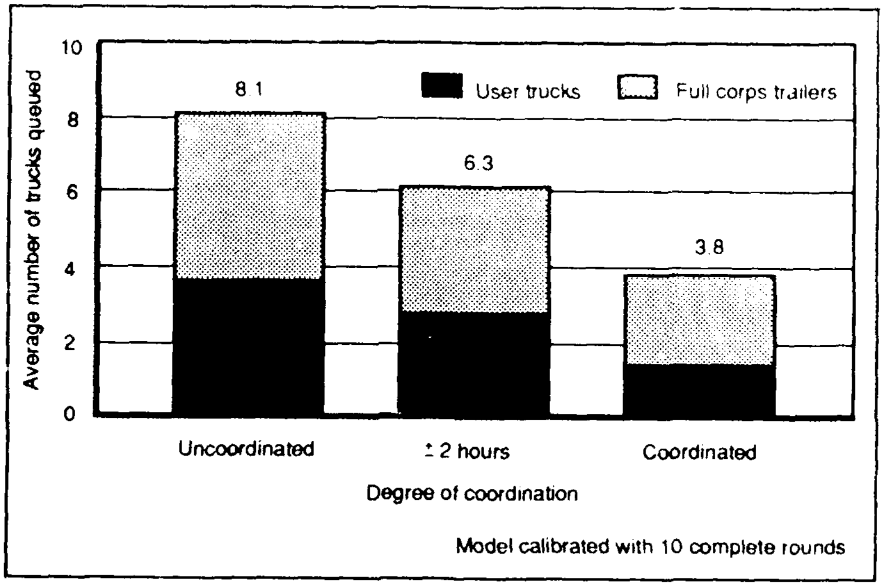

Fig. 2—Improved scheduling coordination at the ATP: Average number of trucks waiting

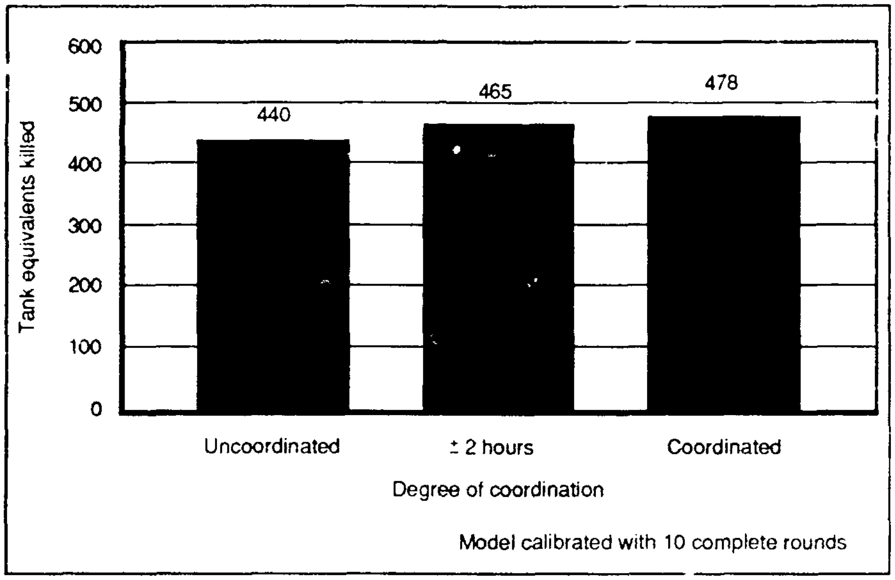

Fig. 3—Improved scheduling coordination at the ATP: Average number of tank equivalents killed

ammunition pickup at the ATP would increase tank kills by approximately 10 percent over the uncoordinated case.

The ability to improve the scheduling of pickup and deliveries at the ATP is just one example of how the WTADS model could be used to evaluate the effects of decision support enhancements. The current phase of our research uses the WTADS model to evaluate several structural and doctrinal changes currently being considered by the Army. These evaluations are described below.

EXTENSION OF PHASE II RESEARCH

The primary rationale for developing the WTADS simulation model was to provide a method for evaluating the combat effects of changes in policy, procedure, or force structure. We will examine three specific logistics infrastructure and policy changes to the ammunition distribution system during the next phase of our research:

- The introduction of the palletized load system (PLS)
- The implementation of certain aspects of the maneuver-oriented ammunition distribution system (MOADS)
- The development of special management procedures for high lethality, high technology munitions.

The PLS is basically a new vehicle that is designed to pick up, transport, and offload pallets of ammunition. The objective of the system is to reduce the requirements for trailers and material handling personnel and to improve the flow of ammunition in the theater. MOADS involves a number of management initiatives including preconfigured ammunition loads and changes to the number and responsibilities of the various ammunition storage points within the theater. High technology munitions are important because of their potential to overcome the quantitative disadvantages faced by U.S. forces. However, because of their high cost, these "silver bullets" are typically in short supply. Special management procedures for the inventory and distribution of these munitions may provide the responsiveness and flexibility needed to overcome the numerical shortfalls.

In addition to the three specific changes described above, we are evaluating a number of management initiatives including changing scheduling operations at storage facilities, using various stockage objectives at ATPs, and providing responsive reallocation of transportation between routes and storage sites.

To evaluate each of the above changes, the WTADS simulation model will be exercised for the current system and for the "changed" system, and the differences in combat outcomes measured. To incorporate each of the above changes into the simulation model, the attributes and behaviors of various simulated objects will be modified to reflect the specific aspects of each change.

Because of the uncertainty surrounding the wartime environment, it will be necessary to evaluate the various changes for a wide range of scenarios.[3] We must understand if proposed procedural and structural changes improve combat performance for only a narrow range of potential courses of action or if they are more robust, improving overall system performance for a wide spectrum of potential scenarios.

As the WTADS model was being developed during Phase II of the research, a second, parallel path examining the potential of applying expert system technology in the WTADS arena was also pursued. The

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[3]Scenario changes will affect the probabilities of combat units assuming different postures in addition to changes in the target density. Higher probabilities of offensive and defensive postures and larger target sets imply a more stressful combat environment.

Phase II results of the expert system assessment and evaluation and the directions of our Phase III research on expert systems are described in the next section.

III. ASSESSMENT AND EVALUATION OF EXPERT SYSTEM TECHNOLOGY

A second high leverage research area identified during Phase I of the project was the further examination of expert system technology to assist WTADS managers. The overall size and complexity of the WTADS suggested that there were numerous problems faced by the system managers whose solutions might be aided by the development of special purpose expert systems. This second research path was directed at developing a list of potential applications for expert systems and a methodology for screening and ranking the problem applications to determine which were the best candidates for prototype expert system development.

This section describes the assessment and evaluation of expert system technology accomplished during Phase II and outlines current analysis in this area. First, we present the rationale for using expert systems for WTADS decisionmaking problems. We then summarize the screening mechanism and describe the results of applying it mechanism to a candidate list of problems faced by WTADS decisionmakers. We conclude the section by discussing one hurdle—the lack of wartime expertise—that must be overcome during the expert system development process and describe the ways we plan to deal with this problem during Phase III of our research.

THE RATIONALE FOR EXPERT SYSTEMS FOR WTADS TASKS

The overall wartime theater ammunition distribution system will be very large and complex, involving numerous decisionmakers interacting to ensure ammunition flows from the ports to the combat users. Decisions must be made about what ammunition to distribute, when to distribute it, where to send it, and how to store, handle, and transport it. Each of these decisions involves a large number of alternatives and factors, resulting in many possible solutions to each individual question. From this large solution space, the system managers must choose effective solutions.

The wartime ammunition distribution system managers' environment will be highly dynamic and stressful. The managers will have to make decisions within a short timeframe; they may not have available all the information they need to make a "good" decision; the information that is available may be corrupted or incorrect; and the consequences of a "bad" decision may be catastrophic.

Adding to the complications caused by the complex and stressful nature of the wartime environment, many distribution managers will be faced with decisions for which they have had little training and experience. Probably more so than other military "systems," the ammunition distribution system operates very differently in peacetime than it will in wartime. By its very nature, little ammunition is expended in peacetime, certainly nowhere near the quantities that must be moved in wartime. Thus, there are few highly trained ammunition distribution managers.

The characteristics of the wartime environment and the small number of experienced WTADS managers suggest that special purpose expert systems could benefit decisionmakers. The inference mechanisms of expert systems permit structured searches through large solution spaces to find appropriate solutions to problems. Expert systems could assist human decisionmakers in collating the numerous factors involved in the WTADS decision process and in evaluating the various alternatives. Expert systems could have explanation procedures to help WTADS decisionmakers understand why specific alternatives are preferred or why other alternatives do not offer feasible solutions. Finally, capturing within an expert system the limited expertise that is available would be one way of distributing that expertise throughout the overall WTADS.

Special purpose expert systems may interface with other decision support technologies, such as traditional operations research tools, to assist WTADS decisionmakers. For certain decision tasks, operations research techniques or improved information processing capabilities may be more appropriate than expert systems. What is required is a mechanism to sort through the numerous tasks faced by WTADS managers and locate those tasks that offer a high payoff for the development of expert decision aids. Specifically, a problem enumeration and expert system screening technique is needed to identify those decision problems faced by WTADS managers that would be amenable to expert system solutions and to determine which of those potential expert systems could and should be developed. An expert system screening mechanism is described next.

MATCHING TASKS TO EXPERT SYSTEM SOLUTIONS

An expert system screening procedure developed at The RAND Corporation and described by Waterman (Ref. 5) was extended and applied to determine the relative merit of developing an expert system for a particular WTADS decisionmaking task. The screening procedure includes questions on whether a problem is *appropriate* for an expert system, whether an expert system is *feasible*, and whether an expert system development effort is *justified*.

Each of these three categories involves a number of finer, more detailed questions. For example, appropriateness includes whether or not the problem is of manageable size, whether it involves a suitable level of difficulty, and whether the solution process is primarily heuristic versus algorithmic, as well as several other similar concerns. Feasibility includes questions involving the availability of experts, the ability of experts to articulate their solution process, and whether there is a consensus among the experts on the solution procedures. Similarly, the development of an expert system is justifiable if expertise is scarce, if available expertise is being lost, or if the expertise is required at several locations. Figure 4 shows one of the worksheets used during the screening process.

In addition to identifying problems that are appropriate for expert system development, the screening mechanism identifies other appropriate solution technologies, such as operations research methods or manual procedures, that might aid WTADS decisionmakers. For some tasks, the screening process might indicate that *no* change in the solution procedures is warranted or that a *combination* of expert system and other technologies are appropriate.

Many of the specific criteria contained in the screening mechanism involve subjective, qualitative evaluations by someone knowledgeable in the policies and procedures of ammunition distribution. The screening procedure proposed by Waterman in essence provided guidelines; the application of those guidelines was not a simple task and involved numerous iterations. To demonstrate the application of the procedure and to identify WTADS tasks that might be aided by expert systems, a knowledge engineer and an ammunition distribution domain expert[1] worked closely through several interactive question and answer sessions. The WTADS tasks that were identified and the results of passing those tasks through the screening procedure are shown in Fig. 5.

Although many (eight of the fourteen) decisionmaking problems were judged appropriate for expert systems and the development of those systems was justifiable, most problems fell short of the feasibility criterion. A serious problem facing the development of expert systems is the apparent lack of WTADS managers with suitable wartime

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[1]LTC Sam Cantey, an Army fellow assigned to The RAND Corporation, has extensive background in the ammunition arena and served as the domain expert during this phase. LTC Jim Price is our current "expert."

Task Appropriate for ES	Necessary Requirements for ES Development	Justification for ES Development	Integration	Data	Knowledge Representation	End Users	Explanation	Alternative Solution Technology

Task Appropriate for ES					
Symbolic	Heuristic	Complexity	Practical Value of Task	Practical Value of ES	Size

Necessary Requirements for ES Development								
Experience / Expertise								
Experts Exist	Experience	Experts Available	Expert Agreement	Method Articulation	Common Sense	Cognitive	Difficulty	Understanding of Task

Justification for ES Development				
High Payoff	Lost Expertise	Scarce Expertise	Hostile Environment	Many Locations

Integration		Data				End Users		
Databases	Networks	Availability	Certainty	Transaction Quantity	Storage	Experience	Expertise	Background

Fig. 4—Expert system screening methodology

Key	Decisionmaker	Decision Task	As Is	Match With Experts
1	DAC	Decide when to schedule unit for ammunition pickup (routine)	×	×
2	DAO	Decide when to schedule unit for ammunition pickup (emergency/unscheduled)	×	+
3	DAO	Evaluate supportability of a course of action	⊗	+
4	DAO	Decide which units will be supported by which ATP or Ammunition Supply Point during each time window	×	×
5	DAO	Decide how to respond to emergency or unforecasted requisitions	+	.
6	Division Materiel Management Center G3	Decide which units get priority of what type of logistics support during each phase	⊗	.
7	Ammo Battalion CO	Decide when to reassign people and equipment between stroage locations	×	×
8	Corp Materiel Mgmt Center Ammunition Officer	Decide when storage locations should relocate	+	.
9	NCOIC (Storage Locations)	Plan how many forklifts and organic trucks will be assigned to each mission during each phase	+	.
10	MCC OIC (Corps or Theater)	Allocate ammunition shipments between available modes of transportation	⊗	⊗
11	CMMC Ammunition Officer	Develop composition of preconfigured ammunition truckloads	+	.
12	Corps - G3	Compute and allocate Controlled Supply Rate for critical ammunition (present filtered set of options for commander's selection)	+	+
13	Storage Site CO	Lay out a field (or fixed) ammunition storage and handling site	⊗	+
14	Storage Site CO	Manage real-time storage site configuration	.	.

NOTE: × = no match; ⊗ = poor match; + = conditional match; . good match.

Fig. 5—Results of applying the expert system screening procedure

expertise.[2] This is also true for other areas of the Combat Service Support system in wartime, notably the management of Class IX (repair parts) and Class III (fuel).

The general lack of domain experts should not be surprising. Policy and force structure changes have been implemented in the last several years that have affected ammunition distribution system management. WTADS managers have not had much opportunity to react to these changes and develop new heuristic procedures required to face the problems arising from the uncertainty of wartime and the complexity of the overall system. Even peacetime field exercises and wargames do not provide the "realism" necessary to develop expertise in making decisions and managing resources. The necessary heuristic rules can only result from managers repeatedly facing unexpected problems and seeing the results of their decisions.

PHASE III RESEARCH OBJECTIVES

The results of the second phase of the research on the application of expert system technology include the adaptation and application of a procedure to screen tasks in order to identify those that might benefit from the development of expert systems and the identification of a potentially serious hurdle for the development of expert systems—the lack of available wartime expertise. The objectives of our research on expert systems are to demonstrate the technology by developing a prototype expert system for a problem where there is an apparent lack of expertise and to explore methods for extending this prototype system by cultivating new knowledge and expertise.

Development of a Prototype Expert System

Identifying problems that appear appropriate for the development of expert systems is only the first step; actually developing the expert system and then evaluating its impact on system performance must also be accomplished.[3]

[2]Twelve of the fourteen tasks failed the feasibility criterion because of the lack of suitable expertise. Only the management of storage site configurations and the layout of storage sites passed the expertise experience filter.

[3]The term "evaluation" carries different connotations. *Technical* evaluation addresses whether the expert system properly represents the solution procedures, *subjective* evaluation is concerned with how the users perceive the strengths and weaknesses of the system, and *empirical* evaluation measures how well the system improves overall performance. We are concerned here with the empirical evaluation of expert systems. Methods for accomplishing the evaluations are discussed in the next section.

Our current research is examining the problem of developing expert systems when there is a lack of expertise and experience. Two approaches to solving this problem include (1) investigating methods to extend existing WTADS domain knowledge and then cultivate the expertise when building an expert system, and (2) examining the technology of systems that can "learn" from actual field use and adapt their behavior based on this learning.

To focus our research efforts, we have constructed a "zero-base" expert system for the problem of relocating ammunition transfer points. This problem includes *when* to relocate an ATP, *where* to relocate it to, and *how* to accomplish the relocation. The ATP relocation problem is important because of the conflicting tradeoffs between the desire to be close to the combat users yet be sufficiently removed from hostilities to reduce the probability of enemy attack. Our view is that current WTADS managers do not understand the implications of these tradeoffs very well. The existence of an expert system for this problem, coupled with the ability to evaluate through the WTADS model the combat effects of alternative decisions and policies, would help WTADS managers develop the needed expertise.

This initial system was developed based on the expertise that does exist and on published doctrine. Our research is now addressing the problem of lack of experience by investigating both methods to cultivate management expertise and systems that can adapt and respond to the uncertainties that arise in wartime.

Extending and Cultivating Expertise

Suitable levels of expertise are lacking among WTADS managers because the majority of system managers have had little or no exposure to the uncertain and dynamic environment of wartime. The constrained, limited types of functions performed in peacetime do not allow the ammunition distribution system decisionmakers to see all of the types of problems that will arise in wartime or to understand the implications of their decisions. Stated doctrine can only take the WTADS managers so far; experience in wartime decisionmaking is required to assist them in developing heuristic procedures for dealing with the problems that fall outside of doctrine.

One way to assist WTADS managers in developing heuristic procedures is to simulate the uncertainties of wartime and present the decisionmakers with representations of realistic problems. This can be accomplished with the WTADS model by replacing one of the objects in the simulation model with a human decisionmaker. Through this human-model interaction, we can represent an environment where an ammunition distribution manager can see the combat effects of his decisions. With repeated trials of similar decision problems, supplemented by feedback mechanisms, the decisionmaker can develop heuristic procedures to address the problems that arise in the uncertain environment of wartime. That is, the WTADS decisionmakers can extend their knowledge base. Based on the results of these experiments, the initial expert system can be refined. The laboratory environment, where a human can work with the simulation model for expertise cultivation and training, is an important aspect of our future research and will be discussed in more detail later.

Adaptive Expert Systems

A second technique for overcoming the lack of wartime expertise is to examine the viability of systems that can extend their knowledge by "learning" based on the data they receive during actual use. Adaptive systems have been of interest in the artificial intelligence community for some time and research in this area, although primarily theoretical, has yielded some commercial applications such as computer programs that can induce rules based on sets of examples. The ability to develop adaptive expert systems can result in decision aids that can function in situations that cannot be represented in a simulated environment.

In this section and the previous one, we have described the results of the two parallel research paths pursued during Phase II and how we are extending these research paths during Phase III. In the next section, we will describe several new research objectives that use the WTADS model for evaluative purposes.

IV. EVALUATION AND IMPLEMENTATION OF WTADS DECISION AIDS

The WTADS simulation model was developed to provide a mechanism for evaluating changes to the wartime ammunition distribution system. Changes to the WTADS could be of a doctrinal or policy nature, such as the number and composition of the various storage locations, or could involve changes to the logistics infrastructure, such as introducing new material handling equipment. The evaluation of PLS and MOADS and the intensive management of high technology munitions fall into these categories. The main thrust of our research, however, is identifying and evaluating changes to the information processing and the decisionmaking aspects of the WTADS. The WTADS model will also be used to evaluate these information management types of changes.

In addition to pursuing the two research paths initiated during the second phase of our research, our Phase III analysis encompasses three new research objectives:

- Predevelopment evaluation of proposed decision aids
- Postdevelopment evaluation of prototype decision aids
- Examination of methods to implement decision aids.

This section describes the rationale for pursuing each of the three objectives and briefly outlines the research approach. Similar to the problem of cultivating expertise among WTADS decisionmakers, research on the evaluation and implementation of decision aids will require interfacing human decisionmakers with the WTADS simulation model. To provide a realistic environment to support our various research objectives, we foresee the need to develop a WTADS laboratory in which to integrate decisionmakers and the WTADS model for observation and analysis. The section concludes by describing the concepts, operations, and benefits of a WTADS laboratory.

EVALUATION OF DECISION AIDS

The term *evaluation of decision aids* has different meanings depending on the context in which it used. Commonly, evaluation of decision aids refers to a *technical* evaluation, or validation, of whether the decision aid correctly performs its intended functions. For example, with expert systems this type of evaluation examines whether the expert system replicates the processes and results of a human "expert" when faced with similar problems and information on those problems. Technical evaluation is usually performed by people knowledgeable in the domain comparing the results of the expert system with the results of human experts, or with the actual "answer," for a range of appropriate case studies. Technical evaluation is necessary for any decision aid or model, but is not the focus of our research.

Evaluation can also refer to the *subjective evaluation* of the strengths and weaknesses of the decision aid when supporting a human to solve problems. This type of evaluation examines the interfaces, displays, input and output requirements, timeliness, and other aspects of the interface between the decision support system and the human decisionmaker. Subjective evaluations are often performed by having a range of decisionmakers use the system and then provide comments on a questionnaire. Subjective evaluations are also necessary and important to ensure that decisionmakers will use the aid and benefit from its availability, and we will make subjective evaluations when investigating ways to implement decision aids within the wartime ammunition distribution system.

We will typically use the term evaluation to refer to the *empirical evaluation* of whether the decision aid has an effect on overall system performance. An aid may be technically sound and may have efficient and effective interfaces with users but may not actually improve the overall decisionmaking capabilities. This type of evaluation is often neglected during the development and implementation of decision aids, usually because the effect on performance is difficult to measure, especially for complex environments such as the wartime theater ammunition distribution system. We intend to use the WTADS model for empirical evaluations of expert systems and decision aids in general, both after a decision aid is developed and before development efforts have begun.

PREDEVELOPMENT EVALUATIONS

Most evaluations of decision aids occur after a prototype or initial version of the software model is available. These evaluations typically address the technical "correctness" of the decision aid or the user perceptions of the interactions with the tool. Such evaluations are important to understand what, if any, improvements are necessary before a decision tool reaches the implementation stage of development. Rarely does the evaluation of the prototype address the overall impact on system performance and never, to the best of our knowledge, are such empirical evaluations conducted before development efforts commence.

The ability to conduct predevelopment evaluations is necessary for a number of reasons. The design and development of decision tools are often expensive undertakings that require significant commitments of time and resources. The predevelopment evaluation of the effect on performance of a proposed decision tool would help in justifying development efforts. There have been efforts in information management to construct methods to estimate the cost of developing decision support or other types of software systems. These efforts permit the examination of one aspect of a cost/benefit analysis of proposed software enhancements. The predevelopment evaluations that we are addressing would examine the benefit side.

Cost/benefit analyses play an important part in choosing between several proposed system improvements, especially when various weapon systems are under consideration. Cost estimates and weapon system effectiveness calculations have been developed and used to address the costs and benefits of proposed hardware systems. Because similar "effectiveness" techniques have not been developed for software enhancements, proposed decision tools often suffer when they must compete with hardware for limited development resources. Predevelopment evaluations of proposed decision aids would greatly help in their competition with weapons for the funding available.

Finally, the ability to make predevelopment evaluations of decision tools is important when several candidate aids are proposed, but only a subset of them can be developed because of limited resources. Within a large complex system such as the theater ammunition distribution system, there are numerous decisionmakers, each with unique problems, at the various nodes of the system. One important research question concerns identifying those decisionmaking problems where improved decision support tools would provide the highest leverage on overall system performance. That is, if a large number of potential management decision aids (expert systems, decision support systems, or even manual aids) can be identified for possible development, we will consider how they could be ranked in terms of their impact on system performance.

The approach we are adopting for predevelopment evaluations is to first run the WTADS model with current decisionmaking capability and measure the logistics and combat outcomes. We then modify the WTADS model to reflect the local impact of a proposed decision aid and measure the changes in both logistics and combat performance. Measuring these changes for a number of proposed decision aids will allow an initial ranking of the benefits of the various proposed enhancements.

Although the approach outlined above is conceptually not difficult, there are a number of technical challenges. A primary concern is how to represent the effects of proposed decision aids in the WTADS model. Our initial impression is that the representation of the capabilities of an aid will be somewhat easier for certain classes or types of decision problems than for others. For example, in Sec. II we gave an example of using the model to examine the effects of improved scheduling of ammunition pickups at an ATP (Figs. 2 and 3). The object-oriented structure of the ROSS language allowed us to represent different scheduling accuracies by changing the messages that are sent or the responses to messages that are received. Other types of decision problems can be represented by changing the appropriate messages and responses. However, some types of decision enhancements may be more difficult to represent. In such cases, other models that can more suitably represent the effect of the proposed decision aid can be interfaced with the WTADS model to understand the effect on combat performance.

A second technical question involves determining the capability of a decision tool before the tool is developed. For example, we may be able to represent "perfect" decisionmaking, as we did with the example of scheduling pickups at ATPs. But, how do we know if a tool could actually achieve that level of capability? One way is to perform sensitivity analyses on the capability of a proposed decision tool. For example, we backed off from perfect scheduling capability in our earlier example to a scheduling capability of plus or minus two hours. By performing a number of these sensitivity runs on the capability of the decision aid, we can draw curves similar to those shown in Fig. 6.

Curves showing the tradeoff between decisionmaking capability and system performance allow one to assess the advantages of increased capability. For example, curve B of Fig. 6 suggests that there is a linear relationship between the capability of a decision aid and the performance of the system. Therefore, if we could develop a decision aid that is 10 percent more capable than current procedures, we could increase the performance of the system by a corresponding proportional amount. The other two curves of Fig. 6 provide other types of information. In curve C, for example, a slight improvement in decisionmaking capability from the present position would result in a larger increase in system performance; curve A suggests the opposite effect. Curves showing the effect on system performance of increased decisionmaking capability can help identify those decision aids that have high leverage impacts. They can also be used, in combination with subjective measures of the potential capability of a decision aid, to estimate the overall impact on system performance (i.e., to determine a specific point on the curve).

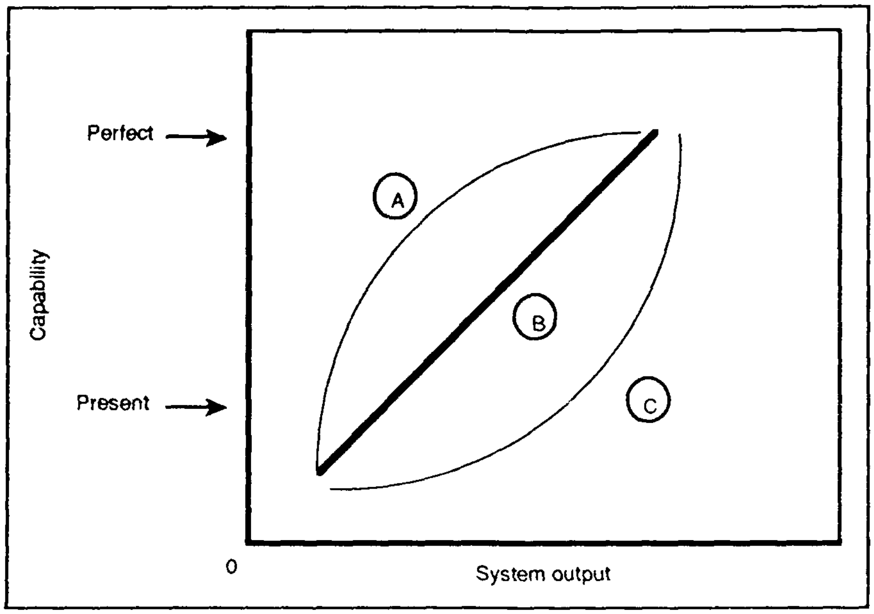

Fig. 6—Decision aid capability vs. system performance curves

A final technical concern involves the *robustness* of a proposed decision aid. For example, a decision aid may have little impact on performance for scenarios that do not result in severe stress on the overall system but may have significant effects for those types of engagements that require large quantities of ammunition to be distributed. To examine the robustness of a proposed decision aid, we will make the predevelopment evaluations for a range of scenarios. We could then draw curves, similar to those in Fig. 6, that show the impact on performance of a decision aid under various degrees of system "stress."

POSTDEVELOPMENT EVALUATIONS

A second research question we are addressing is the evaluation of a decision aid after a prototype has been built. We again use the term "evaluation" to refer to the effect of the decision aid on overall system performance. This postdevelopment evaluation is necessary to determine if a prototype tool has sufficient value to justify further development efforts and ultimately be implemented in the field.

As has been mentioned previously, most postdevelopment evaluations are concerned with the technical correctness of the decisionmaking procedures embodied within the tool or the subjective impressions of the suitability of the human user/decision tool interface. Those few evaluations concerned with the value of a decision aid have usually been conducted in constrained environments, concentrating on the performance improvements of the specific decisionmaker. Although we will also measure local effects during the postdevelopment evaluations, we believe that the complex nature of the WTADS requires an evaluation of the global system performance.

The approach we will adopt to conduct postdevelopment evaluations is to replace one of the simulated objects with a human decisionmaker. We can then use the WTADS model as a driver to present to the human decisionmaker information on the status of the system and the results of the decisions he makes. We will run these experiments with the decisionmaker using current practices and measure local and overall system performance. We will then replicate the experiment but provide the decisionmaker with the decision tool to assist in his decisionmaking processes. Comparing the performance of the unaided and aided experiments will allow us to measure the increase in performance resulting from the use of the decision aid.

There are two technical challenges in this approach to postdevelopment evaluation. We must first ensure that the experimental design eliminates or reduces biases and extraneous effects so that we have confidence that the system performance measures result purely from the presence or absence of the decision aid. For example, the data and information displayed to the human decisionmaker during the experiments must replicate the data and information that would actually be available during wartime. Also, we must ensure that the decisionmaker is adequately trained in using the WTADS model and the decision aid to reduce the effects of any "learning" the decisionmaker achieves during the experiments. These are just some examples of the issues we must address in designing the experiments for postdevelopment evaluations.

A second technical challenge is the procedure for interfacing the human decisionmaker with the WTADS model. This issue was also raised in Sec. III when discussing the cultivation of new expertise. Because humans must interact with the simulation model, we are designing a laboratory environment that will permit the types of research we envision. The concepts and operations of this Decision Support System (DSS) analysis laboratory will be described later in this section.

IMPLEMENTATION OF DECISION AIDS

The final research question is how to implement decision aids after they have been developed, or more specifically, how improved management decisionmaking tools should be introduced to maximize their effectiveness and use. A common problem mentioned in the literature on implementing decision support systems is the overall lack of user acceptance,[1] resulting in expensive decision support tools, sitting unused on managers' shelves.

The goal of this aspect of the research is to determine the best strategy for implementing a decision aid before it is actually fielded. Of particular concern is the interface between the human decisionmaker and the decision aid in terms of input requirements, output displays, and system prompts or help functions. Specific questions center around what data should be displayed, how the data should be displayed, and what data manipulation functions should be provided to the user.

Our approach in examining implementation strategies is similar to the approach we will use for postdevelopment evaluations. We will interface a human decisionmaker with the WTADS simulation model and observe and measure user performance for various methods of implementation. We will follow these controlled experiments with predesigned questionnaires to record the subjective user evaluations of the implementation method. As with our other research objectives and approaches, there are a number of technical challenges.

One primary concern is identifying a representative set of implementation options. We will develop an initial list of different ways to implement a decision support tool, but we expect the list to grow as we receive user impressions and feedback. A second concern is the evaluation of the subjective inputs from the users on individual implementation methods. The questionnaire will include a range of categories addressing different aspects of the user/decision tool interface. The categories and the subjective user responses suggest that a multiattribute utility assessment technique will be required. The final technical question, raised previously during our descriptions of the postdevelopment evaluations, is the procedure for interfacing the human decisionmaker with the WTADS simulation model. The concepts and operations of a laboratory environment to conduct these human/model interfaces and experiments is described next.

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[1]The lack of integration of new decision aids into the current system and the lack of continued funding and maintenance of the decision support tools are also reasons that new systems go unused.

THE OBJECTIVES OF A DSS ANALYSIS LABORATORY

A number of our research objectives, as described in this section and the previous one, require the interaction of a human decisionmaker with the WTADS simulation model. Specifically, we need to interface a human with the model in order to:

- Extend existing WTADS management expertise by developing heuristic decision rules
- Perform postdevelopment evaluations of specific decision support tools
- Examine and evaluate different methods for implementing new decision support tools.

The structure of the ROSS language, and the resulting WTADS simulation model, provide a ready and effective mechanism for human interfaces. Unlike conventional simulation languages, such as FORTRAN or SIMSCRIPT, the physical "objects" in an object-oriented simulation model are really small "simulations," containing all the data and logic peculiar to that "object." Therefore, any of the objects or actors programmed in the model can be replaced by interactive inputs in terms of responses to messages directed to that object. For example, WTADS contains the attributes and behaviors that reflect the management decisionmaking procedures of the Division Ammunition Officer (DAO). As the simulation is running, the DAO object receives various messages and information from other objects in the model. Based on the set of responses contained in the model, the DAO object generates its own messages reflecting decisions that it must make. With ROSS, this DAO object can be represented by inputs into the model. Therefore, a human can be seated at a terminal receiving model output and provide corresponding input representing the DAO's behavior.

By interfacing a human with the simulation model, we can represent an environment in which an ammunition distribution manager can see the combat effects of his decisions. By replicating experiments, the decisionmaker can examine the benefits or limitations of various decision strategies, eventually developing expertise in his domain. The end result should be an increased set of heuristic procedures for dealing with the complexities and uncertainties that will arise in wartime.

Such a laboratory environment would also form the basis for a mechanism to identify and evaluate general types of information and decisionmaking improvements in the ammunition distribution area. This capability would include the *a priori* evaluation of proposed decision support tools, the examination of the effects of improved information content or reduced information "noise," and the evaluation of better short time horizon forecasting capabilities.

The initial hardware concepts for the laboratory include a number of terminals connected to a host computer that will execute the WTADS model. A representation of the laboratory structure is shown in Fig. 7. A human controller and knowledge engineers, in concert with a scenario generator, will interact with the WTADS model to present combat situations to a human decisionmaker. The terminals and other display devices will graphically represent various logistics data and battlefield information. One technical concern is how these data can best be represented in order to provide the necessary information and still realistically portray the data flows that will occur during wartime. It may be necessary to deliberately corrupt the data to attain the proper degree of wartime "realism." The human decisionmaker, based on his perceptions of the course of the battle and the data available, will communicate his decisions to the WTADS model via a terminal.

To capture the specific nuances of the decisionmaking process during laboratory experiments, the environment will include various audio-visual recording and playback equipment. This aspect of the laboratory is especially critical for capturing the protocols of the

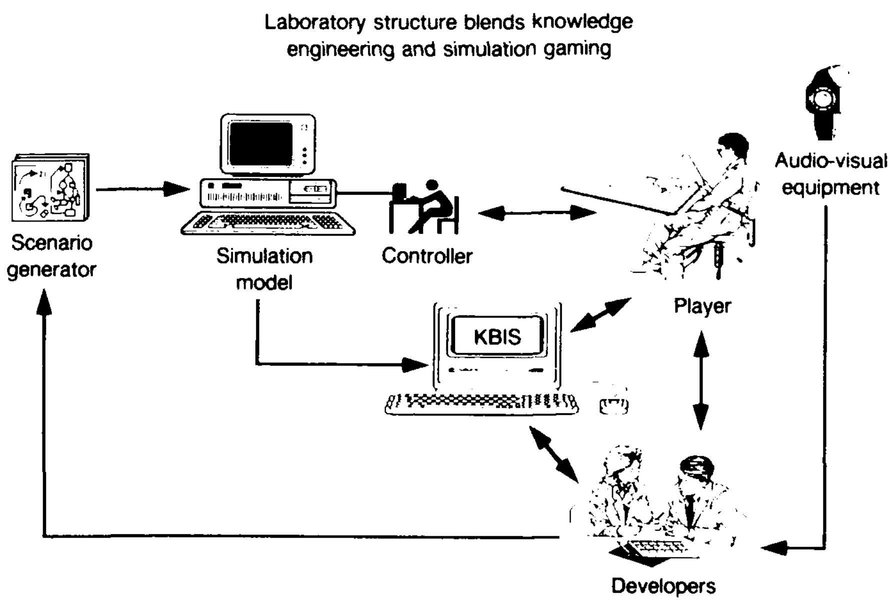

Fig. 7—Prototype DSS laboratory structure

decisionmakers as they solve various problems. Protocol analysis is a necessary step in the development of any decision support system.

Our initial objective in developing the laboratory is to examine our immediate research problems. Although we will begin the development of the laboratory on a narrow basis, we believe that such an environment can easily be extended to encompass additional objectives. For example, the laboratory can provide the Army with a prototype methodology for developing decision support enhancements at relatively low cost, in addition to being adaptable as an Army ammunition manager training device. The laboratory could also provide a training environment for various WTADS managers. Finally, the laboratory could be extended to include other functional areas, such as supply and repair. Such extensions could ultimately lead to the foundations of a logistic wargaming capability.

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