Technical Report 571

HUMAN FACTORS REPRESENTATIONS FOR COMBAT MODELS

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Vector Research, Incorporated

U. S. Army
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Because human factors are not explicitly represented in the combat simulations employed by the Army, a detailed review was made of how 112 combat processes are represented in the following simulations: CARMONETTE, BLDM, DIVLEV, FOURCE, JIFFY, VECTOR-2, CEM, McCLINTIC, and CASTFOREM. From the review it was possible to enumerate the assumptions about human factors implicit in these simulations and describe a structure within which the connections between human characteristics and combat processes could be related. This structure serves as a criterion for evaluating proposed human (Continued)

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factors research projects related to combat simulations. The highest priority combat processes and human factors for research are also enumerated.

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FOREWORD

Although human beings fight wars, human factors are not well represented in simulations of combined arms combat. This is due to a lack of knowledge of the specific effects of human factors on battle processes. This report identifies high-priority behavioral science areas for research on such simulations. The report makes explicit the presently implicit assumptions related to human factors and provides a structure within which to relate characteristics of human behavior to characteristics of combat modeling. Such a structure provides a framework that individual research projects should build upon to improve combat simulations used by the Army.

The research on which this report is based was performed by Vector Research, Inc. (VRI). Besides the authors, other individuals who contributed to the results were Robert Blum, Robert Farrell, and General William DePuy (USA, ret.) of the VRI staff, who furnished useful suggestions and insights; Stanley Spaulding and Jeffrey Alden, who made sensitivity runs with the BLDM combat model; and Stanley Halpin, Irving Alderman, and Robert Sasmor of the Army Research Institute (ARI), who also contributed useful suggestions.

EDGAR M. JOHNSON
Technical Director

HUMAN FACTORS REPRESENTATIONS FOR COMBAT MODELS

EXECUTIVE SUMMARY

Requirement:

Human factors are not explicitly represented in Army simulations of combined arms combat. This is because of a lack of knowledge of the effect of human behavior on the various battlefield processes. Accordingly, the Army Research Institute is developing a program to identify factors, algorithms, and models that could represent the effect of human performance on weapons and tactics.

Procedure:

The approach employed was to analyze nine existing combat simulations:

CARMONETTE	FOURCE	CEM
BLDM	JIFFY	McCLINTIC
DIVLEV	VECTOR-2	CASTFOREM

The methods by which these simulations represent 112 combat processes are described in detail. This information is then used to identify human performance interactions in the simulations and the simulations' sensitivity to these interactions. This information was then used to develop programs and priorities for human factors research related to combined arms simulations.

Findings:

In terms of combat processes, highest priority human factors research topics are:

(1) employment of maneuver-units;
(2) engineering operations; and
(3) fire suppression.

In terms of human abilities, highest priority research topics are:

(1) performance of tasks under adverse conditions;
(2) decision making; and
(3) recognition of features and patterns.

Utilization of Findings:

This report provides a structure that will enable researchers to identify the connections between human behavioral knowledge and the processes in combat simulation. This structure provides the framework that individual research projects should build upon in further studies. Thus, it provides a criterion for evaluation of proposed research in this area.

CONTENTS

Section — Page

1.0 OVERVIEW 1

2.0 COMBAT PROCESSES AND HUMAN FACTORS AREAS 10

2.1 Model Processes 10
2.1.1 Approach 10
2.1.2 Results 14

2.2 A Typology of Human Factors Areas 19
2.2.1 Approach 19
2.2.2 Results 21

2.3 Areas of Model Sensitivity 23
2.3.1 Approach 24
2.3.2 Results 25

3.0 STRUCTURE AND PRIORITIES FOR HUMAN FACTORS RESEARCH 28

3.1 Development of the Research Structure 30
3.2 Development of Research Priorities 33
3.3 Research Priorities and Observations 39

REFERENCES 57

APPENDIX A. COMBAT PROCESSES IN SPECIFIC SIMULATIONS A-1

Maneuver Unit Combat A-4
Artillery Fire A-11
Air-to-Ground Attacks A-15
Air-to-Air Combat A-18
Air Defense A-21
Mobility, Countermobility, and Survivability A-24
Intelligence and Electronic Warfare A-29
Communications A-34
Mission Assignment, Organization for Combat, and Resource Allocation A-37
Maneuver Control A-42
Fire Support Allocation A-46
Resupply and Replacement A-50
Movement A-53
Maintenance and Repair; Medical Support A-56
Construction, Maintenance, and Operation of Airfields A-59

APPENDIX B. A TYPOLOGY OF HUMAN FACTORS AREAS B-1

		Page
APPENDIX C.	SENSITIVITY ANALYSES OF SIMULATIONS	C-1
APPENDIX D.	NOTES ON PRIORITIES FOR HUMAN FACTORS RESEARCH	D-1

LIST OF EXHIBITS

Exhibit 1-1.	Impact on Army Decisions of Human Factors Research for Combat Models	3
1-2.	Conceptual Approach to the Project	4
2-1.	Fleishman Ability Taxonomy	22
3-1.	Typology for Human Factors Representations in Combat Models	29
3-2.	Impact on Army Decisions of Human Factors Research for Combat Models	35
3-3.	Relative Ranking of Model Process Phenomena	40
3-4.	Highest Priority Phenomena	45
3-5.	Relative Ranking of Task Clusters	46
3-6.	Highest Priority Task Clusters	47
3-7.	Relative Ranking of Abilities	48
3-8.	Highest Priority Abilities	49
A-1.	Models Considered	A-2
B-1.	Definitions of Generic Task Clusters	B-2
B-2.	Task Clusters Associated with Each Model Process Phenomenon	B-4
B-3.	Task Analysis--Summary Statistics	B-9
B-4.	Fleishman Ability Taxonomy	B-10
B-5.	Analysis of Abilities Required for Each Task Cluster	B-14
B-6.	Abilities Analysis--Summary Statistics	B-16
C-1.	Summary of BLDM Excursions	C-3

		Page
Exhibit C-2.	Effect of Blue's Time to Fire	C-6
C-3.	Effect of Blue's Priorities	C-7
C-4.	Effect of Blue's Open Fire Decision	C-8
C-5.	Effect of Number of Blue Participants	C-9
C-6.	Effect of Number of Blue and Red Participants	C-10
C-7.	Effect of Blue Round Dispersions	C-11
C-8.	Effect of Blue First Round Dispersions	C-12
C-9.	Effect of Blue Subsequent Round Dispersions	C-13
C-10.	Effect of Blue Round Dispersion Following a Miss . . .	C-14
C-11.	Effect of Blue Round Dispersion Following a Hit	C-15
C-12.	Summary of VECTOR-2 Excursions	C-18
C-13.	Sensitivity Analyses in Terrain Line-of-Sight Study . .	C-22
C-14.	Hand-Off Time and Reaction Time Variations	C-23
C-15.	VECTOR-0 Sensitivity Analyses	C-25
C-16.	Comparison of Effectiveness of Blue Battalion Supported by M9 ACE Versus D7 Dozer	C-29
C-17.	Relative Sensitivity Associated with Each Model Process Phenomenon	C-33
D-1.	Determination of Relative Ranking of Model Process Phenomena	D-2
D-2.	Determination of Relative Ranking of Task Clusters . .	D-9
D-3.	Determination of Relative Ranking of Abilities	D-10

1.0 OVERVIEW

Human participation and influence are pervasive in land and air combat. Although this is well recognized, human behavior and human factors generally are considered only implicitly in force-on-force models employed by the Army analysis community. The implicit nature of the modeling, and the assumptions underlying the models, are due in large part to the absence of knowledge regarding the effect of human factors and behavior on battlefield processes. Accordingly, the Army Research Institute (ARI) is structuring a basic research program to identify appropriate assumptions and models for representing human factors and behavior in combat models. This report describes the work and results of a project performed by Vector Research, Inc. (VRI) for ARI to identify high priority behavioral science efforts for the research program.

The report attempts to make explicit the presently implicit models and assumptions in the human factors area and to provide a structure within which the connections between human behavioral knowledge and combat modeling can be clearly understood. This structure provides a framework within which individual research projects can be conducted with some assurance that they will contribute to improvements in model representations of human factors. Such improvements should have a twofold benefit to the Army. First, they should improve the credibility of Army operational analyses and expand the scope of analysis issues that can be addressed by the operational analysis community. Second, they will result in models which are useful to the Army behavioral science community for analysis of the benefits of training and analysis of recruiting requirements.

The ultimate impact on Army decisions of human factors research to improve combat models is illustrated in exhibit 1-1: The research will result in an improved capability to predict human behavior in combat. Use of this knowledge within combat models will result in analysis results which are more accurate and more sensitive to important human characteristics and interactions. Proper use of these results in Army decision making should effect better decisions in such areas as system procurement, force structuring, training, and recruiting.

The overall approach taken in the project was to analyze existing combat models to identify the explicit and implicit human factors interactions in the models and the sensitivity of simulated battle results to assumptions concerning these interactions. Conceptually, the approach is illustrated in exhibit 1-2. The exhibit indicates that simulated battle results from a combat model can be traced to the representation of combat processes and related phenomena within the model. In the real world, these phenomena are partially based on associated human tasks which, in turn, consist of "behavioral components" describing task performance. Thus, human factors research for improving combat models can be viewed as research to predict task performance as a function of the behavioral components and to relate the behavioral components to measurable human characteristics, aspects of the combat environment, and measures of the training and experience of individuals performing the tasks.[1] For example, a commonly used model output is the loss exchange ratio -- the

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[1]As will be noted later, actual research might not explicitly consider the behavioral components, but might rather attempt to predict task performance directly as a function of human characteristics, the combat environment, and training and experience.

EXHIBIT 1-1: IMPACT ON ARMY DECISIONS OF HUMAN FACTORS RESEARCH FOR COMBAT MODELS

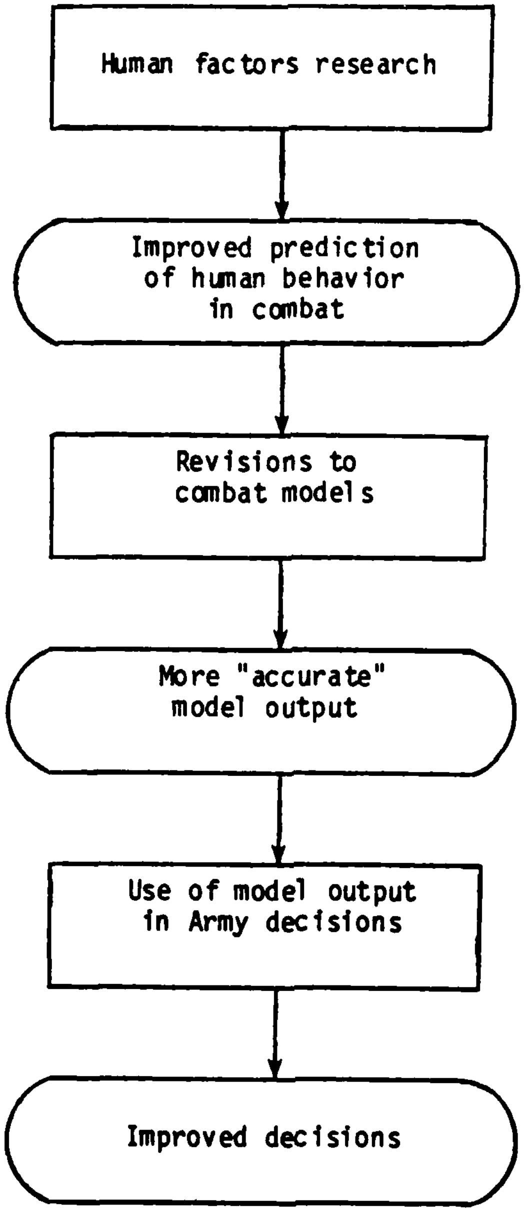
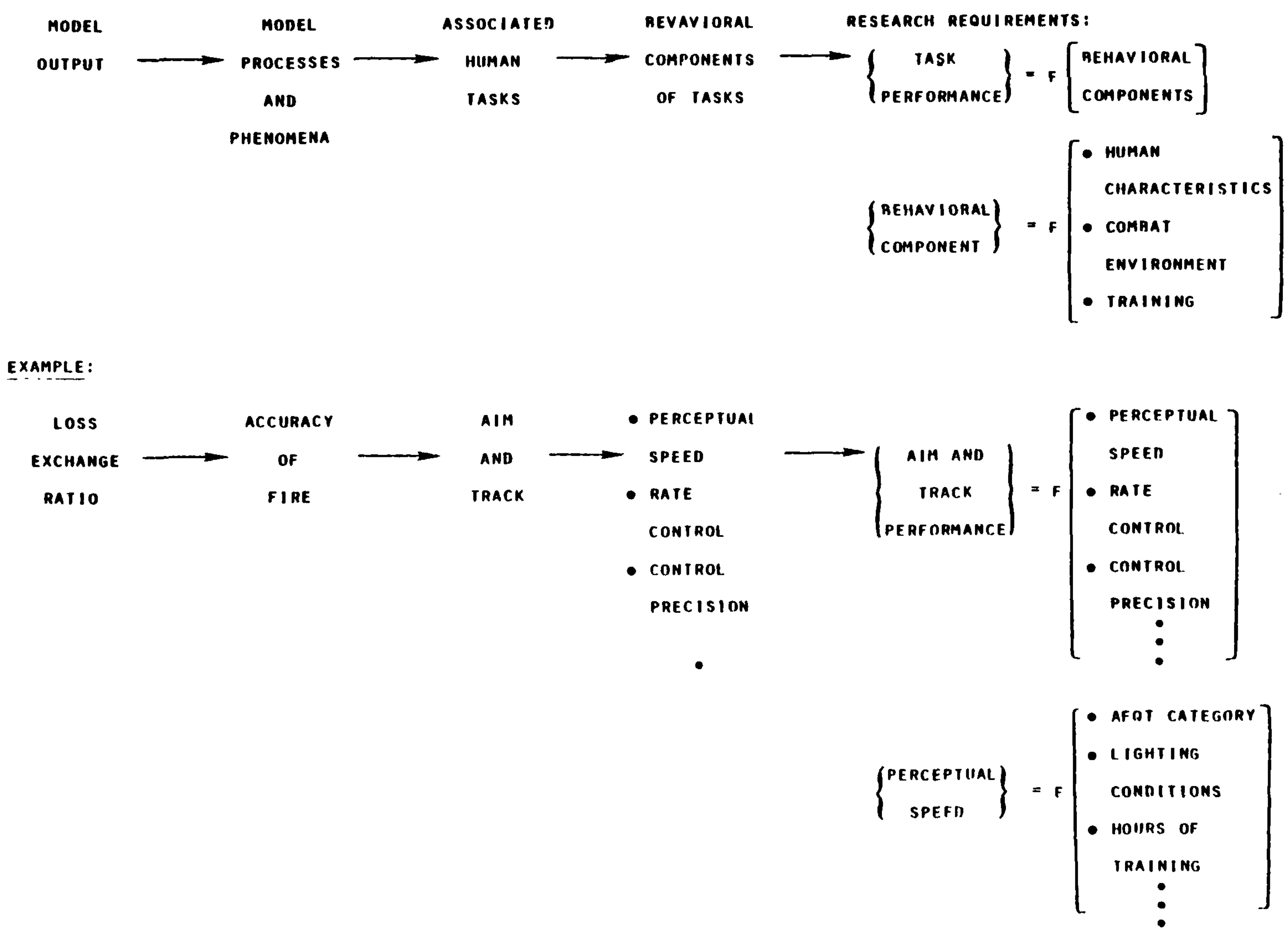


EXHIBIT 1-2: CONCEPTUAL APPROACH TO THE PROJECT



ratio of enemy losses to friendly losses. The value of this output measure depends in part on the model's representation of the accuracy of fire of the weapons involved in the simulated engagement. Accuracy of fire depends on performance of the task "aim and track;" this performance is a function of certain basic abilities of the weapon crew members. Improvement in the capability to predict such task performance can result in improved representation of the accuracy of fire in combat models and thereby provide improved estimates of the loss exchange ratio.

The project tasks, which were designed around this conceptual structure, involved the use of heuristic and judgmental techniques to develop a logical basis for setting research priorities to develop the needed human factors relationships. The project consisted of four substantive tasks:

(1) Identify model processes and phenomena which involve human factors interactions. Fifteen model processes were identified, each comprising three to 12 phenomena involving human factors. A representative set of nine combat models was studied to determine the manner in which each phenomenon is represented in each model.

(2) Organize these processes and phenomena into a structured typology of human factors areas (i.e., identify related tasks and their behavioral components). Eighteen generic groupings of tasks (referred to as "task clusters") were defined, and the task clusters associated with each of the model process phenomena were identified. An analysis was performed of the degree to which each of 37 abilities is required to perform the tasks included in each task cluster.

(3) Identify those human factors areas for which changes in assumptions might lead to significant changes in simulated combat results. A total of 63 runs of two combat models was made and the results of ten previous studies were analyzed to determine the potential sensitivities of simulated battle results to changes in human factors assumptions.

(4) Use the information generated in tasks 1, 2, and 3 to structure a framework for conducting human factors research designed to improve human factors representations for combat models and to identify relevant high priority research efforts.

The sensitivity analysis of task 3 investigated the potential impact of separate changes to each of many assumptions about human factors effects in combat models. Some of these individual effects were found to be highly significant -- a number could cause a change in the predicted winner of an engagement. No analysis was conducted of the potential effect of the simultaneous improvement of human factors representations in a whole spectrum of model phenomena. However, the observed impact of some of the individual changes in assumptions suggests that a general improvement in the treatment of human factors in combat models would be likely to have a very large and unpredictable effect on simulated battle results.

The project thus identified a significant need for research to develop relationships for use in representing human factors in combat models. Two general approaches to human factors research can be taken to provide the needed relationships. The first approach would involve four general types of research:

(1) research to describe, as functions of measurable human abilities,[2] the effect of human factors on the processes and phenomena represented in combat models;

(2) research to develop methods to predict human abilities as functions of demographic descriptors of an individual (such as ASVAB scores, age, sex, and education);

(3) research to predict the effect of the combat environment on abilities; and

(4) research to establish the effect of training and experience on abilities.

The second research approach would omit explicit consideration of human abilities. This approach would have less of a phenomenological structure than the first but would also require less long-range basic research. It thus might produce shorter-term interim results for use with combat models. For this second approach, three general types of research would be needed:

(1) research to describe, as functions of demographic descriptors of an individual, the effects of human factors on model processes and phenomena;

(2) research to predict the relationships between conditions in the combat environment and the human factors effects on model processes and phenomena; and

(3) research to establish relationships between training (and experience) and the human factors effects on model processes and phenomena.

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[2] Precise definitions of "abilities" and other terms used in this research appear later in this report.

In the area of model processes and phenomena, high priority research topics (representing the top 10 to 15 percent of all phenomena identified) involve:

(1) deployment, employment, movement, and maneuver of maneuver unit forces;

(2) engineer operations (primarily because of their potential effect on (1)); and

(3) fire suppression.

Alternatively, priorities for research can be established for sets of generic human tasks, where each set of tasks is associated with a number of model processes and phenomena. High priority research topics for such task clusters (representing the top 33 percent of all task clusters considered) involve:

(1) command, control, communications, and intelligence; and

(2) utilization of weapons under combat conditions (aiming, tracking, loading, and firing).

In the area of human abilities, high priority research topics (representing roughly the top 30 percent of all abilities considered) involve:

(1) abilities necessary to perform tasks under adverse conditions;

(2) abilities required in decision making; and

(3) abilities involving recognition and visualization of features and patterns.

This report consists of three chapters and four appendixes. Following this executive summary, chapter 2.0 describes the work performed on project tasks 1, 2, and 3 (which might be viewed as the information-gathering phase of this research). For each task, the chapter describes the approach taken and summarizes the results of the task. Chapter 3.0 presents a structure for conducting the needed human factors research and suggests priorities for such research, based on the information assembled in the first three tasks. Detailed information developed in each project task is presented in an appendix -- appendix A for task 1, B for task 2, C for task 3, and D for task 4.

2.0 COMBAT PROCESSES AND HUMAN FACTORS AREAS

A large amount of information was collected and analyzed to develop an understanding of current human factors representations in combat models and the potential impacts of changes in these representations. This chapter describes the work performed in this information gathering and analysis portion of the study (tasks 1, 2, and 3) and summarizes results and insights gained in the process of assembling and organizing the information. Section 2.1 discusses the identification of model processes which explicitly or implicitly represent human factors effects (task 1). Section 2.2 describes the methods and results of task 2, which involved restructuring the information assembled in task 1 in terms of human factors considerations. Finally, section 2.3 summarizes the information gathered to assess the sensitivity of models to human factors assumptions and representations.

2.1 MODEL PROCESSES

The first task in this project involved determining the phenomena now represented in combat models which describe, explicitly or implicitly, human factors effects. The approach taken in this task is described in section 2.1.1; results of the task are summarized in section 2.1.2.

2.1.1 APPROACH

In order to develop a description of the ways in which human factors interact with combat models, a representative set of Army models was analyzed to determine those model phenomena which are influenced by human factors and the ways in which those interactions are represented (either explicitly or implicitly) in contemporary models. An attempt was made to identify a broad spectrum of force-on-force models which include representative samples of battalion-level, division-level, and theater-level models; deterministic models and Monte-Carlo simulations; and computerized war games as well as fully automated models. Only dynamic models (models which represent a time trajectory of changing combat conditions) and emulatory models (models which are separable into identifiable entities and processes) were considered.[3] Further requirements for inclusion in this analysis were that a model be actively used or anticipated to be used by the Army, and that the model be reasonably well documented (so that the model's content could be analyzed easily).

Based on these criteria, nine force-on-force Army models were identified for use in this study. Each of these models is described briefly below:

(1) CARMONETTE is a Monte-Carlo simulation of ground combat, generally used to represent combat at company to battalion level. It was one of the first force-on-force models developed for the Army and (with various modifications and improvements) is still in active use by several Army agencies.

(2) BLDM is a deterministic model of ground combat at company to battalion level. It is representative of a set of battalion-level models (including Bonder-IUA, AIDM, TRACOM, etc.) which

[3]Actually, all models contain some non-emulatory features, but for each of the models considered here there is at least some degree to which the processes and entities being represented can be identified in the model structure. It is easier to identify and incorporate human factors representations in an emulatory model than in a non-emulatory one.

use a differential equation or "Lanchester-type" equation structure to represent attrition processes.

(3) CASTFOREM is the lowest-level, highest-resolution model in the hierarchy of models being developed as a part of the Army Models Improvement Program (AMIP).[4] It is a detailed Monte-Carlo simulation of battalion-level combat which employs user-provided decision tables to represent decision processes.

(4) DIVLEV is a division-level combined arms war game (i.e., a player-controlled model). It uses deterministic procedures (including differential equation structures) to assess weapon effects.

(5) FOURCE is a division-level deterministic model which uses Lanchester-type equations to assess maneuver unit attrition. The model emphasizes representation of staff performance and information flow for use in assessing command and control and intelligence alternatives.

(6) JIFFY is a corps-level war game which uses simple equations to assess attrition deterministically.

(7) VECTOR-2 is a corps-to-theater level deterministic model of combined arms combat. It employs differential equation structures to assess maneuver force and some other types of attrition and user-input tactical decision rules to represent decision making.

(8) CEM is a theater-level deterministic model of combined arms combat which uses "firepower potential" (or "firepower score")

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[4]Documentation for the other AMIP models -- CORDIVEM and FORCEM -- was not available in time for inclusion in this analysis.

constructs to assess attrition and built-in decision rules to control the action.

(9) McCLINTIC is a highly aggregated, quick-running theater-level war game whose attrition computations are based on firepower scores.

References to documentation for each of these models can be found in appendix A.

Each of these nine models was evaluated in order to determine the major processes which the models represent. The following processes (which are defined in detail in appendix A) were identified:

(1) maneuver unit combat;

(2) artillery fire;

(3) air-to-ground attacks;

(4) air-to-air combat;

(5) air defense;

(6) mobility, countermobility, and survivability;

(7) intelligence and electronic warfare;

(8) communications;

(9) mission assignment, organization for combat, and resource allocation;

(10) maneuver control;

(11) fire support allocation;

(12) resupply and replacement;

(13) movement;

(14) maintenance and repair, and medical support; and

(15) construction, maintenance, and operation of airfields.

Each process was then subdivided into a set of phenomena which are influenced by human factors. This was accomplished through consideration by the project team (which included individuals knowledgeable in both combat and combat models) of the ways in which humans participate in or otherwise influence each of the processes. For example, for the process of maneuver unit combat, the following phenomena were identified: force participation, initial deployments of weapons, maneuver patterns of individual weapons, target acquisition, target identification, target selection (and target switching), decision to fire, ordnance selection, time to fire or firing rate, accuracy of fire, fire suppression (direct and indirect), and employment of obscuration. Appendix A lists the phenomena associated with each of the processes.

Finally, each model was studied to determine the way in which each of the process phenomena is represented. Sources of this analysis included available model documentation, discussions with model users and developers, and experience of the project staff in developing and using some of the models involved. It should be noted that available documentation for many of the models is old, incomplete, or imprecise. Therefore, the results of this assessment are not a detailed comparison of model capabilities; rather, the results are intended to provide a general indication of the treatment of human factors in existing models. Detailed results of this analysis appear in appendix A; the next section of this chapter summarizes these results.

2.1.2 RESULTS

Two general types of phenomena influenced by human factors were identified -- "human performance phenomena" (those involving the conduct of one or more physical tasks) and "decision making phenomena." The phenomena are generally assumed to be interconnected by "organizational coordination" and to be represented in the context of "battlefield conditions." These general types of phenomena and related model features are discussed separately in the paragraphs below.

Within the human performance phenomena, human factors are sometimes represented explicitly. For example, some of the detailed models of company to battalion level combat include inputs specifying the time to fire a round under various conditions (given the target is moving or is stationary, subsequent to a hit or to a miss on the previous round, etc.). More frequently, however, these phenomena represent human factors implicitly. Some implicit representations are directly relatable to human capabilities. For example, the kill rates which are required as input to some of the differential-equation-based models can be computed externally as functions of measurable performance parameters such as firing times and hit probabilities. Other implicit representations are more abstract (i.e., they are non-emulatory). An example is the firepower score which is used to determine attrition and movement in some aggregated models. It is extremely difficult to predict how such a score would change as a result of a specific change in an assumption about human factors in maneuver unit combat.

The data used to represent human performance phenomena frequently are drawn from non-combat situations. For example, firing accuracy data for maneuver unit weapons are generally collected on firing ranges. It is not known to what extent these data are representative of human performance in combat situations. Furthermore, the individuals used to generate such data may not be typical of those who would perform similar tasks in combat. (They are sometimes preselected for their ability to perform the task for which the data are being collected.) Finally, the data used in current representations of human performance phenomena in combat models generally do not take into account differences among individuals (or even between opposing forces) due to training, combat experience, cultural background, length of service, etc.

Decision making phenomena in combat models are represented in various ways. Some models require decision rules or decision tables as input; others use built-in decision rules, possibly in conjunction with some input parameters which allow the user some control of decision thresholds. In some cases, decisions are represented implicitly by their effects. (Representation of maneuver unit combat results using firepower scores is an example of this -- the effects of many low-level decisions are subsumed into a simple equation involving a single index of firepower potential for each side.) Some of the models are games in which many decisions are made by humans interacting with other parts of the model. Most frequently, a given model will use some combination of these techniques to represent decision making. It should be noted that in all models, regardless of type or level, decision making is never aggregated away completely -- some decision making is always represented explicitly.

Decision rules in models are most frequently based on doctrine. The extent to which doctrine will be followed in actual combat is, of course, unknown. Some decision rules are based on heuristic formulations which may or may not seem reasonable to a tactician or a behavioral scientist. In general, decision rules do not include effects of the characteristics of individual commanders on the decisions or on the ability to implement them. They also tend to ignore the impact of incomplete information and uncertainty on decisions and tend to take very limited account of the impact of external factors (such as anticipated weather conditions) on decisions.

Some people would argue that the limitations of decision rules in a model can be overcome by replacing them with a person who makes the necessary decisions. However, there are several limitations of existing games (and gamers) which tend to reduce the realism of decision making phenomena in models, even when humans are making the decisions. First, in many games the information provided to a gamer differs from that available to a commander in combat. This is particularly true of open games, in which the players representing both Red and Blue have access to the same information and to the decisions made by each other. (Even in some closed games, the gamers know in advance the area in which the major penetration attempt will be made since the scenario threat operational concept is continually replayed.) Secondly, the decisions required of a gamer may differ from those required of a commander in combat. Some games, for example, require a single gamer to make decisions which would be made by several commanders in a real combat situation. Furthermore, the sequence and relative timing of game decisions may differ from that found in combat. Some games, for instance, allow the decision maker to intervene only at prespecified times during the simulated battle (e.g., once every six hours). The gamers themselves may not be representative of commanders in combat, and US gamers certainly do not have the perspective, training, and cultural background of the commanders of Red and Blue ally forces. It is impossible to subject gamers to all the real stresses of combat (such as fear, fatigue, and knowledge of the "real" effects of decisions), although some recent games do attempt to subject the players to realistic time pressures. Finally, unrealistic game rules or assessment logic can result in gamers "playing the game" rather than making realistic decisions. (For example, a gamer's knowledge of a fixed delay imposed on the opposing force when a barrier or minefield is encountered allows that gamer to plan around the delay whose duration he knows in advance.)

The effects of organizational coordination and battlefield conditions are generally not well represented in combat models. Organizational coordination is generally assumed to be perfect, and the effects of fear, fatigue, and confusion caused by battlefield conditions are usually not represented. One exception is that most models include some simple representation of the suppressive effects of fire. However, there exists no experimental basis for these representations -- the suppression process is not sufficiently well understood for there to be any assurance that it has been modeled properly.[5]

In summary, human factors pervade combat, and combat models tend to reflect this pervasiveness, at least implicitly. However, because of a lack of knowledge concerning the details of human interactions in a combat environment, models (and their data) tend to rely on idealized performance to represent behavior, simplistic models of behavior, implicit representation of behavior within more abstract model constructs, doctrine as a proxy for behavior, and the use of gamers to simulate behavior. The ease with which these human factors representations can be improved in a particular model depends in part on the overall model

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[5] For a detailed discussion of the suppression process, including a description of the current state of knowledge about that process and a proposed research program to improve the state of knowledge, see [ODCSRDA, 1975].

structure. For example, models with detailed time resolution can more easily reflect human factors effects on the relative timing of events than can models with a more highly aggregated treatment of time. This suggests that the nature of the changes required to improve human factors representations in models will vary in part as a function of model structure. In some cases, new submodels can be relatively easily added using existing model structures; in other cases some model restructuring may be required to achieve proper representation of human factors.

2.2 A TYPOLOGY OF HUMAN FACTORS AREAS

The summary of the previous section makes it clear that human factors are not well represented in combat models. In order to develop an understanding of the nature of the human factors research required to improve human factors representations, task 2 of the project involved restructuring the information assembled in task 1 in a form that is meaningful to behavioral science researchers. Section 2.2.1 outlines the way in which this was done, while section 2.2.2 summarizes what was learned from this exercise.

2.2.1 APPROACH

The first step in generating the typology of human factors areas was to develop a set of generic tasks or groupings of related tasks encompassing the major human functions included in combat models. These tasks and groupings of tasks will be referred to as task clusters. The following 18 task clusters were identified:

(1) vehicle maneuver,

(2) dismounted weapon maneuver,

(3) visual acquisition,

(4) aiming and tracking,

(5) weapon operation,

(6) individual decision making (threat),

(7) individual decision making (non-threat),

(8) command decision making,

(9) command planning,

(10) radar acquisition,

(11) target and intelligence development,

(12) communication,

(13) driving,

(14) aircraft operation,

(15) construction,

(16) maintenance and repair,

(17) medical care, and

(18) resupply.

Detailed definitions of these task clusters can be found in appendix B.

Next, those task clusters involved in each of the model process phenomena were identified. For example, the phenomenon "initial deployments of weapons" within the model process "maneuver unit combat" involves task clusters 1, 2, and 9 from the above list. The complete set of task cluster-phenomenon associations is listed in appendix B. Identification of the task clusters and association of them with the phenomena were based on the knowledge of project staff members with backgrounds in military operations and combat modeling.

For each of the 18 task clusters, an abilities analysis was conducted to determine the types and degrees of abilities required to perform the associated tasks. The approach used involved a taxonomy of abilities and an assessment scheme developed by Fleishman [1975] (see also [Theologus, Romashko, and Fleishman, 1970]). A list of the 37 abilities included in the Fleishman taxonomy is given in exhibit 2-1. The assessment scheme required that, for each task cluster, an estimate be made of the degree to which each ability is required for errorless performance of the associated tasks. Definitions of the abilities and a more detailed description of the assessment scheme can be found in appendix B.

The abilities analysis was performed by the project staff using information found in Army field manuals, literature describing previous abilities analyses (for example, [ARI, 1979]), and knowledge and experience of the project team. The results of this relatively cursory assessment do not constitute a detailed abilities analysis of all aspects of human factors in combat. However, the results do provide a general indication of the ability levels which must be represented explicitly or implicitly in combat models. This indication provides a means of determining which abilities appear most significant in combat model representations and a way to relate improved knowledge about abilities to improved representations of combat model processes. Details of the abilities analysis can be found in appendix B; a summary of the results of the analysis appears in the next section.

2.2.2 RESULTS

While the primary purpose of this task was to generate information useful in structuring a research program to improve human factors representations in combat models, some information was gleaned from the task which provides an indication of the most prevalent human factors areas in

EXHIBIT 2-1: FLEISHMAN ABILITY TAXONOMY

1. VERBAL COMPREHENSION
2. VERBAL EXPRESSION
3. IDEATIONAL FLUENCY
4. ORIGINALITY
5. MEMORIZATION
6. PROBLEM SENSITIVITY
7. MATHEMATICAL REASONING
8. NUMBER FACILITY
9. DEDUCTIVE REASONING
10. INDUCTIVE REASONING
11. INFORMATION ORDERING
12. CATEGORY FLEXIBILITY
13. SPATIAL ORIENTATION
14. VISUALIZATION
15. SPEED OF CLOSURE
16. FLEXIBILITY OF CLOSURE
17. SELECTIVE ATTENTION
18. TIME SHARING
19. PERCEPTUAL SPEED
20. STATIC STRENGTH
21. EXPLOSIVE STRENGTH
22. DYNAMIC STRENGTH
23. STAMINA
24. EXTENT FLEXIBILITY
25. DYNAMIC FLEXIBILITY
26. GROSS BODY EQUILIBRIUM
27. CHOICE REACTION TIME
28. REACTION TIME
29. SPEED OF LIMB MOVEMENT
30. WRIST-FINGER SPEED
31. GROSS BODY COORDINATION
32. MULTILIMB COORDINATION
33. FINGER DEXTERITY
34. MANUAL DEXTERITY
35. ARM-HAND STEADINESS
36. RATE CONTROL
37. CONTROL PRECISION

combat models. Appendix B includes tables presenting summary statistics collected during the abilities and task cluster analyses described in the previous section. From these tables, it is clear that task clusters 6 (individual decision making [threat]), 8 (command decision making) and 9 (command planning) are the most prevalent of the 18 task clusters; and that abilities 6 (problem sensitivity), 17 (selective attention), 19 (perceptual speed), and 27 (choice reaction time) are the most prevalent of the 37 abilities. These statistics tend to indicate that the most prevalent human factors areas in combat models involve:

(1) decision making; and

(2) performing tasks under adverse conditions (in particular, conditions in which problems are likely, there is distracting stimulation, or there are significant time pressures).

2.3 AREAS OF MODEL SENSITIVITY

The first two tasks of the project provided information describing how human factors representations interact with combat model processes. This information was used to assess what research would be required to improve the human factors representations. However, in order to prioritize such research, it would be useful to have information concerning the relative sensitivity of combat models to potential changes in the human factors assumptions. If simulated battle results are relatively insensitive to potential changes to human factors assumptions in a given area, research in that area might be of lower priority than in an area in which the potential sensitivity appears to be great.

The purpose of the third task of this project was to identify those model process phenomena for which changing human factors assumptions could have a significant impact on model output. Section 2.3.1 below describes the approach used to assess this sensitivity, while section 2.3.2 summarizes the results of the sensitivity analysis.

2.3.1 APPROACH

Two types of sources were used to generate information about the potential impact of human factors assumptions on simulated combat results. First, sensitivity runs of combat models were made to address specific questions concerning model sensitivity. Two of the nine models described in section 2.1.1 were used for this purpose: BLDM (with which a total of 42 runs was made) and VECTOR-2 (with which 21 runs were made). Results of the excursions are summarized in appendix C. Secondly, model runs performed for previous studies were analyzed to develop additional insights into the sensitivity of models to human factors assumptions. Summaries of these runs also can be found in appendix C.

It should be noted that, because of the large number of human factors areas investigated, the results of this task are necessarily based on a limited number of runs in any one area. The results are also subject to the effects of the specific scenario assumptions employed (although an attempt was made to use scenarios typical of those used in current Army studies). Furthermore, it was not feasible to investigate to any significant extent the interactions resulting from changing multiple human factors assumptions simultaneously. Also, it was not always clear to what extent a parameter or assumption should be varied to encompass the entire range of potential effects of changing a human factors assumption. For these reasons, the results of this task are not presented as a comprehensive analysis of the potential impacts of human factors in all situations. However, the results do give a general indication of the relative potential sensitivities in scenarios typically used in studies and in models which represent the current state of the art of representing human factors effects.

2.3.2 RESULTS

The material in appendix C presents the relative sensitivity of combat model output to changes in human factors assumptions related to the various model process phenomena identified in task 1. Those areas which appeared to be associated with the highest sensitivities are:[6]

(1) deployment and maneuver of maneuver unit weapons, including phenomena involving terrain area selection, defender position selection, and attacker route selection;

(2) reserve commitment timing, including decisions to commit reserve or second echelon forces, movement rates of committed reserve units, and delays in arrival of committed forces due to barriers, minefields, etc.;

(3) firing times in maneuver unit combat;[7] and

(4) suppression of maneuver unit forces (both microscopic "pop-down" effects and more macroscopic effects, which might cause a portion of a force to avoid participation in an engagement altogether).

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[6]These four areas are groupings of the 13 phenomena to which combat models have high sensitivity, as indicated in exhibit C-17 of appendix C.

[7]This refers to the time required to fire a round at an available target. One can view the maneuver unit combat process as an attempt by each side to generate the highest possible rate of attriting weapons on the opposing side. Other things being equal, a side's attrition rate is approximately inversely proportional to the averaging firing time.

Note that all of these areas are closely associated with the maneuver unit combat process, leading to the conclusion that representation of human factors effects in maneuver unit combat is a highly significant contributor to simulated battle results.

In several areas there appeared to be very little sensitivity of the model results to changes in human factors assumptions. Two of the more interesting of these areas are those involving delays in communication or in decision making (unless the delays become very long, i.e., several hours or more), and those involving target acquisition capabilities (whether by maneuver unit weapons, attack helicopters, counterbattery radars, Copperhead designators, or air defense radars).[8] This latter observation probably is related to the fact that current scenarios tend to result in a target-rich environment. In such an environment, moderate changes in the ability to acquire a target appear to have little impact, since there are plenty of targets available.

Several general observations can be made concerning the impact on model output of human factors assumptions. First, higher-resolution, lower-level models tend to be more sensitive to a particular human factors assumption than more aggregated, higher-level models. This is simply because a given phenomenon is a greater portion of the overall model content in a lower-level model than in a higher-level one. Thus, the details of the representation of a particular phenomenon are of varying importance, depending on the highest echelon represented by the model. Secondly, human factors assumptions are likely to have a greater effect if the opposing forces are evenly balanced. In appendix C, two examples

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[8] See exhibit C-17 of appendix C.

are given in which unit breakpoints (the criteria used in a model to determine when a maneuver unit will disengage from combat) were varied. In one of the examples, in which the forces were evenly balanced, moderate changes in the breakpoints had an extreme effect on the results, sometimes reversing the course of the battle. In the other example, a moderate change in the defender's breakpoint had little effect, but this was in a situation in which the defender was already losing badly. Thirdly, model results tend to be less sensitive to symmetric changes in human factors assumptions (i.e., when the same change is applied to both opposing forces rather than just to one side). Compare, for example, exhibits C-5 and C-6 of appendix C, which display the effects of one-sided and symmetric changes (respectively) to the number of participants in an engagement. However, in some situations model results can be very sensitive to symmetric changes in human factors representations. For example, the first of the above-mentioned studies in which breakpoints were varied involved symmetric changes in the breakpoint criteria, and the effect was highly significant.

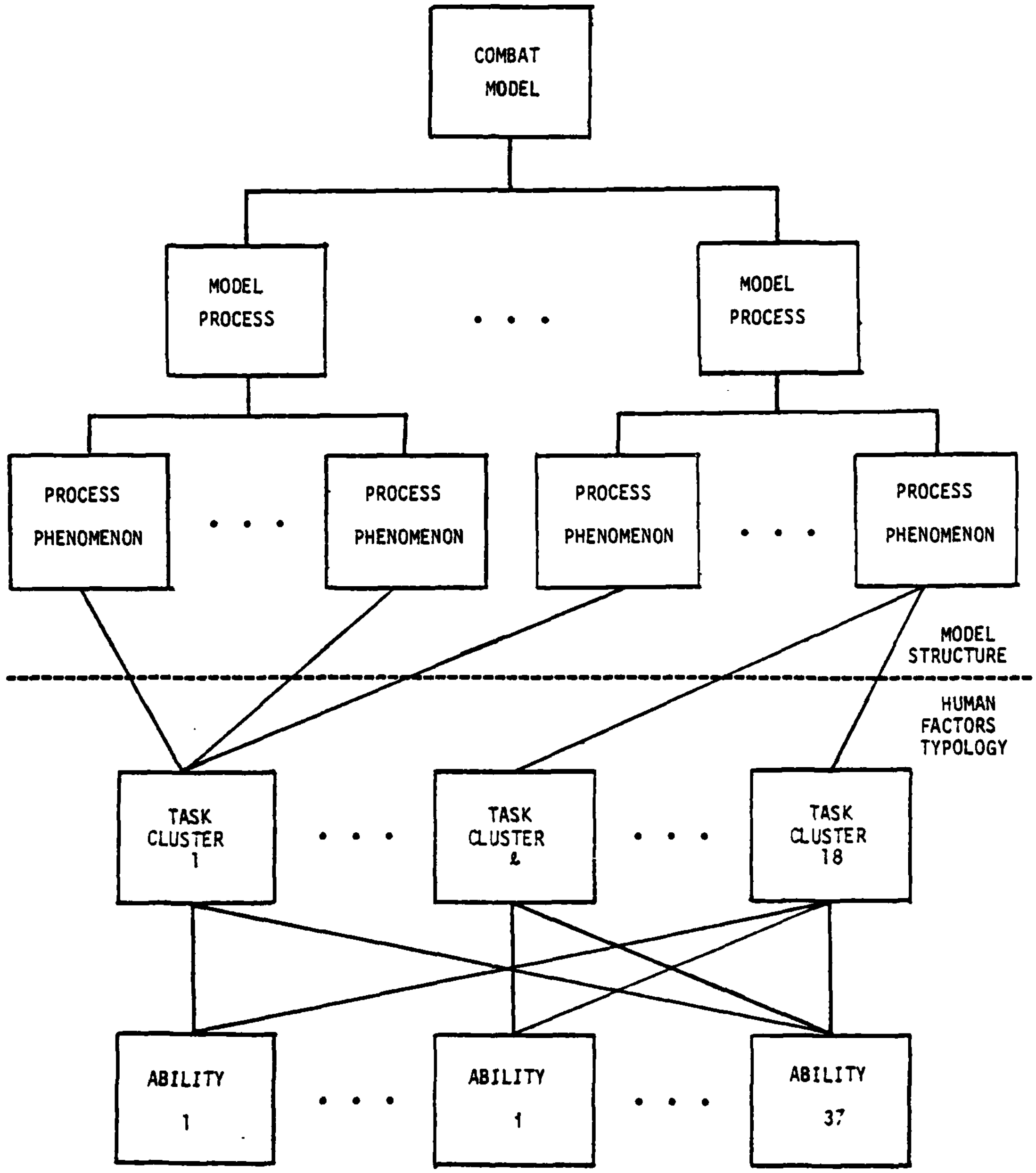
Finally, it should be stressed that this sensitivity analysis investigated the potential impact of separate changes to each of many assumptions about human factors effects in combat models. Some of these individual effects were found to be highly significant -- a number could cause a reversal in the predicted winner of a simulated engagement. No analysis was conducted of the potential effect of the simultaneous improvement of human factors representations in a whole spectrum of model phenomena. However, the observed impact of some of the individual changes in assumptions suggests that a general improvement in the treatment of human factors in combat models would be likely to have a very large and unpredictable effect on simulated battle results.

3.0 STRUCTURE AND PRIORITIES FOR HUMAN FACTORS RESEARCH

The previous chapter described the information gathered to understand current human factors representations in combat models. This information is used to structure a framework for conducting research that will provide knowledge to improve those representations. Exhibit 3-1 summarizes the nature of this information: Models consist of processes which, in turn, include phenomena that are influenced by human factors. A list of such processes and phenomena has been developed, a description of the manner in which each phenomenon is represented in selected models has been generated, and information has been assembled concerning the sensitivity of models to assumptions about human factors interactions with the phenomena. A phenomenon involves one or more task clusters comprising tasks performed by humans. A list of such task clusters has been produced for each phenomenon. Tasks require abilities for their successful performance. As assessment has been conducted of the degree to which various abilities are required for each task cluster.

The purpose of the fourth task of this project was to develop a logical structure for this information and to use the information to identify high priority research areas. The structure is used to organize a research program to acquire the knowledge needed to improve the representation of human factors in combat models. This chapter describes this structure (in section 3.1), describes the development of research priorities (in section 3.2), and presents and discusses the priorities (in section 3.3).

EXHIBIT 3-1: TYPOLOGY FOR HUMAN FACTORS REPRESENTATIONS IN COMBAT MODELS



3.1 DEVELOPMENT OF THE RESEARCH STRUCTURE

Research to improve human factors representations in combat models can be viewed as providing functional relationships for predicting task performance and abilities levels. Conceptually, the research would be designed to develop sets of relationships involving the following parameters:

a_i = level of ability i for an individual (i=1, ..., 37);

Δa_i = change in level of ability i (i=1, ..., 37);

P_j = level of performance by an individual (or crew or other small group of individuals) of tasks in the context of model phenomenon j;

ΔP_j = change in level of task performance;

$\underline{d}$ = set of demographic descriptors of an individual (e.g., ASVAB scores, age, sex, education);

$\underline{\theta}$ = set of descriptors of the combat environment (e.g., weather conditions, intensity of combat, length of time a force has been engaged); and

$\underline{t}$ = characterizations of an individual's training and experience (e.g., time spent in training for a certain task, amount of previous combat experience).

Either of two general approaches to human factors research can be taken to provide the needed relationships. The first approach would allow for more of a scientific basis for the research, but would also require a longer-range research program having more of a basic research content. This approach would involve four general kinds of human factors research:

(1) research to determine functions to predict task performance in the context of a given model phenomenon (e.g., to predict performance of the tasks in the task cluster "aiming and tracking" in terms of the resultant accuracy of fire in maneuver unit combat) as a function of ability levels, i.e., development of the functions g_j, where

$$P_j = g_j(a_1, \ldots, a_{37});$$

(2) research to relate abilities to the demographic descriptors, i.e., development of the functions h_i, where

$$a_i = h_i(\underline{d});$$

(3) research to assess the effect of the combat environment on abilities, i.e., development of the functions r_i, where

$$\Delta a_i = r_i(\underline{\theta});$$

(4) research to establish the effect of training and experience on abilities, i.e., development of the functions s_i, where

$$\Delta a_i = s_i(\underline{t}).$$

The first of these types of research would develop relationships either for direct use in combat models or to provide means of generating model inputs. The second type of research would involve

(1) developing quantitative measures for the abilities where these do not already exist;

(2) developing methods to predict ability levels from measurable human characteristics;

(3) determining the distribution in the Army of ability levels among individuals (so that average values of P_j can eventually be assessed for use in combat models)[9]; and

(4) identifying subjects for use in the first type of research (to develop the g_j functions).[10]

The third and fourth types of research will allow adjusting the basic ability levels to account for actual combat conditions and for the training and experience of individuals likely to be involved in combat. In reality, there is probably some interaction among demographic descriptors, combat environment, and training and experience in the determination of ability levels, but the effects are represented here as though they are independent in order to assure that the research program will be manageable.

The second general research approach would eliminate explicit treatment of abilities from the research program and would instead develop methods to predict task performance directly from demographic descriptors. This approach, while having less of a phenomenological structure than the first approach, would be useful in providing shorter-term results for use with combat models. The resultant relationships might later be improved via longer-term research structured around the first approach. For example, to assess the impact of commander training on the

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[9]Of course, for some applications of combat models, such as investigations of the effects of human abilities on combat effectiveness, use of average values of P_j would not be appropriate.

[10]The Army might wish to conduct this type of research in-house in order to assure that a proper mix of Army personnel with appropriate demographic characteristics is used as subjects in the first type of research. It might be efficient and effective to use the same subjects for development of both the g_i functions and the h_i functions.

quality of command decision making, it might be impractical to relate a commander's abilities to his training (type 4 research) and then to determine decision making effectiveness as a function of ability levels (type 1 research). It might be easier to analyze the impact of commander and unit training directly on unit performance in an experimental setting such as the National Training Center, although some information will be lost as a result of taking this more efficient approach. For this second research approach, three general kinds of human factors research would be needed:

(1) research to determine functions to predict task performance in the context of a given model phenomenon as a function of demographic descriptors of the individuals performing the tasks, i.e., development of the functions G_j, where

$$P_j = G_j(\underline{d}) \ ;$$

(2) research to assess the effect of the combat environment on task performance, i.e., development of the functions R_j, where

$$\Delta P_j = R_j(\underline{\theta}) \ ;$$

(3) research to establish the effect of training and experience on task performance, i.e., development of the functions S_j, where

$$\Delta P_j = S_j(\underline{t}) \ .$$

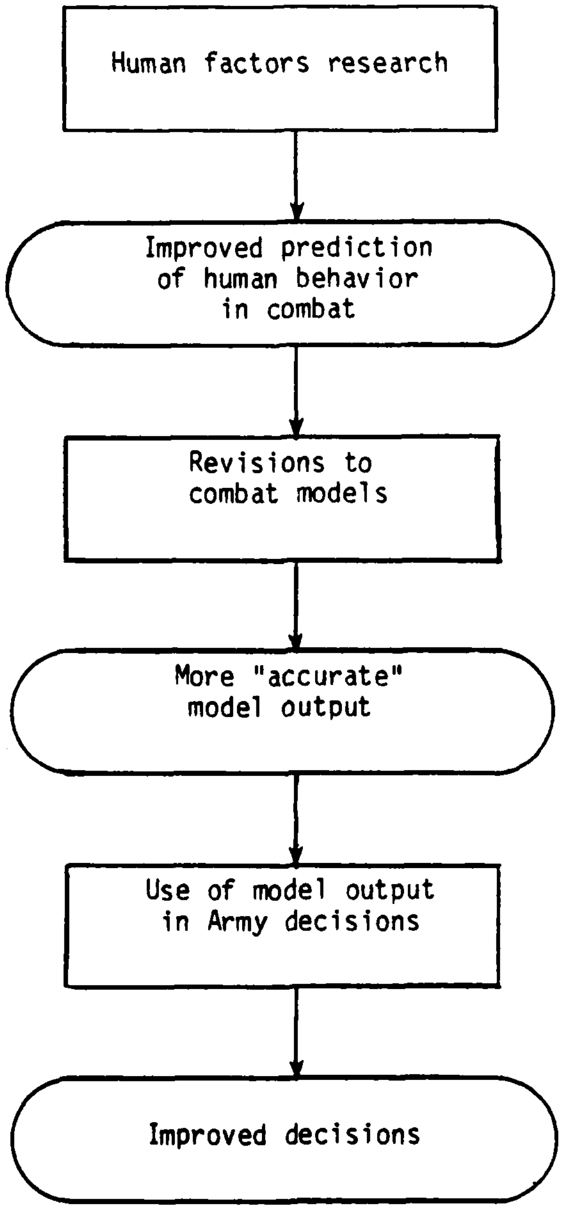
3.2 DEVELOPMENT OF RESEARCH PRIORITIES

From the point of view of improving combat models, research to predict task performance from demographic descriptors is considered essential, while research to assess the effect of the combat environment is of slightly higher priority than research on the effects of training and experience. (For other purposes, e.g., determining training requirements, research on training effects may be more important than research on environmental effects.) In order to prioritize research efforts within type of research (for either of the two research approaches), it would be useful to relate the research to the ultimate potential impact of conducting it. Exhibit 3-2 provides a conceptual representation of the impact on Army decision making of human factors research for improving combat models. As the exhibit illustrates, human factors research will result in an improved capability to predict human behavior in combat. Incorporation of the resulting prediction methods into combat models will result in model output which is more accurate and more sensitive to important human characteristics and interactions. Proper use of this output in Army decision making should result in better Army decisions concerning system procurement, force structuring, training, recruiting, etc.

The discipline of decision analysis provides a framework within which to relate the items in this chain of activities so as to determine (at least conceptually) the potential benefit from improved Army decisions resulting from human factors research in a given area.[11] Consider an oversimplified situation in which the Army wishes to select from among several equal-cost alternative new weapon systems. Suppose the Army desires to select that system which maximizes the probability that a US battalion conducts a successful defense. A combat model (in this case, a battalion-level Monte-Carlo simulation) can be used to estimate this

[11] For a description of the way in which decision analysis can be used to structure problems of this general type see, for example, [Raiffa, 1970] or [Holloway, 1979].

EXHIBIT 3-2: IMPACT ON ARMY DECISIONS OF HUMAN FACTORS RESEARCH FOR COMBAT MODELS



probability with each of the alternative systems. However, the capability of the model to predict this probability is limited by the degree to which human factors interactions are properly represented in the model. If P_j is the level at which the model represents the performance of a single human task, and selection of alternative k results in a weapon system whose performance can be characterized by the parameter W_k, the model result (in this example, the probability of a defender win) can be expressed as a function of P_j and W_k:

$\rho(P_j, W_k)$ = predicted probability the defender wins given human performance level P_j and selection of alternative k.

Current uncertainty concerning the true value of P_j can be represented by a probability distribution:

$f(p_j)$ = probability density function for human performance parameter P_j.

Human factors research concerning P_j can be viewed as reducing this uncertainty. Without such research, the existing uncertainty degrades the capability to select a good alternative system, so that (in principle) the Army must select that k which maximizes the expected benefit of the system:

$$\max_k \int_{p_j} \rho(p_j, W_k)\, f(p_j)\, dp_j.$$

The maximum potential effect of human factors research is to eliminate all uncertainty about P_j, thus allowing the Army to select the best system without degradation in the decision due to uncertainty about P_j. Prior to conducting this human factors research, the estimate of the potential expected benefit from first performing research on P_j and then selecting the best system is

$$\int_{p_j} \max_k \rho(p_j, W_k)\, f(p_j)\, dp_j.$$

Thus, the potential benefit to the Army's decision concerning this weapon system resulting from research on P_j is[12]

$$\int_{p_j} \max_k \rho(p_j,W_k)\, f(p_j)\, dp_j - \max_k \int_{p_j} \rho(p_j,W_k)\, f(p_j)\, dp_j.$$

While this decision-theoretic view is a useful way to conceptualize the potential benefit of human factors research for combat models, it is not practical to use this formal approach to set research priorities. The approach requires the computation of the benefit of research in the context of a specific Army decision problem or a specific set of decision problems. The large number of decision problems to which combat models may be applied in the future would make the approach unfeasible, particularly since most of these problems have not yet even been identified.

Because of this problem (and other only slightly less formidable problems, such as the difficulty of assessing the ρ function for all values of all a_i and all P_j), a more heuristic approach has been taken to set priorities within each of the types of research, based on information developed in tasks 1, 2, and 3 of this project. In developing priorities for investigating task performance to predict P_j or ΔP_j (i.e., to determine the g_j, G_j, R_j, or S_j functions), two approaches were taken. The priority scheme which is more appropriate will depend on the way specific human factors research projects are to be structured. The first approach involved developing priorities for the model process phenomena. Such priorities should be useful in selecting research projects which emphasize the performance of tasks in the context of one or a few related phenomena. The second approach involved developing

[12] In decision theory parlance, this expression gives the "expected value of perfect information" about P_j.

priorities for the 18 task clusters. These priorities should assist in selecting research projects which emphasize the performance of one or more related tasks generally. In such projects individual research efforts would still involve investigation of task performance in the context of individual process phenomena, but with some hope of obtaining insights more generally applicable to phenomena not specifically investigated. Examples of both types of research projects are given in the next section.

In developing priorities for the phenomena, the following criteria (listed in order of importance) were used:

(1) sensitivity of combat model results to changes in human factors assumptions;

(2) current model fidelity in representing the phenomenon (used as a proxy for existing knowledge about human factors interactions with the phenomenon); and

(3) the degree to which the various abilities are required for successful performance of the tasks associated with the phenomenon (used as a measure of the degree to which human factors influence the phenomenon).

The following criterion was used as the basis for prioritizing task clusters: the number of phenomena that require the task and which significantly influence model output. The three types of research regarding prediction of abilities (i.e., to determine the h_i, r_i, and s_i functions) were prioritized using the following criterion: the relative degree to which each ability is required for tasks associated with phenomena that significantly influence model output. All three sets of priorities were developed using quantitative (though heuristic) techniques based on the information developed in tasks 1, 2, and 3 of the project. Details concerning the development of all priorities can be found in appendix D; the priorities themselves are described in the next section.

3.3 RESEARCH PRIORITIES AND OBSERVATIONS

The previous two sections described a structure for organizing and prioritizing research to improve the information base for representing human factors in combat models. This section presents and discusses the priorities derived from use of the structure.

Exhibit 3-3 indicates the relative ranking of all the model process phenomena in terms of the need for research on task performance in the context of individual phenomena (with low numbers indicating a comparatively greater need for such research). The highest priority phenomena are listed in priority order in exhibit 3-4. Exhibit 3-5 provides the relative ranking of the 18 task clusters in terms of the need for research on task performance generally. The highest priority task clusters are listed in priority order in exhibit 3-6. Exhibit 3-7 gives the relative ranking of the 37 abilities in terms of the need for research to develop the h_i, r_i, and s_i functions. The highest priority abilities are listed in priority order in exhibit 3-8. It should be noted that, for research to develop r_i and s_i, the prioritization of abilities could be further refined by adding consideration of *a priori* estimates of the effect of the combat environment on the abilities (for r_i) and the effect of training and experience on the abilities (for s_i).

EXHIBIT 3-3: RELATIVE RANKING OF MODEL PROCESS PHENOMENA

PROCESS PHENOMENON	OVERALL RANK
Maneuver Unit Combat:	
1. Force participation	5 (tie)
2. Initial deployments of weapons	5 (tie)
3. Maneuver patterns of individual weapons	1
4. Target acquisition capabilities	56
5. Target identification capabilities	17
6. Target selection (and target switching)	27 (tie)
7. Decision to fire	27 (tie)
8. Ordnance selection	46
9. Time to fire or firing rate	11
10. Accuracy of fire	24
11. Fire suppression	4
12. Employment of obscuration	37 (tie)
Artillery Fire:	
1. Ordnance selection	16
2. Target element acquisition and selection (if point fire)	48
3. Decision to fire	51 (tie)
4. Delivery pattern	28
5. Delivery accuracy	25
6. Target posture	19
7. Suppressive effects of fire	18 (tie)
8. Effects of fire on communications and decision-making ability	12 (tie)
9. Time to fire or firing rate	26
Air-To-Ground Attacks:	
1. Ability to acquire (or reacquire) the target	52
2. Engagement decision (whether to attack the target)	51 (tie)
3. Ordnance selection	42
4. Target element acquisition and selection (if point fire)	34
5. Aircraft standoff distance and/or maneuver pattern over target	49 (tie)
6. Weapon delivery accuracy	39
7. Target posture	30
8. Suppressive effects of the attack	18 (tie)
9. Effects of the attack on communications and decision-making ability	12 (tie)

-- Continued --

EXHIBIT 3-3: RELATIVE RANKING OF MODEL PROCESS PHENOMENA
(Continued)

PROCESS PHENOMENON	OVERALL RANK
Air-To-Ground Attacks (cont.):	
10. Effects of the attack on airfield sortie generation capability (if target is an airfield)	-
11. Aircraft disengagement decision	51 (tie)
Air-To-Air Combat:	
1. Engagement decisions (whether to engage and type of engagement)	-
2. Aircraft maneuver patterns	-
3. Target acquisition capabilities	-
4. Target selection	-
5. Ordnance selection	-
6. Time to fire	-
7. Accuracy of fire	-
8. Abort decisions	-
Air Defense:	
1. Coordination of fire	33
2. Target acquisition capabilities	57
3. Target selection	41 (tie)
4. Decision to fire	51 (tie)
5. Degraded capability of aircraft to destroy targets on the ground	35 (tie)
6. Aircraft mission abort decisions	41 (tie)
Mobility, Countermobility, and Survivability:	
1. Location, density, and extent of a minefield or obstacle	7
2. Attrition suffered when encountering a minefield	43
3. Delay in movement when encountering a minefield or obstacle	2
4. Reduction in movement rates due to minefields and obstacles	6
5. Increase in exposure due to encountering a minefield or obstacle	32
6. Delays in traveling on damaged roads	3
7. Delays in crossing rivers or gaps	8
8. Degree of protection afforded by a prepared defensive position	20
9. Location and extent of a prepared defensive position	22

-- Continued --

EXHIBIT 3-3: RELATIVE RANKING OF MODEL PROCESS PHENOMENA
(Continued)

PROCESS PHENOMENON	OVERALL RANK
Intelligence and Electronic Warfare:	
1. Collection management decisions - what information to pursue	14 (tie)
2. Collection management decisions - how to collect desired information	37 (tie)
3. Target acquisition capabilities	29
4. Accuracy of target identification (including false targets)	36
5. Target processing time	13 (tie)
6. Target location error	13 (tie)
7. Timeliness of intelligence processing	44 (tie)
8. Accuracy of intelligence processing	44 (tie)
9. Completeness of intelligence processing	44 (tie)
10. Decisions to jam	14 (tie)
11. Effectiveness of jamming	15
12. Collection management decisions - location of sensors	50 (tie)
Communications:	
1. Time to transmit message	55
2. Message content	40 (tie)
3. Transmission accuracy	40 (tie)
4. Reception accuracy	40 (tie)
Mission Assignment, Organization for Combat, and Resource Allocation:	
1. Initial deployments of maneuver units	9 (tie)
2. Changes in these deployments	23 (tie)
3. Cross attachments among maneuver units	45 (tie)
4. Allocation and/or positioning of attack helicopters	45 (tie)
5. Allocation and/or positioning of field artillery forces	45 (tie)
6. Allocation and/or positioning of CAS/BI aircraft	45 (tie)
7. Allocation and/or positioning of air defense forces	45 (tie)
8. Allocation and/or positioning of target acquisition resources	37 (tie)
9. Allocation and/or positioning of supply points	45 (tie)

-- Continued --

EXHIBIT 3-3: RELATIVE RANKING OF MODEL PROCESS PHENOMENA
(Continued)

PROCESS PHENOMENON	OVERALL RANK
Mission Assignment, Organization for Combat, and Resource Allocation (cont.):	
10. Allocation of aircraft to missions	45 (tie)
11. Delays in making and implementing decisions	53
Maneuver Control:	
1. Decisions to change the activity and/or location of a unit	23 (tie)
2. Decisions to request and commit reserves	9 (tie)
3. Decisions for unit retirement	45 (tie)
4. Decisions to request fire support	54 (tie)
5. Decisions to request engineer support	23 (tie)
6. Decisions for the tactical relocation of supporting elements	37 (tie)
7. Delays in making and implementing decisions	50 (tie)
Fire Support Allocation:	
1. Target and mission priorities	54 (tie)
2. Preferences for type and amount of support against a given target in given situation	23 (tie)
3. Preferences for types and amounts of fire to be allocated to pre-planned missions	23 (tie)
4. Criteria for ignoring targets or dropping them from list of acquired targets	50 (tie)
5. Delays in making and implementing decisions	23 (tie)
Resupply and Replacement:	
1. Locations of supply points	45 (tie)
2. Stockpiling decisions at supply points	45 (tie)
3. Quantities of supplies and replacements allocated to units on the battlefield	23 (tie)
4. Delays in decisions to provide supplies or replacements	45 (tie)

-- Continued --

EXHIBIT 3-3: RELATIVE RANKING OF MODEL PROCESS PHENOMENA (Concluded)

PROCESS PHENOMENON	OVERALL RANK
Resupply and Replacement (cont.):	
5. Time required to load and unload allocated supplies	38
Movement:	
1. Aircraft speeds and flight paths	35 (tie)
2. Movement rates of ground forces	10
3. Route selection of forces moving on the ground	45 (tie)
4. Degree of exposure of moving forces (air and ground)	31
Maintenance and Repair; Medical Support:	
1. Rates at which weapons and personnel are returned to duty given availability of support	21
2. Availability of repair capability and medical support	14 (tie)
3. Rate at which damaged capability of a facility is restored	47
Construction, Maintenance, and Operation of Airfields:	
1. Sortie generating capability of an airfield	-
2. Rate of recovery of sortie generating capability following an attack on the airfield	-
3. Construction and repair rates for runways, aircraft shelters, and entire airfields	-
4. Delays in scrambling aircraft	-
5. Degree to which available shelters are in use when an attack of an airfield occurs	-
6. Aircraft basing rules	-

EXHIBIT 3-4: HIGHEST PRIORITY PHENOMENA

RANK	PROCESS AND PHENOMENON
1	Maneuver Unit Combat: Maneuver patterns of individual weapons
2	Mobility, Countermobility, and Survivability: Delay in movement when encountering a minefield or obstacle
3	Mobility, Countermobility, and Survivability: Delays in traveling on damaged roads
4	Maneuver Unit Combat: Fire suppression
5 (tie)	Maneuver Unit Combat: Force participation
5 (tie)	Maneuver Unit Combat: Initial deployment of weapons
6	Mobility, Countermobility, and Survivability: Reduction in movement rates due to minefields or obstacles
7	Mobility, Countermobility, and Survivability: Location, density, and extent of a minefield or obstacle
8	Mobility, Countermobility, and Survivability: Delays in crossing rivers or gaps
9 (tie)	Mission Assignment, Organization for Combat, and Resource Allocation: Initial deployments of maneuver units
9 (tie)	Maneuver Control: Decisions to change the activity and/or location of a unit
10	Movement: Movement rates of ground forces
11	Maneuver Unit Combat: Time to fire or firing rate

EXHIBIT 3-5: RELATIVE RANKING OF TASK CLUSTERS

TASK CLUSTER	RANK
1. Vehicle maneuver	3 (tie)
2. Dismounted weapon maneuver	5 (tie)
3. Visual acquisition	7
4. Aiming and tracking	6 (tie)
5. Weapon operation	5 (tie)
6. Individual decision making (threat)	3 (tie)
7. Individual decision making (non-threat)	8
8. Command decision making	2
9. Command planning	1
10. Radar acquisition	11 (tie)
11. Target and intelligence development	6 (tie)
12. Communication	6 (tie)
13. Driving	4
14. Aircraft operation	9
15. Construction	6 (tie)
16. Maintenance and repair	10
17. Medical care	11 (tie)
18. Resupply	11 (tie)

EXHIBIT 3-6: HIGHEST PRIORITY TASK CLUSTERS

RANK	TASK CLUSTER
1	9. Command planning
2	8. Command decision making
3 (tie)	1. Vehicle maneuver
3 (tie)	6. Individual decision making (threat)
4	13. Driving
5 (tie)	2. Dismounted weapon maneuver
5 (tie)	5. Weapon operation
6 (tie)	4. Aiming and tracking
6 (tie)	11. Target and intelligence development
6 (tie)	12. Communication
6 (tie)	15. Construction

EXHIBIT 3-7: RELATIVE RANKING OF ABILITIES

ABILITY	RANK
1. Verbal Comprehension	12
2. Verbal Expression	18
3. Ideational Fluency	14
4. Originality	7
5. Memorization	9
6. Problem Sensitivity	2
7. Mathematical Reasoning	11
8. Number Facility	15
9. Deductive Reasoning	10
10. Inductive Reasoning	13
11. Information Ordering	16
12. Category Felxibility	19
13. Spatial Orientation	17
14. Visualization	8
15. Speed of Closure	4
16. Flexibility of Closure	6
17. Selective Attention	1 (tie)
18. Time Sharing	5
19. Perceptual Speed	3
20. Static Strength	26
21. Explosive Strength	28
22. Dynamic Strength	33
23. Stamina	24
24. Extent Flexibility	30
25. Dynamic Flexibility	29
26. Gross Body Equilibrium	34
27. Choice Reaction Time	1 (tie)
28. Reaction Time	21
29. Speed of Limb Movement	23
30. Wrist-Finger Speed	27
31. Gross Body Coordination	36
32. Miltilimb Coordination	25
33. Finger Dexterity	35
34. Manual Dexterity	31
35. Arm-Hand Steadiness	32
36. Rate Control	22
37. Control Precision	20

EXHIBIT 3-8: HIGHEST PRIORITY ABILITIES

RANK	ABILITY
1 (tie)	17. Selective Attention
1 (tie)	27. Choice Reaction Time
2	6. Problem Sensitivity
3	19. Perceptual Speed
4	15. Speed of Closure
5	18. Time Sharing
6	16. Flexibility of Closure
7	4. Originality
8	14. Visualization
9	5. Memorization
10	9. Deductive Reasoning
11	7. Mathematical Reasoning

For various reasons, these priorities and the previously described research structure into which they fit are intended to provide general guidelines rather than a rigid organization for research efforts. Listed below are some mediating factors which should also be considered in developing a research plan:

- In reality, there are probably overlapping priorities for work among the types of research so that, for example, higher priority research in the training and experience area is more important than lower-priority research concerning representation of model phenomena.
- Within a given type of research, budget constraints may make the funding of several relatively inexpensive lower-priority items more cost effective than partial funding of a high priority but very expensive item.
- Consideration should be given to possible mutual benefits to several items resulting from the funding of a single research effort.
- There is the possibility of additional benefit from a particular research effort besides the acquisition of information for improving combat models. (For example, research concerning the fire suppression phenomenon might provide knowledge useful in training soldiers to use suppression to their advantage.) Such additional benefit might enhance the overall attractiveness of a particular research effort.

In spite of these caveats, the structure and priorities presented earlier provide an overall framework for organizing human factors research for improving combat models. As an aggregated summary of these priorities, several general topics can be identified as high priority research areas. Concerning the model phenomena, the highest priority area involves research on the deployment, employment, movement, and maneuver of maneuver unit forces (i.e., phenomena with ranks 1, 5, 9, and 10, as listed in exhibit 3-4).[13] Because of its potential effect on this most important area, research concerning engineer operations (mobility, countermobility, and survivability) also is a high priority area (phenomena with ranks 2, 3, 6, 7, and 8). A third topic of high priority involves research on fire suppression and related phenomena (phenomena with ranks 4 and 5).[14] Concerning task clusters, by far the highest priority research involves the broad area of command, control, communications and intelligence or C^3I (corresponding to task clusters with ranks 1, 2, and 6, as listed in exhibit 3-6). Another important area involves the use of weapons under combat conditions, including aiming,

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[13]Two independent sources tend to confirm this result. ARI recently conducted a survey of combat arms officers with previous experience as battalion commanders and currently assigned as faculty members at the Command and General Staff College. When presented with the list of model processes and phenomena developed in this project, the officers identified mission assignment (and related command and control functions) and maneuver unit combat as the two most significant combat processes in terms of the quantity and quality of human involvement required. Within the mission assignment process, the two most significant phenomena were identified to be (1) initial deployments of maneuver units and (2) changes to the activity and/or location of a unit. Within the maneuver unit combat process, the three most significant phenomena were identified to be (1) force participation, (2) maneuver patterns during an engagement, and (3) initial deployments of weapons. In separate discussions with General William DePuy (US Army, Retired), tactical deployment and maneuver of forces were identified as the overriding areas affecting the outcome of actual combat.

[14]For detailed suggestions for a research program in this area, see [ODCSRDA, 1975].

tracking, loading, and firing (task clusters with ranks 5 and 6).[15] Examination of high priority task clusters also tends to confirm the above-mentioned need for research in the area of weapon deployment and maneuver (task clusters with ranks 3, 4, and 5). Concerning abilities, those involving the performance of tasks under adverse conditions (e.g., with distracting stimuli or under time pressure) appear to be most important (i.e., abilities with ranks 1, 2, 3, and 4, as indicated in exhibit 3-8). Also highly important are abilities required in decision making (abilities with ranks 1, 2, 7, 10, and 11) and those involving recognition and visualization of specific features and patterns (such as would be required in identifying targets or performing templating tasks -- abilities with ranks 3, 4, 6, and 8). The following paragraphs describe illustrative examples of research programs in some of these areas.

As an example of research related to a specific model process phenomenon, consider the phenomenon indicated in exhibit 3-4 to be of highest priority: "maneuver patterns of individual weapons." An associated research problem would be: Assess performance of the task cluster "vehicle maneuver" in the context of its effect on maneuver patterns of individual weapons in maneuver unit combat; determine how such performance varies as a function of basic abilities of the crew members operating the vehicles.[16] The required research would consist of the following steps:

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[15] ARI has conducted some research in this area for artillery weapons -- see [Coke, Crumley, and Schwalm, 1980] and [Schwalm, Crumley, Coke, and Sachs, 1980].

[16] Note that this research problem involves development of one of the g_j functions; i.e., it is an example of the first approach to research described earlier.

(1) Determine appropriate measures of task output. For this phenomenon such measures might describe aspects of the weapon-to-weapon line-of-sight processes that result from the maneuver. See [Farrell, 1977] for a discussion of possible measures.

(2) Design and conduct field experiments to measure this output as a function of ability levels.[17] The most important abilities are believed to be spatial orientation, choice reaction time, flexibility of closure, selective attention, and problem sensitivity (see exhibit B-5 of appendix B).

(3) Use the results of the experiments to establish a functional relationship between ability levels and task output.

As an example of a research program structured around task clusters, ARI has already initiated research in the C^3I area (the highest priority set of tasks) which is illustrative of the type of research needed to predict the performance of related tasks across a broad spectrum of model process phenomena [Defense Supply Service, 1982]. The research effort has three major objectives:

(1) identification and categorization of tactical command control decision tasks and component processes in terms of state-of-the art feasibility for representation in combat models;

(2) where currently feasible, development of realistic representations of tactical decision making logic and processes for utilization in combat models; and

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[17]Alternatively, if the second research approach were being taken, the experiments could measure the output as a function of demographic descriptors of crew members.

(3) design of a research program to acquire knowledge needed to represent in combat models the decision logic and processes not currently feasible.

The following steps are involved in the design of the research program associated with this third objective:

(1) Select key kinds of decisions on which to focus the research. In terms of the research structure described in the previous section, this step involves identification of specific process phenomena to provide a context for conducting research on a set of related tasks with the hope that the results of the research will be generalizable to other phenomena (i.e., other kinds of decisions).

(2) Use expert judgment to identify "ground truth" solutions to these decision problems. That is, identify "good" decisions given perfect knowledge of any information bearing on the decisions. (This will provide a standard for decision quality for later use in evaluating experimental results.)

(3) Develop a method for providing systematic deviations from ground truth of the information available for each decision.

(4) Identify a combat simulation for use in generating a decision making environment.

(5) Design experiments which use this simulation to explore decision making in the presence of uncertainties and other deviations from ground truth. These experiments will provide the means to develop the G_j functions describing decision making performance.

Finally, consider an example of basic research concerning prediction of ability levels: Determine the relationship between demographic descriptors and the ability "selective attention," using the range of demographic descriptors of the US Army population. The following steps would constitute the research:

(1) Develop a quantitative measure for selective attention.

(2) Identify demographic descriptors which, *a priori*, are believed potentially useful in predicting an individual's capability for selective attention.

(3) Design and conduct experiments to measure selective attention as a function of the demographic descriptors.

(4) Use the results of the experiments to establish a functional relationship between demographic descriptors and ability level.

(5) Use this relationship and the demographic distribution of the Army population to establish the distribution of levels of the ability in the population.

(6) For later research, identify subjects having a representative mix of the important demographic descriptors.

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APPENDIX A

COMBAT PROCESSES IN SPECIFIC SIMULATIONS

This appendix consists of detailed notes describing combat model processes which are influenced by human factors. As described in section 2.1 of the body of this report, a representative set of nine force-on-force combat models was studied in order to determine

(1) major processes represented in the models,

(2) phenomena associated with each of these processes which are influenced by human factors, and

(3) the manner in which each phenomenon is represented in each of the models.

Exhibit A-1 identifies the nine models and indicates references to model documentation used in the analysis of each of them. The pages which follow the exhibit contain 15 sets of notes regarding each of the following 15 model processes identified in the project:

(1) maneuver unit combat;

(2) artillery fire;

(3) air-to-ground attacks;

(4) air-to-air combat;

(5) air defense;

(6) mobility, countermobility, and survivability;

(7) intelligence and electronic warfare;

(8) communications;

(9) mission assignment, organization for combat, and resource allocation;

(10) maneuver control;

EXHIBIT A-1: MODELS CONSIDERED

MODELS	REFERENCES
CARMONETTE	[GRC, 1974]
BLDM	[VRI, 1975]
CASTFOREM	[TRASANA, undated]
DIVLEV	[AMSAA, 1977] [AMSAA, undated]
FOURCE	[TRASANA, 1978]
JIFFY	[CACDA, 1980]
VECTOR-2	[CCTC, 1978, 1979a, 1979b, 1979c]
CEM	[CAA, 1980]
McCLINTIC	[US Army War College, 1981]

(11) fire support allocation;

(12) resupply and replacement;

(13) movement;

(14) maintenance and repair, medical support; and

(15) construction, maintenance, and repair of airfields.

Each set of notes includes the following information:

- a page defining the model process and listing the phenomena within the process which are influenced by human factors;
- a table containing symbols which indicate the method by which each phenomenon is represented within each of the nine models; and
- a set of definitions of the symbols which appear in the table.[1]

Among the symbols used is an "X" which appears in the corners of many of the model/phenomena cells of the tables. This indicates that the model contains an explicit representation of at least some aspects of the phenomenon in question, or is based on input which can be generated via an explicit representation of the phenomenon. Where no "X" appears, the phenomenon is either not represented, is represented only implicitly, or is assumed always to occur perfectly or be correctly done.

[1]Following the notes for the first model process (maneuver unit combat) is an additional set of definitions of general symbols which appear repeatedly in the tables for all of the model processes.

MODEL PROCESS

- MANEUVER UNIT COMBAT -

DEFINITION:

REPRESENTATION OF FIRE AND MANEUVER OF FRONT-LINE FORCES, RESULTING IN ATTRITION, SUPPLY CONSUMPTION, AND CHANGES IN WEAPON LOCATIONS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- FORCE PARTICIPATION
- INITIAL DEPLOYMENTS OF WEAPONS
- MANEUVER PATTERNS OF INDIVIDUAL WEAPONS
- TARGET ACQUISITION CAPABILITIES
- TARGET IDENTIFICATION CAPABILITIES
- TARGET SELECTION (AND TARGET SWITCHING)
- DECISION TO FIRE
- ORDNANCE SELECTION
- TIME TO FIRE OR FIRING RATE
- ACCURACY OF FIRE
- FIRE SUPPRESSION (DIRECT, INDIRECT)
- EMPLOYMENT OF OBSCURATION

MODEL PROCESS: MANEUVER UNIT COMBAT

MODEL / PROCESS PHENOMENON	1 Force participation	2 Initial deployments of weapons	3 Maneuver patterns of individual weapons	4 Target acquisition capabilities	5 Target identification capabilities	6 Target selection (and target switching)	7 Decision to fire	8 Ordnance selection	9 Time to fire or firing rate	10 Accuracy of fire	11 Fire suppression	12 Employment of obscuration
CARMONETTE	C X	In X	B X	B X	Perf	B X	B X	A X	B X	B X	B X	NR
BLDM	C X	In X	In X	In X	Perf	A X	A X	C X	In X	In X	D X	NR
DIVLEV	D X	B X	Nom	C X	Perf	C X	Nom	Nom	A X	A X	C X	A X
FOURCE	F X	C X	Nom	A X	Perf	A X	A X	Ext X	A X	A X	G X	NR
JIFFY	Gam X	Nom X	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom	F X	V X
VECTOR-2	A X	A X	A X	A X	Perf	A X	A X	Ext X	A X	A X	A X	NR
CEM	B X	Nom X	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom
McCLINTIC	Nom	Nom X	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom
CASTFOREM	E X	In X	C X	In X	Perf	D X	C X	B X	In X	In X	E X	B X

Maneuver Unit Combat

1-A. Nonparticipants (by weapon type) are a function of the amount of exposed flank and the type of engagement and type of unit involved (the latter two considerations are controlled by an input fraction).

1-B. Nonparticipants are a function of the amount of exposed flank. Any other nonparticipation is represented implicitly in input firepower scores.

1-C. All weapons participate, although degree of participation of any weapon can be controlled by pre-specified "orders."

1-D. Based on stylized unit deployments which are built into the model.

1-E. Governed by user-specified decision tables.

1-F. Weapons in a position in which they are out of range of opposing forces (see 2-C) do not participate.

2-A. Input for each weapon type as a function of the type of engagement and type of unit involved.

2-B. Based on stylized unit deployments which are built into the model.

2-C. Weapons in a given unit are deployed uniformly over a rectangular area whose dimensions are input (and which may differ for opposing forces in a given engagement).

3-A. Standard patterns for each weapon type are governed by inputs as a function of the type of engagement and type of unit involved.

3-B. Governed by pre-specified "orders."

3-C. Governed by user-specified decision tables.

4-A. Use of serial or parallel acquisition is input and depends on weapon type. Acquisition may be either visual or pinpoint. No false or dead targets are acquired. Acquisition capabilities are input as functions of firer, target, range, visibility conditions, and movement status of firer and target. Given line of sight, acquisition time is assumed to be exponentially distributed.

4-B. Acquisition represented by a Markov chain model with four states: (1) no information about target; (2) target location known to nearest grid square; (3) target erroneously pinpointed; (4) target accurately pinpointed. State transition probabilities (some input and some computed in the model) depend on existence or absence of line of sight, suppression state of observer, whether the target is firing, movement status of target and observer, target solid angle subtended at the observer, and sensor type. No false targets are acquired, but dead targets which are not "known dead" by the observer may be acquired.

4-C. Implicitly included in input kill rates, which vary with firer, target, range, and target exposure (hull defilade on fully exposed).

6-A. Highest priority target acquired is selected; priorities are input for each firer. (In BLDM, priority is increased if firer and target are on the same "axis.") Parallel acquirers switch to higher priority targets as they are acquired. Otherwise, target is engaged until killed or line of sight is lost.

6-B. Targets are selected from alternative priority lists based on either value or danger of the target. Selection of the list to be used by any firer is prespecified by the user in input "orders." Orders also specify whether suppressive fire into an area is to be employed. Target switching is allowed after each firing. Input probabilities specify the chance of observing that a dead target has been killed; if a target is not known to be dead, additional rounds can be fired at it.

6-C. Fire at any point in time is assumed to be allocated to targets using the following proportions:

$$F_{ij} = U_{ij}N_j / \sum_j U_{ij}N_j,$$

where F_{ij} is the fraction of weapon type i allocated to target type j, U_{ij} is the kill rate for a weapon of type i firing at a target of type j, and N_j is the number of j type targets present.

6-D. Target selection is based on a priority scheme; priority is a function of range, estimated threat, exposure, detection status, time since last fired or moved, number of other weapons firing at the target, fire sector, and turret orientation of the target. Target switching can occur after the desired number of bursts have been fired or the desired (perceived) kill level has been achieved.

7-A. Firing always occurs if ordnance is available and if an acquired target is in range; ranges are input.

7-B. Governed by pre-specified "orders."

7-C. Governed by user-specified decision tables.

8-A. Preferences for ordnance type to be used against a target of specified vulnerability are input. Up to two ordnance types are available for a given weapon; preferred type is used if available.

8-B. Governed by user-specified decision tables.

8-C. Uses rules built into model code, based in part on range to the target.

9-A. Implicitly included in kill rates, which are input as a function of firer, target, range, target exposure (hull defilade or fully exposed), and (for VECTOR-2 and FOURCE) movement status of firer and target.

9-B. Computed in the model from inputs specifying means and standard deviations of times to aim, reaim, and reload the weapon, and average round velocities.

10-A. Implicitly included in kill rates, which are input as a function of firer, target, range, target exposure (hull defilade or fully exposed), and (for VECTOR-2 and FOURCE) movement status of firer and target.

10-B. Computed in the model from average miss distances for each weapon and ordnance type (input as a function of suppression state of the firer, whether the firer and target are moving, range to the target, and whether this is a first or subsequent round) and from target area data.

11-A. If fractional attrition rate of any weapon type exceeds input threshold, all weapons are assumed to increase their use of cover to lower the rate to the threshold. Weapons suppressed in this way cannot move, fire, or be attrited.

11-B. "Neutralization weights" (relative suppressing cpability) of all round types are input; total weight landing in a given area during a user-specified "neutralization interval" is compared with input thresholds to determine if weapons in the area are either partially suppressed or (for dismounted infantry and open vehicles only) pinned down. Partially suppressed ground weapons conduct surveillance and fire at reduced accuracy, require twice the usual time to aim, and move at reduced rates. Partially suppressed helicopters finish guiding any missiles in flight, then drop to treetop level.

11-C. Fraction of defending force in suppressed state due to direct fire equals

$$1 - \exp(- CP_0 X/M),$$

where M is the size of the defending force, X is the size of the portion of the attacking force in overwatch, P_0 is the rate at which an overwatch weapon kills a defending weapon, and C is a constant whose value is determined via detailed consideration of a specific attack scenario. The fraction of a target suppressed by artillery is given by an expression of the form

$$1 - \exp(- KF),$$

where F is the fraction of the target area covered by artillery fire and K is a constant set so that, when F equals 1, the fraction suppressed is .5 for moving targets and .75 for static targets.

11-D. Suppression is caused either by the rate of received fire in the near vicinity of a target or by the rate of non-lethal hits, depending on the version of the model used. Suppressed weapons are unable to fire; in some versions of the model they are also unavailable as targets and previous acquisitions of and by them are lost. Suppression has an input duration dependent on firer and target type.

11-E. Will be represented in CASTFOREM, but existing specifications do not describe how.

11-F. Firepower force ratios are used to determine (via input tables) the fraction of weapons suppressed. Suppressed weapons are not available to fire.

11-G. If an engaged unit is under fire from artillery, the number of weapons that can fire is reduced by an input fraction. The fraction is a function of whether the unit is moving or stationary. The speed of a moving unit is reduced when under fire from artillery or air.

12-A. Either input directly by games or governed by gamer-supplied contingency orders, which can be activated as a function of time, unit location, casualty level, or movement status of a specified unit.

12-B. Will be represented in CASTFOREM, but existing specifications do not describe how.

General Symbols (used in conjunction with all model processes)

Ext. Represented implicitly by model input which can be generated by an explicit external representation of the phenomenon.

Gam. Represented via gaming (i.e., phenomenon is represented through an external player, who inputs its effects into the model interactively).

In. Directly input by the user.

Nom. Represented implicitly at some nominal, constant level based on model input.

Perf. Assumed to be always perfect or correctly done.

NR. Phenomenon is not represented.

-. The process with which this phenomenon is associated is not represented.

X. Represented explicitly (see further description of this symbol in text).

MODEL PROCESS

- ARTILLERY FIRE -

DEFINITION:

REPRESENTATION OF ARTILLERY FIRE AGAINST A TARGET, CAUSING ATTRITION AND DEGRADED FUNCTIONING OF THE TARGET, AND RESULTING IN ORDNANCE CONSUMPTION AND INCREASED DETECTABILITY OF THE FIRING WEAPONS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- ORDNANCE SELECTION
- TARGET ELEMENT ACQUISITION AND SELECTION (IF POINT FIRE)
- DECISION TO FIRE
- DELIVERY PATTERN
- DELIVERY ACCURACY
- TARGET POSTURE
- SUPPRESSIVE EFFECTS OF FIRE
- EFFECTS OF FIRE ON COMMUNICATIONS AND DECISION-MAKING ABILITY
- TIME TO FIRE OR FIRING RATE

MODEL PROCESS: ARTILLERY FIRE

MODEL \ PROCESS PHENOMENON	1 Ordnance selection	2 Target element acquisition and selection (if point fire)	3 Decision to fire	4 Delivery pattern	5 Delivery accuracy	6 Target posture	7 Suppressive effects of fire[1]	8 Effects of fire on communications and decision-making ability	9 Time to fire or firing rate
CARMONETTE	A X	NR	Nom	Nom	Nom	B X	NR	NR	In X
BLDM	B X	B X	A	Ext X	Ext X	D X	NR	NR	In X
DIVLEV	Nom	NR	Nom	A X	In X	C X	D X	NR	B X
FOURCE	NR	NR	A	Ext X	Ext X	Nom	C X	NR	In X
JIFFY	Nom	Nom	Nom	Nom	Nom	Nom	E X	NR	Nom
VECTOR-2	Nom	A X	A	Ext X	In X	A X	A X	A X	In X
CEM	Nom	NR	Nom	Nom	Nom	Nom	B X	Nom	Nom
McCLINTIC	Nom	Nom	Nom	Nom	Nom	Nom	NR	NR	A
CASTFOREM	-	-	-	-	-	-	-	-	-

[1]Suppression of engaged maneuver units by artillery is discussed under "Maneuver Unit Combat."

Artillery Fire

1-A. Preference of ordnance type to be used against targets of a specified vulnerability are input. Up to two ordnance types are available for a given weapon; preferred type is used if available.

1-B. Uses rules built into model.

2-A. Highest priority target element acquired is engaged. Acquisition probabilities and priorities are input.

2-B. Forward observers acquire and select targets using a representation essentially the same as for target acquisition and selection by maneuver unit weapons.

3-A. Firing always occurs if requested.

4-A. Included in area of effects, for which values are built into the model.

6-A. Input as a function of target activity.

6-B. Model determines one of two postures for a target: responding to hostile fire and not responding to hostile fire.

6-C. If target is stationary, all elements are in defilade. Otherwise fraction of exposed elements is a function of current loss rate.

6-D. Based on maneuver patterns of individual target weapons, which are input for all groups of weapons on the battlefield.

7-A. Counterbattery or air defense suppression fire causes an input fraction of target weapons to be suppressed per volley or round fired against them; suppression has an input duration.

7-B. Counterbattery fire can partially neutralize opposing DS artillery. Fraction neutralized for current engagement is

$$1 - e^{-K(C/D)}$$

where K = input coefficient,
C = amount of antipersonnel counterbattery firepower in a subsector,
D = number of DS battalions receiving counterbattery fire.

7-C. Speed of a moving target is reduced by a constant factor when under attack by artillery fire. If artillery is attacked, it cannot fire for 15 minutes (to represent relocation of battery).

7-D. The first attack of an artillery battery on an opposing artillery battery causes total suppression (no firing) for the length of the mission plus 15 minutes. Subsequent attacks within six hours cause total suppression for the length of the mission plus 25 minutes. These times are assumed necessary for battery relocation.

7-E. Firepower score force ratios are used to determine (via input tables) the fraction of weapons suppressed. Suppressed weapons cannot fire.

8-A. Decision time at command posts is increased as a function of fractional damage to command post; amounts of increase are input.

9-A. A three minute delay between volleys is assumed; it takes six hours to reload missile and rocket launchers.

9-B. Built-in firing rates are degraded for personnel casualties by multiplying by a term

$$[1 + e^{-13.73\,(.5 - X)}]^{-1},$$

where X is the fractional amount of personnel lost.

MODEL PROCESS

- AIR-TO-GROUND ATTACKS -

DEFINITION:

REPRESENTATION OF THE EFFECTS OF AIRCRAFT ATTACKING A TARGET ON THE GROUND, CAUSING ATTRITION AND DEGRADED FUNCTIONING OF THE TARGET, AND RESULTING IN ORDNANCE AND POL CONSUMPTION AND INCREASED EXPOSURE OF THE ATTACKING AIRCRAFT

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- ABILITY TO ACQUIRE (OR REACQUIRE) THE TARGET
- ENGAGEMENT DECISION (WHETHER TO ATTACK THE TARGET)
- ORDNANCE SELECTION
- TARGET ELEMENT ACQUISITION AND SELECTION (IF POINT FIRE)
- AIRCRAFT STANDOFF DISTANCE AND/OR MANEUVER PATTERN OVER TARGET
- WEAPON DELIVERY ACCURACY
- TARGET POSTURE
- SUPPRESSIVE EFFECTS OF THE ATTACK
- EFFECTS OF THE ATTACK ON COMMUNICATIONS AND DECISION-MAKING ABILITY
- EFFECTS OF THE ATTACK ON AIRFIELD SORTIE GENERATION CAPABILITY (IF TARGET IS AN AIRFIELD)
- AIRCRAFT DISENGAGEMENT DECISION

MODEL PROCESS: AIR-TO-GROUND ATTACKS[1]

MODEL / PROCESS PHENOMENON	1 Ability to acquire (or reacquire) the target	2 Engagement decision (whether to attack the target)	3 Ordnance selection	4 Target element acquisition and selection (if point fire)	5 Aircraft standoff distance and/or maneuver pattern over target	6 Weapon delivery accuracy	7 Target posture	8 Suppressive effects of the attack[2]	9 Effects of the attack on communications and decision-making ability	10 Effects of the attack on airfield sortie generation capability (if target is an airfield)	11 Aircraft disengagement decision
CARMONETTE	-	-	-	-	-	-	-	-	-	-	-
BLDM	-	-	-	-	-	-	-	-	-	-	-
DIVLEV	-	-	-	-	-	-	-	-	-	-	-
FOURCE	Nom	Nom	Nom	Nom	Nom	Nom	Nom	D X	NR	NR	B X
JIFFY[3]	Nom	Nom	Nom	Nom	Nom	Nom	Nom	Nom	NR	NR	Nom
VECTOR-2	A X	Perf	A X	A X	Ext X	In X	A X	A X	A X	NR	A X
CEM[4]	Nom,Ext X	Nom,Perf	Nom	Nom,Ext X	Nom,Ext X	Nom,Ext X	Nom,Ext X	B,NR X	NR	NR	Nom,Ext X
McCLINTIC	Nom	Nom	Nom	Nom	Nom	Nom	Nom	C X	NR	NR	Nom
CASTFOREM	-	-	-	-	-	-	-	-	-	-	-

[1]Excludes attack helicopter operations in support of engaged maneuver units -- see "Maneuver Unit Combat."

[2]Suppression of engaged maneuver units is discussed under "Maneuver Unit Combat."

[3]JIFFY represents only CAS air-to-ground attacks, although it is usually used in conjunction with a separate air effects model.

[4]Where two symbols appear in this row, the second symbol applies to attack of airfields; the first symbol applies to attack of all other targets.

Air-to-Ground Attacks

1-A. Input probability as a function of type of target, class of sensor making the original acquisition, weather, and time elapsed since the original acquisition.

3-A. Ordnance load selection for a mission is governed by user-specified decision rules, as part of the mission assignment process. Priorities for load selection are input for use in these rules. Ordnance type and quantity selection for a given load is input for each pass over the target.

4-A. Highest priority target element acquired is engaged. Acquisition probabilities and priorities are input.

7-A. Input as a function of target activity.

8-A. Counterbattery or air defense suppression fire causes an input fraction of target weapons to be suppressed per round fired against them; suppression has an input duration.

8-B. Suppressive effects of interdiction strikes represented through increases in time for resupply and higher-level reserve commitment if friendly air superiority does not exist.

8-C. Aircraft attacking a moving target cause a fixed time delay before movement can resume.

8-D. An engaged unit's speed is reduced to an input fraction of its otherwise attainable speed.

9-A. Decision time at command posts is increased as a function of fractional damage to command post; amounts of increase are input.

11-A. Governed by user-specified tactical decision rules and by input limits on the total number of passes to be flown against a given target. Existing rules in most versions allow the input number of passes always to be flown.

11-B. Aircraft are assumed to spend a fixed time over the target, based on an input limit on time of flight.

MODEL PROCESS
- AIR-TO-AIR COMBAT -

DEFINITION:

REPRESENTATION OF ENGAGEMENTS BETWEEN OPPOSING GROUPS OF AIRCRAFT, RESULTING IN ATTRITION TO AIRCRAFT, CONSUMPTION OF ORDNANCE AND POL, AND ABORTS OF OR DELAYS IN ACCOMPLISHMENT OF AIR MISSIONS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- ENGAGEMENT DECISIONS (WHETHER TO ENGAGE AND TYPE OF ENGAGEMENT)
- AIRCRAFT MANEUVER PATTERNS
- TARGET ACQUISITION CAPABILITIES
- TARGET SELECTION
- ORDNANCE SELECTION
- TIME TO FIRE
- ACCURACY OF FIRE
- ABORT DECISIONS

MODEL PROCESS: AIR-TO-AIR COMBAT

MODEL / PROCESS PHENOMENON	Engagement decisions (whether to engage and type of engagement)	1 Aircraft maneuver patterns	2 Target acquisition capabilities	3 Target selection	4 Ordnance selection	5 Time to fire	6 Accuracy of fire	7 Abort decisions
CARMONETTE	-	-	-	-	-	-	-	-
BLDM	-	-	-	-	-	-	-	-
DIVLEV	-	-	-	-	-	-	-	-
FOURCE	-	-	-	-	-	-	-	-
JIFFY[1]	-	-	-	-	-	-	-	-
VECTOR-2	Perf	A X	Ext X	A X	Ext X	Nom	A X	A X
CEM	Perf	Ext X	A X	B X	Nom	NR	Ext X	B X
McCLINTIC	Nom	Nom	Nom	Nom	Nom	Nom	Nom	C X
CASTFOREM	-	-	-	-	-	-	-	-

[1]Although usually used in conjunction with another air effects model, JIFFY itself does not represent air-to-air combat.

Air-to-Air Combat

2-A. Details of maneuver patterns represented only implicitly by effects data; determination of whether standoff or duel-type combat occurs for a given part of the battle is determined dynamically during the engagement by types of ordnance available (i.e., whether standoff ordnance is carried) and by either user-specified decision rules or by an input specifying a maximum number of standoff exchanges to be followed by a single dual phase. Existing rules default to the input maximum number of standoff exchanges.

3-A. A single input probability represents entire intercept process against penetrating aircraft: detection by ground control system, availability of interceptor for the engagement, and probability of successful intercept.

4-A. Specified by either user-input decision rules or by a model algorithm which allocates aircraft randomly to targets. Existing rules default to the random allocation algorithm.

4-B. Allocation is random and assumes one-on-one engagements only.

7-A. Implicitly included in air-to-air exchange rates, which are input as a function of firer type, target type, and whether aircraft are using standoff or duel type ordnance.

8-A. Governed by user-provided tactical decision rules, or by a model-specified rule which bases abort decisions on a penetrator-to-interceptor strength ratio (after each standoff exchange) or on surviving friendly strength (after the duel phase).

8-B. All intercepted penetrators abort their air-to-ground missions. Aborts of air-to-air engagements are represented implicitly only through input mission kill probabilities.

8-C. Unescorted penetrators jettison ordnance and return home if attacked. Other types of aborts not explicitly represented.

MODEL PROCESS

- AIR DEFENSE -

DEFINITION:

REPRESENTATION OF FIRE BY AIR DEFENSE ARTILLERY, RESULTING IN ATTRITION OR DEGRADED FUNCTIONING OF TARGET AIRCRAFT, AND ORDNANCE CONSUMPTION AND INCREASED DETECTABILITY OF THE FIRING WEAPONS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- COORDINATION OF FIRE
- TARGET ACQUISITION CAPABILITIES
- TARGET SELECTION
- DECISION TO FIRE
- DEGRADED CAPABILITY OF AIRCRAFT TO DESTROY TARGETS ON THE GROUND
- AIRCRAFT MISSION ABORT DECISIONS

MODEL PROCESS: AIR DEFENSE[1]

MODEL \ PROCESS PHENOMENON	1 Coordination of fire	2 Target acquisition capabilities	3 Target selection	4 Decision to fire	5 Degraded capability of aircraft to destroy targets on the ground	6 Aircraft mission abort decisions
CARMONETTE	-	-	-	-	-	-
BLDM	-	-	-	-	-	-
DIVLEV	-	-	-	-	-	-
FOURCE	-	-	-	-	-	-
JIFFY[2]	Nom	Nom	Nom	Nom	Nom	Nom
VECTOR-2	A	In	A	Nom	NR	A
CEM	Nom	In	Nom	Nom	NR	NR
McCLINTIC	Nom	Nom	Nom	Nom	NR	NR
CASTFOREM	-	-	-	-	-	-

[1]Not including air defense fire against attack helicopters during maneuver unit combat. See "Maneuver Unit Combat" for details.

[2]JIFFY represents only local air defense of maneuver units under attack, although it is usually used in conjunction with a separate air effects model.

Air Defense

1-A. Assumed that no more than one air defense site on the average will fire for every two aircraft in an overflying group.

3-A. Air defense fire is distributed randomly among target aircraft.

6-A. Not represented on overflight; governed by user-input tactical decision rules in target area. Current rules do not abort missions.

MODEL PROCESS

- MOBILITY, COUNTERMOBILITY, AND SURVIVABILITY -

DEFINITION:

REPRESENTATION OF ENGINEERING OPERATIONS AND THEIR EFFECTS ON OTHER PROCESSES, INCLUDING ATTRITION, DELAYS, AND INCREASED EXPOSURE DUE TO MINEFIELDS AND OBSTACLES; THE VULNERABILITY OF FORCES DEFENDING AT PREPARED POSITIONS; AND THE ABILITY TO MOVE ON ROADS AND ACROSS RIVERS AND GAPS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- LOCATION, DENSITY, AND EXTENT OF A MINEFIELD OR OBSTACLE
- ATTRITION SUFFERED WHEN ENCOUNTERING A MINEFIELD
- DELAY IN MOVEMENT WHEN ENCOUNTERING A MINEFIELD OR OBSTACLE
- REDUCTION IN MOVEMENT RATES DUE TO MINEFIELDS AND OBSTACLES
- INCREASE IN EXPOSURE DUE TO ENCOUNTERING A MINEFIELD OR OBSTACLE
- DELAYS IN TRAVELING ON DAMAGED ROADS
- DELAYS IN CROSSING RIVERS OR GAPS
- DEGREE OF PROTECTION AFFORDED BY A PREPARED DEFENSIVE POSITION
- LOCATION AND EXTENT OF A PREPARED DEFENSIVE POSITION

MODEL PROCESS: MOBILITY, COUNTERMOBILITY, AND SURVIVABILITY

MODEL / PROCESS PHENOMENON	1 Location, density, and extent of a minefield or obstacle	2 Attrition suffered when encountering a minefield	3 Delay in movement when encountering a minefield or obstacle	4 Reduction in movement rates due to minefields and obstacles	5 Increase in exposure due to encountering a minefield or obstacle	6 Delays in traveling on damaged roads	7 Delays in crossing rivers or gaps	8 Degree of protection afforded by a prepared defensive position	9 Location and extent of a prepared defensive position
CARMONETTE	A X	NR	NR	B X	NR	NR	B X	C X	B X
BLDM	In X	In X	In X	In X	C X	NR	B X	C X	B X
DIVLEV	In X	NR	NR	In X	B X	NR	NR	In X	In X
FOURCE	A X	NR	NR	B X	NR	NR	B X	D X	D X
JIFFY	D X	D X	NR	D X	NR	NR	Nom	Nom	Nom
VECTOR-2	In X	A X	NR	A X	NR	NR	A X	A X	In X
CEM	In X	NR	A X	In X	NR	A X	A X	B	A X
McCLINTIC	B X	B X	B X	NR	A X	In X	In X	In X	In X
CASTFOREM	C X	C X	C X	C X	C X	B X	C X	In X	C X

Mobi ity, Countermobility, and Survivability

1-A. Could be represented via inputs describing characteristics of terrain and ability to move on it.

1-B. Locations are governed by gamers. Density and extent are not explicitly represented.

1-C. Locations of minefields are controlled by user-specified decision tables governing minefield emplacement. Density and extent are assumed constant based on user inputs.

1-D. Decisions concerning minefield location and density are made by gamers. Extent of a minefield is computed internally as a function of resources available to emplace the minefield, rate of emplacement using these resources, time available to emplace the minefield, and a "work degradation factor" which degrades emplacement rates as a function of level of the hostilities.

2-A. Both discovery losses and crossing losses are input; the latter depend on whether the minefield is in an urban area and the method used to cross or clear the minefield.

2-B. Percentage attrition is built into the model.

2-C. If a minefield has a breachpath, all vehicles are assumed to know its location; otherwise input probabilities determine whether a minefield is detected when encountered. If undetected, minefield will be crossed and input probabilities determine whether vehicle survives the crossing.

2-D. Attrition is assessed only if the crossing force is using a hasty breach technique. Attrition is then computed as a function of fraction of trafficable terrain frontage covered by the portion of the minefield not bypassed, the fraction of the force used to clear the minefield, and input casualty data.

3-A. Assumed to require one division period (12 hours).

3-B. Delay is a random time between two and four hours.

3-C. If a minefield is detected (see 2-C) user-specified decision tables specify the response; the response results in an input delay.

4-A. Input factor is a function of whether the minefield is in an urban area, whether it is covered by fire, and the method used to cross or clear it.

4-B. Could be represented via inputs describing characteristics of terrain and ability to move on it.

4-C. When crossing a breachpath, vehicles travel at reduced speeds.

4-D. Rates of advance are reduced to 75 percent of their normal values when minefields or barriers are being crossed.

5-A. Combat strength of a unit in an overwatched minefield is halved.

5-B. "Percent weapon enhancement" for ambush areas is input for each barrier.

5-C. Exposure corresponds to the terrain on which the minefield is located.

6-A. Additional (input) delay is imposed in delivery of supplies and replacements and in commitment of army and corps reserves if friendly air environment does not exist. Friendly air environment is present if enemy air sortie losses exceed an input threshold.

6-B. Delays governed by input; repair is specified by user-provided decision tables.

7-A. Directly input for front-line forces; represented implicitly for forces in the rear.

7-B. Could be represented via inputs describing characteristics of terrain and ability to move on it.

7-C. Delays governed by input; bridging is specified by user-provided decision tables.

8-A. Defenders at defensible positions (located via input) are assumed to be in hull defilade (or to have some other degree of added protection, as specified by kill rate data).

8-B. Represented implicity via firepower scores, which vary depending on whether position is prepared or hasty.

8-C. Could be represented via inputs describing characteristics of terrain.

8-D. An input fraction of stationary vehicles in hull defilade (and therefore with decreased vulnerability to direct fire weapons) depends on whether the force is in a "fortified position," a "prepared position," or "conducting a hasty defense."

9-A. Whether defending force has had time for current position to be prepared is a function of recent FEBA movement -- position is prepared if average movement is below an input threshold.

9-B. Could be represented via inputs describing characteristics of terrain.

9-C. Construction of prepared positions is governed by user-specified decision tables. They have a standard size based on user input.

9-D. Blue battalions are assumed to be in "fortified positions" initially, and in "prepared positions" at each successive destination.

MODEL PROCESS

- INTELLIGENCE AND ELECTRONIC WARFARE -

DEFINITION:

REPRESENTATION OF THE ACQUISITION AND DEVELOPMENT OF TARGETS FOR FIRE SUPPORT; THE ACQUISITION AND DEVELOPMENT OF INTELLIGENCE CONCERNING ENEMY ORDER OF BATTLE, CAPABILITIES, ACTIVITIES, ETC.; AND THE USE OF COUNTERMEASURES AND COUNTER-COUNTERMEASURES TO CONTROL THE USE OF THE ELECTROMAGNETIC SPECTRUM

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- COLLECTION MANAGEMENT DECISIONS - WHAT INFORMATION TO PURSUE
- COLLECTION MANAGEMENT DECISIONS - HOW TO COLLECT DESIRED INFORMATION
- TARGET ACQUISITION CAPABILITIES
- ACCURACY OF TARGET IDENTIFICATION (INCLUDING FALSE TARGETS)
- TARGET PROCESSING TIME
- TARGET LOCATION ERROR
- TIMELINESS OF INTELLIGENCE PROCESSING
- ACCURACY OF INTELLIGENCE PROCESSING
- COMPLETENESS OF INTELLIGENCE PROCESSING
- DECISIONS TO JAM
- EFFECTIVENESS OF JAMMING
- COLLECTION MANAGEMENT DECISIONS - LOCATION OF SENSORS

MODEL PROCESS: INTELLIGENCE AND ELECTRONIC WARFARE[1]

MODEL / PROCESS PHENOMENON	1 Collection management decisions - what information to pursue	2 Collection management decisions - how to collect desired information	3 Target acquisition capabilities	4 Accuracy of target identification (including false targets)	5 Target processing time	6 Target location error	7 Timeliness of intelligence processing	8 Accuracy of intelligence processing	9 Completeness of intelligence processing	10 Decisions to jam	11 Effectiveness of jamming	12 Collection management decisions - location of sensors
CARMONETTE	-	-	-	-	-	-	-	-	-	-	-	-
BLIM	-	-	-	-	-	-	-	-	-	-	-	-
DIVLEV	NR	NR	In X	Perf	NR	Ext X	D X	D X	D X	NR	NR	NR
FOURCE	B X	A X	In X	B X	A X	A X	E X	E X	E X	NR	NR	B X
JIFFY	Nom	Nom	C X	Perf	NR	Nom	NR	NR	NR	Gam X	C X	Nom
VECTOR-2	Perf	In X	A X	Perf	In X	In X	A X	A X	A X	NR	Nom	A X
CEM	NR	NR	Nom	Perf	NR	Nom	B X	B	B	NR	Nom	NR
McCLINTIC	A X	Nom	B X	A X	NR	Nom	C X	C X	C X	A	A X	Nom
CASTFOREM	NR	NR	NR	NR	NR	NR	NR	NR	NR	B X	B X	NR

[1] Excluding target acquisition by individual engaged front-line weapons -- see "Maneuver Unit Combat."

Intelligence and Electronic Warfare

1-A. HUMINT missions on enemy activities in a specified area are called for by gamers. Other types of collection occur automatically within the model.

1-B. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

2-A. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

3-A. Input as a function of sensor type, target type, target activity, range to the target, target strength, and weather visibility.

3-B. Input for acquisition of units by overflying aircraft. Built into the model for national sources. Most other capabilities represented implicitly.

3-C. Represented as overall acquisition probabilities or "percent of knowledge" values input as a function of target type.

4-A. Fixed probability of identification of targets by national sources is built into the model. Other sources identify targets accurately.

4-B. Target is identified as maneuver unit unless it is known to be artillery.

5-A. Staff element processing times are modeled explicitly using a priority queueing structure for handling incoming messages. Minimum processing times and maximum acceptable throughput times are input for each message type. Messages are lost if the system is overloaded.

6-A. Locations of sightings are reported; actual target locations can differ because of target movement.

7-A. Previously acquired targets are dropped from lists as they become stale. Time by which a target of a given type is stale is input. Other targets not under direct observation may remain on the list even if they are no longer present.

7-B. Intelligence concerning enemy strengths is weighted average of two recent actual strength levels -- timeliness is thus determined by values of weights.

7-C. HUMINT and national intelligence information is delayed a fixed time before being made available to gamers.

7-D. Governed by controller inputs to gamers..

7-E. Staff element processing times are modeled explicitly using a priority queueing structure for handling incoming messages. Minimum processing times and maximum acceptable throughput times are input for each message type. Messages are lost if the system is overloaded.

8-A. OB intelligence consists of estimates (derived from sensor reports) of opposing strengths, updated periodically via a Bayesian processing scheme. Thus, inaccuracies of initial estimates and of sensor reports result in inaccurate intelligence. Weather, terrain, and friendly situation are assumed to be known accurately. Weather forecasts are input (and can be incorrect).

8-B. Except for time lag (see 7-B) intelligence is assumed to be accurate.

8-C. Fixed probability of identification of a unit's activity by national sources is built into the model. Other intelligence information (but see 4-A above) is reported accurately as of the time of collection.

8-D. Governed by controller inputs to gamers.

8-E. Processing is based on built-in rules which determine how to merge existing information with new sensor-provided data. Because both new data and existing data can be incorrect (e.g., stale or incomplete), erroneous inferences can be drawn.

9-A. OB intelligence consists of estimates (derived from sensor reports) of opposing strengths, updated periodically via a Bayesian processing scheme. Thus, incompleteness in initial estimates and in sensor reports result in incomplete intelligence. Weather, terrain, and friendly situation are assumed to be known. Weather forecasts are input.

9-B. OB intelligence is complete in the sense that no relevant information is assumed to be missed by the process, except as affected by time lags (see 7-B).

9-C. Intelligence information includes unit type, location, activity, and strength. A fixed percentage of enemy orders are also intercepted.

9-D. Governed by controller inputs to gamers.

9-E. If processing system is overloaded, some messages will be lost. System produces estimates of opposing force strengths and location of Red main thrust.

10-A. A fixed percentage of orders are jammed (not based on any explicit decision to jam). Other types of jamming are represented only implicitly.

10-B. Will be represented in CASTFOREM, but existing specifications do not describe how.

11-A. Jammed orders are not received, and sender is not informed of the jamming.

11-B. Probability of reception of a message is computed based on carrier propagation theory and whether the receiver is jammed.

11-C. Degradation factors (which are drawn at random from sets of input factors) reduce firepower scores for use in force movement computations and decrease the number of artillery battery missions available.

12-A. General position on battlefield is directly input. Detailed siting decisions represented implicitly via input line-of-sight probabilities, which depend on sensor type, terrain type, and range to the target.

12-B. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

MODEL PROCESS
- COMMUNICATIONS -

DEFINITION:

REPRESENTATION OF THE TRANSMISSION OF MESSAGES ON THE BATTLEFIELD, WITH INHERENT ERRORS AND DELAYS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- TIME TO TRANSMIT A MESSAGE
- MESSAGE CONTENT
- TRANSMISSION ACCURACY
- RECEPTION ACCURACY

MODEL PROCESS: COMMUNICATIONS

MODEL / PROCESS PHENOMENON	1 Time to transmit a message	2 Message content	3 Transmission accuracy	4 Reception accuracy
CARMONETTE	A X	Perf	Perf	Perf
BLDM	In X	Perf	Perf	Perf
DIVLEV	Nom	Nom	Nom	Nom
FOURCE	In X	Perf	Perf	Perf
JIFFY	Nom	Nom	Nom	Nom
VECTOR-2	In X	Perf	Perf	Perf
CEM	Nom	Nom	Nom	Nom
McCLINTIC	NR	Gam X	Gam X	A X
CASTFOREM	B X	Perf	Perf	B X

Communications

1-A. Frequency with which accumulated intelligence information is passed is input.

1-B. Queueing of messages in the communication net (with resultant delays) is simulated to generate a time of reception.

4-A. A fixed percentage of messages (orders) are not received, to represent the effects of jamming.

4-B. Messages are accurate if received, but probability of reception is based on carrier propogation theory and on whether the receiver is jammed.

MODEL PROCESS

- MISSION ASSIGNMENT, ORGANIZATION FOR COMBAT, AND RESOURCE ALLOCATION -

DEFINITION:

REPRESENTATION OF MISSION ASSIGNMENT, FRONTING, AND ORGANIZATION FOR COMBAT OF MANEUVER UNITS; MISSION ASSIGNMENT, ALLOCATION, AND POSITIONING OF COMBAT SUPPORT AND SERVICE SUPPORT RESOURCES; AND THE ASSIGNMENT OF MISSIONS TO AIRCRAFT

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- INITIAL DEPLOYMENTS OF MANEUVER UNITS
- CHANGES IN THESE DEPLOYMENTS
- CROSS ATTACHMENTS AMONG MANEUVER UNITS
- ALLOCATION AND/OR POSITIONING OF
  - ATTACK HELICOPTERS
  - FIELD ARTILLERY FORCES
  - CAS/BI AIRCRAFT
  - AIR DEFENSE FORCES
  - TARGET ACQUISITION RESOURCES
  - SUPPLY POINTS
- ALLOCATION OF AIRCRAFT TO MISSIONS
- DELAYS IN MAKING AND IMPLEMENTING DECISIONS

MODEL PROCESS: MISSION ASSIGNMENT, ORGANIZATION FOR COMBAT, AND RESOURCE ALLOCATION

MODEL / PROCESS PHENOMENON	1 Initial deployments of maneuver units	2 Changes in these deployments	3 Cross attachments among maneuver units	4 Allocation and/or positioning of attack helicopters	5 Allocation and/or positioning of field artillery forces	6 Allocation and/or positioning of CAS/BI aircraft	7 Allocation and/or positioning of air defense forces	8 Allocation and/or positioning of target acquisition resources	9 Allocation and/or positioning of supply points	10 Allocation of aircraft to missions	11 Delays in making and implementing decisions
CARMONETTE	-	-	-	-	-	-	-	-	-	-	-
BLDM	-	-	-	-	-	-	-	-	-	-	-
DIVLEV	In X	B X	In X	In X	C X	NR	Gam X	NR	B X	NR	NR
FOURCE	A X	C X	B X	C X	D X	C X	NR	B X	NR	NR	B X
JIFFY	In X	Gam X	Gam X	Gam X	Gam X	NR	Gam X	NR	NR	NR	NR
VECTOR-2	In X	In X	In X	A X	A X	A X	A X	A X	A X	A X	NR
CEM	In X	A X	A X	B X	B X	B X	NR	NR	NR	B X	A X
McCLINTIC	In X	Gam X	Nom	Gam X	Gam X	Gam X	Nom	NR	In X	Gam X	Gam X
CASTFOREM	-	-	-	-	-	-	-	-	-	-	-

Mission Assignment, Organization for Combat, and Resource Allocation

1-A. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

2-A. Built-in rules proceed through command heirarchy, (1) allocating reinforcing divisions, (2) replacing weak front-line divisions or brigades, (3) deciding whether to commit or hold a reserve corps in an army, a reserve division in a corps, and (for Blue) a reserve brigade in a division, (4) adjusting frontages, based primarily on unit missions, strength estimates (and corresponding force ratios), frontage restrictions, and penetration depths. Input thresholds govern many decisions.

2-B. Either input directly by gamers or governed by gamer-supplied contingency orders, which can be activated as a function of time, unit location, casualty level, or movement status of a specified unit.

2-C. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

3-A. Input for battalions and brigades. For higher-level units, see 2-A.

3-B. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

4-A. Governed by user-provided tactical decision rules. Existing rules in most versions allocate forces not organic to a division as a function of friendly to enemy force ratios and the number of maneuver units being supported (model then assumes most forces "float" with the FEBA).

4-B. For Blue only, model rules allocate corps helicopters to divisions in proportion to artillery allocation; allocate to brigades equally with a later adjustment possible (if one brigade is in reserve) based on estimated outcome of the current period's combat.

4-C. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

5-A. Governed by user-provided tactical decision rules. Existing rules in most versions allocate forces not organic to a division as a function of friendly to enemy force ratios and the number of maneuver units being supported (model then assumes most forces "float" with the FEBA).

5-B. Model rules allocate artillery battalions through the command heirarchy. Divisional artillery for front-line divisions is used as DS for the division. A fraction of corps artillery (and Blue reserve division artillery) may also be used in this role if estimated by division to be needed for a favorable outcome. Artillery is allocated down to division generally in support of strength on offense and weakness on defense, where strength is measured by forc- ratios.

5-C. Gamers set priorities for allocation of artillery to support specific maneuver units. Movement of artillery is automatically initiated in the model to assure all units are between 30 percent and 70 percent of their maximum range from the FEBA. Such movement can be precluded by gamer input.

5-D. Governed by built-in decision rules designed to represent Blue and Red doctrine in Blue division-level defensive scenario.

6-A. Governed by user-provided tactical decision rules. Existing rules in most versions allocate forces not organic to a division as a function of friendly to enemy force ratios and the number of maneuver units being supported (model then assumes most forces "float" with the FEBA).

6-B. CAS aircraft are allocated to divisions in proportion to artillery allocations.

6-C. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

7-A. Governed by user-provided tactical decision rules. Existing rules in most versions allocate forces not organic to a division as a function of friendly to enemy force ratios and the number of maneuver units being supported (model then assur-s most forces "float" with the FEBA).

8-A. Governed by user-provided tactical decision rules. Existing rules in most versions allocate forces not organic to a division as a function of friendly to enemy force ratios and the number of maneuver units being supported (model then assumes most forces "float" with the FEBA).

8-B. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

9-A. Governed by user-provided tactical decision rules. Existing rules in most versions do not reallocate or relocate supply points (although model assumes they "float" with the FEBA).

9-B. Model automatically updates positions to keep them within the bounds of their parent units.

10-A. Governed by user-provided tactical decision rules. Existing rules base these allocations on acquired targets, suitability of the aircraft for the possible missions, and current "air posture" -- a function of aircraft inventory, recent aircraft loss exchange ratio, and current mission of ground forces.

10-B. Percentage of aircraft on each mission are input for first period and adjusted thereafter automatically as a function of aircraft loss rates in the air and on the ground. If recent FEBA movement is rearward and exceeds input thresholds, aircraft otherwise assigned to other missions are diverted to CAS.

11-A. Commitment of army and corps reserves occurs after input delays (which include implementation time as well as travel time). Other decisions are implemented without delay.

11-B. Staff element processing times are modeled explicitly using a priority queueing structure for handling incoming messages. Minimum processing times and maximum acceptable throughput times are input for each message type. (Messages are lost if the system is overloaded.)

MODEL PROCESS

- MANEUVER CONTROL -

DEFINITION:

REPRESENTATION OF THE CONTROL OF ACTIVITIES AND SUPPORT OF FRONT-LINE MANEUVER UNITS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- DECISIONS TO CHANGE THE ACTIVITY AND/OR LOCATION OF A UNIT (INCLUDING CRITERIA FOR INITIATING AND BREAKING OFF FROM COMBAT)
- DECISIONS TO REQUEST AND COMMIT RESERVES
- DECISIONS FOR UNIT RETIREMENT
- DECISIONS TO REQUEST FIRE SUPPORT
- DECISIONS TO REQUEST ENGINEERING SUPPORT
- DECISIONS FOR THE TACTICAL RELOCATION OF SUPPORTING ELEMENTS (SUCH AS FIELD ARTILLERY BATTERIES)
- DELAYS IN MAKING AND IMPLEMENTING DECISIONS

MODEL PROCESS: MANEUVER CONTROL[1]

MODEL \ PROCESS PHENOMENON	1. Decisions to change the activity and/or location of a unit	2. Decisions to request and commit reserves	3. Decisions for unit retirement	4. Decisions to request fire support	5. Decisions to request engineer support	6. Decisions for the tactical relocation of supporting elements	7. Delays in making and implementing decisions
CARMONETTE	C X	NR	NR	C X	NR	NR	NR
BLDM	NR	NR	NR	E X	NR	NR	NR
DIVLEV	D X	B X	B X	D X	NR	Ext X	NR
FOURCE	F X	D X	D X	G X	NR	A X	B X
JIFFY	Gam X	Gam X	Gam X	Nom	Gam X	Gam X	NR
VECTOR-2	A X	A X	.A X	A X	A X	Nom	A X
CEM	B X	Nom	Nom	B X	Nom	Nom	NR
McCLINTIC	Gam X	Gam X	Gam X	Gam X	Gam X	Gam X	Gam X
CASTFOREM	E X	C X	C X	F X	B X	NR	In X

[1]This category refers to detailed control of units in contact. For periodic reallocation of forces (which may itself include some reserve commitment and retirement of forces) see "Mission Assignment, Organization for Combat, and Resource Allocation."

Maneuver Control

1-A. Governed by user-provided tactical decision rules. Existing rules in most versions base decisions on mission of friendly force, front-line strengths and attrition, command post strengths, availability of artillery and air defense weapons, availability of POL, and proximity of opposing forces and of neighboring friendly forces.

1-B. Activity changes are represented implicitly in input firepower scores. Location changes are based on firepower score force ratios, and limited by rules restricting amount of exposed flank allowed.

1-C. Engagement termination criteria include an input number of surviving weapons on a side being within an input distance of a user-specified location, personnel casualties exceeding an input threshold, or vehicle casualties exceeding an input threshold.

1-D. Either input directly by gamers or governed by gamer-supplied contingency orders, which can be activated as a function of time, unit location, casualty level, or movement status of a specified unit.

1-E. Based on user-specified decision tables.

1-F. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

2-A. Governed by user-provided tactical decision rules (and by the availability of reserve forces). Existing rules in most versions base decisions on strengths and activities of the forces involved and, for Red, the time at the front and the amount or rate of advance of the front-line force.

2-B. Either input directly by gamers or governed by gamer-supplied contingency orders, which can be activated as a function of time, unit location, casualty level, or movement status of a specified unit.

2-C. Based on user-specified decision tables.

2-D. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

3-A. Governed by user-provided tactical decision rules. Existing rules in most versions base decisions on unit strengths, time at the front, and amount of advance of the front-line force.

3-B. Either input directly by gamers or governed by gamer-supplied contingency orders, which can be activated as a function of time, unit location, casualty level, or movement status of a specified unit.

3-C. Based on user-specified decision tables.

3-D. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

4-A. Governed by user-provided tactical decision rules. Existing rules in most versions base decisions primarily on current or scheduled maneuver unit activities.

4-B. Primarily represented implicitly in input firepower scores. However, DS artillery can be employed at two ordnance expenditure levels -- division commander requests higher level for next division cycle if estimate of situation indicates it is necessary to accomplishment of mission.

4-C. Command units base calls for artillery and attack helicopter support on target information supplied them by their subordinate. Target priorities for such calls are input.

4-D. Calls for artillery and helicopter support occur automatically in the model as a function of loss rates. (Artillery is requested if current loss rate exceeds ten percent of the player-input acceptable loss rate.)

4-E. Forward observers who call for fire in areas containing acquired targets are simulated using input priorities. In some versions, preplanned fire is delivered to specified positions on the battlefield at specified times, based on input.

4-F. Employment of helicopters is governed by user-specified decision tables.

4-G. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

5-A. Requests for laying minefields are governed by user-provided tactical decicion rules. Existing rules in most versions do not make such requests.

5-B. Based on user-specified decision tables.

6-A. Relocation of command posts above battalion and Blue artillery batteries is governed by built-in decision rules. Relocation of other supporting elements is represented implicitly by maintaining a fixed relationship with the unit they support.

7-A. Durations of delays are input as a function of type of decision, whether the force is engaged, which headquarters (battalion, brigade, etc.) participate in the decision and (if the decision is a change in activity) the type of activity to be adopted.

7-B. Staff element processing times are modeled explicitly using a priority queueing structure for handling incoming messages. Minimum processing times and maximum acceptable throughput times are input for each message type. Messages are lost if the system is overloaded.

MODEL PROCESS

- FIRE SUPPORT ALLOCATION -

DEFINITION:

REPRESENTATION OF THE ALLOCATION OF AVAILABLE FIRE SUPPORT RESOURCES (ARTILLERY, FIXED-WING AIRCRAFT, ATTACK HELICOPTERS, AIR DEFENSE WEAPONS) FOR USE ON PREPLANNED MISSIONS AND AGAINST TARGETS OF OPPORTUNITY

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- TARGET AND MISSION PRIORITIES
- PREFERENCES FOR TYPE AND AMOUNT OF SUPPORT AGAINST A GIVEN TARGET IN A GIVEN SITUATION
- PREFERENCES FOR TYPES AND AMOUNTS OF FIRE ALLOCATED TO PREPLANNED MISSIONS (PREPARATION, FINAL PROTECTIVE FIRES, ETC.)
- CRITERIA FOR IGNORING TARGETS OR DROPPING THEM FROM THE LIST OF ACQUIRED TARGETS
- DELAYS IN MAKING AND IMPLEMENTING DECISIONS

MODEL PROCESS: FIRE SUPPORT ALLOCATION

MODEL \ PROCESS PHENOMENON	1 Target and mission priorities	2 Preferences for type and amount of support against a given target in a given situation	3 Preferences for types and amounts of fire to be allocated to preplanned missions	4 Criteria for ignoring targets or dropping them from list of acquired targets	5 Delays in making and implementing decisions
CARMONETTE[1]	-	-	-	-	-
BLDM	-	-	-	-	-
DIVLEV	B X	A X	A X	NR	B X
FOURCE	D X	C X	C X	NR	C X
JIFFY	C X	B X	B X	NR	NR
VECTOR-2	In X	In X	In X	A X	In X
CEM	A X	In X	In X	NR	NR
McCLINTIC	Gam X	Gam X	Gam X	Gam X	A X
CASTFOREM	-	-	-	-	-

[1]CARMONETTE and BLDM represent fire support only in response to calls from engaged maneuver elements. See "Artillery Fire" and "Maneuver Control."

Fire Support Allocation

1-A. Selection of artillery mission types (and corresponding target types) depends on divisional commander's estimates of success at each of two levels of artillery allocated to the direct support role. Artillery not in the DS role is allocated implicitly (based on effects data) between enemy artillery and reserve maneuver units. See "Mission Assignment..." section for allocation of aircraft to missions. Allocation to targets within a given mission type is generally assumed to be uniform.

1-B. Priorities for support of maneuver units are input; priorities for attack of targets in the rear are built into the model. Maneuver unit requests have priority over deep targets.

1-C. Available artillery fire of a given type is distributed among target types appropriate to that artillery type in proportion to weights, each of which equals the product of the number of targets and an input "military worth" of the target. If the gamer calls for final protective fires, all indirect fire means are used for this purpose for an input time period.

1-D. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

2-A. Based on built-in allocation factors which do not vary with situation.

2-B. Available artillery fire of a given type is distributed among target types appropriate to that artillery type in proportion to weights, each of which equals the product of the number of targets and an input "military worth" of the target. If the gamer calls for final protective fires, all indirect fire means are used for this purpose for an input time period.

2-C. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

3-A. Preparatory fires based on built-in allocation factors; other fire plans can be prespecified by the gamers to occur at indicated times or when a unit reaches an indicated location. Allocation of helicopters to maneuver unit can be prespecified to occur at indicated times.

3-B. Treated within the allocation scheme described in 1-C.

3-C. Governed by built-in decision rules designed to represent Blue and Red doctrine in a Blue division-level defensive scenario.

4-A. Targets are ignored if support is unavailable which can reach the target. "Stale" targets are dropped from the list after an input period of time.

5-A. In addition to gamer delays in making decisions, a 15 minute delay between requesting and receiving fire is assessed.

5-B. Time to shift fire to a new target is input as a function of artillery type.

5-C. Staff element processing times are modeled explicitly using a priority queueing structure for handling incoming messages. Minimum processing times and maximum acceptable throughput times are input for each message type. Messages are lost if the system is overloaded.

MODEL PROCESS
- RESUPPLY AND REPLACEMENT -

DEFINITION:

REPRESENTATION OF THE STOCKPILING OF SUPPLIES AND INDIVIDUAL REPLACEMENTS AND THEIR ALLOCATION TO USER UNITS

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- LOCATIONS OF SUPPLY POINTS
- STOCKPILING DECISIONS AT SUPPLY POINTS
- QUANTITIES OF SUPPLIES AND REPLACEMENTS ALLOCATED TO UNITS ON THE BATTLEFIELD
- DELAYS IN DECISIONS TO PROVIDE SUPPLIES OR REPLACEMENTS
- TIME REQUIRED TO LOAD AND UNLOAD (OR OTHERWISE HANDLE) ALLOCATED SUPPLIES

MODEL PROCESS: RESUPPLY AND REPLACEMENT

MODEL / PROCESS PHENOMENON	1 Locations of supply points	2 Stockpiling decisions at supply points	3 Quantities of supplies and replacements allocated to units on the battle-field	4 Delays in decisions to provide supplies or replacements	5 Time required to load and unload allocated supplies
CARMONETTE	-	-	-	-	-
BLOM	-	-	-	-	-
DIVLEV	In X	C X	D X	NR	NR
FOURCE	-	-	-	-	-
JIFFY	-	-	-	-	-
VECTOR-2	In X	A X	A X	NR	NR
CEM	NR	B X	C X	A X	A X
McCLINTIC	In X	In X	Gam X	Gam X	NR
CASTFOREM	In X	In X	B X	In X	In X

Resupply and Replacement

2-A. Amounts to be added to stockpiles periodically are directly input by the user. User-specified resupply rules can assure that these stockpiles remain at acceptable levels; most existing rules do not do so.

2-B. Amounts to be added to stockpiles periodically are directly input by the user.

2-C. Initial stocks are set by the model as a function of the number and type of units for which the supply area is responsible.

3-A. Governed by user-provided tactical decision rules. Most existing rules attempt to resupply so as to minimize fractional shortfalls from TOE levels.

3-B. Specified by the user via input decision tables.

3-C. Available resources are distributed to units in proportion to unit need to replace losses and consumption. Optionally, replenishment of Red units may be limited to "decimated" divisions.

3-D. Amount of resupply requested is twice the current shortfall from maximum supply load, or zero, if the shortfall is less than 1/8 the maximum load. Units are resupplied in these amounts in priority order subject to available supplies and hauling capability.

4-A. Availability of replacements is delayed an input time, which can (in part) reflect decision delays.

5-A. See 4-A. Also, replacement personnel to a unit must be assimilated into the unit over a period of time. Assimilation rates are governed by input.

MODEL PROCESS

- MOVEMENT -

DEFINITION:

REPRESENTATION OF TRANSPORTATION AND TACTICAL MOVEMENT OF FORCES ON THE GROUND AND IN THE AIR, RESULTING IN NEW LOCATIONS OF UNITS, SUPPLIES, ETC., WITH ASSOCIATED DELAYS, POL CONSUMPTION, AND CHANGES IN VULNERABILITY

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- AIRCRAFT SPEEDS AND FLIGHT PATHS
- MOVEMENT RATES OF GROUND FORCES (UNITS, SUPPLIES IN TRANSIT, ETC.)
- ROUTE SELECTION FOR FORCES MOVING ON THE GROUND
- DEGREE OF EXPOSURE OF MOVING FORCES (AIR AND GROUND)

MODEL PROCESS: MOVEMENT

MODEL \ PROCESS PHENOMENON	1 Aircraft speeds and flight paths	2 Movement rates of ground forces[1]	3 Route selection of forces moving on the ground	4 Degree of exposure of moving forces (air and ground)
CARMONETTE	-	-	-	-
BLDM	-	-	-	-
DIVLEV	NR	C X	Gam X	Nom
FOURCE	Nom	E X	A X	B X
JIFFY	NR	F X	Nom	Nom
VECTOR-2	A X	In X	A X	C X
CEM	NR	A X	A X	Nom
McCLINTIC	In X	B X	Gam X	Nom
CASTFOREM	In X	D X	B X	A X

[1]Exludes maneuver patterns of individual maneuver - unit weapons - see "Maneuver Unit Combat."

Movement

1-A. Average speeds are input. Simplistic, notional flight paths, built into model logic, depend on type of mission and location of airfields and targets.

2-A. FEBA movement is governed by firepower score force ratios. Movement of forces in the rear is represented only through input delays for commitment of higher-level reserves and for replacement resources.

2-B. Specified by gamers for each move, subject to input maximum speeds.

2-C. Unopposed movement rates are input as a function of unit type, terrain, on or off road, barriers, and day or night. Current velocity is the product of unopposed movement rate and unit posture. Posture is a linear function of current loss rate, equals 1 if loss rate is 0 and equals 0 if loss rate equals or exceeds input acceptable loss rate.

2-D. Maximum movement and acceleration rates are input and depend on terrain. The ordered speed may be changed at any time using user-specified decision tables.

2-E. Speed is based on inputs which vary with familiarity with terrain (friendly or enemy territory) and terrain characteristics (speed of engaged forces is further degraded -- see "Maneuver Unit Combat," "Air-to-Ground Attacks," and "Artillery Fire").

2-F. Input as a funtion of firepower score force ratio, unit activity, visibility conditions, type of terrain, whether weapons are mounted or dismounted.

3-A. FEBA movement follows routes specified by an input terrain map. Route selection in the rear is represented implicitly.

3-B. Selection from among input routes is governed by user-specified decision tables.

4-A. Representative cover for moving forces is related to mean surface feature height of the terrain truncated to 1 meter maximum. Other aspects of exposure use functions of the terrain type being traversed.

4-B. Posture of a moving Blue battalion is "hasty defense" (rather than "fortified position" or "prepared position"). Posture affects vulnerability to direct fire. Moving forces can also be given different "activity factors" from stationary ones; this affects their detectability.

4-C. A maneuver unit's movement status can affect its detectability and posture. (Posture affects vulnerability to fire support.)

MODEL PROCESSES

- MAINTENANCE AND REPAIR; MEDICAL SUPPORT -

DEFINITION:

REPRESENTATION OF THE RETURN TO DUTY OF DAMAGED FACILITIES AND EQUIPMENT AND OF INJURED PERSONNEL

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- RATE AT WHICH WEAPONS AND PERSONNEL ARE RETURNED TO DUTY GIVEN AVAILABILITY OF REPAIR CAPABILITY AND MEDICAL SUPPORT
- AVAILABILITY OF REPAIR CAPABILITY AND MEDICAL SUPPORT
- RATE AT WHICH DAMAGED CAPABILITY OF A FACILITY IS RESTORED

MODEL PROCESS: MAINTENANCE AND REPAIR; MEDICAL SUPPORT

MODEL \ PROCESS PHENOMENON	1 Rates at which weapons and personnel are returned to duty given availability of support	2 Availability of repair capability and medical support	3 Rate at which damaged capability of a facility is restored
CARMONETTE	-	-	-
BLDM	-	-	-
DIVLEV	-	-	-
FOURCE	-	-	-
JIFFY	D X	Nom	NR
VECTOR-2	A X	Nom	A X
CEM	B X	Nom	NR
McCLINTIC	-	-	-
CASTFOREM	C X	A X	NR

Maintenance and Repair; Medical Support

1-A. Temporarily damaged artillery and air defense weapons are returned to duty at an input rate; no other weapons nor personnel are returned to duty once damaged.

1-B. Decimated divisions are delayed an input minumum time before they may be returned to duty. Sick and injured personnel require an input time in hospital before being returned to duty. Damaged weapons require an input repair time before being returned to duty. They are also subject to input repair capacity constraints.

1-C. Rates to diagnose lightly, moderately, or severly wounded (damaged) or dead personnel (equipment) are input. Times to aid (repair) wounded (damaged) personnel (equipment) in the above categories are input.

1-D. Input percentages divide weapons lost in combat into four classes: nonrecoverable and three levels of recoverability, each level having a different repair time. For Blue losses only, the percentages depend on type of damaged weapon, whether the damage was due to direct or indirect fire, and whether the damaged weapon was attacking or defending. Operational availability probabilities are also input and used to reflect unavailability of weapons due to routine maintenance.

2-A. Personnel and equipment necessary for diagnosis, aid, and repair of casualties or damaged equipment are input as a function of degree of damage or injury and must be colocated with the damaged equipment or injured person to provide the needed support. They may be unavailable because they were not in the unit, have been attrited, are at the wrong location, etc.

3-A. Capability of damaged command posts (reflected in magnitude of decision delays) is restored at an input rate. Repair at other facilities (other than airfields) is not represented.

MODEL PROCESS

- CONSTRUCTION, MAINTENANCE, AND OPERATION OF AIRFIELDS -

DEFINITION:

REPRESENTATION OF AIRFIELD CONSTRUCTION, MAINTENANCE, AND OPERATION, RESULTING IN CHANGES IN AIRFIELD CAPACITIES, AIR SORTIE GENERATION CAPABILITIES, AND VULNERABILITY OF PARKED AIRCRAFT

PHENOMENA INFLUENCED BY HUMAN FACTORS:

- SORTIE GENERATING CAPABILITY OF AN AIRFIELD
- RATE OF RECOVERY OF SORTIE GENERATING CAPABILITY FOLLOWING AN ATTACK ON THE AIRFIELD
- CONSTRUCTION AND REPAIR RATES FOR RUNWAYS, AIRCRAFT SHELTERS, AND ENTIRE AIRFIELDS
- DELAYS IN SCRAMBLING AIRCRAFT
- DEGREE TO WHICH AVAILABLE SHELTERS AND REVETMENTS ARE IN USE WHEN AN ATTACK OF AN AIRFIELD OCCURS
- AIRCRAFT BASING RULES

MODEL PROCESS: CONSTRUCTION, MAINTENANCE, AND OPERATION OF AIRFIELDS

MODEL / PROCESS PHENOMENON	1 Sortie generating capability of an airfield	2 Rate of recovery of sortie generating capability following an attack on the airfield	3 Construction and repair rates for runways, aircraft shelters and entire airfields	4 Delays in scrambling aircraft	5 Degree to which available shelters are in use when an attack of an airfield occurs	6 Aircraft basing rules
CARMONETTE	-	-	-	-	-	-
BLDM	-	-	-	-	-	-
DIVLEV	-	-	-	-	-	-
FOURCE	-	-	-	-	-	-
JIFFY	-	-	-	-	-	-
VECTOR-2	B X	NR	A X	In X	In X	A X
CEM	NR	NR	NR	A X	Perf	B X
McCLINTIC	A X	NR	NR	Nom	Nom	Gam X
CASTFOREM	-	-	-	-	-	-

Construction, Maintenance, and Operation of Airfields

1-A. A fixed percentage of aircraft availability is built into the model as a function of number of days into the war. A fixed time between sorties is imposed for a given air unit.

1-B. Tactical decision rules are structured to limit availability of aircraft due to turnaround requirements at the airfield.

3-A. Runway repair (and damage) is not represented. Shelters and airfields are constructed at input rates under conditions specified by user-input tactical decision rules. Existing rules do not call for any such construction.

4-A. Represented by input probabilities only for determining air-to-ground effects against parked aircraft.

6-A. Governed by user-provided tactical decision rules, subject to airfield basing constraints. Existing rules allocate aircraft to corps or army sectors based on input TOE levels, and allocate to bases within sectors using input preferences for basing each aircraft type within a specific distance of the FEBA.

6-B. Aircraft are based at either primary or sanctuary bases, depending on model inputs. (Those at sanctuary bases are invulnerable to air-to-ground attack.)

APPENDIX B

A TYPOLOGY OF HUMAN FACTORS AREAS

As discussed in section 2.2, task 2 of this project involved classifying the information about model processes developed in task 1 into a typology which allows the information to be related to potential human factors research areas. This appendix describes details of the conduct and results of that task.

The first step of the process involved identification of a set of generic task clusters which (1) affect model process phenomena defined in appendix A; and (2) encompass significant aspects of human factors. Exhibit B-1 contains a list of these task clusters and their definitions. The task clusters associated with each of the model phenomena are indicated in exhibit B-2. Exhibit B-3 gives summary statistics concerning the frequency with which each task cluster is involved in the processes and phenomena. As indicated in section 2.2, these statistics provide information about the pervasiveness of certain types of tasks in combat models.

Next, an analysis of the abilities required to perform the tasks of each task cluster was conducted. The analysis used an ability taxonomy and rating scheme of Fleishman (see [Fleishman, 1975] and [Theologus, Romashko, and Fleishman, 1970]) to determine the degree to which various abilities are required for successful performance of each task. Exhibit B-4 lists and briefly defines the 37 abilities included in the Fleishman taxonomy. The rating process involved evaluating the degree to which each of the 37 abilities is required for errorless performance of each of the 18 task clusters listed in exhibit B-1. For each task cluster, each

EXHIBIT B-1: DEFINITIONS OF GENERIC TASK CLUSTERS

1. Vehicle maneuver: movement of combat vehicles in contact with an enemy force, including use of terrain for cover and concealment and selection of firing positions.

2. Dismounted weapon maneuver: movement of dismounted combat personnel and their weapons while in contact with an enemy force, including use of terrain for cover and concealment and selection of firing positions.

3. Visual acquisition: search for, sighting, and identification of targets using (possibly aided) visual means.

4. Aiming and tracking: pointing of a direct-fire weapon (or designator) at a stationary or moving target for the time required to effect successful ordnance delivery.

5. Weapon operation: processes associated with loading and firing a weapon.

6. Individual decision making (threat): selection of an alternative course of action by an individual or crew commander where the consequence of the decision may pose a threat to the safety of the decision maker (e.g., a decision to engage a particular target). Includes processing of any sensory inputs; excludes any physical response to the decision.

7. Individual decision making (non-threat): selection of an alternative course of action by an individual or crew commander where there is no immediate danger associated with the decision (e.g., an ordnance selection decision). Includes processing of any sensory inputs; excludes any physical response to the decision.

8. Command decision making: selection of an alternative course of action for a force where the decision must be made under time pressure (e.g., a decision to break off an engagement). Includes processing of any sensory inputs and initial communication of decision to subordinates.

9. Command planning: selection of a future course of action for a force where there is comparatively little time pressure (e.g., decisions associated with pre-planning of air flights for the following day). Includes processing of any sensory inputs and initial communication of decision to subordinates.

10. Radar acquisition: detection and reporting of targets with the use of a radar screen.

11. Target and intelligence development: processing of target acquisitions and other information to determine the identity, location, strength, intent, etc., of opposing forces either for targeting or order-of-battle intelligence.

EXHIBIT B-1: DEFINITIONS OF GENERIC TASK CLUSTERS
(Concluded)

12. Communication: sending and receiving messages (assumed to be by voice over radio or telephone).

13. Driving: movement of any vehicle while out of contact with enemy maneuver forces, possibly in coordination with other vehicles.

14. Aircraft operation: operation of an aircraft in flight or in preparation for flight.

15. Construction: operations involving the building or repair of bridges, roads, runways, aircraft shelters, etc., as well as the preparation of defensive positions and the emplacement of conventional land mines.

16. Maintenance and repair: performance of routine or emergency repair of mechanical or electronic equipment.

17. Medical care: provision of emergency and non-emergency care to the sick and wounded.

18. Resupply: loading, unloading, and moving supplies (excludes driving -- see 13).

EXHIBIT B-2: TASK CLUSTERS ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON

PROCESS PHENOMENON	ASSOCIATED TASKS
Maneuver Unit Combat:	
1. Force participation	1,2,8
2. Initial deployments of weapons	1,2,9
3. Maneuver patterns of individual weapons	1,2
4. Target acquisition capabilities	3
5. Target identification capabilities	3
6. Target selection (and target switching)	6
7. Decision to fire	6
8. Ordnance selection	7
9. Time to fire or firing rate	5
10. Accuracy of fire	4
11. Fire suppression	1,2,3,4,5,6
12. Employment of obscuration	8
Artillery Fire:	
1. Ordnance selection	7
2. Target element acquisition and selection (if point fire)	3,6
3. Decision to fire	6
4. Delivery pattern	7
5. Delivery accuracy	4 or 5
6. Target posture	1,2,6,13
7. Suppressive effects of fire	3,4,5,6,13
8. Effects of fire on communications and decision-making ability	8,12
9. Time to fire or firing rate	5
Air-To-Ground Attacks:	
1. Ability to acquire (or reacquire) the target	3
2. Engagement decision (whether to attack the target)	6
3. Ordnance selection	7
4. Target element acquisition and selection (if point fire)	3,6
5. Aircraft standoff distance and/or maneuver pattern over target	14
6. Weapon delivery accuracy	4 or 5
7. Target posture	1,2,6,13
8. Suppressive effects of the attack	3,4,5,6,13
9. Effects of the attack on communications and decision-making ability	8,12

-- Continued --

EXHIBIT B-2: TASK CLUSTERS ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON (Continued)

PROCESS PHENOMENON	ASSOCIATED TASKS
Air-To-Ground Attacks (cont.):	
10. Effects of the attack on air-field sortie generation capability (if target is an airfield)	15,16
11. Aircraft disengagement decision	6
Air-To-Air Combat:	
1. Engagement decisions (whether to engage and type of engagement)	6
2. Aircraft maneuver patterns	14
3. Target acquisition capabilities	3 or 10
4. Target selection	6
5. Ordnance selection	7
6. Time to fire	5
7. Accuracy of fire	4
8. Abort decisions	6
Air Defense:	
1. Coordination of fire	6,9
2. Target acquisition capabilities	3 or 10
3. Target selection	6
4. Decision to fire	6
5. Degraded capability of aircraft to destroy targets on the ground	14
6. Aircraft mission abort decisions	6
Mobility, Countermobility, and Survivability:	
1. Location, density, and extent of a minefield or obstacle	15,9
2. Attrition suffered when encountering a minefield	8,1
3. Delay in movement when encountering a minefield or obstacle	8,1
4. Reduction in movement rates due to minefields and obstacles	8,1
5. Increase in exposure due to encountering a minefield or obstacle	8,1
6. Delays in traveling on damaged roads	13,15
7. Delays in crossing rivers or gaps	13,15
8. Degree of protection afforded by a prepared defensive position	1,2,15
9. Location and extent of a prepared defensive position	9,15

-- Continued --

EXHIBIT B-2: TASK CLUSTERS ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON (Continued)

PROCESS PHENOMENON	ASSOCIATED TASKS
Intelligence and Electronic Warfare:	
1. Collection management decisions - what information to pursue	9
2. Collection management decisions - how to collect desired information	9
3. Target acquisition capabilities	10
4. Accuracy of target identification (including false targets)	11
5. Target processing time	11
6. Target location error	11
7. Timeliness of intelligence processing	11
8. Accuracy of intelligence processing	11
9. Completeness of intelligence processing	11
10. Decisions to jam	8
11. Effectiveness of jamming	12
12. Collection management decisions - location of sensors	9
Communications:	
1. Time to transmit message	12
2. Message content	12
3. Transmission accuracy	12
4. Reception accuracy	12
Mission Assignment, Organization for Combat, and Resource Allocation:	
1. Initial deployments of maneuver units	9
2. Changes in these deployments	9
3. Cross attachments among maneuver units	9
4. Allocation and/or positioning of attack helicopters	9
5. Allocation and/or positioning of field artillery forces	9
6. Allocation and/or positioning of CAS/BI aircraft	9
7. Allocation and/or positioning of air defense forces	9
8. Allocation and/or positioning of target acquisition resources	9
9. Allocation and/or positioning of supply points	9

-- Continued --

EXHIBIT B-2: TASK CLUSTERS ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON (Continued)

PROCESS PHENOMENON	ASSOCIATED TASKS
Mission Assignment, Organization for Combat, and Resource Allocation (cont.):	
10. Allocation of aircraft to missions	9
11. Delays in making and implementing decisions	9,13,14
Maneuver Control:	
1. Decisions to change the activity and/or location of a unit	8
2. Decisions to request and commit reserves	8
3. Decisions for unit retirement	8
4. Decisions to request fire support	8
5. Decisions to request engineer support	8
6. Decisions for the tactical relocation of supporting elements	8
7. Delays in making and implementing decisions	8
Fire Support Allocation:	
1. Target and mission priorities	8
2. Preferences for type and amount of support against a given target in given situation	8
3. Preferences for types and amounts of fire to be allocated to pre-planned missions	9
4. Criteria for ignoring targets or dropping them from list of acquired targets	8
5. Delays in making and implementing decisions	8
Resupply and Replacement:	
1. Locations of supply points	9
2. Stockpiling decisions at supply points	9
3. Quantities of supplies and replacements allocated to units on the battlefield	9
4. Delays in decisions to provide supplies or replacements	9

-- Continued --

EXHIBIT B-2: TASK CLUSTERS ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON (Concluded)

PROCESS PHENOMENON	ASSOCIATED TASKS
Resupply and Replacement (cont.):	
5. Time required to load and unload allocated supplies	18
Movement:	
1. Aircraft speeds and flight paths	14
2. Movement rates of ground forces	13
3. Route selection of forces moving on the ground	9
4. Degree of exposure of moving forces (air and ground)	13,14
Maintenance and Repair; Medical Support:	
1. Rates at which weapons and personnel are returned to duty given availability of support	16,17*
2. Availability of repair capability and medical support	9
3. Rate at which damaged capability of a facility is restored	15,16*
Construction, Maintenance, and Operation of Airfields:	
1. Sortie generating capability of an airfield	16,18
2. Rate of recovery of sortie generating capability following an attack on the airfield	15,16,18
3. Construction and repair rates for runways, aircraft shelters, and entire airfields	15
4. Delays in scrambling aircraft	14,16
5. Degree to which available shelters are in use when an attack of an airfield occurs	9,14
6. Aircraft basing rules	9

*Also included here might be other tasks whose effective performance can be damaged and require time to be reinstated or relearned.

EXHIBIT B-3: TASK ANALYSIS -- SUMMARY STATISTICS

TASK CLUSTER	NUMBER OF PROCESSES INVOLVING THIS TASK CLUSTER	NUMBER OF PHENOMENA INVOLVING THIS TASK CLUSTER
1	4	11
2	4	7
3	5	10
4	4	7
5	4	8
6	5	19*
7	4	5
8	7	20*
9	10*	27*
10	3	3
11	1	6
12	4	7
13	5	9
14	6	8
15	4	9
16	3	6
17	1	1
18	2	3

*Asterisks mark especially high values.

EXHIBIT B-4: FLEISHMAN ABILITY TAXONOMY

1. Verbal Comprehension: the ability to understand language.

2. Verbal Expression: the ability to utilize language (either oral or written) to communicate information or ideas to another person or persons.

3. Ideational Fluency: the ability to produce a number of ideas concerning a given topic.

4. Originality: the ability to produce unusual or clever responses related to a given topic or situation.

5. Memorization: the ability to memorize and retain new information which occurs as a regular or routine part of the task.

6. Problem Sensitivity: the ability to recognize or identify the existence of problems.

7. Mathematical Reasoning: the ability to reason abstractly using quantitative concepts and symbols.

8. Number Facility: the ability to manipulate numbers in numerical operations.

9. Deductive Reasoning: the ability to apply general concepts or rules to specific cases or to proceed from stated premises to their logical conclusions.

10. Inductive Reasoning: the ability to find the most appropriate general concepts or rules which fit sets of data or which explain how a given series of individual items are related to each other.

11. Information Ordering: the ability to apply rules or objectives to given information in order to arrange that information into the best or most appropriate sequence.

12. Category Flexibility: the ability to produce alternative groupings or categorizations for a set of items, based upon rules or specifications produced by the individual who is carrying out the categorization.

13. Spatial Orientation: the ability to maintain one's orientation with respect to objects in space or to comprehend the position of objects in space with respect to the observer's position.

14. Visualization: the ability to manipulate or transform the visual images of spatial patterns or objects into other spatial arrangements.

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EXHIBIT B-4: FLEISHMAN ABILITY TAXONOMY
(Continued)

15. Speed of Closure: the speed with which a set of apparently disparate sensory elements can be combined and organized into a single, meaningful pattern or configuration.

16. Flexibility of Closure: the ability to identify or detect a previously specified stimulus configuration which is embedded in a more complex sensory field.

17. Selective Attention: the ability to perform a task in the presence of distracting stimulation or under monotonous conditions without significant loss in efficiency.

18. Time Sharing: the ability to utilize information obtained by shifting between two or more channels of information.

19. Perceptual Speed: the speed with which sensory patterns or configurations can be compared in order to determine identity or degree of similarity.

20. Static Strength: the degree of muscular force which can be exerted against a fairly immovable or heavy external object in order to lift, push, or pull that object.

21. Explosive Strength: the ability to expend energy in one or a series of explosive muscular acts.

22. Dynamic Strength: the power of arm and trunk muscles to repeatedly or continuously support or move the body's own weight.

23. Stamina: the capacity to maintain physical activity over prolonged periods of time.

24. Extent Flexibility: the ability to extend, flex, or stretch muscle groups.

25. Dynamic Flexibility: the ability to make repeated trunk and/or limb flexing movements where both speed and flexibility of movement are required.

26. Gross Body Equilibrium: the ability to maintain the body in an upright position or to regain body balance especially in situations where equilibrium is threatened or temporarily lost.

27. Choice Reaction Time: the ability to select and initiate the appropriate response relative to a given stimulus in the situation where two or more stimuli are possible and where the appropriate response is selected from two or more alternatives.

-- Continued --

EXHIBIT B-4: FLEISHMAN ABILITY TAXONOMY
(Concluded)

28. Reaction Time: the speed with which a single motor response can be initiated after the onset of a single stimulus.

29. Speed of Limb Movement: the speed with which discrete movements of the arms or legs can be made.

30. Wrist-Finger Speed: the speed with which discrete movements of the fingers, hands, and wrists can be made.

31. Gross Body Coordination: the ability to coordinate movements of the trunk and limbs.

32. Multilimb Coordination: the ability to coordinate the movements of two or more limbs (e.g., two legs, two hands, one leg and one hand).

33. Finger Dexterity: the ability to make skillful, coordinated movements of the fingers where manipulations of objects may or may not be involved.

34. Manual Dexterity: the ability to make skillful, coordinated movements of a hand, or of a hand together with its arm.

35. Arm-Hand Steadiness: the ability to make precise, steady arm-hand positioning movements where both strength and speed are minimized.

36. Rate Control: the ability to make timed, anticipatory motor adjustments relative to changes in the speed and/or direction of a continuously moving object.

37. Control Precision: the ability to make controlled muscular movements necessary to adjust or position a machine or equipment control mechanism.

ability was assigned a value between 0 and 7, where 0 means that the ability was not required to perform the associated tasks, 1 means that the ability is required at a very low level of proficiency, 7 implies that the ability is required at a very high level of proficiency, and a rating of 2, 3, 4, 5, or 6 means that some intermediate level of proficiency is required. These proficiency ratings, which were assigned by the project team for each of the 18 task clusters, are displayed in exhibit B-5. Exhibit B-6 presents summary statistics concerning the ratings. As discussed in section 2.2, these statistics provide an indication of the degree to which various types of abilities are required by the phenomena represented in combat models.

EXHIBIT B-5: ANALYSIS OF ABILITIES REQUIRED FOR EACH TASK CLUSTER

	TASK CLUSTER																	
ABILITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	2	2	0	1	2	2	2	4	5	2	4	3	2	4	2	3	6	1
2	0	0	1	0	0	0	0	4	4	2	4	3	0	3	2	2	4	1
3	3	3	1	0	2	3	3	3	4	1	5	2	2	3	1	3	6	1
4	4	4	1	0	2	4	4	5	5	1	5	3	2	3	1	3	5	1
5	3	3	3	1	2	3	3	4	4	3	5	3	3	3	2	2	3	1
6	5	5	2	2	2	5	4	6	6	2	4	2	3	4	1	4	5	2
7	1	1	0	1	1	3	3	4	5	1	5	2	1	4	1	3	3	1
8	1	0	1	0	3	3	3	4	4	2	4	2	1	4	2	2	3	2
9	3	3	1	1	2	3	3	4	4	1	5	2	2	4	1	3	3	1
10	3	3	2	1	0	3	3	4	4	3	5	1	2	2	1	3	5	2
11	1	1	0	0	2	3	3	3	4	2	4	1	2	2	2	3	3	2
12	1	1	1	0	1	1	1	2	4	3	4	1	1	1	1	2	3	2
13	5	5	5	4	1	4	2	0	0	0	0	0	4	5	2	1	1	1
14	3	3	3	2	2	3	3	5	5	2	5	1	2	4	3	3	4	2
15	4	4	5	4	0	4	4	5	4	3	5	5	3	4	1	4	5	1
16	5	5	5	5	1	4	4	4	3	3	5	5	3	4	2	2	2	2
17	5	5	6	7	5	7	5	5	4	5	4	5	4	5	5	3	3	3
18	4	3	5	3	2	4	4	5	4	2	5	5	3	5	1	1	1	1

-- Continued --

EXHIBIT B-5: ANALYSIS OF ABILITIES REQUIRED FOR EACH TASK CLUSTER
(Concluded)

	TASK CLUSTER																	
ABILITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19	3	3	6	5	2	4	4	5	4	4	5	4	3	4	3	3	5	3
20	2	3	0	1	3	0	0	0	0	0	0	0	2	1	5	3	1	5
21	2	5	0	1	2	0	0	0	0	0	0	0	2	1	2	2	1	3
22	1	3	0	1	1	0	0	0	0	0	0	0	1	1	3	3	1	3
23	1	6	0	0	4	0	0	0	0	0	0	0	1	1	6	2	1	5
24	1	4	0	1	2	0	0	0	0	0	0	1	1	1	3	3	1	2
25	1	4	0	1	3	0	0	0	0	0	0	0	1	1	5	3	1	5
26	1	3	0	0	1	0	0	0	0	0	0	0	1	5	2	1	1	1
27	5	5	6	5	3	6	5	6	5	5	4	5	4	5	3	3	4	2
28	4	4	0	4	3	0	0	0	0	0	0	2	3	5	2	2	2	1
29	3	4	0	4	2	0	0	0	0	0	0	1	3	3	1	1	1	2
30	3	1	0	2	1	0	0	0	0	0	0	4	2	2	1	1	2	1
31	0	5	0	0	1	0	0	0	0	0	0	0	0	0	3	1	1	2
32	3	0	0	3	2	0	0	0	0	0	0	1	3	4	3	3	4	2
33	2	0	0	0	1	0	0	0	0	0	0	2	1	1	1	4	5	1
34	2	0	0	0	2	0	0	0	0	0	0	1	2	2	3	5	6	2
35	1	1	0	4	1	0	0	0	0	0	0	2	1	2	1	4	6	1
36	3	2	4	5	3	0	0	0	0	0	0	0	2	5	3	2	0	2
37	4	0	0	5	4	0	0	0	0	0	0	3	4	5	4	4	0	3

EXHIBIT B-6: ABILITIES ANALYSIS -- SUMMARY STATISTICS

ABILITY	MINIMUM PROFICIENCY OVER ALL TASK CLUSTERS	AVERAGE PROFICIENCY OVER ALL TASK CLUSTERS	AVERAGE PROFICIENCY WEIGHTED BY NUMBER OF PHENOMENA INVOLVED
1	0	2.6	2.6
2	0	1.7	1.9
3	0	2.6	2.7
4	0	2.9	3.4
5	1	2.9	3.1
6	1	3.6	4.1*
7	0	2.2	2.7
8	0	2.3	2.6
9	1	2.6	2.9
10	0	2.6	2.8
11	0	2.1	2.3
12	0	1.7	1.8
13	0	2.2	2.2
14	1	3.1	3.4
15	0	3.6	3.8
16	1	3.6	3.7
17	3*	4.9*	5.0*
18	1	3.3	3.7
19	2*	4.0*	4.0*
20	0	1.4	1.1
21	0	1.2	0.9
22	0	1.0	0.7
23	0	1.5	1.1
24	0	1.1	0.8
25	0	1.4	1.0
26	0	0.9	0.7
27	2*	4.6*	4.9*
28	0	1.8	1.4
29	0	1.4	1.1
30	0	1.1	0.9
31	0	0.7	0.5
32	0	1.6	1.2
33	0	1.0	0.6
34	0	1.4	0.9
35	0	1.3	0.8
36	0	1.9	1.5
37	0	2.0	1.7

*Asterisks mark especially high values.

APPENDIX C

SENSITIVITY ANALYSES OF SIMULATIONS

This appendix describes work performed in examination of sensitivities of force-on-force combat models to obtain information on the relative need for model improvements in human factors areas. Included is summary information concerning model sensitivity analyses performed specifically for this study (in section C.1) and summary information concerning previous analyses which were used to assess the sensitivity of models to human factors assumptions (in section C.2). Finally, section C.3 combines the assembled information into a rough assessment of the relative potential sensitivity of combat models to assumptions made in various human factors areas.

C.1 SENSITIVITY ANALYSES PERFORMED FOR THIS STUDY

Sensitivity analyses were conducted using two VRI models: BLDM, a battalion-level model; and VECTOR-2, used as a corps-level model in this analysis. Results from each model are described separately in the two subsections which follow. Little attempt is made here to interpret the results; the primary purpose of this section is to display summary results in a useful format.

C.1.1 ANALYSIS WITH BLDM

The BLDM model was employed in a NATO scenario with a delaying US company team opposed by two reinforced Soviet tank battalions. A 1990s time frame was assumed. The following runs were made:

(1) two baseline runs (designated runs 1 and 22) for comparison with excursions;

(2) runs to investigate the impact of time required to fire a round (runs 2, 5, 6, 9, 10, 13, and 14);

(3) two runs (numbers 3 and 12) to investigate the effect of target priorities (or the effect of ability to identify targets);

(4) one run (number 4) to investigate the effect of target acquisition rates;

(5) three runs (numbers 7, 8, and 15) to investigate the impact of open-fire decisions;

(6) several runs (runs 11 and 16 through 21) which examined the portion of the force participating in the engagement (this could vary as a result of weapons being poorly deployed or because individuals did not participate in the engagement); and

(7) several runs to determine the impact of varying round dispersions (runs 23 through 42).

The runs are summarized in exhibit C-1. For each run, the exhibit displays both the loss exchange ratio (the number of Red weapons lost divided by the number of Blue weapons lost) and the percent survivor ratio (percent of Blue survivors divided by percent Red survivors) at the end of each run (i.e., after 8.5 minutes of simulated combat). These same two measures are plotted for several sets of the runs in exhibits C-2 through C-11.

C.1.2 ANALYSIS WITH VECTOR-2

The analysis with the VECTOR-2 model employed a NATO scenario involving the US V Corps. A summary description of the scenario and data used can be found in [VRI, 1981a].

EXHIBIT C-1: SUMMARY OF BLDM EXCURSIONS

RUN NUMBER	DESCRIPTION	LOSS EXCHANGE RATIO	SURVIVOR RATIO
1	Baseline run	14.34	6.04
2	Double time to fire for Blue	4.56	0.93
3	Set priorities equal for Blue	8.90	3.41
4	Double time for stationary Blue to acquire targets	14.34	6.04
5	Double time to fire first round for Blue	5.52	1.21
6	Double time to fire subsequent round for Blue	7.88	2.20
7	Halve the effective maximum firing range for Blue weapon types	1.23	0.27
8	Reduce maximum firing range for Blue by 10%	10.44	3.85
9	Increase firing time for Blue by 50%	6.53	1.59
10	Increase first round firing time for Blue by 50%	7.35	1.99
11	Reduce the number of Blue weapons by 25%	6.86	1.05
12	Reverse order of Blue's priorities	6.31	1.72
13	Increase firing time for Blue by 25%	10.32	4.03
14	Increase firing time for Blue by 75%	5.21	1.11
15	Reduce maximum firing range for Blue by 25%	4.54	0.92
16	Decrease number of Blue weapons by 10%	10.15	3.08
17	Decrease number of Blue weapons by 20%	7.88	1.57
18	Decrease number of Blue weapons by 30%	6.19	0.86
19	Decrease number of Blue and Red weapons by 10%	14.26	5.97
20	Decrease number of Blue and Red weapons by 20%	14.09	5.84
21	Decrease number of Blue and Red weapons by 50%	12.35	4.85
22	Revised baseline run for use with dispersion sensitivities	14.04	6.59

-- Continued --

EXHIBIT C-1: SUMMARY OF BLDM EXCURSIONS
(Continued)

RUN NUMBER	DESCRIPTION	LOSS EXCHANGE RATIO	SURVIVOR RATIO
23	Increase all Blue dispersions by 25% using new base	10.48	4.12
24	Increase all Blue dispersions by 50% using new base	9.30	2.75
25	Increase all Blue dispersions by 75% using new base	7.95	1.96
26	Increase all Blue dispersions by 100% using new base	6.84	1.51
27	Increase Blue first round dispersions by 25% using new base	11.90	5.06
28	Increase Blue first round dispersions by 50% using new base	10.96	4.43
29	Increase Blue first round dispersions by 75% using new base	10.07	3.46
30	Increase Blue first round dispersions by 100% using new base	9.49	2.96
31	Increase Blue subsequent round dispersions by 25% using new base	11.96	5.48
32	Increase Blue subsequent round dispersions by 50% using new base	10.13	3.64
33	Increase Blue subsequent round dispersions by 75% using new base	9.57	3.02
34	Increase Blue subsequent round dispersions by 100% using new base	8.48	2.25
35	Increase Blue round dispersions following a hit by 50% using new base	12.06	5.62
36	Increase Blue round dispersions following a hit by 75% using new base	11.41	5.18
37	Increase Blue round dispersions following a hit by 100% using new base	10.94	4.84

-- Continued --

EXHIBIT C-1: SUMMARY OF BLDM EXCURSIONS
(Concluded)

RUN NUMBER	DESCRIPTION	LOSS EXCHANGE RATIO	SURVIVOR RATIO
38	Increase Blue round dispersions following a miss by 25% using new base	13.24	6.16
39	Increase Blue round dispersions following a miss by 50% using new base	11.72	4.91
40	Increase Blue round dispersions following a miss by 75% using new base	10.83	4.36
41	Increase Blue round dispersions following a miss by 100% using new base	10.04	3.54
42	Increase Blue round dispersions following a hit by 25% using new base	13.37	6.27

EXHIBIT C-2: EFFECT OF BLUE'S TIME TO FIRE
(END OF GAME)

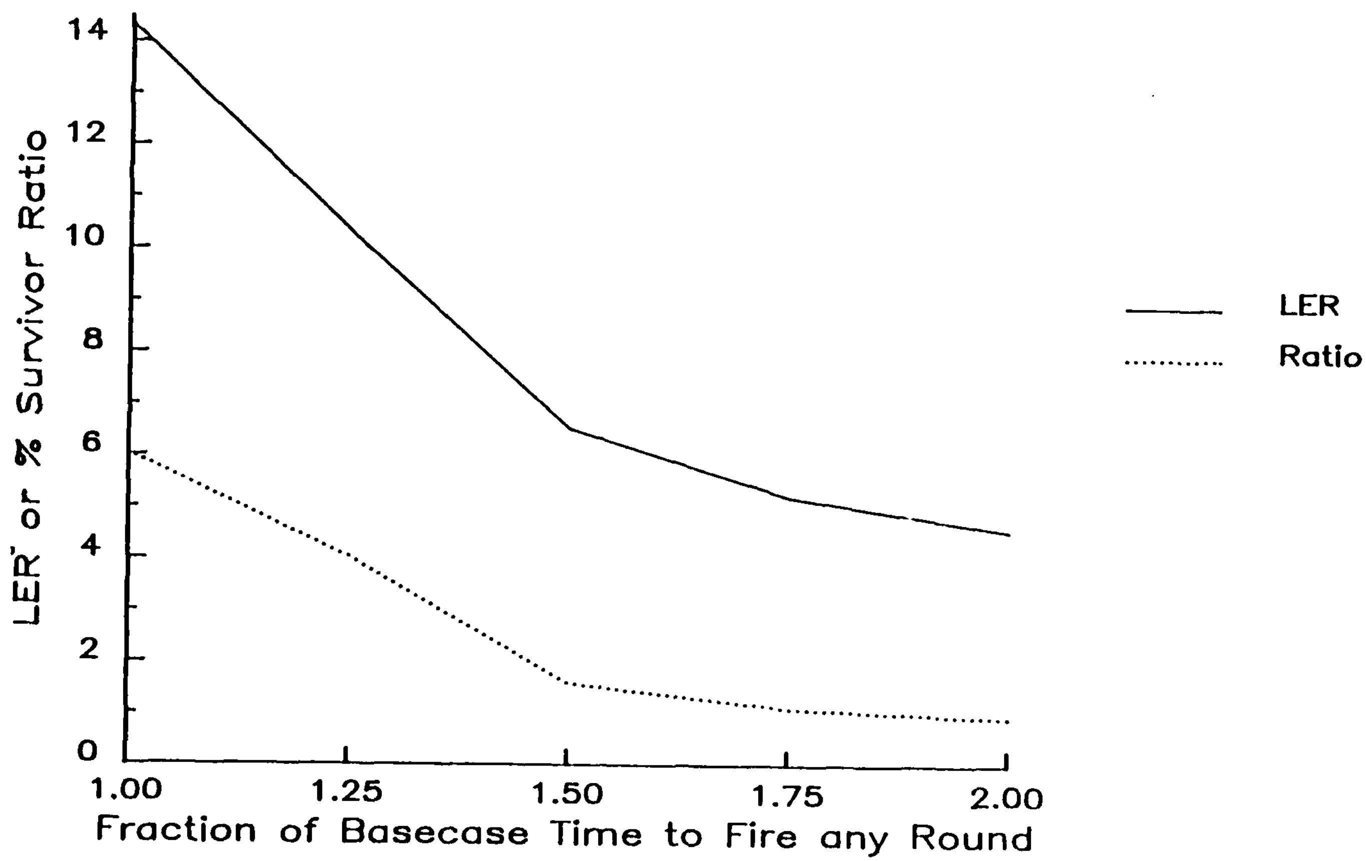


EXHIBIT C-3: EFFECT OF BLUE'S PRIORITIES
(END OF GAME)

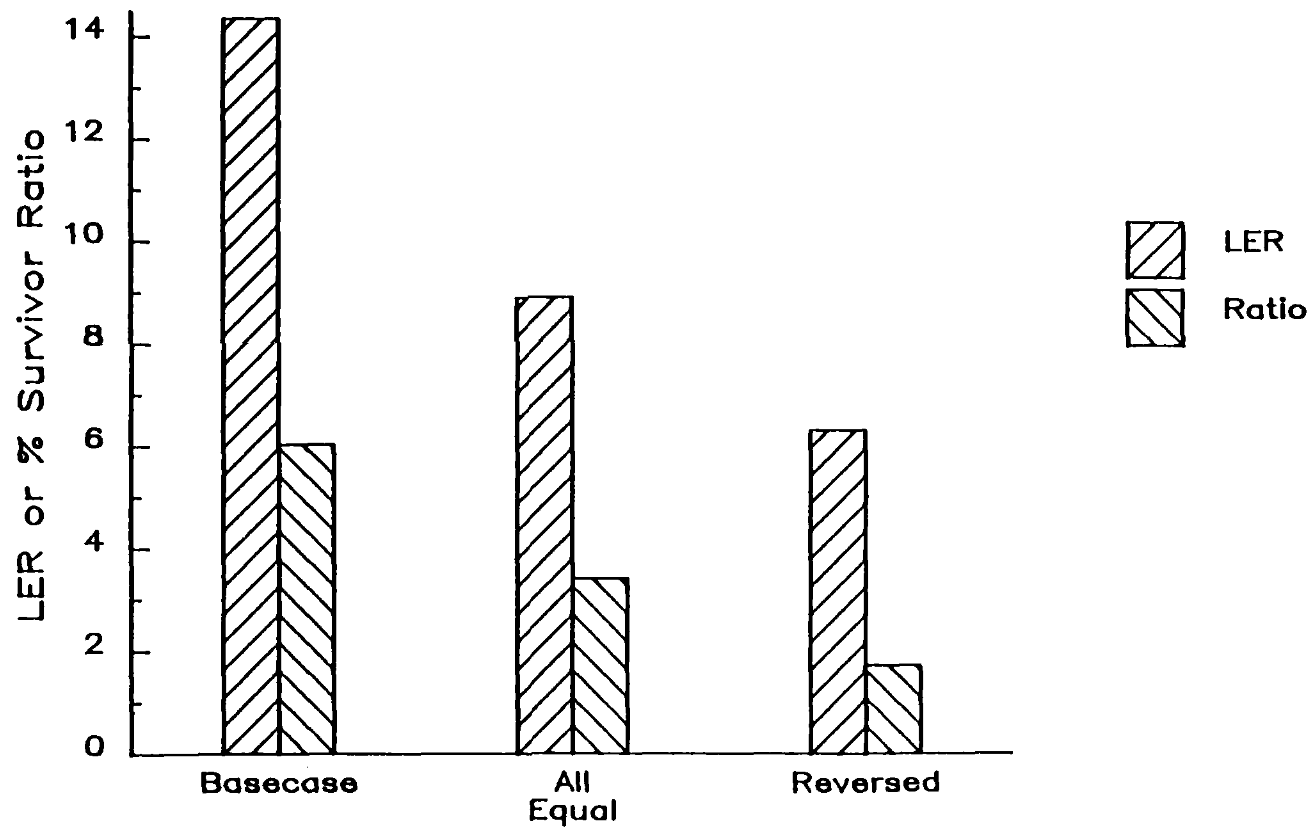


EXHIBIT C-4: EFFECT OF BLUE'S OPEN FIRE DECISION
(END OF GAME)

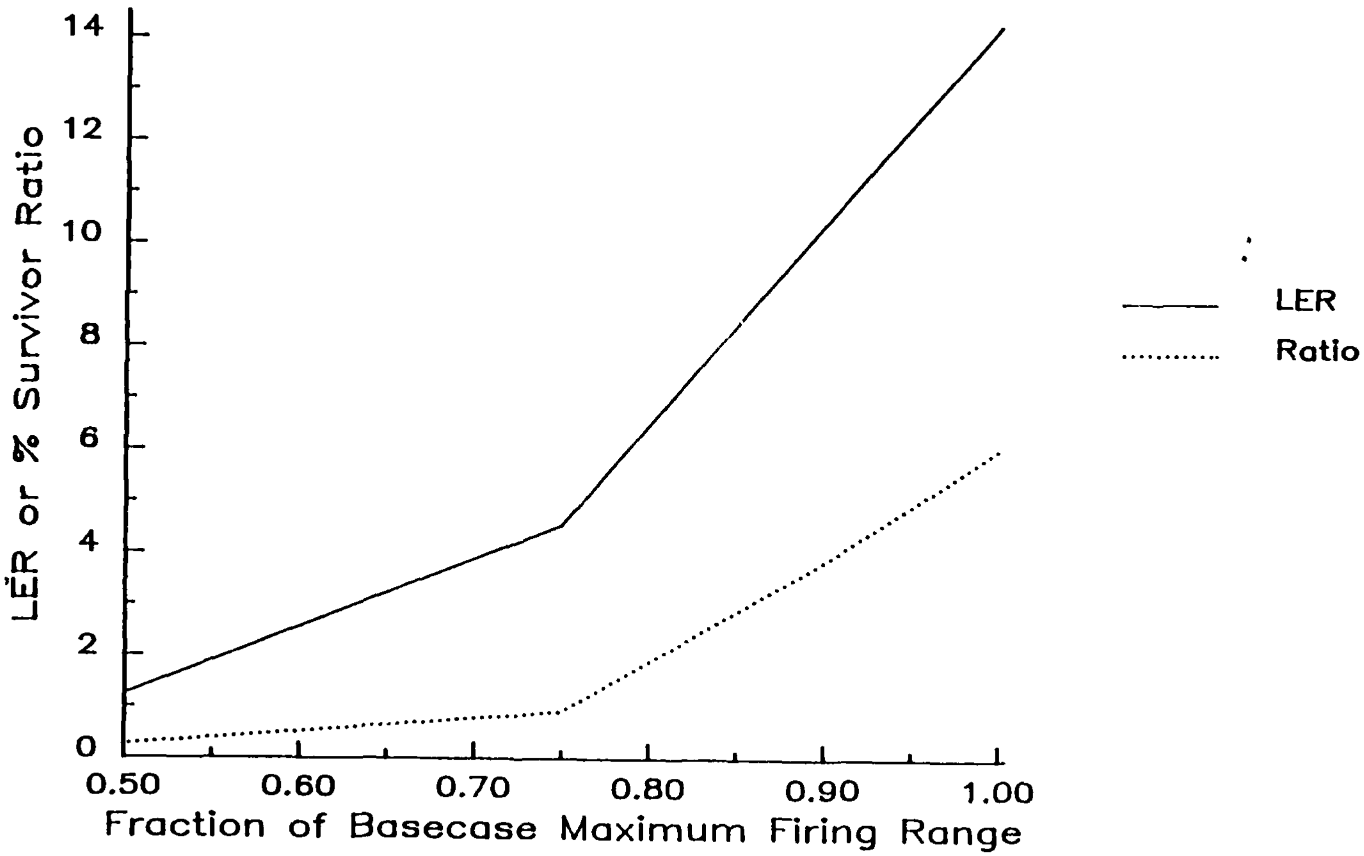


EXHIBIT C-5: EFFECT OF NUMBER OF BLUE PARTICIPANTS
(END OF GAME)

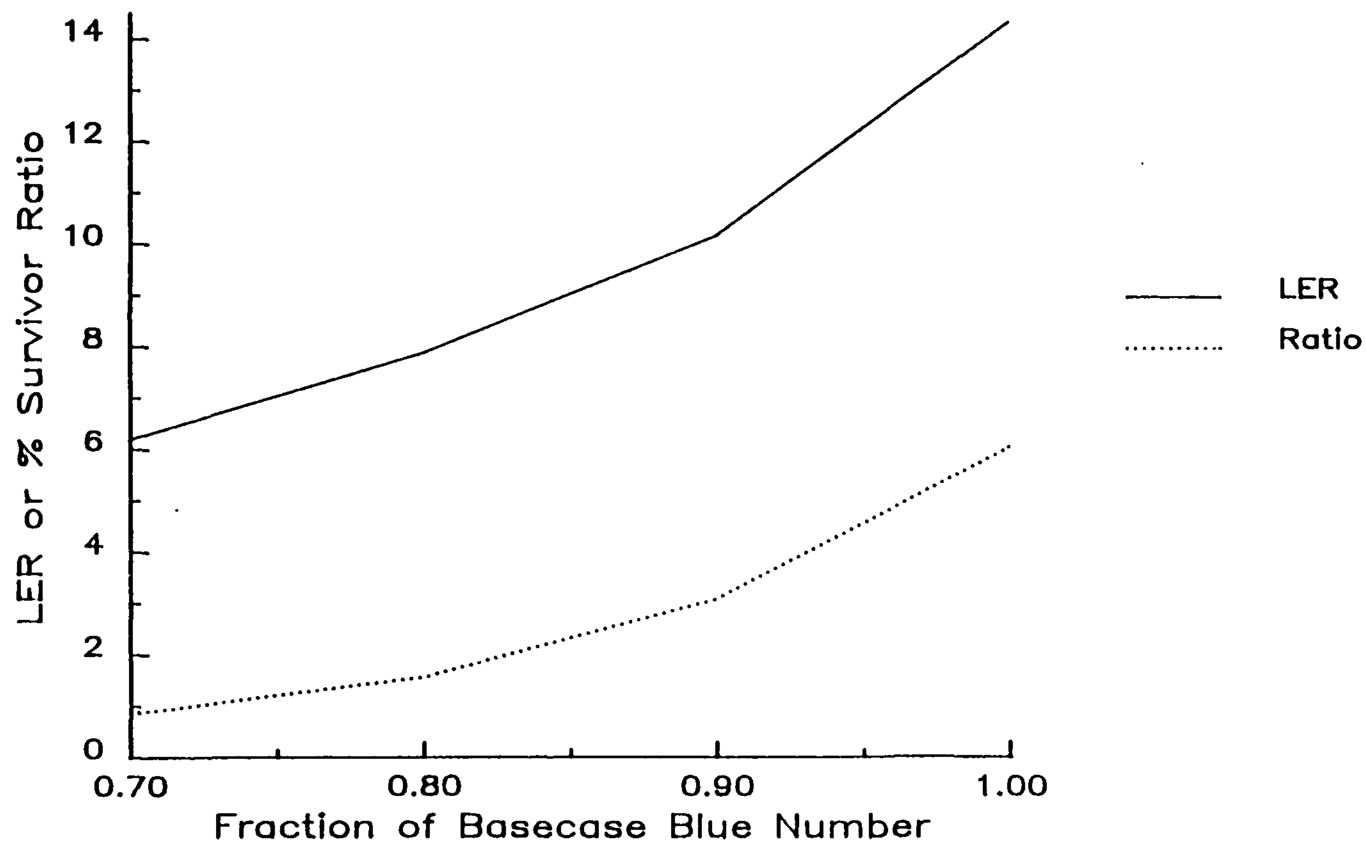


EXHIBIT C-6: EFFECT OF NUMBER OF BLUE AND RED PARTICIPANTS
(END OF GAME)

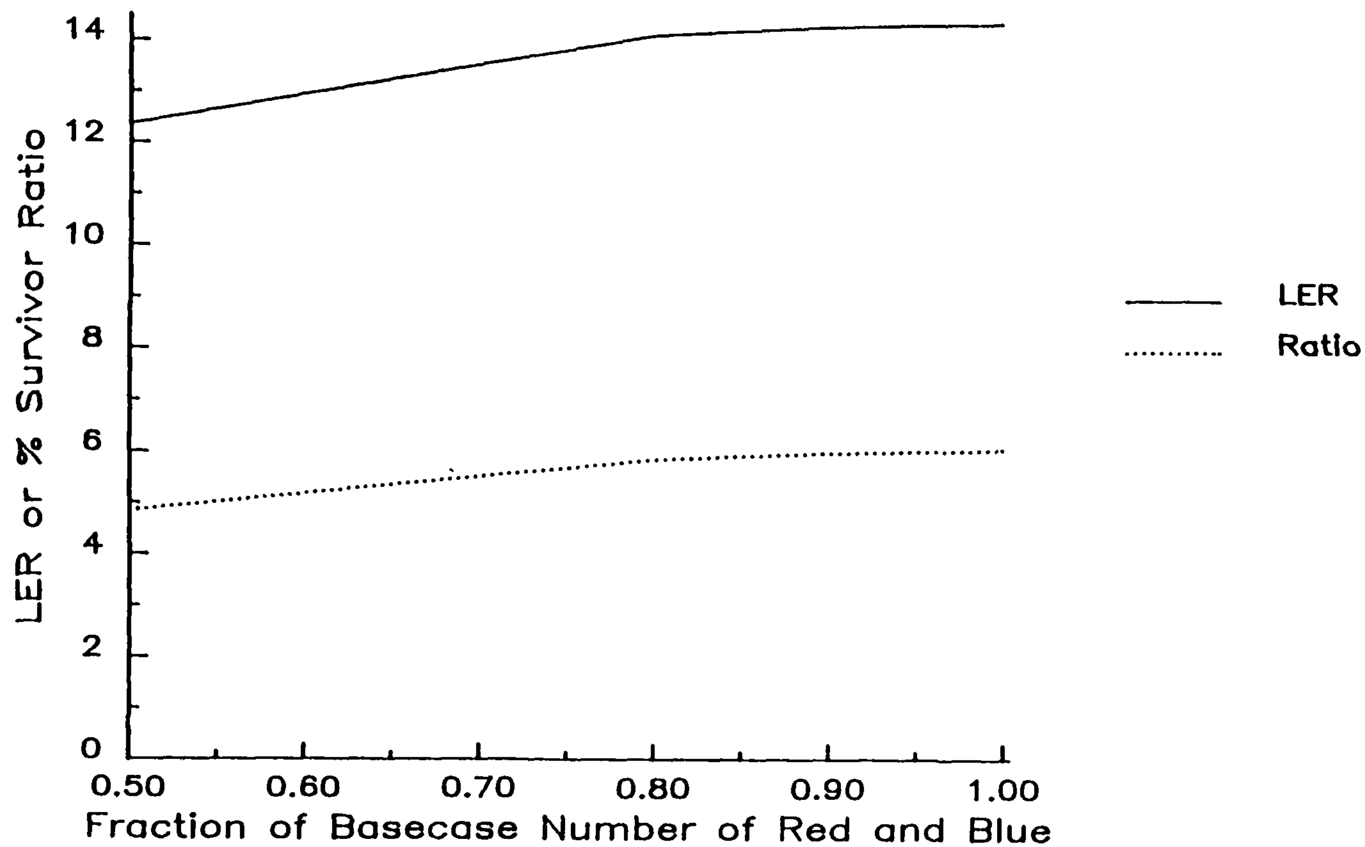


EXHIBIT C-7: EFFECT OF BLUE ROUND DISPERSIONS
(END OF GAME)

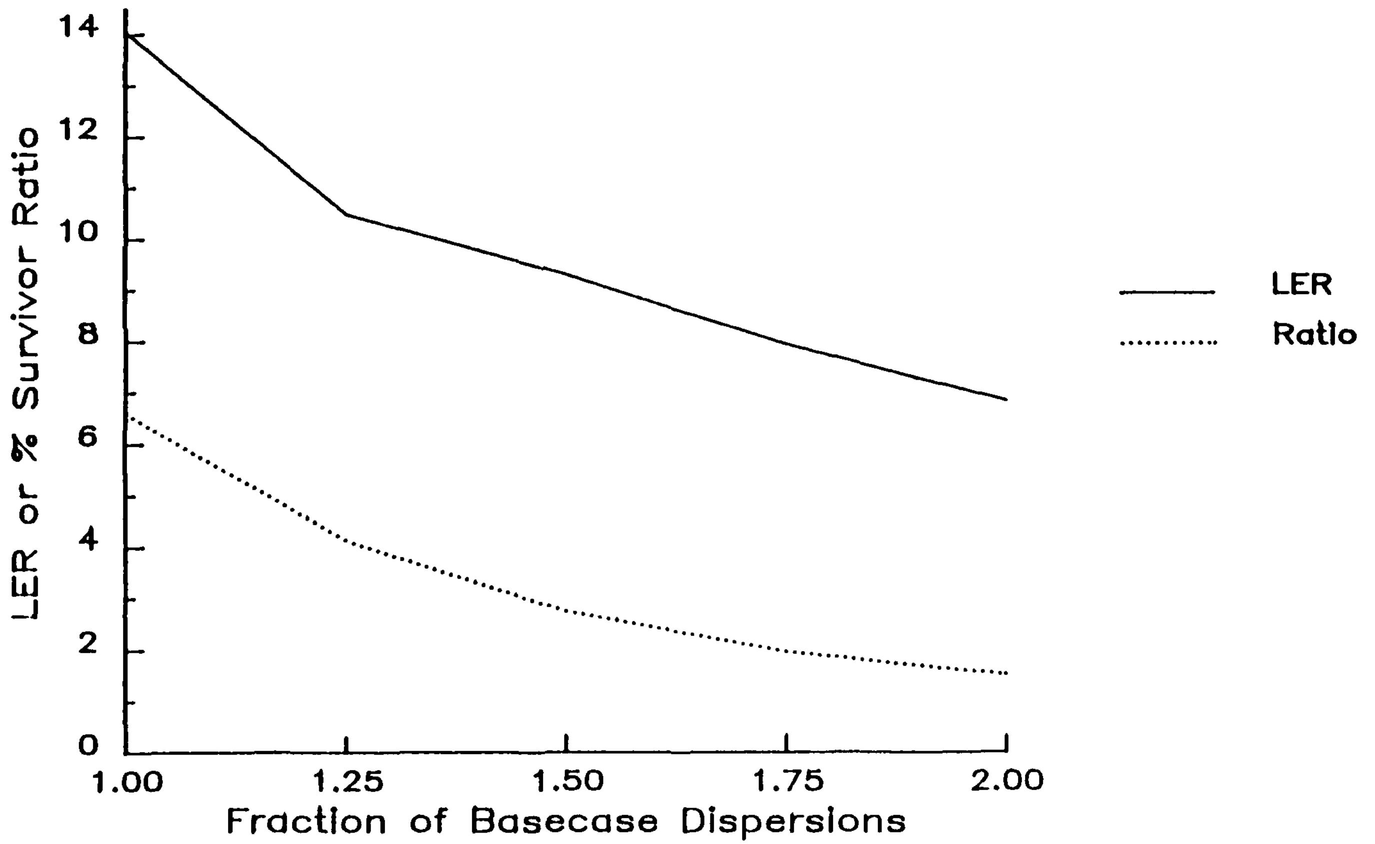


EXHIBIT C-8: EFFECT OF BLUE FIRST ROUND DISPERSIONS
(END OF GAME)

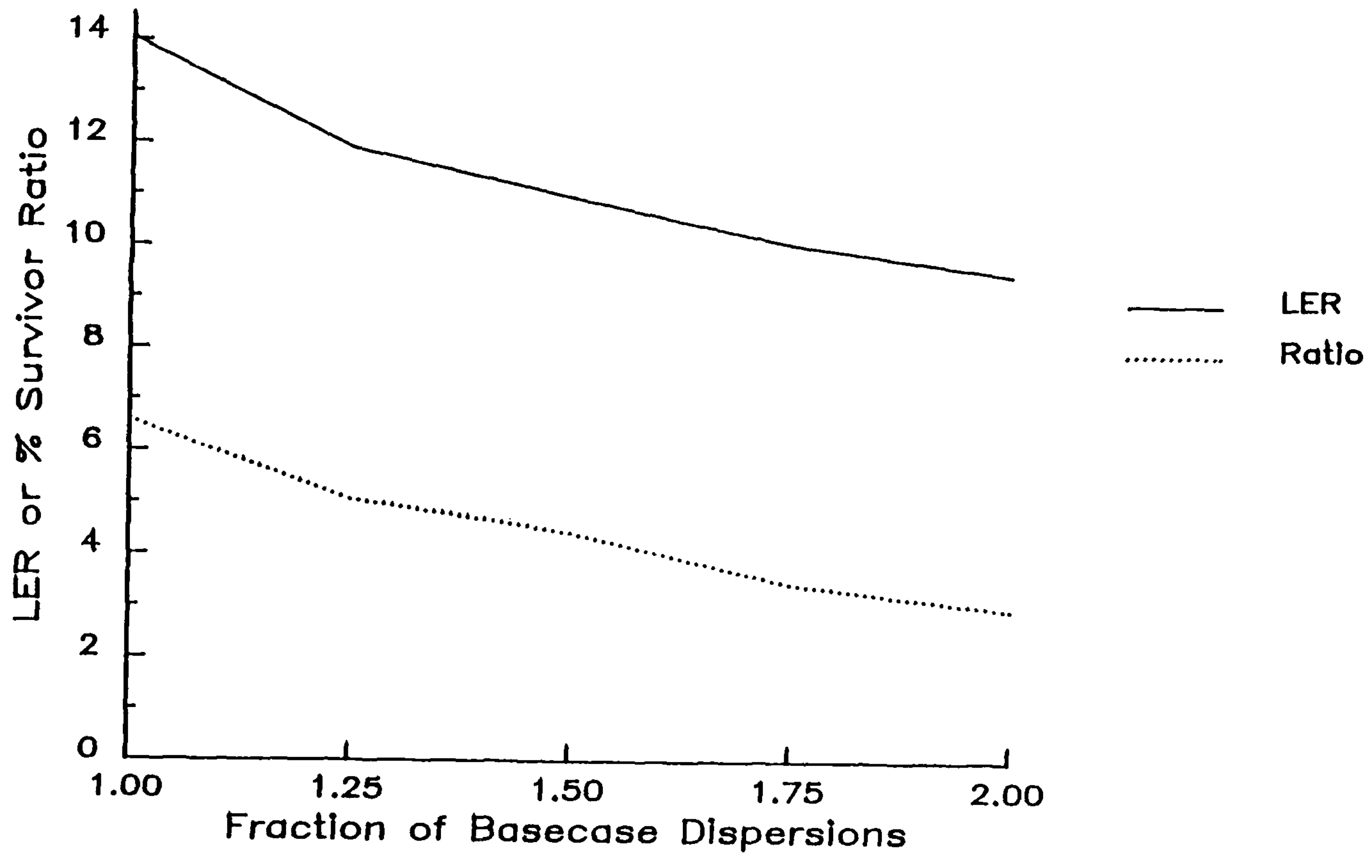


EXHIBIT C-9: EFFECT OF BLUE SUBSEQUENT ROUND DISPERSIONS
(END OF GAME)

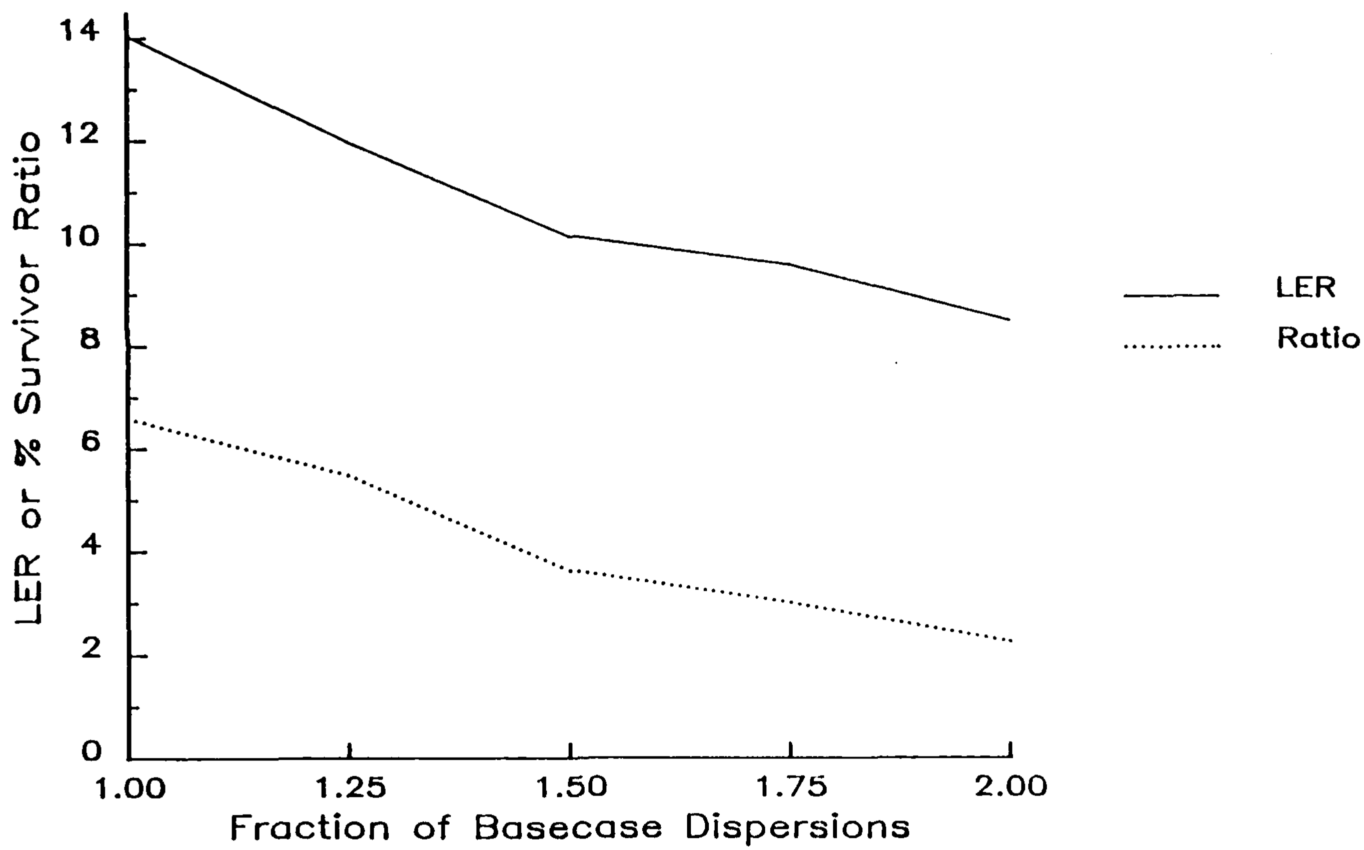


EXHIBIT C-10: EFFECT OF BLUE ROUND DISPERSION FOLLOWING A MISS
(END OF GAME)

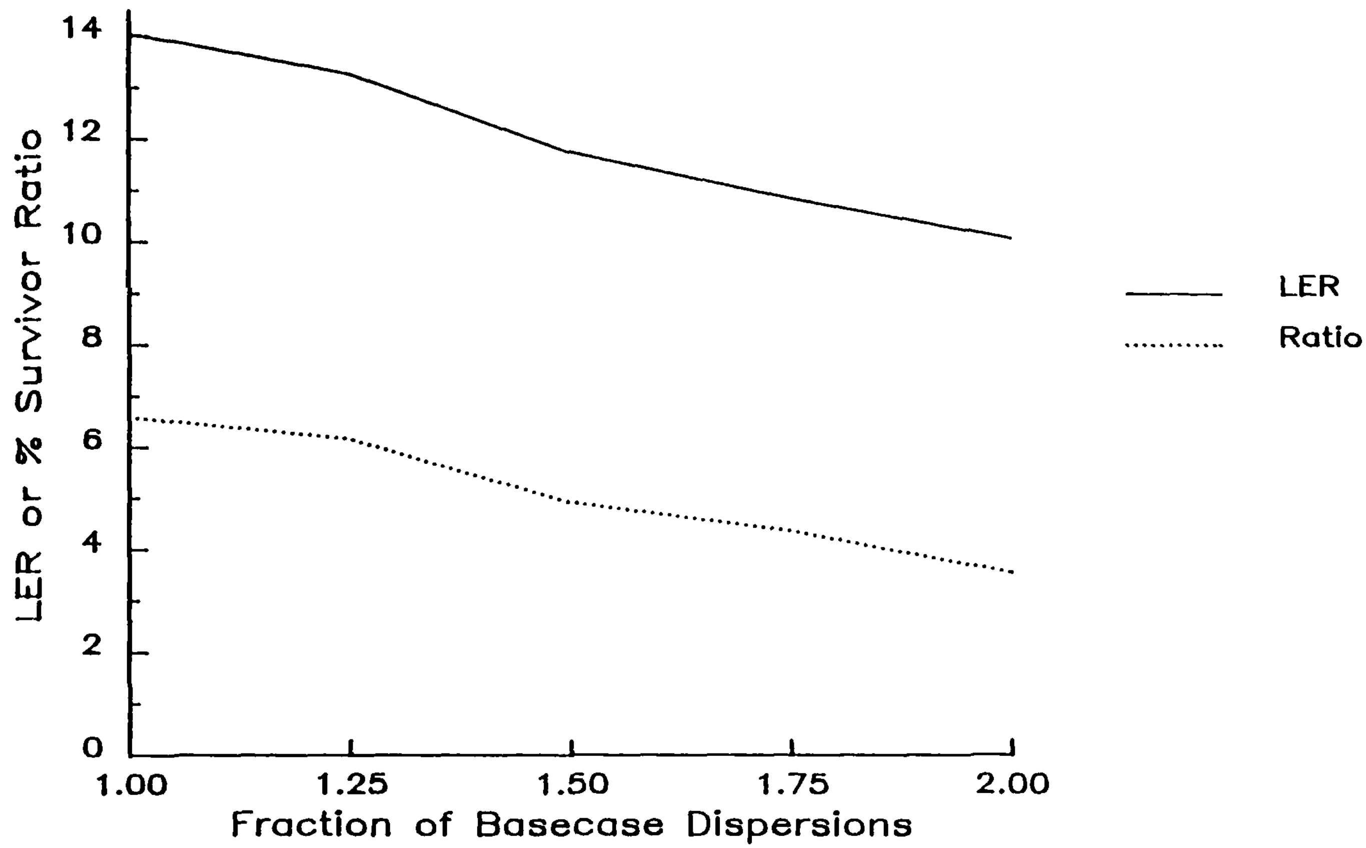
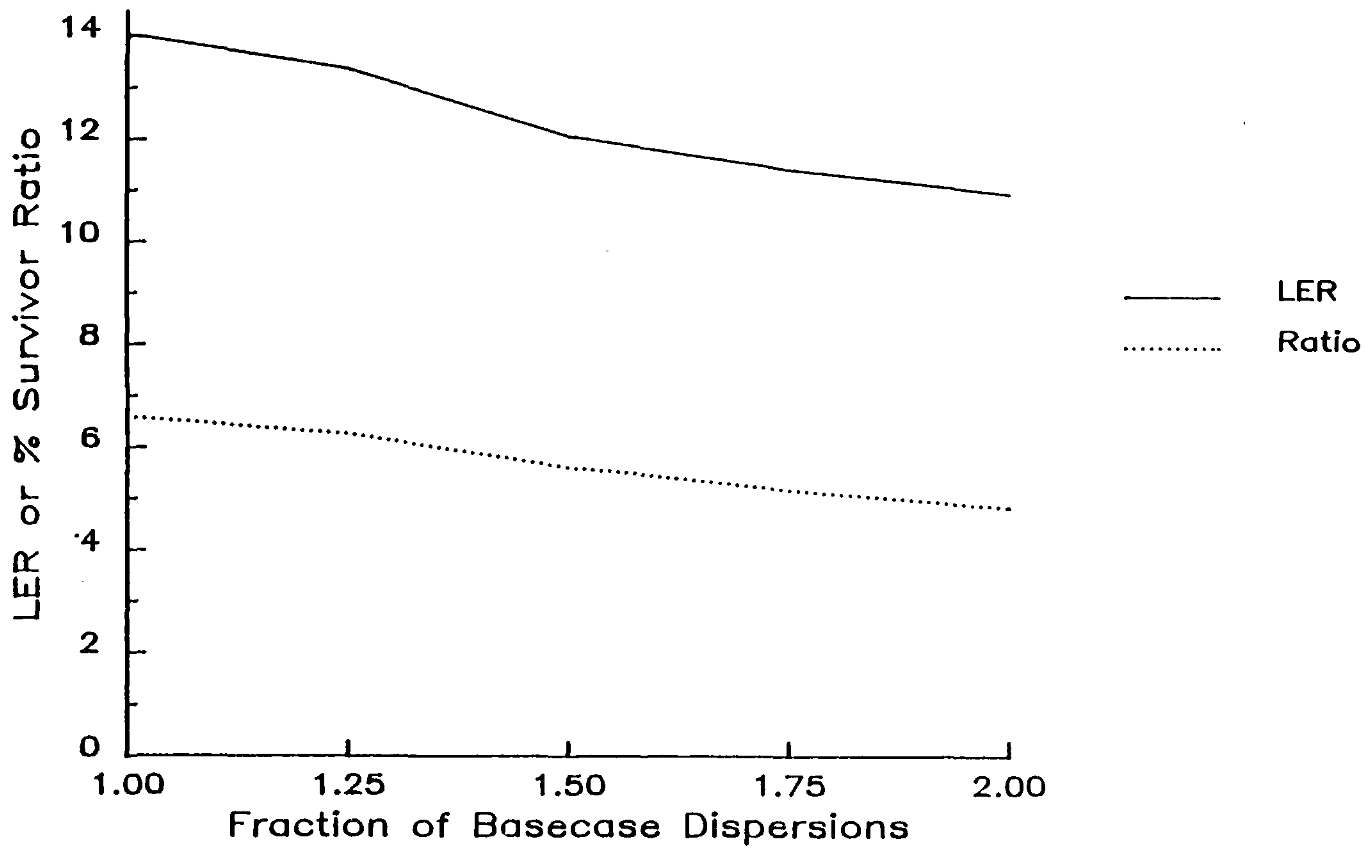


EXHIBIT C-11: EFFECT OF BLUE ROUND DISPERSION FOLLOWING A HIT
(END OF GAME)



The following listing summarizes the runs that were made. Except where noted otherwise, each run simulated a single day of combat in the entire corps area. A quantitative comparison of run results follows the listing.

(1) A baseline run was made with which to compare excursions. This five-day run corresponds to the "NATO reinforced case" described in [VRI, 1981a].

(2) Two runs investigated artillery delivery accuracy and/or target location errors.

(3) Two runs modified artillery effects data. This could represent changes in artillery ordnance selection or target posture. Although not represented directly by these runs, the impact of changes in artillery delivery patterns might be indirectly inferred from these results.

(4) Two runs investigated target acquisition capabilities and/or decisions to fire by air defense units. The second of these was a two-day run.

(5) One run examined the suppressive effects of artillery in counterbattery fire.

(6) One run varied the effective fields of view of Blue counterbattery radars, which could change as a result of decisions concerning siting of sensors.

(7) Two runs examined variations in the time required to process an acquired target by sensors used for fire support allocation.

(8) One run substantially increased communication delays (these could also be viewed as decision delays).

(9) Three runs involved changes to the amount of artillery fire allocated against a target.

(10) One run investigated the effect of round selection for artillery (in particular, employing Copperhead rounds in preference to conventional 155mm rounds against front-line maneuver units).

(11) Two runs involved modifications to achievable firing rates for artillery.

(12) One run modified the probability of finding a target for Copperhead.

(13) Two runs investigated the impact of changes in the time to restore to service a damaged command post.

Exhibit C-12 displays summary results of all the runs. The first column of the exhibit indicates the group of runs involved, using the numbers from the above listing. This is followed by a brief description of the modifications made for the run. Finally, the last four columns indicate the overall combat vehicle loss exchange ratio (the ratio of Red losses to Blue losses) and the average distance the Blue force withdrew, and the percentage deviation from the baseline run for each of these two measures.

C.2 SENSITIVITY ANALYSES FROM PREVIOUS STUDIES

Because of the large number of human factors areas of interest in this study, it was not possible to perform model runs addressing model sensitivity to all of them. Fortunately, model runs made for previous studies provide some of the needed information; information concerning these runs was assembled as part of task 3.

EXHIBIT C-12: SUMMARY OF VECTOR-2 EXCURSIONS

RUN GROUP	DIFFERENCES FROM BASELINE RUN	LOSS EXCHANGE RATIO		AVERAGE BLUE WITHDRAWAL	
		ACTUAL	% DEVIATION	ACTUAL	% DEVIATION
1.	None				
	One day results-	4.7	0	10.0	0
	Two day results-	4.0	0	17.5	0
2.	A. Double CEPs for all conventional Red artillery	5.3	13	8.3	-17
	B. Halve CEPs for all conventional Red artillery	4.2	-11	10.4	4
3.	A. Double lethal radii for all Red conventional artillery volleys	1.9	-60	17.4	74
	B. Halve lethal radii for all Red conventional artillery volleys	6.7	43	6.0	-40
4.	A. Halve length of time Red aircraft are exposed to air defense fire	4.7	0	10.0	0
	B. Reduce length of time Red aircraft are exposed by 90% (2 day run)	4.0	0	17.6	1
5.	Require Blue artillery engaged by opposing artillery to be unavailable for 30 minutes	4.7	0	9.7	-3
6.	Halve effective range of Blue counter-battery radar	4.3	-9	10.0	0
7.	A. Quadruple sensor processing times for Blue sensors	4.4	-6	9.8	-2
	B. Set all Blue sensor processing times to 0.	4.7	0	10.0	0
8.	Set all Blue communication delays to 16 minutes	4.7	0	10.2	2

-- Continued --

EXHIBIT C-12: SUMMARY OF VECTOR-2 EXCURSIONS
(Concluded)

RUN GROUP	DIFFERENCES FROM BASELINE RUN	LOSS EXCHANGE RATIO		AVERAGE BLUE WITHDRAWAL	
		ACTUAL	% DEVIATION	ACTUAL	% DEVIATION
9.	A. Double number of Blue artillery rounds allocated per target	6.0	28	9.2	-8
	B. Halve number of Blue artillery rounds allocated per target	3.8	-19	10.0	0
	C. Double number of Blue artillery rounds allocated per target and limit available rounds to number fired in baseline	5.5	17	7.9	-21
10.	Modify priorities to make Copperhead higher priority than conventional 155mm rounds against Red front-line forces	4.7	0	9.5	-5
11.	A. Double Red artillery firing rates	4.0	-15	12.7	27
	B. Halve Red artillery firing rates	5.7	21	6.5	-35
12.	Multiply probability of acquiring a target for Copperhead by 0.2	4.5	-4	10.0	0
13.	A. Multiply rate at which service is restored to a damaged Red command post by 0.1	4.6	-2	10.4	4
	B. Multiply rate at which service is restored to a damaged Red command post by 10	4.7	0	10.0	0

This section describes several studies which contribute evidence concerning the sensitivity of models to human factors representations. Each of the subsections below briefly describes one such study and presents summary statistics concerning the human factors areas that were investigated. These summaries are not intended as complete descriptions of the analyses; they simply indicate the nature of any evidence concerning human factors sensitivities.

C.2.1 TERRAIN LINE-OF-SIGHT STUDY

This study [Farrell and Freedman, 1975] investigated the sensitivity of predicted combat results to the choice of terrain lines of sight. A Monte-Carlo combat simulation was used to represent an engagement involving 15 tanks attacking a position defended by three tanks and three mounted anti-tank missile launchers. The study focused on the combined effects of terrain area selection, defender location selection, and attacker route selection on simulation results. Other model sensitivities were also briefly addressed.

A general statement which summarizes some of the principal results of the study is as follows: A standard 95 percent confidence interval for the mean probability that the attacker wins the engagement, averaged over scenarios (terrain and movement assumptions) which are believed *a priori* to be equivalent, will cover a range of win probabilities at least .50 wide (i.e., the probabilities of a win are estimable only within plus or minus 25 percentage points). Other measures of effectiveness also were highly sensitive to the assumed use of the terrain. Loss exchange ratios, for example, were as much as 600 percent better for Blue on the most favorable of "equivalent" terrains than on the least favorable.

Results of additional model sensitivity analyses are summarized in exhibit C-13.

C.2.2 SENSITIVITY ANALYSIS OF BLDM ACQUISITION AND FIREPOWER ALLOCATION

A sensitivity analysis conducted at CACDA [Pickett and AuBuchon, 1976] found almost no difference in results of the BLDM model to changes in maneuver unit weapon target acquisition capabilities in the presence of high target densities. Capabilities to acquire both firing and non-firing targets were varied. The report suggested that the insensitivities may be due to inadequacies in the detection and firepower allocation logic of the model.

C.2.3 REACTION TIME ANALYSIS

In an analysis of scout helicopter operations [VRI, 1981b], the BLDM model was used to investigate the effects of (among other things):

(1) scout helicopter hand-off time (the time between target detection by a scout helicopter and the time at which an attack helicopter learns of the target from the scout), and

(2) artillery reaction time (the time between a call for support and the time at which that support -- a Copperhead round -- arrives).

The results of these investigations are summarized in exhibit C-14.

C.2.4 VECTOR-O SENSITIVITY ANALYSES

A report describing detailed results of initial testing of the VECTOR-O theater-level combat model [VRI, 1973] contains several sets of results whose differences can be interpreted as caused by different

EXHIBIT C-13: SENSITIVITY ANALYSES IN TERRAIN LINE-OF-SIGHT STUDY

ISSUE UNDER INVESTIGATION	CONDITION VARIED	PROBABILITY DEFENDER WINS
Target assignment logic	Select nearest target	.28
	Select target at random	.26
Sensitivity to acquisition	Instantaneous acquisitions	.26
	Poisson-distributed acquisition times	.34
Sensitivity to suppression parameters	τ = .39, ℓ = 5[1]	.62
	τ = .39, ℓ = 15	.70
	τ = .39, ℓ = 30	.66
	τ = .63, ℓ = 5	.36
	τ = .63, ℓ = 15	.44
	τ = .63, ℓ = 30	.44
	τ = 1.0 (no suppression)	.34

[1] τ = risk threshold (accepted probability of a kill before a popdown), ℓ = down time per popdown (in seconds).

EXHIBIT C-14: HAND-OFF TIME AND REACTION TIME VARIATIONS

VARIATIONS		LOSS EXCHANGE RATIO
Scout hand-off time (time to fire first round):		
2 seconds		8.74
10 seconds		7.61
20 seconds		6.57
Artillery reaction time:		
Message prep. and trans. time	FDC and gun lay time	
60 sec.	180 sec.	4.26
10 sec.	180 sec.	4.56
10 sec.	30 sec.	5.90

assumptions concerning human factors. Sensitivities to the following phenomena appear to be relevant to the present study:

(1) the ability to resupply or repair tanks;

(2) the ability to replace personnel; and

(3) attack helicopter operations in the target area (represented via simultaneous changes in Blue helicopter effectiveness and Red air defense effectiveness against the attacking helicopters).[1]

The results of these excursions, which are based on a NATO scenario, are summarized in exhibit C-15.

C.2.5 DRAGON STUDY

In a study of alternative improvements to the Dragon missile system, Bonder and Proegler, et al. [1978] used a company-level Monte Carlo simulation to evaluate the effectiveness of an infantry platoon equipped with Dragon systems in a defense against a Soviet tank company. Some of the study results can be viewed as caused by variations in human factors assumptions:

(1) The same forces were evaluated in each of three different engagement types, corresponding to differing assumptions about force deployment and maneuver.

(2) A sensitivity analysis to assumed open-fire ranges was conducted.

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[1]This could be interpreted as representing differing abilities of helicopters to acquire the target, criteria for aborting a mission, or decisions concerning standoff distance and maneuver pattern at the target. It could also represent the effects of open-fire decisions by the air defense weapons.

EXHIBIT C-15: VECTOR-O SENSITIVITY ANALYSES

CASE	RESULTS AFTER 100 DAYS OF COMBAT	
	MEAN RED ADVANCE (KM)	TANK LOSS EXCHANGE RATIO
Base	650	5.2
50% arriving individual replacement tanks for both sides	170	6.5
25% arriving individual replacement tanks for both sides	120	5.8
12 1/2% arriving individual replacement tanks for both sides	110	5.3
200% personnel arrivals for both sides	350	4.0
Doubled Red effectiveness vs. helicopters, doubled Blue effectiveness of helicopters	640	Not available
Halved Red effectiveness vs. helicopters, halved Blue effectiveness of helicopters	650	Not available

(3) Two differing gunner launch decision rules were evaluated. In the first, the probability of gunner launch was assumed to be a function of the line-of-sight window length to the target. In the second, the gunner was assumed to launch a round whenever a target was detected.

While detailed results of the study are classified, the following general statements can be made concerning sensitivities in these three areas:

(1) Results were highly sensitive to engagement type. For each system examined, loss exchange ratios increased by more than 100 percent in changing from Blue's least advantageous to his most advantageous engagement type. In some cases, the increase was several hundred percent. Furthermore, the engagement type which was most advantageous for Blue differed depending on the system being evaluated, and the relative ranking of the systems varied somewhat depending on the engagement type assumed.

(2) Results were moderately sensitive to open-fire ranges. Comparison of best to worst loss exchange ratios always showed differences considerably less than 100 percent.

(3) Changing gunner launch decision rules had no significant impact on battle results.

C.2.6 NEUTRALIZATION RECOVERY RATE SENSITIVITY

In a study of nuclear combat using the VECTOR-1 theater-level model [VRI, 1977], it was found that results were extremely sensitive to the recovery rate of neutralized Red units. That is, the size of the nuclear strike required to defeat Red is sensitive to the distribution of time a Red company which was not destroyed by the strike remains neutralized because of the disruption caused by the attack. (Details of the study are classified.)

C.2.7 DIVOPS SENSITIVITIES

The initial study which applied the DIVOPS division-level model to a European scenario [VRI, 1974] included an analysis of the sensitivity of the model to assumptions used in the study. Some of these assumptions involved human factors issues. The following excursions had a significant impact on battle results (measured primarily by Blue's ability to hold against Red's attack):

(1) The criteria used for initiation or termination of an attack could affect which side was successful. For example, a decrease in the maximum casualty level either side would accept before disengaging resulted in Blue being unable to hold his position in a situation in which he was otherwise able to do so.

(2) A reduction in Red's division frontage resulted in Blue being unable to stop Red's advance when he was otherwise able to do so. (However, the reduction in Red frontages was significant, and Blue was assumed unable to redeploy his force to counter Red's massing).

(3) The relative timing of reserve commitments was found to affect results significantly, sometimes changing the course of the battle. For example, delay of the commitment of a Red second echelon unit until Blue was able to counterattack successfully against unreinforced Red units meant that Blue gained the ability subsequently to defend successfully against an attack by the reinforced Red force.

Additional excursions had little or no impact on battle results:

(1) Two ways of varying the amount of air support delivered by Blue (dropping low priority missions versus flying all missions with fewer sorties per mission) showed little difference in battle outcomes for a given level of support delivered.

(2) Modifying artillery allocation priorities by removing "stationary maneuver units with ten or more armored vehicles" from the list of targets for Blue artillery had essentially no effect.

(3) Reducing from ten to five the number of armored vehicles which must be detected before requesting Blue air support had only minor effects.

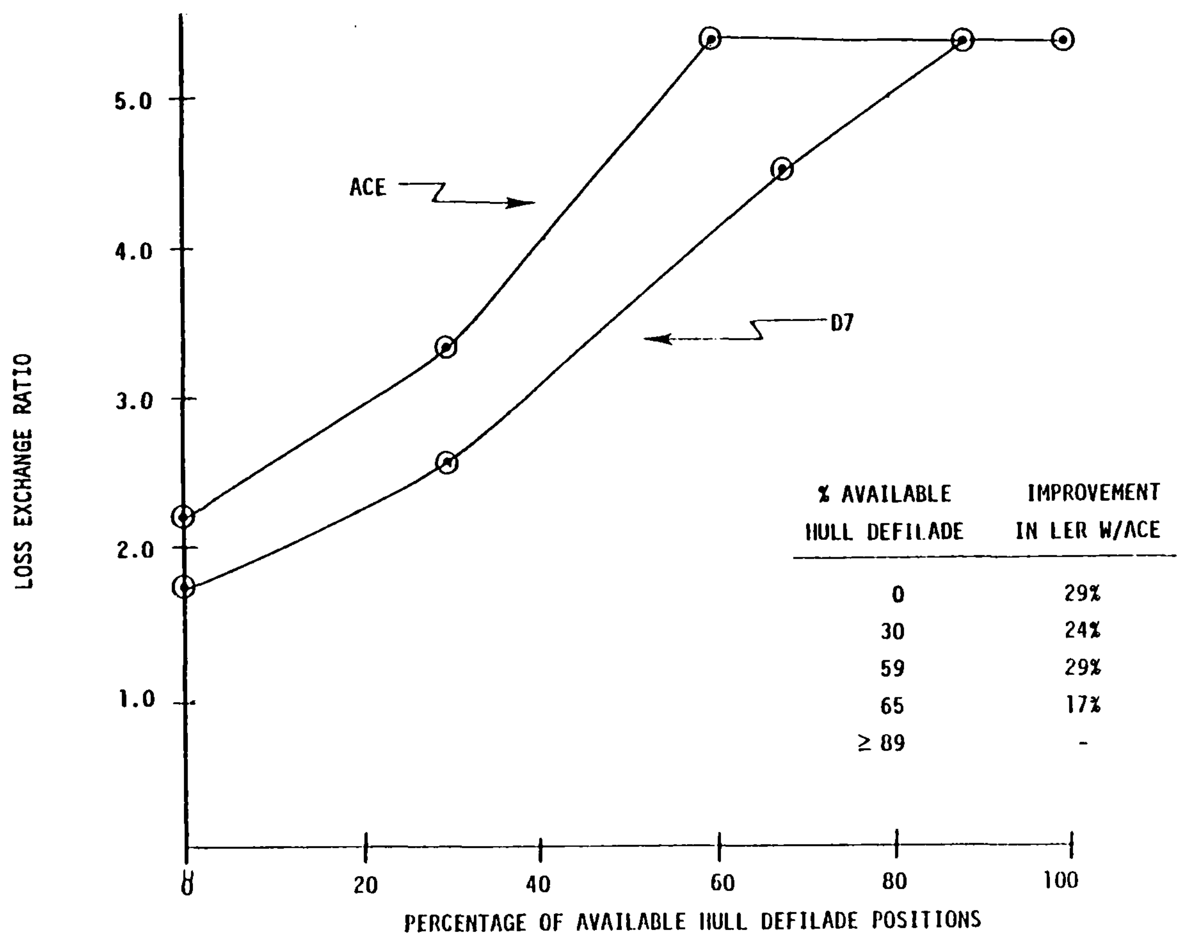
C.2.8 ENGINEER STUDY

In a study for the 1981 Army Engineering Systems Program Review, VRI used the BLDM model to examine the benefits of improved capability to prepare defensive positions. The purpose of the study was to assess the additional effectiveness provided by the M9 ACE over that provided by the D7 dozer, but the results could also be interpreted in terms of different assumptions concerning human factors. Results are summarized in exhibit C-16 as a function of the percentage of naturally available hull defilade positions.

C.2.9 ARAB-ISRAELI WAR STUDY

Thompson and White, et al. [1981] used the VECTOR-2 model in a verification study of the 1973 Arab-Israeli War. Various excursions were made from the historical results to examine questions concerning the

EXHIBIT C-16: COMPARISON OF EFFECTIVENESS OF BLUE BATTALION SUPPORTED BY M9 ACE VERSUS D7 DOZER



% AVAILABLE HULL DEFILADE	IMPROVEMENT IN LER W/ACE
0	29%
30	24%
59	29%
65	17%
≥ 89	-

capabilities and tactics of the forces involved; some of these excursions involved changes in assumptions concerning human factors. Because the study results are classified, they cannot be summarized here. However, they have been taken into account in this assessment of model sensitivities.

C.2.10 TARGET VALUE ANALYSIS

The VECTOR-2 model was used to generate combat results for determining relative target values as part of the Army's Fire Support Mission Area Analysis [Field Artillery School, 1980]. The scenario involved the US V Corps in European combat in a 1986 time frame. Several of the excursions from the base case can be interpreted as analyses of human factors issues:

(1) Four Red regiments were prevented from resuming their supporting attack for 11 hours on the second day of the war. (This could be caused, for example, by a disruption in command and control.) After five days of combat, this change had an insignificant effect on loss exchange ratios, reduced Red's penetration in the supporting attack area by 1/3, and slightly reduced Red's penetration in the main attack area, when compared with the base case.

(2) Modest delays (between 6 and 12 hours) were imposed on Red's ability to commit second echelon divisions to the breakthrough attempt in the main attack area. After five days of combat, this change had only a minor effect on loss exchange ratios, but reduced Red's penetration by at least 25 percent in the main attack area and by 1/3 in the area of the supporting attack.

(3) A 12 hour delay was imposed on Red's ability to commit his second echelon division to the supporting attack. After five days of combat, Red's penetration was slightly less in the main attack area and was reduced by 1/3 in the supporting attack area.

(4) Red's capability to detect Blue FARRPs (and thereby destroy Blue helicopters on the ground) was denied him. In this run, the maintenance units of two Red divisions were also prevented from replacing or repairing a portion of their losses. The result was a reduction of Red's penetration by at least 25 percent in the main attack area and by 1/3 in the supporting attack area. Examination of detailed outputs led to the conclusion that all of this change was caused by the increased availability of Blue helicopters; there was no apparent effect associated with Red's decreased maintenance capability.

(5) The rate at which all Red following divisions could advance to the front was decreased somewhat. (For example, availability of Red second echelon divisions in the first echelon army was delayed by one day.) This change had no major effect on loss exchange ratios but had an extreme effect on Red's advance: Blue was able to prevent Red's breakthrough. Apparently the delayed availability of second echelon forces allowed Blue to defeat Red in detail.

C.3 SUMMARY OF RELATIVE SENSITIVITIES

This section contains estimates of the relative potential sensitivities of models to human factors assumptions concerning each of a set of model process phenomena. The estimates are based on the information outlined in the previous two sections. The summary appears in exhibit C-17. For each phenomenon, one of the following estimates of the relative sensitivity is given:

(1) "H" if the available evidence seems to indicate that varying human factors assumptions concerning this phenomenon could cause extreme variation in predicted combat outcomes;

(2) "M" if the evidence is mixed or if it appears that only a moderate effect on model output could result from differing human factors assumptions related to the phenomenon;

(3) "L" if it appears that models are relatively insensitive to changes in human factors assumptions concerning the phenomenon; and

(4) "U" if no sensitivity information has been identified concerning the phenomenon.

Most of the phenomena marked "U" concern model processes assumed to be of little direct interest to Army behavioral scientists (e.g., air-to-air combat). Following the estimates of sensitivity, the table contains an indication of the previous sections of this appendix on which the estimates were based.

EXHIBIT C-17: RELATIVE SENSITIVITY ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON

PROCESS PHENOMENON	SENSITIVITY	RELEVANT STUDIES[1]
Maneuver Unit Combat:		
1. Force participation	H	1.1, 2.6, 2.9
2. Initial deployments of weapons	H	1.1, 2.1, 2.5
3. Maneuver patterns of individual weapons	H	2.1, 2.5
4. Target acquisition capabilities	L	1.1, 2.1, 2.2
5. Target identification capabilities	M	1.1
6. Target selection (and target switching)	M	1.1, 2.1
7. Decision to fire	M	1.1, 2.5
8. Ordnance selection	U	--
9. Time to fire or firing rate	H	1.1, 2.3, 2.9
10. Accuracy of fire	M	1.1, 2.9
11. Fire suppression	H	2.1
12. Employment of obscuration	U	--
Artillery Fire:		
1. Ordnance selection	M	1.2
2. Target element acquisition and selection (if point fire)	L	1.2
3. Decision to fire	M	1.2
4. Delivery pattern	M	1.2
5. Delivery accuracy	M	1.2
6. Target posture	M	1.2
7. Suppressive effects of fire	M	1.2, 2.6
8. Effects of fire on communications and decision-making ability	M	2.10
9. Time to fire or firing rate	M	1.2, 2.3
Air-To-Ground Attacks:		
1. Ability to acquire (or reacquire) the target	L[2]	2.4
2. Engagement decision (whether to attack the target)	L[2]	2.4
3. Ordnance selection	U	--
4. Target element acquisition and selection (if point fire)	U	--
5. Aircraft standoff distance and/or maneuver pattern over target	L[2]	2.4
6. Weapon delivery accuracy	U	--
7. Target posture	U	--
8. Suppressive effects of the attack	M	2.6
9. Effects of the attack on communications and decision-making ability	M	2.10

[1]Numbers indicate sections within appendix C in which the studies are described.

[2]For attack helicopters only.

-- Continued --

EXHIBIT C-17: RELATIVE SENSITIVITY ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON
(Continued)

PROCESS PHENOMENON	SENSITIVITY	RELEVANT STUDIES
Air-To-Ground Attacks (cont.):		
10. Effects of the attack on airfield sortie generation capability (if target is an airfield)	U	--
11. Aircraft disengagement decision	L[1]	2.4
Air-To-Air Combat:		
1. Engagement decisions (whether to engage and type of engagement)	U	--
2. Aircraft maneuver patterns	U	--
3. Target acquisition capabilities	U	--
4. Target selection	U	--
5. Ordnance selection	U	--
6. Time to fire	U	--
7. Accuracy of fire	U	--
8. Abort decisions	U	--
Air Defense:		
1. Coordination of fire	U	--
2. Target acquisition capabilities	L	1.2
3. Target selection	U	--
4. Decision to fire	L	1.2, 2.4
5. Degraded capability of aircraft to destroy targets on the ground	U	--
6. Aircraft mission abort decisions	U	--
Mobility, Countermobility, and Survivability:		
1. Location, density, and extent of a minefield or obstacle	H	2.7, 2.9
2. Attrition suffered when encountering a minefield	U	--
3. Delay in movement when encountering a minefield or obstacle	H	2.7, 2.9
4. Reduction in movement rates due to minefields and obstacles	H	2.7, 2.9
5. Increase in exposure due to encountering a minefield or obstacle	U	--
6. Delays in traveling on damaged roads	H	2.7, 2.9, 2.10
7. Delays in crossing rivers or gaps	H	2.7, 2.9, 2.10
8. Degree of protection afforded by a prepared defensive position	M	2.8
9. Location and extent of a prepared defensive position	M	2.8

[1] For attack helicopters only.

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EXHIBIT C-17: RELATIVE SENSITIVITY ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON
(Continued)

PROCESS PHENOMENON	SENSITIVITY	RELEVANT STUDIES
Intelligence and Electronic Warfare:		
1. Collection management decisions - what information to pursue	M	2.10
2. Collection management decisions - how to collect desired information	U	--
3. Target acquisition capabilities	M	2.10
4. Accuracy of target identification (including false targets)	U	--
5. Target processing time	M	1.2, 2.3
6. Target location error	M	1.2
7. Timeliness of intelligence processing	U	--
8. Accuracy of intelligence processing	U	--
9. Completeness of intelligence processing	U	--
10. Decisions to jam	M	2.10
11. Effectiveness of jamming	M	2.10
12. Collection management decisions - location of sensors	L	1.2
Communications:		
1. Time to transmit message	L	1.2, 2.3
2. Message content	U	--
3. Transmission accuracy	U	--
4. Reception accuracy	U	--
Mission Assignment, Organization for Combat, and Resource Allocation:		
1. Initial deployments of maneuver units	H	2.1, 2.7
2. Changes in these deployments	M	2.7, 2.9
3. Cross attachments among maneuver units	U	--
4. Allocation and/or positioning of attack helicopters	U	--
5. Allocation and/or positioning of field artillery forces	U	--
6. Allocation and/or positioning of CAS/BI aircraft	U	--
7. Allocation and/or positioning of air defense forces	U	--
8. Allocation and/or positioning of target acquisition resources	U	--
9. Allocation and/or positioning of supply points	U	--

-- Continued --

EXHIBIT C-17: RELATIVE SENSITIVITY ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON
(Continued)

PROCESS PHENOMENON	SENSITIVITY	RELEVANT STUDIES
Mission Assignment, Organization for Combat, and Resource Allocation (cont.):		
10. Allocation of aircraft to missions	U	--
11. Delays in making and implementing decisions	L	1.2
Maneuver Control:		
1. Decisions to change the activity and/or location of a unit	M	2.7, 2.9
2. Decisions to request and commit reserves	H	2.7, 2.9
3. Decisions for unit retirement	U	--
4. Decisions to request fire support	L	2.7
5. Decisions to request engineer support	M	2.8
6. Decisions for the tactical relocation of supporting elements	U	--
7. Delays in making and implementing decisions	L	1.2
Fire Support Allocation:		
1. Target and mission priorities	L	2.7
2. Preferences for type and amount of support against a given target in given situation	M	1.2, 2.7
3. Preferences for types and amounts of fire to be allocated to pre-planned missions	M	1.2
4. Criteria for ignoring targets or dropping them from list of acquired targets	L	2.7
5. Delays in making and implementing decisions	M	2.3
Resupply and Replacement:		
1. Locations of supply points	U	--
2. Stockpiling decisions at supply points	U	--
3. Quantities of supplies and replacements allocated to units on the battlefield	M	2.4
4. Delays in decisions to provide supplies or replacements	U	--

-- Continued --

EXHIBIT C-17: RELATIVE SENSITIVITY ASSOCIATED WITH EACH MODEL PROCESS PHENOMENON
(Concluded)

PROCESS PHENOMENON	SENSITIVITY	RELEVANT STUDIES
Resupply and Replacement (cont.):		
5. Time required to load and unload allocated supplies	U	--
Movement:		
1. Aircraft speeds and flight paths	U	--
2. Movement rates of ground forces	H	2.9, 2.10
3. Route selection of forces moving on the ground	U	--
4. Degree of exposure of moving forces (air and ground)	U	--
Maintenance and Repair; Medical Support:		
1. Rates at which weapons and personnel are returned to duty given availability of support	M	2.4, 2.9, 2.10
2. Availability of repair capability and medical support	M	2.4, 2.9, 2.10
3. Rate at which damaged capability of a facility is restored	L	1.2
Construction, Maintenance, and Operation of Airfields:		
1. Sortie generating capability of an airfield	U	--
2. Rate of recovery of sortie generating capability following an attack on the airfield	U	--
3. Construction and repair rates for runways, aircraft shelters, and entire airfields	U	--
4. Delays in scrambling aircraft	U	--
5. Degree to which available shelters are in use when an attack of an airfield occurs	U	--
6. Aircraft basing rules	U	--

APPENDIX D

NOTES ON PRIORITIES FOR HUMAN FACTORS RESEARCH

As described in chapter 3.0, the information developed in tasks 1, 2, and 3 was combined to generate overall priorities for conducting human factors research to improve combat models. Priorities were developed for the model process phenomena (defined in appendix A), the 18 task clusters (defined in appendix B), and the 37 Fleishman abilities (defined in appendix B).

Exhibit D-1 contains the information used to rank the model process phenomena. The column of the exhibit labeled "model sensitivity" contains the same estimate of relative potential sensitivity to human factors assumptions as given in section C.3 of appendix C. The column labeled "model fidelity" contains a subjective estimate of the fidelity with which the human factors effects on each phenomenon is represented. The estimates are based on the information presented in appendix A. A "G" in this column means that model fidelity is typically reasonably good; a "P" indicates generally poor fidelity. The column of the exhibit labeled "abilities score" contains a number for each phenomenon intended to represent the relative degree to which human factors influence the phenomenon. This number is the sum of the abilities ratings for all task clusters associated with the phenomenon (see appendix B).

The final column of the exhibit ranks the phenomena in order of the relative need of combat models for human factors research on each phenomenon. (A low number indicates a comparatively great need for such research.) These ranks are based on the information in the previous three columns of the exhibit combined as follows:

EXHIBIT D-1: DETERMINATION OF RELATIVE RANKING OF MODEL PROCESS PHENOMENA

PROCESS PHENOMENON	MODEL SENSITIVITY	MODEL FIDELITY	ABILITIES SCORE	OVERALL RANK
Maneuver Unit Combat:				
1. Force participation	H	G	281	5 (tie)
2. Initial deployments of weapons	H	G	281	5 (tie)
3. Maneuver patterns of individual weapons	H	P	199	1
4. Target acquisition capabilities	L	G	58	56
5. Target identification capabilities	M	P	58	17
6. Target selection (and target switching)	M	G	69	27 (tie)
7. Decision to fire	M	G	69	27 (tie)
8. Ordnance selection	U	G	63	46
9. Time to fire or firing rate	H	G	71	11
10. Accuracy of fire	M	G	74	24
11. Fire suppression	H	G	471	4
12. Employment of obscuration	U	P	82	37 (tie)
Artillery Fire:				
1. Ordnance selection	M	P	63	16
2. Target element acquisition and selection (if point fire)	L	P	127	48
3. Decision to fire	L	P	69	51 (tie)
4. Delivery pattern	M	G	63	28
5. Delivery accuracy	M	G	74 or 71	25
6. Target posture	M	G	345	19
7. Suppressive effects of fire	M	G	349	18 (tie)
8. Effects of fire on communications and decision-making ability	M	P	154	12 (tie)
9. Time to fire or firing rate	M	G	71	26
Air-To-Ground Attacks:				
1. Ability to acquire (or reacquire) the target	L	P	58	52
2. Engagement decision (whether to attack the target)	L	P	69	51 (tie)
3. Ordnance selection	U	P	63	42
4. Target element acquisition and selection (if point fire)	U	P	127	34
5. Aircraft standoff distance and/or maneuver pattern over target	L	P	113	49 (tie)
6. Weapon delivery accuracy	U	P	74 or 71	39
7. Target posture	U	P	345	30
8. Suppressive effects of the attack	M	G	349	18 (tie)
9. Effects of the attack on communications and decision-making ability	M	P	154	12 (tie)

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EXHIBIT D-1: DETERMINATION OF RELATIVE RANKING OF MODEL PROCESS PHENOMENA
(Continued)

PROCESS PHENOMENON	MODEL SENSITIVITY	MODEL FIDELITY	ABILITIES SCORE	OVERALL RANK
Air-To-Ground Attacks (cont.):				
10. Effects of the attack on airfield sortie generation capability (if target is an airfield)	-	-	-	-
11. Aircraft disengagement decision	L	P	69	51 (tie)
Air-To-Air Combat:				
1. Engagement decisions (whether to engage and type of engagement)	-	-	-	-
2. Aircraft maneuver patterns	-	-	-	-
3. Target acquisition capabilities	-	-	-	-
4. Target selection	-	-	-	-
5. Ordnance selection	-	-	-	-
6. Time to fire	-	-	-	-
7. Accuracy of fire	-	-	-	-
8. Abort decisions	-	-	-	-
Air Defense:				
1. Coordination of fire	U	P	151	33
2. Target acquisition capabilities	L	G	58 or 47	57
3. Target selection	U	P	69	41 (tie)
4. Decision to fire	L	P	69	51 (tie)
5. Degraded capability of aircraft to			113	35 (tie)
destroy targets on the ground	U	P	69	41 (tie)
6. Aircraft mission abort decisions	U	P		
Mobility, Countermobility, and Survivability:				
1. Location, density, and extent of a minefield or obstacle	H	G	167	7
2. Attrition suffered when encountering a minefield	U	G	177	43
3. Delay in movement when encountering a minefield or obstacle	H	P	177	2
4. Reduction in movement rates due to minefields and obstacles	H	G	177	6
5. Increase in exposure due to encountering a minefield or obstacle	U	P	177	32
6. Delays in traveling on damaged roads	H	P	162	3
7. Delays in crossing rivers or gaps	H	G	162	8
8. Degree of protection afforded by a prepared defensive position	M	G	284	20
9. Location and extent of a prepared defensive position	M	G	167	22

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EXHIBIT D-1: DETERMINATION OF RELATIVE RANKING OF MODEL PROCESS PHENOMENA
(Continued)

PROCESS PHENOMENON	MODEL SENSITIVITY	MODEL FIDELITY	ABILITIES SCORE	OVERALL RANK
Intelligence and Electronic Warfare:				
1. Collection management decisions - what information to pursue	M	P	82	14 (tie)
2. Collection management decisions - how to collect desired information	U	P	82	37 (tie)
3. Target acquisition capabilities	M	G	47	29
4. Accuracy of target identification (including false targets)	U	P	87	36
5. Target processing time	M	P	87	13 (tie)
6. Target location error	M	P	87	13 (tie)
7. Timeliness of intelligence processing	U	G	87	44 (tie)
8. Accuracy of intelligence processing	U	G	87	44 (tie)
9. Completeness of intelligence processing	U	G	87	44 (tie)
10. Decisions to jam	M	P	82	14 (tie)
11. Effectiveness of jamming	M	P	72	15
12. Collection management decisions - location of sensors	L	P	82	50 (tie)
Communications:				
1. Time to transmit message	L	G	72	55
2. Message content	U	P	72	40 (tie)
3. Transmission accuracy	U	P	72	40 (tie)
4. Reception accuracy	U	P	72	40 (tie)
Mission Assignment, Organization for Combat, and Resource Allocation:				
1. Initial deployments of maneuver units	H	G	82	9 (tie)
2. Changes in these deployments	M	G	82	23 (tie)
3. Cross attachments among maneuver units	U	G	82	45 (tie)
4. Allocation and/or positioning of attack helicopters	U	G	82	45 (tie)
5. Allocation and/or positioning of field artillery forces	U	G	82	45 (tie)
6. Allocation and/or positioning of CAS/BI aircraft	U	G	82	45 (tie)
7. Allocation and/or positioning of air defense forces	U	G	82	45 (tie)
8. Allocation and/or positioning of target acquisition resources	U	P	82	37 (tie)
9. Allocation and/or positioning of supply points	U	G	82	45 (tie)

-- Continued --

EXHIBIT D-1: DETERMINATION OF RELATIVE RANKING OF MODEL PROCESS PHENOMENA (Continued)

PROCESS PHENOMENON	MODEL SENSITIVITY	MODEL FIDELITY	ABILITIES SCORE	OVERALL RANK
Mission Assignment, Organization for Combat, and Resource Allocation (cont.):				
10. Allocation of aircraft to missions	U	G	82	45 (tie)
11. Delays in making and implementing decisions	L	G	272	53
Maneuver Control:				
1. Decisions to change the activity and/or location of a unit	M	G	82	23 (tie)
2. Decisions to request and commit reserves	H	G	82	9 (tie)
3. Decisions for unit retirement	U	G	82	45 (tie)
4. Decisions to request fire support	L	G	82	54 (tie)
5. Decisions to request engineer support	M	G	82	23 (tie)
6. Decisions for the tactical relocation of supporting elements	U	P	82	37 (tie)
7. Delays in making and implementing decisions	L	P	82	50 (tie)
Fire Support Allocation:				
1. Target and mission priorities	L	G	82	54 (tie)
2. Preferences for type and amount of support against a given target in given situation	M	G	82	23 (tie)
3. Preferences for types and amounts of fire to be allocated to pre-planned missions	M	G	82	23 (tie)
4. Criteria for ignoring targets or dropping them from list of acquired targets	L	P	82	50 (tie)
5. Delays in making and implementing decisions	M	G	82	23 (tie)
Resupply and Replacement:				
1. Locations of supply points	U	G	82	45 (tie)
2. Stockpiling decisions at supply points	U	G	82	45 (tie)
3. Quantities of supplies and replacements allocated to units on the battlefield	M	G	82	23 (tie)
4. Delays in decisions to provide supplies or replacements	U	G	82	45 (tie)

-- Continued --

EXHIBIT D-1: DETERMINATION OF RELATIVE RANKING OF MODEL PROCESS PHENOMENA (Concluded)

PROCESS PHENOMENON	MODEL SENSITIVITY	MODEL FIDELITY	ABILITIES SCORE	OVERALL RANK
Resupply and Replacement (cont.):				
5. Time required to load and unload allocated supplies	U	P	73	38
Movement:				
1. Aircraft speeds and flight paths	U	P	113	35 (tie)
2. Movement rates of ground forces	H	G	77	10
3. Route selection of forces moving on the ground	U	G	82	45 (tie)
4. Degree of exposure of moving forces (air and ground)	U	P	190	31
Maintenance and Repair; Medical Support:				
1. Rates at which weapons and personnel are returned to duty given availability of support	M	G	205	21
2. Availability of repair capability and medical support	M	P	82	14 (tie)
3. Rate at which damaged capability of a facility is restored	L	P	182	47
Construction, Maintenance, and Operation of Airfields:				
1. Sortie generating capability of an airfield	-	-	-	-
2. Rate of recovery of sortie generating capability following an attack on the airfield	-	-	-	-
3. Construction and repair rates for runways, aircraft shelters, and entire airfields	-	-	-	-
4. Delays in scrambling aircraft	-	-	-	-
5. Degree to which available shelters are in use when an attack of an airfield occurs	-	-	-	-
6. Aircraft basing rules	-	-	-	-

(1) Model sensitivity was taken to be the most significant criterion, so the phenomena were sorted by the sensitivity estimate in the following order -- H (most important), M, U, and L (least important).

(2) Within a given model sensitivity class, those phenomena with poor (P) model fidelity were assumed to be of higher priority than those with good (G) fidelity. The rationale for this ranking was that a reasonable degree of fidelity probably means that some knowledge already exists concerning the effect of human factors on the phenomenon. Furthermore, a greater degree of fidelity usually means that model data requirements are more physically based, and thus the data are easier to develop.

(3) Finally, within a given model sensitivity and fidelity class, the phenomena were ranked in order of decreasing abilities scores. This ranking was based on the assumption that these scores serve as a reasonable proxy for the degree to which human factors can have an impact on each of the phenomena, and hence the degree to which human factors research is likely to have an impact on the representation of a phenomenon, in combat models.

Excluded from this priority scheme were those phenomena believed to be of little direct interest to Army behavioral scientists; i.e., those involving air-to-air combat and airfield operations.

In addition to ranking the phenomena, the 18 task clusters were ranked as indicated in chapter 3.0 to provide an alternate basis for prioritizing research on task performance. The priorities were determined from a score computed for each task cluster; the score was the number of phenomena which involved the task cluster and for which model sensitivity was not low (L).[1] The score thus provides an indication of the degree to which representation of performance of tasks in the task cluster is likely to affect model output. The tasks were ranked in order of decreasing scores. The scores and corresponding ranks can be found in exhibit D-2.

Finally, the 37 abilities were ranked as discussed in chapter 3.0 in order to provide guidelines for prioritizing research on predicting abilities from demographic data and estimating the effect of environmental conditions, training, and experience on the abilities. To do this, a score was computed for each of the abilities which was the sum of the ratings for an ability for all task clusters associated with phenomena for which the model sensitivity was not low (L).[1] These scores are thus intended to indicate the potential relative impact of each ability on combat model output. The abilities were then ranked in order of decreasing scores. The scores and corresponding ranks are displayed in exhibit D-3.

[1]Phenomena involving air-to-air combat and airfield operations were not included in computing these scores.

EXHIBIT D-2: DETERMINATION OF RELATIVE RANKING OF TASK CLUSTERS

TASK CLUSTER	SCORE	RANK
1. Vehicle maneuver	11	3 (tie)
2. Dismounted weapon maneuver	7	5 (tie)
3. Visual acquisition	5	7
4. Aiming and tracking	6	6 (tie)
5. Weapon operation	7	5 (tie)
6. Individual decision making (threat)	11	3 (tie)
7. Individual decision making (non-threat)	4	8
8. Command decision making	16	2
9. Command planning	23	1
10. Radar acquisition	1	11 (tie)
11. Target and intelligence development	6	6 (tie)
12. Communication	6	6 (tie)
13. Driving	8	4
14. Aircraft operation	3	9
15. Construction	6	6 (tie)
16. Maintenance and repair	2	10
17. Medical care	1	11 (tie)
18. Resupply	1	11 (tie)

EXHIBIT D-3: DETERMINATION OF RELATIVE RANKING OF ABILITIES

ABILITY	SCORE	RANK
1	355	12
2	231	18
3	341	14
4	434	7
5	388	9
6	517	2
7	356	11
8	307	15
9	357	10
10	345	13
11	285	16
12	223	19
13	248	17
14	417	8
15	459	4
16	448	6
17	582	1 (tie)
18	453	5
19	466	3
20	115	26
21	106	28
22	74	33
23	122	24
24	91	30
25	103	29
26	73	34
27	582	1 (tie)
28	169	21
29	135	23
30	108	27
31	59	36
32	121	25
33	65	35
34	88	31
35	81	32
36	152	22
37	174	20