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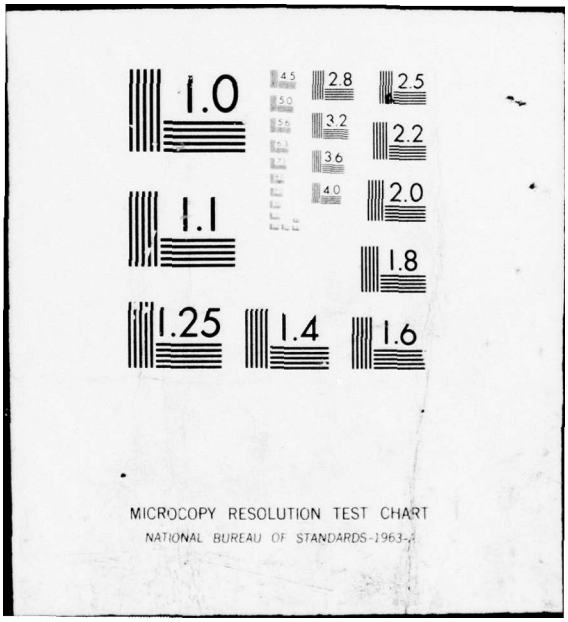
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A DISCUSSION OF LAND COMBAT MODELS: THEIR CHARACTERISTICS AND A METHODOLOGY FOR ILLUMINATING THEIR ATTRIBUTES

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R&D Associates
P.O. Box 9695
Marina Del Rey, California 90291

December 1975

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This report presents the results of work undertaken for the Defense Nuclear Agency and for the International Security Affairs Division of Department of Energy to identify and describe land combat simulation models applicable for evaluating the use of tactical nuclear weapons. Part I of the report discusses the primary kinds of land combat models that have been developed, identifies the types best suited for sensitivity and tradeoff → next page

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20. ABSTRACT (Continued)

analyses of mixed conventional and tactical nuclear combat, and describes three specific models which are appropriate for such studies. Part II of the report develops a generalized methodology for describing in a concise and convenient format, the basic attributes, capabilities and limitations of such models. This methodology is applied to five land combat models of varying scope, including the three models selected in Part I, to illustrate its utility for delineating models and identifying their particular capabilities.

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SUMMARY

This report presents the results of work undertaken for the Defense Nuclear Agency (DNA) and for the International Security Affairs (ISA) division of the Energy Research and Development Administration (ERDA) concerning land combat simulation models. The initial task, performed for both agencies, was to identify and describe land combat models that would be applicable for evaluating the introduction and use of tactical nuclear weapons in a high-intensity conventional conflict. Background work included developing a general understanding and overview of the various types of land combat models and the methodologies employed. A primary study objective was to select one or more specific digital computer models that could readily be implemented by the non-developer to perform sensitivity analyses and tradeoffs regarding the employment of nuclear weapons.

Although some models could be readily identified as either suitable or unsuitable from their general descriptions, the particular limitations or restrictions of others became apparent only upon detailed review of substantial model documentation. During this study it became evident that what might present serious modeling limitations for a particular study might be of no consequence for another application, and that the kind of detailed information which allowed such judgments to be made, should be more readily available. For example, one of DNA's far-term analysis objectives is to obtain a capability to analyze the effectiveness and vulnerability of specific weapon systems, tactics options, targeting, and associated command, control and communications problems, by examining in a more detailed manner the highly complex interactions within a corps or division. Obviously, this

second application leads to a somewhat different group of models, in terms of scope and level of detail, from those that had been selected to perform tradeoff studies on nuclear weapons employment options. Unfortunately, the information that had been acquired about all of the models surveyed during the initial study was not in a convenient or standardized form that would facilitate selection of a model suitable for this long-term objective. Furthermore, there existed no consistent means or methodology for reviewing and comparing at a sufficiently detailed level the large number of available candidate models.

Therefore, at the completion of the first study, a second task was undertaken for DNA. This was to devise a means of presenting detailed information about a variety of land combat models having differing capabilities and scopes, in a format that would make it possible for an analyst to more readily identify those models best suited for his specific study application. Such a methodology could be employed by DNA in their efforts to select a model to meet their long term analysis objectives. In addition, information presented in this form would have repeated utility and could be used by other analysts to choose land combat models appropriate for their particular needs.

Part I of this study presents the results of the initial investigation which was aimed at identifying models specifically applicable for examining tactical nuclear warfare. It includes a discussion of the primary types of land combat models that have been developed, what elements and events such models should include, what factors should be considered by the analyst when selecting a combat simulation model, and the characteristics of those best suited for sensitivity and tradeoff analyses. Each of the three tactical nuclear models that was selected as particularly appropriate for such analyses

is described in terms of its methodology, scope, capabilities and applications.

Part II discusses the generalized methodology subsequently developed for DNA to illuminate in a convenient form the basic attributes of both conventional and tactical nuclear land combat models. This work included defining more completely and in greater detail all of the components and events that are important in simulating both types of combat, and developing a format to present the information in a compact and descriptive manner. The utility of this methodology was tested by applying it to the three land combat models selected in Part I plus two other simulation models that included other facets of land combat. To further aid DNA in their identification of possible models suitable for meeting their long-term analysis objectives, several other nuclear combat models prominent within the analytic community were reviewed and described, but at a less detailed level.

PREFACE

The authors wish to express appreciation for the cooperation and suggestions of Mr. John Bode, BDM Corporation; Mr. Robert Gard and Mr. Ken Froeschner, Lawrence Livermore Laboratory; and Mr. Gene Ostermann and Mr. Greg Johnson, Lulejian and Associates.

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PART I

CHARACTERISTICS OF LAND COMBAT MODELS AND A REVIEW OF THREE THAT ARE APPLICABLE FOR ANALYSIS OF TACTICAL NUCLEAR WARFARE

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SECTION 1. INTRODUCTION

Within the past few years, military analysts and planners have become increasingly concerned about the possible role of tactical nuclear weapons on the battlefield. Of particular interest to them are land combat models that can be used to examine the introduction and use of tactical nuclear weapons in a medium- or high-intensity conventional conflict, such as might occur in Europe between NATO and Warsaw Pact forces. Such models could be used to perform sensitivity analyses and tradeoff options concerning the types and number of tactical nuclear weapons required to achieve particular goals, alternative employment plans, the resulting collateral damage, etc. The purpose of Part I of this report is to:

1. Review briefly the types of land combat models that have been developed to date;

2. Identify those types best suited for sensitivity and tradeoff analyses of mixed conventional and nuclear forces in land combat;

3. Select specific models appropriate for such analyses, and describe their methodologies, scope, capabilities, and applications.

The investigation of types of existing models was accomplished by (1) reviewing a number of previously published catalogues [I-1 through I-4] which briefly outlined the capabilities and utility of models already developed; (2) reviewing the specific documentation for some of the models, when available; and (3) in some cases, discussing model concepts and capabilities directly with the developers and/or users. This latter

procedure was employed for some of the more recently developed models where little or no documentation yet exists. Through this process, three specific, recently developed models were chosen for a more detailed examination of their design and capabilities. These particular models were selected primarily because it appeared they could be readily used to perform some of the sensitivity and tradeoff analyses of interest for the employment of tactical nuclear weapons in mixed conventional and nuclear land combat. This is not to say that they were the only applicable models; but, they did appear to be three with a high potential utility, and applications for their use are suggested.

Section 2 addresses the first two objectives of this study. It presents a discussion of the various types of models that exist and indicates the nature and requirements of those applicable for investigating theater-level or division-level mixed conventional and nuclear land combat. Section 3 discusses and compares the capabilities and limitations of three models selected that could be employed in such studies, and Section 4 amplifies on each model's particular utility.

SECTION 2. MODELS: OVERVIEW

2.1 TYPES OF EXISTING MODELS

To perform a detailed investigation of the many aspects of tactical land warfare, one usually thinks first of digital-computer combat simulation models, and indeed there is an ever-growing number of such models. However, not all simulations of land combat are restricted solely to using computer models. At the other end of the simulation spectrum are map exercises and war games, which can provide the analyst with data and insights on facets of a combat such as effective changes in strategies, tactics and force allocations during the conflict; command and control; troop movements, etc., that cannot be readily duplicated mathematically. The difficulty with this type of simulation is that it is expensive and time-consuming, and essentially nonrepeatable; thus, it does not lend itself to the tradeoff analysis or parametric study approach. As a result, there have been a number of simulation models developed in which man and computer interact to various degrees.

One may envision the group of land combat models as consisting of the following classes:

1. Digital computer models.
2. User-assisted computer models.
3. Computer-assisted map exercises, or war games.
4. Map-exercises or war games unassisted by computers.

The hybrid classes (2 and 3), in which both man and computer are involved in decision-making during the simulation of a battle, provide a method by which the "commander" or analyst

can supplement or replace the computer at particular times of interest. For some models, this may mean that at the end of each sortie or simulated day, the analyst reviews the computer results to date and makes force and weapon choices for the next "cycle." For other models, which may employ a direct interactive link with the computer, the user may be able to monitor the course of the engagement (as determined by the computer) on printed output or video display and intervene when he wants to make a change.

An additional distinction which needs to be made about all classes of battlefield models simulated by computers is that many models are designed principally to evaluate weapons effects. Such models do not attempt to take into account all of the major elements of land combat. They are concerned primarily with the casualties to troops, equipment, supplies, and possibly civilian population, resulting from the specific employment of certain weapons. These models are used to evaluate weapons and weapon strategies and mixes, and hence are limited to assessing the weapon effects results of employing conventional or tactical nuclear weapons, not in determining the overall outcome of the battle.

Of the four classes of models listed above, the first two (i.e., digital-computer simulation combat models, with or without user-interaction) appear to be the most desirable for sensitivity and tradeoff analyses, particularly those that can simulate many complete battles with little or no user interaction. For these two classes, the roster of major models being used to simulate combat between military forces grows larger every year. Not only do new models appear, but often existing ones are modified and expanded so extensively in order to better serve a specific study that they virtually

consitute new models in terms of program input/output and capabilities.

In general, the digital computer models which simulate theater-level conventional warfare, or some aspect of this type of conflict, are the larger, more detailed and consequently more complicated programs. Most are the result of a fairly long evolutionary process during which the developers expanded, combined and reorganized earlier models to improve simulation capabilities as required for particular tasks. Consequently, these models have the virtue of being fairly complete in that they account for most of the key elements of combat at a fairly detailed level and usually possess a considerable degree of flexibility.*

One might expect that such models would be further expanded to handle the employment of tactical nuclear weapons so that a single model could be used for studies of conventional and/or tactical nuclear warfare. In general, this has not been the case. Because tactical nuclear weapons impact on so many aspects of conventional battle, the inclusion of these effects in the more detailed conventional combat models usually represents a major reprogramming task. Examining the impact of these weapons on the course of the battle requires incorporating additional features such as radiation effects, which produce delayed casualties, restrict troop movements, and interfere with some forms of communication. One can readily imagine that to modify and expand conventional land combat

*However, the implementation of these models by an outside user generally requires substantial manpower, calendar time and often computing time. Documentation is often not completely up to date and for a new user to develop even a complete set of inputs can take weeks to months.

models and yet maintain the same level of detail, can result in computer programs that are extremely large and complicated to use, and are not easily implemented by outside users.

On the other hand, a major limitation of many current models that do simulate the employment of nuclear weapons on enemy forces is that they were initially developed specifically to evaluate only the effectiveness of various nuclear weapons, deployments, and attacks. They do not take into account many of the other major aspects of combat and therefore must be classified primarily as weapon effects models, which calculate primary and collateral damage, and prompt and delayed casualties.

2.2 MODEL REQUIREMENTS

Regardless of the type of model, in order for it to simulate realistically a complete combined-arms land combat, it should include or represent all of the key elements and events encountered in theater-level warfare. Table I-1 presents a list of the key elements and their typical "components" which are a part of any major tactical conflict involving land and air forces. The components of the three types of force elements, as well as the logistic and reserve elements, are readily quantifiable in terms of the number of men, weapons, supplies and their various combat capabilities. However, the remaining three major elements listed, doctrine and missions, C^3 (command, control and communication), and environment are much more difficult to define and model. Consequently, even models which purport to be "complete" land combat simulations seldom model all of these key elements to the same level of detail or complexity. Furthermore, as would be expected, most models are developed in conjunction

Table I-1. Major Elements of Combined-Arms Land Combat

MAJOR ELEMENT	COMPONENTS
GROUND FORCES	• ARMOR (TANKS, APCs, ETC.) • INFANTRY (RIFLES, MORTARS, ETC.) • ARTILLERY (TUBES, ROCKETS, MISSILES) • ANTI-ARMOR (AIR AND GROUND LAUNCHED MISSILES) • RECONNAISSANCE UNITS (AIRCRAFT, PATROLS, ETC.)
TACTICAL AIR FORCES	• CLOSE-AIR SUPPORT AIRCRAFT • DEEP STRIKE AIRCRAFT (AIRBASE ATTACK, INTERDICTION, ETC.) • SAM SUPPRESSION AIRCRAFT • FIGHTER SWEEPS, CAP AND ESCORTS • RECONNAISSANCE AIRCRAFT
AIR DEFENSE FORCES	• SAMs (FIXED SITES AND MOBILE UNITS) • AAA (FIXED SITES AND MOBILE UNITS) • AIRCRAFT (INTERCEPTORS AND FIGHTERS)
LOGISTICS AND RESERVES	• NUMBERS OF MEN AND EQUIPMENT, AND TYPE • SUPPLY DEPOTS, RESERVE LOCATIONS • RESUPPLY AND TROOP RESERVE MOVEMENT ROUTES AND MEANS • POLICIES AND SCHEDULES FOR RESUPPLY AND REINFORCEMENT
DOCTRINE AND MISSION	• OVERALL OBJECTIVES, GOALS AND PLANS • INDIVIDUAL FORCE UNIT OBJECTIVES AND MISSIONS (ATTACK, DEFEND, DELAY, ETC.) • METHOD OF CARRYING OUT MISSIONS • ALLOCATION OF FORCES • RESTRICTIONS ON USE OF FORCES AND RULES OF ENGAGEMENT (CONVENTIONAL AND NUCLEAR)
C^3	• COMMAND, CONTROL AND COMMUNICATIONS (EQUIPMENT, PERSONNEL AND PROCEDURES)
ENVIRONMENT	• WEATHER • TERRAIN • CIVILIAN POPULATION CENTERS

with a particular study addressing specific questions. They therefore emphasize the portions or aspects of the battle of most importance for the analysis; facets having less impact on the result, or more readily evaluated outside the model, are usually represented in less detail or even omitted entirely.

The simulation of a complete land battle will consist of actions and interactions involving the seven key elements given in Table I-1. These interactions have been condensed to consist of the five major events given in Figure I-1. The ordering of the events within the block is not intended to define a particular sequential ordering. At various times, all or most of the events will be taking place in parallel. The intent of this figure is to identify the major events and indicate their conceptual relationship with the key elements discussed above. The main point is that if a model is going to try to represent an actual combat realistically, then it must model or take into account in some form these five major events that comprise land warfare.

2.3 MODEL SELECTION

Although there exist a number of large detailed computer models that collectively cover almost every aspect of conventional/nuclear combat, the approach of using a family of models to perform a sensitivity or tradeoff analysis (timing, number, yield, etc.) of the employment of tactical nuclear weapons is not usually desirable or even practical--particularly if one is fairly limited in manpower and resources. This is especially true if the results of one model are used to establish the inputs for another because there is often difficulty in reconciling or structuring the data to conform

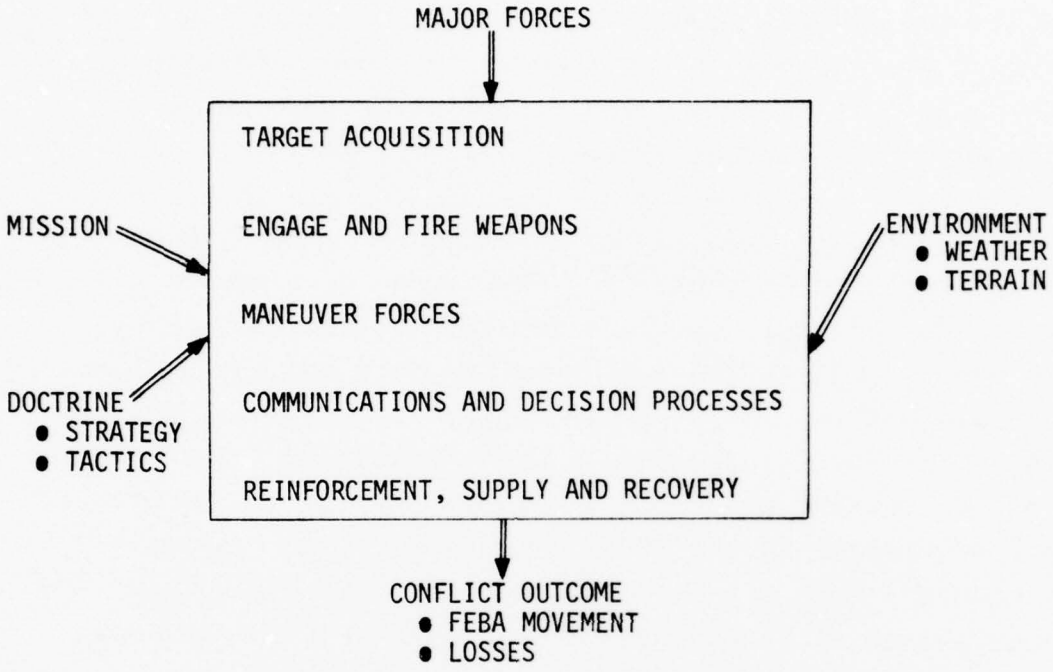

Figure I-1. Major Events in Land Combat

to that required by the subsequent model. Under these circumstances, the manpower, calendar time, and computer time required to obtain the results needed for analysis are often prodigious. For this type of analysis, the use of a single computer model which includes all or most of the major elements and events of land combat, and can perform the necessary calculations quickly in a parametric mode of operation, appears much more satisfactory.

As a result of this need, a few models have recently been developed that are suitable for these types of tradeoff analyses. In general, they are theater- or division-level models which simulate the employment of both conventional and nuclear weapons in a high-level conflict. As a rule, because of the requirement to simulate a large number of "wars" rapidly, they do not include the depth of detail of some of the previously developed, larger "conventional-only" or "nuclear-only" models. Most of these recent models treat many key elements, especially those associated only with conventional combat, in a much more aggregate or average manner. Thus, the analyst is probably not able (<u>if</u> the need arises) to examine <u>all</u> facets of a simulated combat covering an extended time period (on the order of weeks) to the same <u>degree</u> of detail as he would with a family of larger combat models.

However, with these newer models he is able to perform types of analyses (sensitivities and tradeoffs) that are not possible nor practical with larger models or families of models. If they are used properly, these newer, more aggregated models can effectively help answer some of the major questions concerning the employment of tactical nuclear weapons in support of conventional forces.

Three such models that were specifically designed for the investigation of the employment of tactical nuclear weapons in a conventional land combat are COMBAT II developed by Braddock, Dunn and McDonald; L&A TAC NUC model* developed at Lulejian & Associates, Inc.; and DWEEPS developed by Lawrence Livermore Laboratory. These models represent three different levels of force in land combat: COMBAT II models the entire theater-level war, L&A TAC NUC models a sector-level combat, and DWEEPS models the nuclear portions of a division-level battle. The following section is devoted to discussing the capabilities and utility of these three specific models in the context of their ability to model the elements and events discussed in this section.

A methodology for screening models and determining which are appropriate for a given purpose is presented in Part II. The three models referred to above, plus two other models--a model currently in development at Lawrence Livermore Laboratory called JEREMIAH, and a specialized model developed by Lulejian & Associates called LULEJIAN I--are treated as examples in that part of the report.

*The Lulejian model has never been officially given a name.

SECTION 3. CAPABILITIES AND UTILITIES OF SELECTED MODELS FOR INVESTIGATING TACTICAL NUCLEAR COMBAT

Table I-2 presents an overview of the characteristics and capabilities for each of the three models identified as being applicable for investigating facets of tactical nuclear warfare: COMBAT II, L&A TAC NUC, and DWEEPS. The first two models are completely computerized digital computer programs, and the third is a user-assisted nuclear targeting effects computation model. All three of these models were designed specifically for investigating the employment of tactical nuclear weapons in a high-intensity, land combat situation, and all three have been used recently in at least one study of tactical nuclear warfare.

For each model, Table I-2 presents a list of its major features and characteristics, the key elements and events that it considers, the major program inputs and outputs, the measures of combat outcome used, and an overview of the utility of the model (i.e., size of the program and magnitude of the effort required to implement it by a new user).* The characteristics and capabilities of each of these models are discussed in more detail in the following paragraphs with suggestions of ways in which each could be used in analyzing the employment of tactical nuclear weapons.**

---

*Table II-2 presents a more detailed matrix description of these models, along with JEREMIAH and LULEJIAN I.

**For a more complete description see Appendices A, B, C, D, and E of Part II.

Table I-2. Characteristics and Capabilities of Selected Computer Models

MODEL	BASIC DESCRIPTION	KEY ELEMENTS	EVENTS SIMULATED	INPUT/OUTPUT AND MEASURES	MODEL UTILITY	REMARKS
COMBAT-II BRADDOCK, DUNN & MCDONALD, INC. 1974	LAND COMBAT COMPUTER MODEL ASSESSES INTERACTIONS AMONG COMBINED-ARMS COMBAT FORCES CONVENTIONAL AND NUCLEAR TWO-SIDED SYMMETRICAL THEATER-LEVEL CONFLICT (3 FRONTS) MINIMUM UNIT SIZE: BATTALIONS OR REGIMENTS SOLUTION METHODOLOGY (MATHEMATICAL PROCEDURE DETERMINISTIC FLOW-RATE MODEL SIMULTANEOUS SOLUTION OF ABOUT 100 DIFFERENTIAL EQUATIONS)	GROUND FORCES TACTICAL AIR AIR DEFENSE LOGISTICS, RESERVES DOCTRINE: ALLOCATION AND ATTACK ENVIRONMENT	TARGET ACQUISITION ENGAGE AND FIRE WEAPONS MANEUVER FORCES DECISION PROCESS: ALLOCATION OF THEATER LEVEL WEAPON (AIRCRAFT, SSM) REINFORCEMENT, RESUPPLY AND RECOVERY	INPUTS: FORCE NUMBERS AND DISTRIBUTION ALLOCATION FACTORS FLOW RATE LIMITS COUPLING COEFFICIENTS BASE OCCUPANCY LAUNCH AND SORTIE RATES OUTPUTS AND MEASURES*: FEBA MOVEMENTS ON 3 FRONTS FORCE SIZE ATTRITION RATES RESOURCES, ETC. TIME HISTORIES OF 1100 STATE VARIABLES	SIZE: 4000 CARDS INPUTS: 830 COMPUTATION TIME: TENS OF SECONDS FOR 10-DAY WAR OUTPUT: DETAILED NUMERICAL AND GRAPHICAL AVAILABILITY: AUGUST 1975, DNA SPONSORED PROGRAM IMPLEMENTATION: LESS THAN A MONTH (APPLICABLE FOR SENSITIVITY ANALYSES)	MODEL CAN BE OPERATED AT THEATER, DIVISION OR CORPS LEVEL FEBA MOVEMENT BASED ON HEURISTIC EXPRESSION OF LANCHESTER e.g., EACH OF THREE FRONTS MOVES IN A STRAIGHT LINE MODEL CALCULATES FEBA MOVEMENT AND LOSSES BASED ON INPUT ACQUISITION AND KILL FACTORS ETC. IT IS A P_K TYPE BOOKKEEPING MODEL WHICH DOES NOT SIMULATE THE ACTION OF THE FORCES. NUCLEAR STORAGE SITES NUCLEAR ARTILLERY AND SSMS NO DELAYED EFFECTS OF NUCLEAR DETONATION (NO DELAYED CASUALTIES)
TAC NUC MODEL LULEJIAN & ASSOC. 1973	LAND COMBAT COMPUTER MODEL ASSESSES INTERACTIONS AMONG COMBINED-ARMS COMBAT FORCES CONVENTIONAL AND NUCLEAR ATTACER VS DEFENDER CORPS LEVEL CONFLICT MINIMUM UNIT SIZE: BATTALIONS (MATHEMATICAL PROCEDURE: DETERMINISTIC TIME-STEP MODEL-ITERATIVE SOLUTION OF FORCE INTERACTION EQUATIONS)	GROUND FORCES TACTICAL AIR: CLOSE AIR SUPPORT ONLY LOGISTICS, RESERVES DOCTRINE: ALLOCATION AND ATTACK/DEFEND ENVIRONMENT	TARGET ACQUISITION ENGAGE AND FIRE WEAPONS MANEUVER FORCES FORCE ALLOCATION REINFORCEMENT	INPUTS: FORCE NUMBERS AND DISTRIBUTION ALLOCATION FACTORS ACQUISITION FACTORS KILL FACTORS (MAE, P_K, CEP) ATTRITION THRESHOLD LEVELS MOVEMENT RATE LIMITS CAS SORTIE RATES OUTPUTS AND MEASURES: FEBA MOVEMENT FORCE SIZE AND THEIR COMBAT EFFECTIVENESS ATTRITION RATES	SIZE: 2000 CARDS INPUTS: 300 COMPUTATION TIME: SECONDS FOR A 10-DAY WAR OUTPUT: DETAILED NUMERICAL AVAILABILITY: NOVEMBER 1974; ISA SPONSORED PROGRAM IMPLEMENTATION: LESS THAN A MONTH	MODEL TO BE EXPANDED TO THEATER LEVEL NO NUCLEAR STORAGE LOCATIONS NO CIVILIAN COLLATERAL DAMAGE NO THEATER LEVEL SURFACE-TO-SURFACE MISSILES DOES NOT INCLUDE DEEP STRIKE AIRCRAFT, AIR DEFENSE AIRCRAFT OR SAMS FRIENDLY CASUALTIES NUCLEAR: PROMPT AND DELAYED CASUALTIES COLLATERAL DAMAGE UNILATERAL OR BILATERAL USE OF NUCLS ONLY TUBE LAUNCHED NUCLEAR ORDNANCE AVERAGES OVER A DAY
DWEEPS LAWRENCE LIVERMORE LABORATORIES 1970/1975**	USER-ASSISTED WEAPONS EFFECTS COMPUTER MODEL EVALUATES INITIAL EFFECTS OF EMPLOYING TAC NUCS IN A BATTLEFIELD ENVIRONMENT SUPERIMPOSES NUCLEAR ATTACK ON PREDEFINED CONVENTIONAL LAND COMBAT NUCLEAR ATTACK BY ONE SIDE DIVISION LEVEL CONFLICT MINIMUM UNIT SIZE: PLATOONS MATHEMATICAL PROCEDURE: MONTE CARLO TIME-STEP MODEL	ENEMY GROUND FORCES CIVILIAN POPULATION CENTER DOCTRINE: NUCLEAR EMPLOYMENT PLAN DEVELOPED BY USER	TARGET ACQUISITION FIRING NUCLEAR WEAPONS NUCLEAR EFFECTS ONLY	INPUTS: ENEMY FORCE TYPES, NUMBERS, DISTRIBUTION, AND TIME-HISTORY MOVEMENT LOCATION AND SIZE OF CIVILIAN POPULATION CENTER NUCLEAR WEAPON EMPLOYMENT PLAN MAP LAYOUT OF BATTLE AREA OUTPUT: ACQUIRED TARGETS (ALL PROMPT NUCLEAR EFFECTS) MILITARY AND CIVILIAN CASUALTIES AND DAMAGE	SIZE: 1000 CARDS INPUTS: 700 COMPUTATION TIME: TENS OF SECONDS FOR A 5-HR BATTLE OUTPUT: DETAILED NUMERICAL AVAILABILITY: 1970 PROGRAM IMPLEMENTATION: ABOUT TWO WEEKS TO A MONTH	DISPOSITION AND MOVEMENT OF ENEMY GROUND FORCES MUST BY INPUT TO MODEL: e.g., THE OUTCOME OF A PREDETERMINED CONVENTIONAL BATTLE USER EMPLOYS ACTUAL MAPS, WEAPON EFFECTIVENESS TEMPLATES, AND GRAPHICALLY DISPLAYED TARGET ACQUISITION INFORMATION TO TARGET NUCLEAR WEAPONS USER DEVELOPES OWN NUCLEAR WEAPONS EMPLOYMENT PLAN PROMPT NUCLEAR EFFECTS ONLY

*AVAILABLE AS A FUNCTION OF TIME.

**LLL IS CURRENTLY COMPLETING WORK ON A NEW VERSION WHICH IS DESIGNED FOR AN INTERACTIVE VIDEO-GRAPHIC COMPUTER SYSTEM. ALSO, MOVEMENT OF ENEMY FORCES ARE ALTERED AS A FUNCTION OF EFFECTS OF NUCLEAR ATTACK, MAY 1975.

3.1 COMBAT II

The COMBAT II model was developed by Braddock, Dunn and McDonald (BDM) during the past two years specifically to investigate conventional land combat supported by nuclear weapons in a theater-level intensity conflict [I-5]. BDM's objective was to provide analysts with a tool that would allow them to identify and examine the key drivers in such combat and how they varied as a function of time. In designing this model, two important additional criteria were established. These were that the resulting digital-computer program be relatively simple in terms of its required inputs and that it have a fast computer running time commensurate with performing parametric analyses and tradeoff studies. To achieve this, BDM employed an "outside-in" approach and did not attempt to model the key elements and events using a detailed "inside-out" procedure. Consequently, the various major subprocesses of a combat are related to each other through coupling equations, which determine the relative contribution of each to the final outcome and provide a means of examining the evolution of the battle.

3.1.1 Basic Description*

COMBAT II has the capability to examine the interactions among the ground and air combined-arms forces engaged in the conventional, tactical nuclear or mixed conflict. The model is configured to be completely two-sided, with no built-in asymmetries, and if inputs for the two sides are reversed, the results will be a complete mirror image. The various force elements are aggregated at the battalion or division

*See also Appendix A, Part II.

level, and the model does provide for FEBA movement in three separate fronts. Each front, which is about 300 km wide and 30 km deep, moves independently or can have a functional relationship at the option of the user; however, there is no mechanism for simulating "flank attacks," encirclement, local breakthroughs or the like.

The mathematical methodology employed for ease and speed of program operation is that of a deterministic differential equation flow-rate model. In this type of program, the key parameters and events are modeled using a set of interrelated ordinary differential equations that are solved simultaneously. Each equation defines the time rate of change of some variable of state such as the number of ground troops, interceptor aircraft, surface-to-surface missiles, all of which change as a function of time due to their interactions with other components. For example, the time rate of change of the number of ground troops at a front could be expressed as a function of their losses to each of the various weapon systems plus the net flow of reserve troops from the rear. In such equations, each of these individual terms is defined mathematically in terms of acquisition, attrition and other factors associated with the particular variable.

In COMBAT II, a set of approximately one hundred such equations is numerically integrated over time to generate the evolution of the battle and calculate the attrition of the various combat systems. The model has been designed so as to provide the analyst both with an overview of theater-level mixed combat and with detailed time-histories of all components of the engagements, so that he can determine their contribution to the overall outcome. The model is geared for investigating force mixes, strategies, optimum weapon deployment and timing,

in a parametric fashion, and determining the driving factors during the course of the battle.

3.1.2 Key Elements

The model was designed to be used for studies of NATO/Warsaw Pact conflicts and hence takes into account in a highly aggregated fashion most of the key elements discussed in the previous section. The combat systems associated with each of the three fronts include ground forces (with their share of conventional artillery units), nuclear artillery, tactical missiles, supplies and nuclear warheads. In the rear are reserve forces and supplies, airbases, aircraft, centrally controlled surface-to-surface missiles, and nuclear storage sites. The aircraft may be designated as interceptors that engage enemy aircraft or nuclear-capable aircraft, which may be specifically allocated to either ground support or long-range attack and interdiction.

Logistics are simulated in that troops and supplies flow from the rear to the fronts and vice versa. The program permits moving these resources from one front to another by withdrawing and reallocating them. Based on user input allocations and options, the model's doctrine provides for conventional and/or nuclear exchanges, including ground-to-ground duels, tactical missile exchanges, aircraft air-to-air battles and ground attacks.

Environmental characteristics such as weather and terrain are not modeled explicitly within the program but are accounted for indirectly through user inputs concerning target acquisition factors, maximum movement rates of the FEBA, reinforcements, and resupply units.

3.1.3 Events Simulated

As indicated in Table I-2, the COMBAT II model attempts to take into accout all of the major events of land combat previously identified, with the exception of C^3. Using inputs concerning target acquisition factors, weapon kill factors, allocation factors, and maximum expenditure and flow rates, the program evaluates the interactions between various weapon systems by solving its set of simultaneous differential equations. For those combat systems defined as being at one of the three fronts, interchanges are permitted only between opposing ground force units and include both conventional and nuclear artillery. However, surface-to-surface missiles are able to attack all opposing elements within the front.

All aircraft are located at airbases in the rear area. These bases can be specified as being within or beyond range of the enemy's tactical surface-to-surface missiles. The air battle simulation involves both conventional and nuclear-capable aircraft. The conventional aircraft may be specified as interceptors or allocated to a ground attack role, while those aircraft carrying nuclear weapons may be assigned to various types of ground targets. The conventional interceptors that survive the air combat return to base while the surviving conventional and nuclear ground attack aircraft continue on to their targets and are subjected to area and terminal air defenses. Those that survive deliver their weapons on the assigned target types.

The flow of reserves and resupplies from the rear to the fronts are controlled by response equations which reconcile the maximum allowable densities, the actual and commanded FEBA advance rates, and the maximum flow rates specified to define the resulting flow rates used in the set of differential equations.

In designing this model, emphasis was placed on giving the analyst the ability to readily investigate the contributions and interactions of the component weapon systems and strategies to the outcome of the battle. Naturally for any simulated combat extending for more than a few hours, the time-dependent results must include not only force drawdowns and weapon system attrition, but also the movement of ground forces. In this model, the FEBA movement is modeled heuristically so as to range from zero, when the opposing forces approximate parity, to a maximum unopposed rate, which is input by the user. The particular functional relationship employed is based on extending the Lanchester Equations so as to represent the total attrition of ground forces due to all causes. However, the calculations of FEBA movement are performed independently of the integration of simultaneous differential equations.

3.1.4 Inputs/Outputs and Measures

As indicated above, the types of inputs required for this kind of model include allocation, acquisition and kill factors, and maximum expenditure and flow rates. The initial disposition of forces and weapon systems is specified in terms of the numbers and distribution of men, weapons and supplies at each of the three fronts and in the rear, and thereby define an aggregated order of battle for the two sides. Other inputs, such as acquisition and kill factors, and maximum expenditure and force and supply movement rates represent average values associated with the various systems and their interactions. These factors determine values for the coupling coefficients used in the differential equations to interrelate the various combat systems. Naturally, the selection of appropriate values by the analyst can be extremely important to the

outcome of the battle, especially when different magnitudes are used for the two sides. Therefore, these factors are usually chosen on the basis of a combination of other model results, available combat data, military judgments and estimates, tempered with the particular analysis or trade-off study being performed. For mixed weapon type combat, an additional important key input is that of the time (specified in hours) at which tactical nuclear weapons are first employed.

Program outputs include a tape which contains time histories of all the nearly 1100 variables of state that are kept track of within the program. Using this tape as input to a post processor program, the analyst can obtain printer output and time-history plots of any of these parameters of interest, as well as summary tables displaying the composition and distribution of each of the combat systems throughout the battle. With these data, one should be able to identify which factors dominate and how they change as a function of time. However, the program does not calculate or account for collateral damage to the civilian population or the delayed casualties caused by nuclear radiation effects.

3.1.5 Model Utility

Because of the designer's aims and methodology, this model could probably be readily implemented by other users. It is programmed in FORTRAN (total deck size about 4000 cards) and requires 100K of storage, plus two on-line disk or tape files. Computation time on the CDC 6000-7000 computer systems is typically under two CPU (central processor units) minutes for a ten-day war. Program input preparation time for a completely new problem is usually less than a week, and the evaluation of the results can be accomplished in less than a day.

This model appears to offer the analyst a very convenient tool for examining conventional and/or tactical nuclear warfare involving theater-level mixed combat. Although it accounts for most of the key elements and events of interest in this level of conflict, the program is not intended to generate absolute quantitative answers. Its utility is to provide a method of comparing the effects of various weapons, options and strategies in a relative way, and to identify what factors are driving the results.

3.2 L&A TAC NUC MODEL*

The L&A TAC NUC model, recently developed by Lulejian & Associates, Inc., is a completely computerized, land combat model [I-6 through I-8]. It simulates the interaction among friendly and enemy combined-arms combat forces, and assesses the outcome of the battle in terms of the forces lost by each side and the movement of the FEBA. The model handles a mixture of both nuclear and conventional ordnance employed by either or both sides. The TAC NUC model was designed primarily to assess the battlefield employment of tactical nuclear weapons, and is a reduced/modified version of Lulejian's Theater Level Model of conventional land combat.

3.2.1 Basic Description

The L&A TAC NUC model is a nuclear land combat model which accounts for most, but not all, of the major elements and events that comprise a combined-arms conflict. Unlike the previous model discussed, it is not a theater-level model;

*See also Appendix E, Part II.

it is limited to one sector of the battle front (typically, a corps zone approximately 60 km wide).

The doctrine built into the model limits it to examining a situation in which one side is the attacker and the other is the defender. Reversing roles (or counter attacks) in the same computer run is not possible.

The basic ground force unit used in this model is an average size maneuver battalion. The area covered by the battalion is defined by the representative relative positions and distances among the companies and platoons that comprise a battalion, based on nominal deployment concepts. However, this deployment array can be modified to account for massing or dispersal, in keeping with the tactics for deployment of forces in a conventional or nuclear battlefield environment.

Maneuver-unit targets (tanks and infantry) are assumed to be detected and acquired by visual sensors only. Enemy artillery is detected using other sensors, such as counterbattery radars. The desired number of nuclear weapons employed against each target type is an input, but the number modeled is restricted by the number of artillery tubes and weapons available, their fire rate, and realistic employment delays. No air-delivered nuclear weapons are considered.

Basically, the L&A TAC NUC model is a deterministic, expected value, time-step digital computer model, with the time-step increment (or "integration step-size") being one day. That is, the losses and FEBA movement for that full day are determined on the basis of the forces available at the beginning of the day, and the number of targets acquired, the number of weapons used, etc., for that particular day.

The values of force losses and FEBA movement for a given day are determined simultaneously by obtaining an iterative solution to a set of algebraic equations which represent the interaction among the various forces: interdependent FEBA movement equations and force loss equations. The basic form of the equation that relates the FEBA movement to the losses is given as:

$$\begin{matrix}\text{FEBA}\\ \text{Movement}\\ \text{Rate}\end{matrix} = \left(\begin{matrix}\text{Unopposed}\\ \text{Rate}\end{matrix}\right)\left(1 - \frac{\text{Actual Losses}}{\text{Threshold Level}}\right)$$

where the unopposed rate and threshold level are input values. The actual losses are calculated as a function of the types and number of forces involved, the separation distances between them, and the appropriate effectiveness parameters (acquisition and kill probabilities, which depend on the separation distances). FEBA movement is then determined by losses sustained by each side's tanks and infantry. There are four FEBA movement equations like this one: two for tanks (friendly and enemy) and two for infantry. The four associated separation distances (enemy tanks to friendly infantry, enemy tanks to friendly tanks, etc.) and resulting losses on both sides are adjusted so that each equation yields the same FEBA movement. Unopposed rates of 64 km per day and threshold loss levels of 15 percent per day are assumed nominal values.

As for nuclear damage calculations, blast is assumed to be the primary tank-kill mechanism, and prompt radiation effects account for the personnel losses. Both initial and delayed casualties resulting from initial and cumulative doses of radiation are determined. Collateral damage is assessed in terms of the area that is subjected to various levels of

radiation. No civilian data base is input, nor estimate of their casualties attempted.

Even though the model has certain limitations, as indicated above, it can be used effectively to examine certain land combat situations. It was recently used to simulate a portion of the Barbarossa II scenario for ISA. This involved a short ten-day battle between different numbers of Pact and NATO divisions. The Pact forces massed a number of divisions against a single U.S. division over a 60-km wide sector in which NATO employed only hold and block tactics against the Pact attack. This model has also been used to make a comparison between the use of advanced precision-guided munitions and tactical nuclear weapons in the area of the FEBA.

3.2.2 Key Elements

This model accounts for all of the major forces for both sides except for a part of the tactical air forces and the air defenses (SAM, AAA and aircraft). Close-air-support (CAS) sorties are inputs to the model, and their effects on the ground combat are determined; but, the rest of the tactical air missions and air defense missions, and their impact on the ground war, are not considered. Reserve maneuver battalions are accounted for by committing them to the front line area as the battle progresses. The doctrine which determines the allocation of forces can be chosen as fixed by the input, or can be altered day by day based on the outcome of the battle to date or the desired outcome of the next day's battle. However, as indicated above, the basic doctrine of each side is fixed for the duration of the conflict, with one side being the attacker and one being the defender.

The effects of the environment, terrain and weather are not modeled explicitly. However, variations from the norm can be roughly accounted for by changing the input values for target acquisition probabilities and unopposed force movement rates. As for collateral damage to the civilian populace, no account of them is made. However, the cumulative ground area that is affected by the nuclear weapons is calculated (blast, thermal and nuclear radiation) and termed the collateral damage area.

3.2.3 Events Simulated

As indicated above, the major events simulated or modeled by L&A TAC NUC are the acquisition of enemy targets, the engaging of enemy ground forces and firing of conventional and nuclear ordnance, the maneuvering of these forces based on acceptable losses, and the allocation of reserve battalions and nuclear weapons. Although the use of reserve maneuver battalions is taken into account based on the doctrine selected (e.g., attack or defend), in general the communication and decision processes and reinforcement, supply and recovery are not modeled in any detail. However, the simulation does take into account troop combat ineffectiveness, and the communication of target location information for support fire and nuclear delivery systems is explicitly modeled. The basic doctrine for attacking or defending is fixed once the battle begins; only the decision regarding the allocation of nuclear weapons and reserve battalions is processed by the model, based on the selected mode of operation of the model and the built-in allocation algorithms.

3.2.4 Inputs/Outputs and Measures

As shown in Table I-2, the necessary inputs to the L&A TAC NUC model consist primarily of those that define the initial disposition of forces for both sides, the target acquisition and kill factors, and the limits on force movement rates and acceptable attrition levels. The initial disposition of the forces is input in terms of the number and area covered by each side's "average" maneuver battalion and the density of battalions on line (i.e., along the front line and in reserve). Kill factors for the weapons employed are input in terms of the mean area of effectiveness (MAE), circular area probability (CEP), and/or probability of kill against a particular type of target. In addition to these inputs, the number and rate of CAS sorties employed by each side are a major model input.

The basic model outputs, which are used as measures of battle outcome, are FEBA movement, distance and rate, and the size and combat effectiveness of the forces on each side as a function of time. The size of the remaining forces is a measure of the attrition rate sustained; the fraction of these forces (troops) that are ineffective is a function of the prompt and delayed effects of nuclear radiation, as well as the casualties sustained due to conventional weapons.

3.2.5 Model Utility

This model is relatively small considering it is a computerized model of a sector-level (several divisions) combined-arms land battle. It is composed of only about 2000 FORTRAN statements (~2000 cards or one box of cards), and requires only 300 input values. As for computer time per run, it takes about 30 CPU (central processor units) seconds on a CDC-6600 computer to

model a ten-day war involving bilateral use of nuclear weapons. Under nominal conditions, this program could probably be implemented for use by a new user and be operating with a new data base in less than a month of calendar time.

It appears that even though this model has certain limitations due to its omission of tactical air (except CAS) and air defense forces, it can still be effectively used in sensitivity analyses of land combat involving conventional and nuclear weapons under certain conditions. That is, this model is applicable for investigating the initial phases (short period of time--several days) of such a conflict before the deep-strike missions would begin to have any pronounced effect on the ground war. Furthermore, the input number and rate of CAS sorties should be commensurate with the expected losses to enemy air defenses in the forward battle area.

As for other possible applications, since the L&A TAC NUC model only models one sector of an entire theater front, it might be used to perform calculations for several adjacent battlefields (or sectors), each having different forces, ratios, terrains, etc., and different FEBA movements and force losses. In this way, realistic, uneven force deployments and FEBA movements (bulges in the line) could be simulated. However, in some instances, this mode of model usage would require the question of "open flanks" to be addressed and taken into account.

3.3 DWEEPS MODEL*

The DWEEPS model, developed by Lawrence Livermore Laboratory (LLL), is considerably different from the two computer models

*See also Appendix B, Part II.

discussed above. That is, it is not a completely computerized combined-arms, land combat model; instead it is a player- or user-assisted, nuclear weapons effects computer model [I-9]. In essence, this model simulates the acquisition of enemy ground troops, and the employment and effects of tactical nuclear weapons on a predetermined, moving target array. As a result, this model can effectively be used to evaluate the impact of the initial employment of tactical nuclear weapons (e.g., artillery launched) on a conventional land combat conflict.* It has been used at LLL to investigate relationships among military effects, collateral damage, weapon system characteristics, and employment doctrine.

3.3.1 Basic Description

Basically, the DWEEPS model superimposes a one-sided nuclear attack on a predefined conventional land combat; it does not simulate the conventional conflict. The position time histories of all the enemy forces, as determined from some other source (other model, map exercise, etc.) are inputs to DWEEPS along with the fixed position of civilian population areas. Using this information as a data base, the model determines (through a simulation process) which targets are acquired and identified, and presents the results to the user as a function of time. Based on this target acquisition time history, the available nuclear weapons, military objectives

*LLL has completed work on a new version of the DWEEPS model, which is designed to operate on a special interactive video-graphics computer (XDS Sigma 7 computer with interactive video-graphical input/output capability). The version of DWEEPS discussed here is the earlier version that operates on a standard digital computer system (e.g., CDC 7600 with no special peripheral equipment other than a plotter).

and employment constraints and doctrine, the user selects targets for his nuclear weapons consisting of weapon aimpoints and times of employment. Upon inputing the selected weapons employment plan, the model then simulates the nuclear attack and calculates the enemy troop and equipment losses, and collateral civilian casualties and damage.

The DWEEPS model is nominally configured to handle a one to two division land conflict over a 30-km front, with the minimum size of the unit accounted for being a platoon (tank platoon, infartry platoon, etc.). Basically, the model uses both time-step and Monte Carlo mathematical processes. The movement of forces, the time the enemy forces (units) are acquired, and the time the weapons are called for are determined in a time-step fashion every 5 min. However, the actual number and location of the enemy units acquired, the actual arrival time and detonation location of a particular nuclear weapon, etc., are determined by a Monte Carlo process. As a result, each individual run represents a single possible outcome; several different computer runs for the same situation are made to determine the expected outcome.

3.3.2 Key Elements

As indicated above, the key elements or forces accounted for in this model are the enemy ground units, the civilian population centers, the nuclear weapons available, and the nuclear employment plan or doctrine. For the most part, all of the major elements for the enemy forces are taken into account except for his tactical air force and doctrine in response to a nuclear attack. However, none of the major elements for the friendly forces are taken into account except the number and type of available nuclear weapons and the usage

doctrine (which is input by the user). As for the battlefield environment, only the location of the civilian population centers are considered; weather and terrain effects are not modeled directly (although the input enemy force movements may have accounted for them).

3.3.3 Events Simulated

As shown in Table I-2, the major events simulated directly by the DWEEPS model are acquisition of enemy targets and firing of nuclear weapons (employment of nuclear weapons and nuclear weapons effects). The other three major events--namely, (1) force movement, (2) communication and decision processes, and (3) reinforcement, resupply and recovery operations (after the nuclear attack)--are not simulated.* As a result, no interaction between enemy forces and friendly forces (nuclear) is modeled.

3.3.4 Inputs/Outputs and Measures

As stated above, the major inputs to this model are the numbers and distribution of all the enemy ground forces as a function of time, and the locations of all the civilian population centers. In addition, a map of the battle area, although not necessary, is helpful in developing the weapon employment plan once the target acquisition data become available. Also, to develop the employment plan, templates representative of the size of the area that will be affected by each type of nuclear weapon are additional necessary tools.

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*The new interactive video-graphics version of DWEEPS does alter the input enemy force movements as a function of the efforts of the nuclear attack.

These are used to help the planner target the weapons for maximum coverage of those targets acquired, and at the same time minimize the risk of collateral damage to the civilian populace.

The model measures the success of the nuclear attack in terms of the military and civilian casualties, and losses and damage to enemy equipment that result from prompt nuclear radiation, thermal radiation, and blast. That is, the model determines exactly which enemy force and civilian population centers are affected by the nuclear detonations.

The targets killed or damaged may or may not be those targeted, depending on the movement rates of the forces, the size of the target acquisition errors, and the delivery accuracy, delivery time and yield of the specific detonation (as determined by a Monte Carlo process). The specific forces destroyed or damaged will be those that are inside the weapon's effective region at the time of the detonation. This may well include unseen enemy forces. These damage calculations account for multiple weapon effects where applicable.

3.3.5 Model Utility

The DWEEPS model is relatively small, uses little computer computation time and is relatively easy to operate. The basic program consists of about 1000 FORTRAN statements (i.e., 1000 cards), and requires about 700 inputs, most of which define the locations (coordinates) of the enemy forces as a function of time, and the location and size of the civilian population centers. A 5-hr battle in which 20 nuclear weapons are employed typically requires only about a minute of computer time per run (CDC 7600); however, the development of the

weapons' employment plan (after the model presents the target acquisition information) may take up to an hour or two, depending on the experience of the user, the number and types of weapons to be employed and the particular employment doctrine. With the new interactive video-graphic version, the entire simulation can be performed in about 10 min.

As for implementing the model for use by a new user and preparing the military and civilian data bases, this can probably be accomplished in about two weeks to a month. This time depends on the form of the target array and the particular computer facilities available to the user.

It appears that the DWEEPS computer model could be very useful in assessing the impact of the initial introduction of the tactical nuclear weapons into a conventional land combat. It could be used as an effective tool, in conjunction with a map exercise or computer model simulation of the conventional combat, to answer such questions as: At what point in time in the conventional battle would the introduction of nuclear weapons be the most effective, and what level of employment (numbers and types of weapons) would be sufficient to stop the enemy's advance?

SECTION 4. OBSERVATIONS AND POTENTIAL APPLICATIONS

To investigate the subject of land combat involving the possible employment of tactical nuclear weapons, one needs a model that will take into account all or most of the key elements and events occurring in theater-level warfare. Moreover, if the model's primary use is to be that of performing sensitivity and tradeoff analyses concerning the employment of tactical nuclear weapons, then it must be easy to run in a parametric fashion and not consume large amounts of computer time. The model should be one that can be readily implemented and used with a reasonable expenditure of both man power and computer power.

For a model to have utility (especially for the nondeveloper user), it must be manageable in terms of its program size, required data, number of inputs, etc. The model should not be so large or complicated that the user cannot follow the program flow. He should be able to find exactly how and where the various elements and events are simulated or calculated within the program so as to be aware of the model's built-in assumptions and limitations and employ it properly.

All of these requirements lead to models that treat military force components and interactions in a more aggregated method than do the more detailed and complete land combat models. Consequently, one cannot expect such models to simulate all of the major factors of combat realistically or to the same level of detail. In models that meet the utility criteria mentioned above, it is especially difficult to simulate certain elements and events because they vary considerably as a function of time and space. For example, the FEBA does not move in a straight line; terrain and weather can have

wide fluctuations within a theater-wide area; and C^3 is a complex aspect of warfare, not easily simulated in any computer model. In addition, if one is performing tradeoff analyses concerning tactical nuclear weapon employment options and yields, it is desirable that the simulation provide information concerning the associated civilian collateral damage and delayed casualties. Therefore, it should be recognized that the more aggregated types of models do have certain limitations as to their realism, and cannot be used to provide definitive numerical results. However, they can be employed to investigate strategies and options in a comparative way and to examine some of the factors that drive the outcome of the battle.

Each of the three models discussed in the previous section is one that can be relatively easily implemented by outside users to perform sensitivity investigations of some of the key aspects of conventional/tactical nuclear warfare. COMBAT II models the entire theater-level war, L&A TAC NUC simulates a sector-level combat, and DWEEPS models only the nuclear portion of a division-level battle. Consequently, each program is particularly applicable for investigating certain aspects of warfare involving the employment of tactical nuclear weapons.

COMBAT II is particularly suited for examining conventional and/or tactical nuclear warfare at the theater level in that it accounts for (in an aggregated manner) most of the key elements and events. Its ease of operation, fast running time, and flexible form of output make it a very convenient tool for performing sensitivity analyses and determining the key drivers for combats ranging from a few days to several weeks. However, it does not assess civilian collateral

damage nor take into account the delayed casualties caused by nuclear radiation effects. The L&A TAC NUC model is also easy to implement; but, because of its omission of tactical air (except CAS) and air defense, it is primarily applicable for investigating the first few days of a conflict, before any deep-strike missions would have a pronounced effect on the ground war. By using the model "in parallel" to perform calculations for several adjacent sectors, each having different force ratios, deployment, terrain, etc., one could obtain a more realistic representation of the uneven nature of FEBA movement across a theater front. For this application, the question of "open flanks" would then have to be considered and taken into account.

The third model, DWEEPS, differs considerably from the first two models in that it is primarily a nuclear weapon effects model in which the user develops a one-sided nuclear attack against a predefined conventional battle. Using the positional time histories of the enemy forces, the model simulates the acquisition of enemy units and presents this information to the user as a function of time. Based on these data, the user develops a nuclear employment plan; the model uses this plan and simulates the specified series of nuclear attacks, calculating the losses to enemy troops and equipment as well as the collateral civilian casualties. Thus, this model is particularly useful in assessing the impact of the initial introduction of tactical nuclear weapons, determining the time at which their introduction is most effective, and estimating the level of tactical nuclear weapons required in the context of examining the dual criteria of military effectiveness and civilian casualties.

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PART II

A METHODOLOGY FOR ILLUMINATING THE ATTRIBUTES OF LAND COMBAT MODELS, WITH SELECTED EXAMPLES

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SECTION 1. INTRODUCTION

In performing the research for completing the study of land combat models reported in Part I, the following facts became apparent:

- There are a large number of land combat models.
- Models that simulate combined-arms warfare are complex by the very nature of the complexities of the combat they replicate.
- Because of these complexities, such models are dissimilar in structure, content and utility, and hence are difficult to describe and compare.
- A model's value cannot be assessed in an absolute sense per se; it is in large part determined by its applicability to a particular analysis.

Thus, finding and selecting one or more land combat models that are suitable or easily adaptable for a given study can be a formidable and time-consuming task. Not only is the number of existing models very large but often it is difficult to readily determine a model's primary capabilities and limitations. Moreover, the group of land combat simulations actively used within the defense community changes from year to year, as new models are developed and old models are expanded, combined, and renamed. For example, the latest edition of SAGA's "Catalogue of War Gaming and Military Simulation Models" [II-1] lists more than 150 simulations and models, of which only half are listed in the previous edition.

For the prospective user of combat models to pick one or more models that are suitable for his requirements (or capable of being readily modified), he must have available basic descriptive data on the model's characteristics that will help him to zero-in on those that appear most promising. To have utility, such descriptions must include a greater level of detail than exists within the current catalogue approach (SAGA) and must be standardized enough to delineate model differences. Therefore, the approach in this second part of the study of land combat models is directed towards solving the above-noted problems. The objectives are:

- To develop a generalized methodology to illuminate in a concise and convenient format the basic attributes, capabilities and limitations of land combat models.

- To test the use of the methodology as a screening mechanism to aid in the selection of a model (or models) to study aspects of land combat of particular interest to DNA.

As is noted in Part I, in order for a land combat model to be described as "complete" it should include or account for all of the major elements and events. Clearly, no computer model can embody all of the primary facets of combat, or model them to the level of detail and fidelity desired by all users. But, to have utility for the analyst, the model must achieve a satisfactory compromise between the practical constraints of manpower, computer power, calendar time and cost, and the desire for simulation integrity.

These two sets of requirements are usually reconciled by the fact that most simulation models are developed to serve a particular study addressing a specific set of questions or options.

Consequently, those phases of combat most important to the understanding and analysis of the particular problem are usually modeled more completely. Aspects that are irrelevant to the required simulation and analysis are often omitted, and those that can be adequately treated in a more aggregated or approximate method are so modeled. Therefore, answering the question of how "good" or "complete" a model is, is not a simple or straightforward task. The answer depends on the analyst's particular application and whether the model incorporates the key elements and events which must be included in the simulation for it to be valid for his analysis.

It was concluded that to best serve an analyst who needs to obtain a first-order description and assessment of the capabilities, limitations and utilities of land combat models, the information should be presented in a compact, matrix-type format. This would consist of a table in which the first column would specify a list of model descriptors and attributes, and each subsequent column would be used to define a particular model in terms of these characteristics. Consequently, the resulting matrix could be used in dual fashion. That is, it would provide the reader with an overview of a particular model as to what it included and its methodologies. In addition, it could be used as a screening mechanism to enable a prospective user to identify the group of models that included the components and features required for this study and were worthy of further investigation. The specific matrix methodology developed for this model comparison task is discussed in detail in the following section, Section 2.

In applying this matrix comparison methodology to selected examples, models were chosen that represent each of the following classes of land combat: simulations involving the employment of 1) only conventional weapons, 2) only tactical-nuclear weapons, and 3) mixed combat that included both conventional and tactical

nuclear weapons. Because DNA's primary interest lies within this third category, two additional examples were drawn from the last group and examined using this approach. Each of these five models (listed below) are described in the matrix (p. 49) and in appendices, (A through E) and are further discussed and compared in Section 4.

Conventional: LULEJIAN I - a two-sided theater-level conflict involving ground and air elements over a 30-90 day period.

Nuclear: DWEEPS - a weapon-effect model designed to assess the initial employment of nuclear weapons on a predefined conventional moving target array for a corps/division front.

Combined: COMBAT II - a highly-aggregated deterministic flow-rate model designed to examine parametrically the interactions and weapon trade-off options of opposing ground and air combined arms forces.

L&A TAC NUC - an attacker versus defender simulation developed to investigate the battlefield employment of conventional and tactical nuclear weapons.

JEREMIAH - a high-resolution Monte Carlo model (currently under development) which simulates the interactions of small units and major weapon systems within a battalion-sized area over a period of hours.

In addition five other models which have the capability to simulate various portions of a combined nuclear and non-nuclear battle, and which are currently in use by the analytic community, are also examined, but in less detail. They are CASCADE III, DIVWAG/QTEM, MAFIA, TANREM, UNICORN; these are described briefly in Appendix F.

SECTION 2. DEVELOPMENT OF MATRIX METHODOLOGY

2.1 ORGANIZATION OF MATRIX

The initial task in formulating a matrix was to attempt to define the key aspects of combat that are relevant and important in the simulation of both conventional and tactical nuclear combined-arms combat. The resulting set of descriptors that comprise the vertical axis of the matrix had its genesis in the work undertaken in Part I. The major model elements, events, characteristics and capabilities identified then were used as a starting point to develop a more comprehensive and detailed set of model attributes. To aid in developing this more detailed and inclusive list, suitable for describing simulations of conventional-only, tactical-nuclear-only, or mixed conventional/nuclear combat, models were identified that belonged to each of these three categories. These models, listed in Table II-1, are ones prominent in the analytic community, either because of their newness, current applicability, or significant utilization in the past. Documentation was subsequently obtained on many of these programs and provided additional source material for establishing the final set of over seventy model descriptors [II-2 through II-33].

The individual descriptors, which logically fall into one of seven major categories, are grouped on the matrix under one of the following headings or subheadings:

- General Characteristics
- Environment
- Combat Participants
  - Ground Combat Elements
  - Air Combat Elements
  - Air Defense Elements

Table II-1. Selected Land Combat Models*

CONFLICT LEVEL SIMULATED \ CONFLICT TYPE	CONVENTIONAL	TACTICAL NUCLEAR	CONVENTIONAL AND TACTICAL NUCLEAR
THEATER	ATHENA - GRC ATLAS - GRC CEM/CONAF - GRC GACAM - IDA IDAGAM I - IDA LULEJIAN I - L&A VECTOR I - VRI VECTOR II - VRI	NAR III B - CAA SATAN III - ANAGRAM CORP/NMCSSC TANDEM - RAND	CASCADE III - NMCSSC COMBAT II - BDM TANREM (NUREX/NUFAM) - CAA IDA TACNUC** - IDA
CORPS	CBM - GRC TAGS - RAND TALLEY/TOTEM - RAND TARTARUS IV N/COCO - CAA		L&A TAC NUC - L&A
DIVISION	DBM - GRC DIVOPS - VRI/BDM	DWEEPS - LLL	DIVWAG/QTEM - CACDA/SANDIA
OTHER	BONDER/IUA - VRI CARMONETTE IV - GRC DYNTACS - OSU STATE II - STC	FORECAST II - CAA	MAFIA - TRW UNICORN - SAI JEREMIAH** - LLL

*IDENTIFIED BY SHORT TITLE OF MODEL AND ITS DEVELOPER:

CAA	CONCEPTS ANALYSIS AGENCY (U.S. ARMY)
CACDA	COMBINED ARMS COMBAT DEVELOPMENT AGENCY (U.S. ARMY)
GRC	GENERAL RESEARCH CORP.
IDA	INSTITUTE FOR DEFENSE ANALYSES
L&A	LULEJIAN & ASSOCIATES, INC.
LLL	LAWRENCE LIVERMORE LABORATORY
NMCSSC	NATIONAL MILITARY COMMAND SYSTEM SUPPORT CENTER (DEFENSE COMMUNICATIONS AGENCY)
OSU	SYSTEMS RESEARCH GROUP, OHIO STATE UNIVERSITY
SAI	SCIENCE APPLICATIONS, INC.
STC	SHAPE TECHNICAL CENTER, NATO
VRI	VECTOR RESEARCH, INC.

**UNDER DEVELOPMENT.

- Support
  - Logistics
  - Command, Control, Communications
- Combat Functions and Events
  - Actions and Events
  - Weapons Employment and Effects
- Outputs
- Model Utility

2.2 MAJOR CATEGORIES AND THEIR DESCRIPTORS

The ordering of these major categories and the individual descriptors that comprise each group is sequenced on the matrix in much the same fashion as would be used by a model designer in giving a verbal overview of his model. Taken together, the attributes listed under the first two categories are intended to define a model's basic characteristics as to its scope, type, level of conflict simulated, mathematical methodology employed, and the fidelity of time and space representation within the model. The specific items included are:

General Characteristics

- Conflict level
- Conflict representation
- Smallest element resolved
- Decision point process
- Typical conflict duration
- Simulation time-increment
- Treatment of probabilistic events
- Primary attrition methodology
- FEBA movement methodology
- Geometric representation
  - Element locations represented explicitly
  - Implicit geometry of elements
- Optimizational aspects

Environment

- Terrain
- Road networks
- Natural obstacles
- Weather
- Time of day or day/night
- Civilian population centers

With this overview of the characteristics and nature of the model established, the key elements and events defined within the next three major categories can then be put in better perspective. The combat elements are identified in terms of the various types of force units, major weapon systems or support systems as follows:

Combat Participants

- Ground Combat Elements
  - Armor
  - Infantry
  - Artillery
  - Antiarmor
  - Reconnaissance
  - Aggregated combined-arms unit
- Air Combat Elements
  - Close air support aircraft
  - Deep strike aircraft
  - Air defense suppression aircraft
  - CAP, sweep, escort aircraft
  - Reconnaissance aircraft
  - Airbases
- Air Defense Elements
  - Surface-to-air missiles
  - Air defense artillery
  - Air defense aircraft
  - Aggregated air defense unit

Support

- Logistics
  - Men, equipment, depots
  - Modes and routes
  - Nuclear storage sites
- Command, Control, Communications Elements
  - Communications equipment
  - Communications network
  - Command centers - ground and/or airborne

Once these combat and support elements are delineated, the next logical step is to categorize their actions and interactions and the resulting events that may occur during the course of combat. These are addressed in terms of the following model descriptors:

Combat Functions and Events

- Actions and Events
  - Ground force tactical actions
  - Tactical air actions
  - Suppression of direct fire weapons
  - Suppression of indirect fire weapons
  - Suppression of air defenses
  - Intelligence
  - Target acquisition
  - Communications process
  - Electronic warfare
  - Ground force action decisions
  - Tactical air allocation decisions
  - Disruption, delays of command process
  - Resupply of men and equipment
  - Employment of reserves
  - Breakthroughs/open flanks

Weapons Employment and Effects
- Conventional
  - Small arms
  - Direct fire
  - Indirect fire
  - Aggregated ground force weapons
  - Surface-to-surface missiles
  - Surface-to-air
  - Air-to-surface
  - Air-to-air
- Nuclear
  - Radiation, thermal and blast effects
    - TAC air-delivered
    - Artillery
    - Surface-to-surface missiles
    - Atomic demolition munitions
  - Other nuclear effects

A description of a land combat model specified in terms of all of the individual attributes defined above should permit one to form a fairly well-defined picture of the capabilities and limitations of any particular model. However, the applicability of a specific simulation to a given problem is also determined by the type and level of information the model provides concerning the course of the simulated conflict and its eventual outcome. The next major matrix category identifies those primary outputs typically generated by combat models. These are:

<u>Outputs</u>
- Force Size/Disposition
- Attrition
  - Personnel
  - Units

Major weapons
Support resources
Collateral Damage
Delayed Casualties
FEBA Movement/Representation

Although these parameters represent the major measures of combat effectiveness that are usually of interest to analysts, they are by no means the only output information typically provided by simulations. In most models, additional and more detailed data results concerning combat elements, events, and interactions are also printed or available to the user as printout options. Furthermore, any parameter calculated within a given program that is of interest can be included as part of the output if one is willing to invest in additional programming.

The remaining category, entitled Model Utility, concerns the practical aspects of using a specific simulation. It attempts to define for the potential user the ease with which a model can be implemented and the extent to which it has been used thus far. The following descriptors are used:

Model Utility
- Programming Language
- Computer Used
- Program Size (number of statements)
- Program Storage Requirements (number of words)
- Acquire/Structure Inputs (manweeks)
- Typical Running Time on Computer in CPU Seconds
- Documentation
- Extent of use by Developer/Proponent
- Extent of use by Non-Developer

2.3 MATRIX LEGEND

It was decided that for this matrix approach to be of greater utility it should provide more than a simple "yes" or "no" answer as to whether a model includes a given component or attribute. Therefore, a more explicit format was devised. However, the graduated legend employed in this matrix is not intended to be a definitive grading system that can be used in effect to rate and compare models in an absolute sense. The basic intent is to indicate to the reader, in a general way, the level of detail to which a model simulates the particular facets it includes. Four generic levels of detail were selected to define the extent to which a given attribute or component is modeled; if information was not available or the descriptor was inappropriate for the particular model, this was also indicated. The associated symbols used on the matrix are as follows:

○	Not included.
◒	Nominally included; modeled to a limited degree.
◒	Included; modeled in an aggregated way but accounts for most of the major aspects.
●	Included; modeled in considerable detail. Accounts for almost all of the major aspects.
---	Information unavailable.
N.A.	Not applicable.

Examples of the meaning and interpretation of the three graduated levels of modeling detail will be given in the context of discussions of the individual model descriptors.

This subjective appraisal of a model's level of detail is unavoidably somewhat arbitrary and hence imperfect. However, it is felt that this approach is justified because it does help to identify and define the areas and general levels of detail included in a given model and allows the information to be presented in a compact format.

An additional caveat to be noted regarding this form of model description is that in using a completed matrix one should not assume that those models with many black circles are somehow inherently "better" or give more valid results than those simulations in which many components are modeled in a more aggregated fashion. The identification of appropriate models is highly dependent on the study requirements and the type of analysis to be performed. For some types of tradeoff analyses, the more aggregated models that include to some degree almost all of the major combat elements are of greater utility than those that cover a majority of the components in more detail, but completely omit, or include only nominally others.

The significance and interpretation of this "calibrated" symbology, as applied to a specific attribute will become clearer from the commentary that follows concerning the individual descriptors. In those cases for which this type of indicator is inappropriate or uninformative (e.g., some parts of general characteristics and model utility), a word or phrase is used instead to characterize the model's attribute. The following subsections contain brief explanations of each of the model descriptors that comprise the vertical axis of the matrix.

2.4 DEFINITION OF INDIVIDUAL DESCRIPTORS

2.4.1 General Characteristics

The descriptors listed under this category have to do with the type of combat being simulated and the mathematical methodology being employed. In completing these entries for specific models, words rather than a symbol have been used as indicated below.

Conflict Level. This entry is used to define the highest or typical level of the combat that the model simulates, e.g., theater for a theater-level combat or battalion for an engagement between two battalions.

Conflict Representation. This descriptor is used to define whether the military forces of one-side or two-sides are simulated in the model. One-sided simulations are those in which the force movements and actions of the other side have been predefined prior to running the model, and are supplied to the simulation as part of the data base or program input. This entry also identifies whether the representation is symmetrical or asymmetrical. If all of the input data for the opposing sides can be reversed, and the simulated outcome for each remains the same, the model is termed symmetrical; if in the simulation one side is predefined as the attacker and the other as the defender with the forward edge of the battle area (FEBA) able to move in only one direction, the model is considered asymmetrical. Similarly, models for which the data and force representation for the two sides cannot be interchanged because of input limitations would also be classed as asymmetrical.

Smallest Element Resolved. This refers to the smallest force component manipulated and evaluated within the model. Although the input data may be at an even finer level of detail, the level of aggregation used within the program for keeping track of units and their disposition is specified here.

Decision Point Process. The procedure by which major decisions are made to define successive actions in the simulation can be internal to the program, specified by the user, or some combination of both. This descriptor is intended to indicate the degree of user-control in defining or selecting action options. The four general types of decision processes identified are as follows:

- The user inputs a sequence of actions and options;
- The actions are derived from the program's internal logic;
- Any decisions are a result of a combination of user inputs and internal program logic; and
- The user and model operate in an interactive mode, with the user making decisions as a result of the model's simulation results to date.

Typical Conflict Duration. The duration for which the combat is usually simulated, e.g., a 10-day war, or a 2-hour engagement. The meaningful maximum value for a given simulation is generally set by implicit model constraints. For example, a model that does not include logistics support for the resupply of men and equipment would have limited validity in simulating a 30-day conflict.

Simulation Time-Increment. The method and increment by which simulated time is advanced within the model. The most common method is a fixed time-step, which may be anything from seconds to days, depending on the model. However, if the model employs a flow-rate methodology to simulate the conflict, the time step may be thought of as essentially continuous. In this type of modeling a set of coupled differential equations defining the interactions of elements and events is integrated as a function of time. A third and less common modeling procedure sometimes used to advance time is based on the occurrence of events. This method advances model time in irregular increments coinciding with the occurrence of events of interest, and is identified in the matrix as event-stepped.

Treatment of Probabilistic Events. This model characteristic is of particular interest because the method in which a model handles probabilistic events determines whether or not the simulation must be run a number of times to obtain valid results for a given set of initial conditions. If the model uses expected value probabilities in determining the occurrence of events, the results are established by these fixed values and will be repeatable for a specific set of input conditions. However, if a probability distribution is employed to describe the likelihood of an occurrence and the particular value used is selected based on a random number, then the process is described as a Monte Carlo procedure and will require a number of simulation repetitions to obtain a meaningful average. The entry of expected value or Monte Carlo for this line indicates which probabilistic modeling method is used.

Primary Attrition Method. This line entry is intended to indicate the general level of detail employed in calculating the attrition of the primary force components included in the model. For this matrix four methods of calculating attrition in increasing levels of detail are defined:

- By input (e.g., 0.01 losses per sortie).
- Using firepower or combat capability functions.
- Using P_K and weapons effects at an aggregated level.
- Using P_K and weapons effects at a detailed level.

FEBA Movement Methodology. The various methods and procedures used in models to determine FEBA movement are difficult to define explicitly in a concise manner. However, it appears that one fundamental difference which is meaningful to the analyst is whether the movement is determined from a firepower-based combat capability function, or is based on the attrition to the two sides. This basic distinction is made for this descriptor.

Geometric Representation. The way in which space (geometry) is defined and used in a simulation. The most familiar is that of specifying an area in which force elements and places are explicitly located in terms of some coordinate system, such as latitude and longitude, x and y position or the like. In some models the area is defined in terms of a square or rectangular geometric grid of a given number of rows and columns, and elements are located only as being within a certain grid square rather than at a precise coordinate location. In either case, the use of this kind of geometric representation in a model is identified on the matrix as "position locations represented explicitly."

However, even models that have no direct method of specifying geometry or force element locations often contain a considerable degree of built-in "implicit geometry." In these simulations the designers have defined and modeled which force elements, units, and weapons can interact with those of the opponents. Thus short-range weapons exchanging fire with enemy forces must be at the front; airbases, subject to attack only by long-range bombers or missiles, must be located in the rear; and those forces safe from all enemy action are presumably in sanctuaries.

Optimizational Aspects. Because of the complex interactions of combat elements and events, the analysis of various force mixes, options and strategies can often entail a parametric study effort of almost unmanageable proportions. To reduce the magnitude of such investigations, models may employ some type of optimizational procedure for a particular preselected set of parameters and predefined goal or payoff. Depending on the type and purpose of the optimization, a simulation may provide for this procedure to be invoked at the option of the analyst, or have it as a fixed built-in feature of the model. It is not feasible within the matrix format to define the particulars of the variables and facets of combat being optimized or their importance within the model. The intent of this descriptor is only to indicate if any form of optimization is included, even in a restrictive sense of attempting to maximize or minimize some subset of interactions or allocatable resources that are not direct measures of the outcome of the combat. Optimizational procedures can serve to assure that the simulation results are not biased due to poor choices or decisions by the user concerning the interactions being optimized. Thus, they help to establish the upper bound of a force's capability within a given context, and thereby reduce the number of variables a

user must investigate to determine the best mix for a given payoff. As would be expected this advantage is not free, and in this case the cost is measured in terms of increased program running time.

2.4.2 Environment

The major category, Environment, consists of six descriptors. These attributes in conjunction with those listed under general characteristics provide a fairly good indication of the model's overall level of detail, both for its required initial data base and simulation of combat. For these components and most of the others that follow, the symbol format is employed to indicate the degree to which the facet is modeled. Examples of what is represented by some particular symbol are included to help calibrate the reader to the symbol system.

Terrain, Road Networks, and Natural Obstacles. Although in principle these first three tangible environmental characteristics are fairly easy to define, their realistic representation within a model is usually costly in terms of increased program size and running time. The inclusion of fairly detailed terrain features, roads and obstacles permits the model to simulate appropriate rates of advance of forces. Thus, the model may account for choke points, such as bridges or road passes that channel and possibly retard troop movements, and barriers, such as mountains, lakes and rivers that inhibit troop movement in certain directions. If these environmental characteristics are included in a model in explicit geometric format, a solid circle would be used on the matrix. However if the terrain is represented in some very aggregated and approximate manner (e.g., sector one is rough, sector two is smooth, etc.), or the user inputs average rates of advance, then these characteristics would be classed as nominally included.

Weather and Time of Day or Day/Night. These two characteristics of environment are seldom modeled in detail or even explicitly addressed in most land combat models. However, if for example the user can specify various acquisition factors in a manner that can represent performance under various weather conditions and time of day, then the simulation would be considered to account for these aspects of environment in a nominal fashion.

Civilian Population Centers. In models that simulate weapons effects in some detail, assess collateral damage, and possibly employ logic to determine weapon employment that minimizes collateral damage, the inclusion of civilian population centers is important. Demographic data bases have been developed that are suitable for any model that represents position locations explicitly. The inclusion of such data would be indicated on the matrix as a solid circle. However, population treated as an average density distribution over a corps or larger area would be indicated as nominally modeled.

2.4.3 Combat Participants

The third major category of the matrix identifies the Combat Participants and consists of three types of elements: ground combat, air combat, and air defense. The legend entries in this section give an indication of the manner in which these elements are simulated. For example, a nominal representation of a particular element could refer to its inclusion simply in terms of its total number of units (as input) which is used in some fashion in the model to add to the side's firepower. If its representation employed not only this input value, but calculated or explicitly accounted for the element's integral functions or subtasks (e.g., target acquisition, firing,

mining, lethality against particular target types), then its simulation would be termed as aggregated but essentially complete. At the most detailed level of representation, an element type would be specified in terms of its many single entities, each with its own location, posture, etc., and simulating a particular sequence of actions and interactions at the weapon versus weapon level. The components within each of these subsets are as follows:

Ground Combat Elements:

- Armor (Tanks, APCs, etc.)
- Infantry (Rifles, mortars, etc.)
- Artillery (Tubes, rockets, missiles)
- Antiarmor (Air and ground launched missiles)
- Reconnaissance (Patrols, etc.)
- Aggregated Combined-Arms Unit (Usually includes all or most of the individual elements listed above. Used in some of the more highly aggregated models to define a typical unit instead of specifying individual types of elements.)

Air Combat Elements:

- Close Air Support Aircraft (Provide air support to ground combat units)
- Deep Strike Aircraft (Airbase attack, interdiction)
- Air Defense Suppression Aircraft
- Combat and Patrol (CAP), Sweep, Escort Aircraft
- Reconnaissance Aircraft
- Airbases

Air Defense Elements:

- Surface-to-Air Missiles (Fixed and mobile units)
- Air Defense Artillery (Fixed sites and mobile units)

Air Defense Aircraft (Interceptor/fighter aircraft)
Aggregated Air Defense Units (Includes all or most of individual elements listed above. Used in some of the more highly aggregated models.)

2.4.4 Support

This category consists of two subsets, Logistics and C^3 (Command, Control and Communications). Although both of these are recognized as very important aspects of land combat, a majority of the models simulating combined-arms combat do not include either of these support systems to any degree of detail. The subset Logistics is defined in terms of the following three descriptors:

Men, Equipment, Depots. This includes the numbers and types of troops, weapons, and other equipment which are moved from ports and depots as reinforcements and resupply for the combat zones.

Modes and Routes. These features of combat support are used to define the land and air vehicles required to transport men, equipment and supplies, and the specific logistic routes for those models in which road networks and terrain are specified in detail. However, typically these functions are simulated in a nominal fashion (e.g., in terms of average rates for reinforcement and resupply) which may or may not be subsequently adjusted by program logic according to calculated demands.

Nuclear Storage Units. This descriptor refers to model representation of the location and logistics aspects of supplying nuclear weapons to the delivery systems. A simulation used to investigate the details of employing tactical nuclear

weapons should also include a representation of the associated command and control release procedures.

The subset identified as Command, Control and Communications (C^3) is used to define the major physical components that make up the communications support systems. These are the Communications Equipment, the Communications Networks, and the Command Centers. For simulation of high level conflicts this could include both ground and airborne C^3 systems that are used to link the command echelons with combat units. The degree to which a model portrays these elements is dependent upon the model's requirements for simulating the intelligence, acquisition, and decision-making processes.

2.4.5 Combat Functions and Events

The major category of the matrix entitled Combat Functions and Events deals with the manner in which the key force and support elements discussed above interact. Therefore, this category is of primary importance to a user attempting to determine whether a model will serve his particular set of analysis requirements in its simulation of the dynamics of combat. It should be noted, however, that some of the actions listed, although highly desirable for any "complete" combat model, are rarely if ever simulated in combined-arms combat models. Nevertheless, they are included in the matrix, if only to serve as reminders of some features of combat that are often not simulated. The major category is divided into two subsets: Actions and Events, and Weapons Employment and Effects.

Actions and Events include:

- Ground Force Tactical Action (Advance, envelop, retreat, etc.)
- Tactical Air Actions (Conduct of missions, flight profiles, maneuvers, etc.)
- Suppression of Direct Fire Weapons
- Suppression of Indirect Fire Weapons
- Suppression of Air Defenses

  (Attacks or other actions armed at reducing effectiveness of these weapons)
- Intelligence Process (Data collection, processing, interpretation, and use)
- Target Acquisition (Element by element, or aggregated acquisition)
- Communications Process (Time delays, message queuing, routing, etc.)
- Electronic Warfare (Electronic interference with communications, surveillance equipment and weapon systems)
- Ground Force Action Decisions (Attack, defend, delay, etc.)
- Tactical Air Allocation Decisions (Allocation of aircraft to missions)
- Disruption, Delays of Command Process (Due to degradation or loss of communication capability, key personnel, etc.)
- Resupply of Men and Equipment (Changes in combat capability and force structure)
- Employment of Reserves (Timing and force implications)
- Breakthrough/Open Flanks (Effect of these on attacker and adjacent defender).

Most of these descriptors are self-explanatory, but a few can benefit from additional clarification. The first two refer

to Actions the units undertake, such as advancing towards a specific objective, engaging the enemy, retreating, conducting close air support sorties, etc. The Intelligence process involves the collection, flow and update of information as provided by the communication process. The effects of Electronic Warfare on various support and combat elements are difficult to quantify, and consequently these operations are not usually modeled in combined-arms land combat simulation. The Ground Force Action Decisions and Tactical Air Allocation Decisions refer to the processes of deciding what actions to take next based on the information on hand, objectives and overall doctrine. The assessment of the situation and the generation of "orders" down the chain of command may be subject to Disruption and Delays. The last item listed, Breakthroughs/Open Flanks, refers to ground force actions that are very difficult to simulate realistically in computer simulations both in terms of troop movements and in the subsequent actions, decisions and deployment of forces. Because many of these actions and events are especially difficult to model in a detailed realistic fashion, they are often omitted, or in some cases included in a nominal manner in an attempt to approximate the imperfect interactions encountered in the real world.

The second portion of Combat Functions and Events consists of the subset Weapon Employment and Effects. This is concerned with how well or to what level of detail the employment of various weapons are simulated and their effects evaluated. This information is grouped under conventional and nuclear weapon types as follows:

Conventional:

- Small Arms (Rifles, machine guns)
- Direct Fire (Guns, antitank guided missiles, recoilless rifles)
- Indirect Fire (Cannons, mortars, rockets)
- Aggregated Ground Force Weapons
- Surface-to-Surface Missiles (Guided and unguided)
- Surface-to-Air (Missiles, air defense artillery)
- Air-to-Surface (Rockets, bombs, missiles, guided and unguided)
- Air-to-Air (Missiles, guns)

Nuclear:

- Radiation, Thermal and Blast Effects
  - TAC Air Delivered (Bombs)
  - Artillery (Artillery projectiles)
  - Surface-to-Surface Missiles (Guided and unguided)
  - Atomic Demolition Munitions
- Other Nuclear Effects (Fallout, rainout, EMP, cratering).

2.4.6 Outputs

The sixth category of the matrix concerns a model's primary outputs, and represents some of the measures an analyst may use in performing a tradeoff study or investigating a set of options. These include:

- Force Size/Disposition (Size, location, status of combat participants)
- Attrition of Personnel (Force casualties)
- Attrition of Units (Composite group consisting of men and major weapons)

Attrition of Major Weapons (Tanks, aircraft, etc.)
Attrition of Support Resources (Men, supplies, equipment)
Collateral Damage (Undesired damage to area or civilian casualties)
Delayed Casualties (Nuclear casualties from radiation effects days after initial exposure)
FEBA Movement/Representation

A description of these model characteristics is made in terms of the standard symbols except in the case of FEBA Movement/Representation, which is described in words. Because in almost all models the representation of the FEBA is of necessity stylized and thus unrealistic, information about the way in which a model approximates FEBA position is of interest to the analyst. Therefore its representation in a particular model is categorized with a short word description. If a combat model consists of a single front, or combat assessment is performed in some nominal fashion, then the FEBA may be depicted as a single straight line, representing the "average" position across the entire front. However, if the combat area is divided into a series of adjacent segments or sectors, each of which is evaluated separately, then the FEBA may be represented by a series of parallel line segments. If these segments are small enough or force unit positions are defined in a somewhat precise way, then the FEBA may be represented in enough detail to, in effect, depict an irregular line.

2.4.7 Model Utility

The final category in the matrix, Model Utility, is used to provide basic information about the practical aspects of employing a given program. The intention is to indicate the computing power and time requirements a user may be faced with

when utilizing a particular model. For example, if a model requires large amounts of computer core, includes assembly language routines for a different type of computer, or is not documented and requires substantial amounts of computer time per case, then its overall utility to a given project may be greatly diminished no matter how appropriate it appears otherwise. The following program characteristics are included within this category:

Programming Language. The most widely used programming language is FORTRAN, which in general presents a minimum of problems when implementing a code at a different facility or on a different type of computer. However, if the model is written in some other language, or employs assembly language for even a few of the program's subroutines, then substantial difficulties and delays may be experienced in getting the program running.

Computer Used. Identification of the type of computer a program has been run on is also useful in estimating program implementation time. Converting a program to run on a different type of computer may involve delays because of problems with mathematical precision, program logic statements and output due to differences in word lengths and compilers. If more than one type of computer is tabulated for this entry, the first one listed is the one on which the program is primarily run.

Program Size. This descriptor is of interest to the potential user because it serves as a first-order indicator of the magnitude of the task of becoming familiar with and using a program. Although program length by itself may not necessarily be a meaningful measure, this entry (the number

of programming statements to the nearest thousand) does give an indication of the size of the source program.

Program Storage Requirements. The amount of core storage a computer program requires when running is important to a potential user in determining whether the program can be run as it exists on his computer configuration, or whether it must be modified to reduce its core size requirements. Models usually require large amounts of core storage if combat forces and environmental features are represented in the simulation in detail. The units used to specify the amount of core vary among computers; for consistency on the matrix, all core storage requirements are given as the number of words for the computer type initially listed in the preceding entry. This information, in conjunction with that given for the first three items of this major category, should help to establish the feasibility of getting a model operational on a particular computing system.

Acquire/Structure Inputs. The time and manpower requirements for developing and structuring a data base, and other required inputs are an important consideration when selecting a particular model. On the matrix, the time requirements for this phase of program implementation are specified in equivalent man-weeks. Clearly the values given represent only average numbers for typical model applications. In some instances this time can be reduced if applicable data bases exist and are available from the model developers or other users. It should be noted that although this initial investment of time by a new user may be quite large for some models, much of it may be a one-time-only task that will serve for subsequent tradeoff and sensitivity studies involving the same basic scenario, combat region and participants.

Typical Running Time on Computer. It is not practical to select a common denominator that would be appropriate in defining typical running time for many different models. Therefore, the program running time is given in computer central processing unit (CPU) seconds for a typical duration of simulated time (cycle, sorties, day) applicable to the particular model.

Documentation. The time and effort that must be expended in learning to use a model is certainly influenced by the presence and completeness of the model documentation available. The intent of this entry is to indicate if such material is available. If the documentation includes a detailed discussion of model methodology, program flow and a programmer's guide to preparing the data base and program inputs, it is identified as extensive. However, for those models with little or no documentation, personal communication with the developer may be the only effective method for learning how to use the model.

Extent of Use. The intent of this descriptor is to identify programs that have had considerable use on the assumption that the more a program has been used, the more completely it will have been checked out as to programming bugs and other anomalies. A further useful distinction for prospective users is whether a model's use has been limited to the original developer and proponents (i.e., the group for which the model was designed), or whether it has been used by others. Clearly, the successful implementation of a model by a non-developer user is very encouraging when one is trying to determine the feasibility of learning a program and getting it running within a given time period. However, these categories should not be interpreted as indicating a model's basic

worth or utility; that is, the fact that a model has not been used much does not mean that it is not a good model or has very limited utility, and is not worthy of further consideration.

SECTION 3. MATRIX IMPLEMENTATION

To test and validate the utility of this matrix approach for describing and defining individual land combat models, and for serving as a screening mechanism to aid in model selection, this methodology was applied to several simulations of current interest to DNA. As is shown in Table II-2, the five models selected cover the range from theater-level to less than division-level conflicts and represent simulations of conventional-only, tactical-nuclear-only, and mixed conventional/tactical nuclear combat.

Three of the models, COMBAT II, DWEEPS and L&A TAC NUC, are ones that were previously identified (Part I) as being of particular utility in studies of tactical nuclear warfare because they are wholly computerized and can be used in sensitivity analyses to investigate certain aspects of the employment of tactical nuclear weapons. JEREMIAH was selected not only because it is new (currently under development) and employs a considerably different methodology but also because it represents the other end of the conflict simulation spectrum, i.e., a short firefight between battalion-sized units, modeled in considerable detail. The fifth model, LULEJIAN I, was selected because it models a theater-level conventional conflict and thus is concerned with simulating a somewhat different set of elements and events, and because it provides an interesting comparison with the tactical nuclear model subsequently developed by Lulejian.

The completion of the matrix for each of these five models was carried out in an iterative fashion, until agreement was reached on which of the defined symbols "best" represented the treatment of each model's attribute. This study and deliberation included renewing available documentation as

Table II-2. Selected Land Combat Models*

CONFLICT LEVEL SIMULATED \ CONFLICT TYPE	CONVENTIONAL	TACTICAL NUCLEAR	CONVENTIONAL AND TACTICAL NUCLEAR
THEATER	ATHENA - GRC ATLAS - GRC CEM/CONAF - GRC GACAM - IDA IDAGAM I - IDA LULEJIAN I - L&A VECTOR I - VRI VECTOR II - VRI	NAR III B - CAA SATAN III - ANAGRAM CORP/NMCSSC TANDEM - RAND	CASCADE III - NMCSSC COMBAT II - BDM TANREM (NUREX/NUFAM) - CAA IDA TACNUC** - IDA
CORPS	CBM - GRC TAGS - RAND TALLEY/TOTEM - RAND TARTARUS IV N/COCO - CAA		L&A TAC NUC - L&A
DIVISION	DBM - GRC DIVOPS - VRI/BDM	DWEEPS - LLL	DIVWAG/QTEM - CACDA/SANDIA
OTHER	BONDER/IUA - VRI CARMONETTE IV - GRC DYNTACS - OSU STATE II - STC	FORECAST II - CAA	MAFIA - TRW UNICORN - SAI JEREMIAH** - LLL

*IDENTIFIED BY SHORT TITLE OF MODEL AND ITS DEVELOPER:

CAA	CONCEPTS ANALYSIS AGENCY (U.S. ARMY)
CACDA	COMBINED ARMS COMBAT DEVELOPMENT AGENCY (U.S. ARMY)
GRC	GENERAL RESEARCH CORP.
IDA	INSTITUTE FOR DEFENSE ANALYSES
L&A	LULEJIAN & ASSOCIATES, INC.
LLL	LAWRENCE LIVERMORE LABORATORY
NMCSSC	NATIONAL MILITARY COMMAND SYSTEM SUPPORT CENTER (DEFENSE COMMUNICATIONS AGENCY)
OSU	SYSTEMS RESEARCH GROUP, OHIO STATE UNIVERSITY
SAI	SCIENCE APPLICATIONS, INC.
STC	SHAPE TECHNICAL CENTER, NATO
VRI	VECTOR RESEARCH, INC.

**UNDER DEVELOPMENT.

[ ] MODELS SELECTED TO BE DESCRIBED USING MATRIX METHODOLOGY.

well as personal and telephone communication with the principals involved with each model's development.

The completed matrix for these five models is presented and discussed in the following section, which assesses the utility of the methodology in the context of specific examples. In addition, each model is discussed individually in a short write-up in Appendices A through E. These discussions are intended to help put the data on the matrix in better perspective by amplifying the models' attributes, capabilities, limitations and most appropriate applications.

SECTION 4. OBSERVATIONS AND SUGGESTIONS

4.1 ASSESSMENT OF METHODOLOGY

To illustrate and evaluate the application of the model description methodology delineated in Section 2, the matrix format was employed for five selected land combat models specified on Table II-2. The completed matrix of these models (COMBAT II, DWEEPS, JEREMIAH, LULEJIAN I, and L&A TAC NUC), is presented at the end of this section (p. 49) as a foldout sheet. In this way the reader can readily refer to it while reading the comments that follow concerning the matrix and the information it contains.

It appears that the matrix format developed to describe and define the characteristics of land combat models is a very convenient way for presenting a considerable amount of information about a wide variety of models in a compact form. One of its primary functions is to serve as an initial screening mechanism for providing the analyst with an overview of a number of models that will help the potential user to identify those simulations that appear applicable and merit further investigation.

Because of the impossibility of predicting what aspects of a model will determine its utility for a given user, it is thought that this methodology is a good approach for presenting basic factual information in an unbiased manner without, in effect, passing judgment on a model's worth. Most models are developed in conjunction with a particular study investigating specific questions. Consequently, they model most completely those facets that are central to the issues being examined. Aspects of combat thought to have little or no impact on the

results, or more readily accounted for outside the model, or impossible to model satisfactorily are usually treated in a nominal fashion or omitted entirely. Thus a model's suitability is often in the eye of the potential user, and if it includes the levels of detail the analyst believes are appropriate for his application, then it may serve very well.

The matrix format and its ordering should be thought of as a shorthand way of giving a description of a model, in much the same sequence as would be used by a developer giving a verbal overview. By carefully reviewing the list of descriptors and the level-of-detail indicators assigned to a particular model, one can obtain a reasonably well-defined estimate of a model's major capabilities and limitations. In particular, the information provided in the first two major matrix categories (General Characteristics and Simulation of Environmental Elements), enables one to put the factual material that follows concerning combat elements and events in better context as to their levels of detail and realism. If, in addition, there is a brief companion write-up of the model (of the form contained in Appendices A through E) to amplify on important features of the simulation, it can give additional perspective on the model's utility. With this overall appreciation of each model, one can then use the matrix expeditiously in an informed way.

Based on this prototype testing of the matrix, which covers models of differing characteristics and scope, it appears that this arrangement is useful in several ways. Obviously, this format makes it easy to determine whether or not the facets of combat defined by the model descriptors are included in any degree in a particular model. For example:

- Of the five models described, the only one that simulates in some detail many of the elements and events over a theater wide conflict is LULEJIAN I. Although this model includes a logistics system and thus can account for the resupply of men and equipment in a combat extending over a period of weeks, it is limited to simulating the employment of conventional weapons only. As is true of most of the other models listed, the elements and functions of command, control and communications, intelligence, disruptions and delays in the command processes and electronic warfare are not included.

- If one wishes to examine air/ground combat at the theater level to evaluate both conventional and tactical nuclear weapon allocations, tradeoffs and timing in an aggregated parametric fashion, COMBAT II is well suited. However, it cannot be used to assess collateral damage or delayed casualties resulting from the employment of nuclear weapons.

- The L&A TAC NUC model can provide a moderately detailed simulation of a conventional/tactical nuclear ground combat but is limited to simulating a single sector of a battle front. Moreover, with the exception of CAS, it does not include the air combat and air defense units, and therefore cannot account for the effect these elements can have upon an extended ground battle.

- The DWEEPS model is useful only to investigate the initial introduction of tactical nuclear weapons by one side against a predefined moving ground

force target array. It is designed for examining the relationships among weapon system characteristics, employment doctrine, military effects and collateral civilian damage within this framework. In essence it is a one-sided weapon effects model that requires as input a target data base defining force movements during a conventional conflict and the associated civilian population centers.

- If one is interested in investigating the detailed interactions of small combat units (squads) and major weapon systems during a short firefight, the JEREMIAH model (now under development) provides a very high resolution simulation. Although it is currently limited to modeling only direct fire weapons, it will eventually include indirect fire and nuclear weapons. Its very detailed representation of the terrain plus the force action methodology employed may result in highly realistic simulations that include breakthroughs, open flanks, encirclements, etc., and can provide insights about forces in contact not available in the other models.

Thus it is seen that each of the five models has its particular utility in assessing various aspects of combat. Furthermore, it appears that two of the models could be used together propitiously to examine the initial transition from conventional to tactical nuclear warfare including a detailed evaluation of civilian collateral damage. The LULEJIAN I model, which simulates conventional conflict, might be employed to establish an enemy force target array that could subsequently be used in DWEEPS to evaluate the initial introduction of tactical nuclear weapons by the other side. If one wanted

to investigate the exchange of tactical nuclear weapons for a theater-wide conflict, in more detail than is provided by COMBAT II, he might wish to use the L&A TAC NUC model in a parallel fashion to simulate combat on several adjacent sectors. Thus differences in forces, terrain, etc., could be accounted for and uneven force deployments and FEBA movements could be simulated.

In addition to making it easier to identify models that are not appropriate for a particular analysis, the matrix can illuminate other potential problem areas. For example, the model utility descriptors help to pinpoint programs that under certain circumstances must be eliminated because of practical operational considerations. Obviously, no matter how applicable a model is for a specific study, if it requires substantially more manpower and computer power than the analyst has available or can afford, then it is no longer a feasible candidate, and the sooner he becomes aware of this, the better.

Not only does the matrix provide a starting point for sorting out a group of combat models and identifying those that seem promising, but it is a convenient way of later jogging ones memory about the details of models, instead of plowing through pages of documentation. This latter aspect should be especially helpful when an analyst has reviewed a considerable number of models in some detail (including additional documentation or discussions with the developers) and must then decide what it all means. That is, are there several models that meet his needs? What are their relative merits and deficiencies? If none of the existing models suffice, does it appear more satisfactory to develop a new model or to attempt to substantially modify an existing one? Must one

pay a considerable price in terms of program size, complexity, implementation and running time to obtain the desired type of simulation and level of detail? For example, even for the small group of models described in Table II-2 a number of general observations can be made:

- The logistics and C^3 elements and functions are often omitted or modeled in only a nominal fashion.

- Suppression effects are not modeled to any degree of detail in any of these existing models.

- Theater-level simulations model elements and events in a more aggregated manner. Those simulations which do model combat elements and actions in detail will generally be examining a smaller conflict area (COMBAT II versus JEREMIAH).

- If the model is to assess collateral damage and delayed casualties, the geometry must be represented explicitly or at a moderate level of detail. Thus DWEEPS and L&A TAC NUC can account for these facets (at differing levels of detail) while COMBAT II is not able to do so.

- The less detail present in the model, the more artificiality in the representation of the FEBA.

- Simulations that model tactical nuclear weapon employment in some detail tend to treat conventional weapons in less detail or omit them entirely--e.g., COMBAT II and DWEEPS.

- Detailed simulations are relatively costly in terms of preparation and running time.

- The more detailed programs may use interactive procedures to increase program flexibility and reduce user time for program preparation (DWEEPS, JEREMIAH).

- Interactive programs may require substantial computer resources (LLL).

- Breakthroughs and open flanks are difficult to simulate.

4.2 SUGGESTIONS FOR FURTHER IMPLEMENTATION OF THE MATRIX

The current list of model descriptors developed for this study represents a first-cut at using a compact stylized approach for describing land combat models. These descriptors were developed primarily by reviewing available program documentation, talking with model builders, and subsequently refining the classifications and identifiers during the course of testing the methodology on five specific models. However, the degree to which this procedure can describe models and their strengths and weaknesses could be considerably increased by expanding the list of descriptors in a few specific areas.

For example, for some models the acquisition and structuring of the required input data base can be a very complex and lengthy procedure. Generic information as to how or where these inputs are obtained (e.g., existence and type of source document, combat data, or results of other simulation models)

is useful not only in better defining time requirements for program implementation, but also in clarifying the level of realism and detail simulated in the model. The matrix section on program outputs could also be enlarged so as to be more explicit and informative about the data generated by the simulation, and the measures of effectiveness that are readily available to the analyst.

Another area of interest to the user concerns the model's degree of flexibility. This includes its potential for various types of studies and investigations, the ease with which the program can be modified or expanded, the implicit or built-in assumptions or "virtual" inputs (i.e., setting fixed values for certain "variables" which may not be properly validated, but are built into the model) that impact on a model's utility, and the simulation's sensitivity to program inputs and options. One further area in which greater detail would be desirable on the matrix concerns more specifics about the methods used to calculate target acquisition, attrition and the like.

To complete a definitive set of model descriptors appropriate for classifying in more detail the model features discussed above, one needs to extend this study to another level of detail. This would include discussions with model developers and users, utilizing program source listings and computer outputs, and learning how the models have been employed in past studies. Under these circumstances, it appears that an equally productive next step towards enhancing this set of descriptors might be to have the developers/users of many of the models listed in Table II-1 use this methodology to describe their own programs. By supplying them with the descriptor definitions given in this report and sanctioning them to expand or modify the descriptors or symbology if

necessary, one should subsequently be able to refine the matrix format and increase its descriptive capabilities.

An added advantage of completing the matrix for a substantial number of models is that one could then test the following premise: If the matrix is completed for a large number of models, this methodology might be used to better identify common characteristics or limitations of models simulating a given type or level of conflict. For example, programs that simulate theater-level engagements must of necessity aggregate many facets of combat. If none of the existing theater models are able to account for certain elements or events with the degree of detail and realism that is clearly desirable at this level of conflict, then one must conclude that this limitation has a more fundamental basis than just lack of interest or skill on the part of the model designer. By reviewing the matrix, an analyst who is considering developing a new, more "complete" land combat model may gain a better appreciation of the task he has set for himself and the likelihood of success.

Model development usually entails a series of compromises as one tries to reconcile practical constraints, such as the size of the data base, the availability of credible inputs, formulating a suitable methodology for modeling the desired function or event, and producing a program of manageable size and computer requirements. Thus, the end-product is often a program that is extremely satisfactory for the study it was designed for, but has major constraints for other applications even if they are similar. A completed matrix describing a number of models of the same scope and level of conflict may help to give model builders additional insight as to how to improve best program flexibility and utility.

If the designer can devise better and more effective ways to do this, then analysts may be able to readily adapt and modify existing models to serve their particular studies.

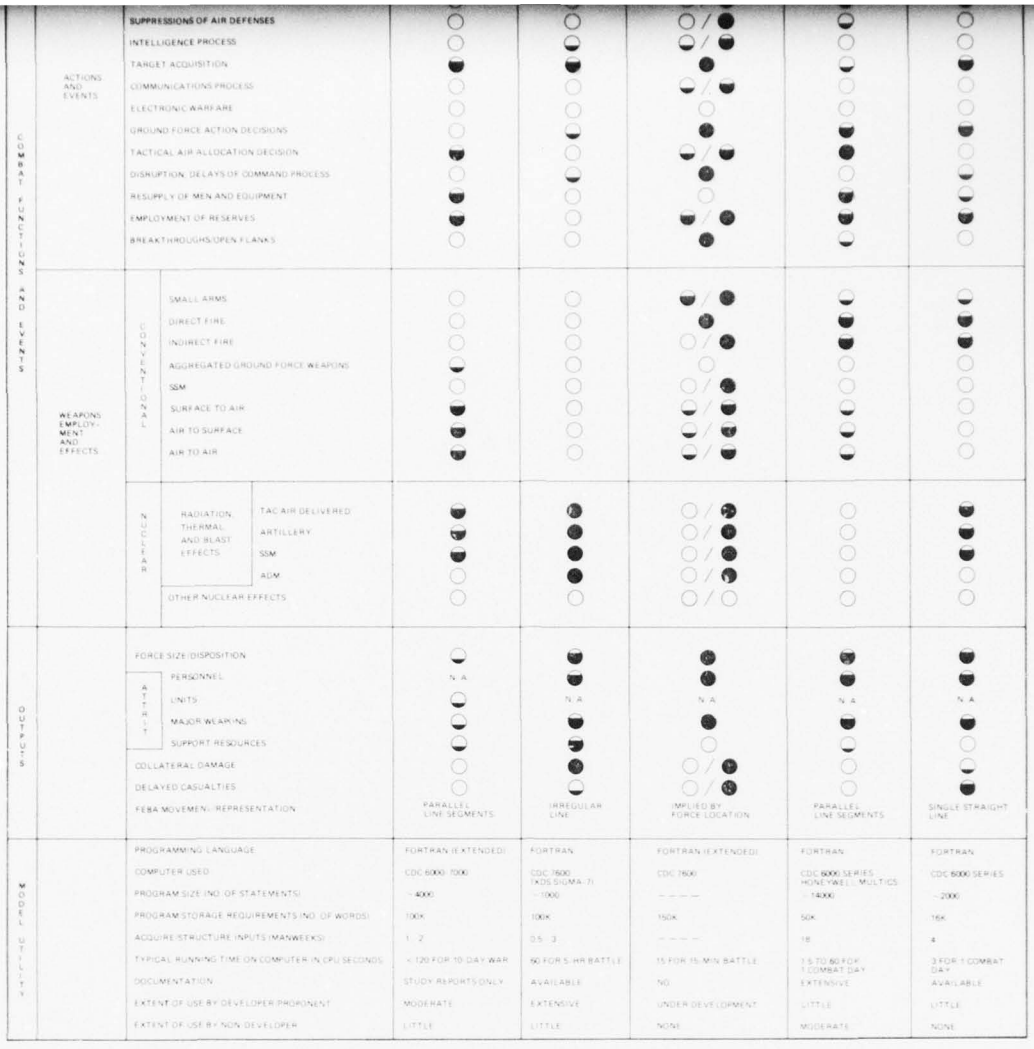
One approach that has been used to improve the flexibility of land combat models has been to utilize interactive computer systems, in which both man and the model participate in the simulation's decision-making processes. With the increase in available computer power, capabilities and responsiveness, model designers have found that for some types of simulations it is now feasible to have the user interact with the program during its execution. By structuring a simulation to run on this type of system, the designer can provide for the analyst to make decisions for selected conditions about options and events that are difficult to model or evaluate mathematically within the program. This may produce a more realistic simulation of combat facets that are hard to define mathematically, and may allow a model to be used more readily to investigate a broader range of options or strategies. On the other hand, the results from an interactive model may be highly influenced by the user's choices, to a degree that far overshadows its sensitivities to weapon system capabilities. Thus, this type of simulation may require extensive use for a given analysis to identify its sensitivities to the analyst's decisions, over and above those inherent in the model.

As has been emphasized previously, the matrix format was developed to provide the analyst with a convenient vehicle for displaying and describing the components and features of various types of land combat models in a compact way. The particular models selected to test this methodology were ones considered to be of current interest to DNA, and represent various types and levels of land combat simulations. These

matrix descriptions were completed based on information obtained from general model documentation, formal briefings, and personal discussions with the developers. However, in order to identify the more subtle limitations or weaknesses of these models (or indeed of any model) that result from intrinsic or built-in assumptions and "virtual" inputs, one must study the simulations in considerably more detail. This would include obtaining program listings, understanding the program flow, and if possible, exercising the models so as to become familiar with their sensitivities and range of utility. Therefore, although the completed matrix presented here can identify the major capabilities and limitations of these five models, it must be recognized that another, more detailed level of investigation of these models could result in a deeper understanding and appreciation of their individual attributes.

Table II-3. Matrix Description of Capabilities of Selected Land Combat Models

MODEL NAME DEVELOPER/YEAR			COMBAT - II BDM/1975	DWEEPS LLL/1973	JEREMIAH LLL/1974-75 PROTOTYPE/UNDER DEV	LULEJIAN-I L&A/1972-74	L&A TAC NUC L&A/1973-74
GENERAL CHARACTERISTICS		CONFLICT LEVEL	THEATER	CORPS/DIV	BATTALION/CORPS	THEATER	CORPS
		CONFLICT REPRESENTATION	SYM, 2-SIDED	ASYM, 1-SIDED	SYM, 2-SIDED	SYM, 2-SIDED	ASYM, 2-SIDED
		SMALLEST ELEMENT RESOLVED	BATTALION EQUIV	PLATOON	SQUAD OR MAJOR WPN	BATTALION	PLATOON
		DECISION POINT PROCESS	INTERNAL LOGIC	USER ASSISTED	MIXED/INTERACTIVE	INTERNAL LOGIC	INTERNAL LOGIC
		TYPICAL CONFLICT DURATION	10 DAYS	FEW HOURS	4 HOUR/SEVERAL HRS	30-90 DAYS	10 DAYS
		SIMULATION TIME INCREMENT	FLOW RATE CONTINUOUS	TIME, 5 MIN	TIME, 10 SEC	TIME, ONE COMBAT DAY	TIME, ONE COMBAT DAY
		TREATMENT OF PROBABILISTIC EVENTS	EXPECTED VALUE	MONTE CARLO	MONTE CARLO	EXPECTED VALUE	EXPECTED VALUE
		PRIMARY ATTRITION METHODOLOGY	INPUT & P_K (AGGREGATED)	P_K (DETAILED)	P_K (DETAILED)	P_K (AGGREGATED)	P_K (AGGREGATED)
		FEBA MOVEMENT METHODOLOGY	ATTRITION	INPUT/ATTRITION	N.A.	ATTRITION	ATTRITION
	GEOM REP	ELEMENT LOCATIONS REPRESENTED EXPLICITLY	N.A.	◕	◕	N.A.	N.A.
	GEOM REP	IMPLICIT GEOMETRY OF ELEMENTS	◒	N.A.	N.A.	◒	●
		OPTIMIZATIONAL ASPECTS	○	○	◒	◕	○
ENVIRONMENT		TERRAIN	◒	◒	◕	◒	◒
		ROAD NETWORKS	○	◒	○ / ◕	○	○
		NATURAL OBSTACLES	○	◒	◕	○	○
		WEATHER	◒	○	◒	○	◒
		TIME OF DAY OR DAY/NIGHT	◒	○	○	○	○
		CIVILIAN POPULATION CENTERS	○	●	◒ / ◕	○	○
COMBAT PARTICIPANTS	GROUND COMBAT ELEMENTS	ARMOR	○	◒	◕	◕	◕
	GROUND COMBAT ELEMENTS	INFANTRY	○	◒	◕	◕	◕
	GROUND COMBAT ELEMENTS	ARTILLERY	○	◒	○ / ◕	◕	◕
	GROUND COMBAT ELEMENTS	ANTI-ARMOR	○	◒	◕	◕	◕
	GROUND COMBAT ELEMENTS	RECONNAISSANCE	○	◒	◒ / ◕	○	○
	GROUND COMBAT ELEMENTS	AGGREGATED COMBINED ARMS UNIT	◒	○	○	○	○
	AIR COMBAT ELEMENTS	CLOSE AIR SUPPORT AIRCRAFT	◒	○	◒ / ◕	◕	◒
	AIR COMBAT ELEMENTS	DEEP STRIKE AIRCRAFT	◒	○	○ / ◕	◕	○
	AIR COMBAT ELEMENTS	AIR DEFENSE SUPPRESSION AIRCRAFT	○	○	○ / ◕	◕	○
	AIR COMBAT ELEMENTS	CAP, SWEEP, ESCORT AIRCRAFT	◒	○	◒ / ◕	◕	○
	AIR COMBAT ELEMENTS	RECONNAISSANCE AIRCRAFT	○	○	○ / ◕	○	○
	AIR COMBAT ELEMENTS	AIRBASES	◒	○	○ / ◕	◒	○
	AIR DEFENSE ELEMENTS	SURFACE TO AIR MISSILES	○	◒	◒ / ◕	◕	○
	AIR DEFENSE ELEMENTS	AIR DEFENSE ARTILLERY	○	◒	◒ / ◕	◕	○
	AIR DEFENSE ELEMENTS	AIR DEFENSE AIRCRAFT	◒	○	◒ / ◕	◕	○
	AIR DEFENSE ELEMENTS	AGGREGATED AIR DEFENSE UNIT	◒	○	○	○	○
SUPPORT	LOGISTICS	MEN, EQUIPMENT, DEPOTS	◒	○	○	◕	○
	LOGISTICS	MODES AND ROUTES	◒	○	○	◕	○
	LOGISTICS	NUCLEAR STORAGE SITES	◒	○	○	○	○
	C3 ELEMENTS	COMMUNICATIONS EQUIPMENT	○	○	◒ / ◕	○	○
	C3 ELEMENTS	COMMUNICATIONS NETWORK	○	○	◒ / ◕	○	○
	C3 ELEMENTS	COMMAND CENTERS - GROUND AND/OR AIRBORNE	○	◒	◒ / ◕	○	○
COMBAT FUNCTIONS AND EVENTS	ACTIONS AND EVENTS	GROUND FORCE TACTICAL ACTIONS	◒	○	●	◕	◕
	ACTIONS AND EVENTS	TACTICAL AIR ACTIONS	◕	○	◒ / ◕	◕	◒
	ACTIONS AND EVENTS	SUPPRESSION OF DIRECT FIRE WEAPONS	○	○	○ / ◕	○	○
	ACTIONS AND EVENTS	SUPPRESSION OF INDIRECT FIRE WEAPONS	○	○	○ / ◕	◒	◒
	ACTIONS AND EVENTS	SUPPRESSIONS OF AIR DEFENSES	○	○	○ / ◕	◒	○
	ACTIONS AND EVENTS	INTELLIGENCE PROCESS	○	◒	◒ / ◕	○	○
	ACTIONS AND EVENTS	TARGET ACQUISITION	◕	◒	●	◒	◕
	ACTIONS AND EVENTS	COMMUNICATIONS PROCESS	○	○	◒ / ◕	○	○
	ACTIONS AND EVENTS	ELECTRONIC WARFARE	○	○	○	○	○
	ACTIONS AND EVENTS	GROUND FORCE ACTION DECISIONS	○	◒	●	◕	◕
	ACTIONS AND EVENTS	TACTICAL AIR ALLOCATION DECISION	◕	○	◒ / ◕	●	○
	ACTIONS AND EVENTS	DISRUPTION, DELAYS OF COMMAND PROCESS	○	◒	●	○	◒
	ACTIONS AND EVENTS	RESUPPLY OF MEN AND EQUIPMENT	◕	○	○	◕	◒
	ACTIONS AND EVENTS	EMPLOYMENT OF RESERVES	◕	○	◒ / ●	◕	◒
	ACTIONS AND EVENTS	BREAKTHROUGHS/OPEN FLANKS	○	○	●	○	○
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	SMALL ARMS	○	○	◒ / ●	○	◒
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	DIRECT FIRE	○	○	◕ / ●	◕	◒
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	INDIRECT FIRE	○	○	○ / ●	◕	◒
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	AGGREGATED GROUND FORCE WEAPONS	◒	○	○	○	○
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	SSM	○	○	○ / ●	○	○
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	SURFACE TO AIR	◕	○	◒ / ◕	◒	○
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	AIR TO SURFACE	◕	○	◒ / ◕	◒	○
	WEAPONS EMPLOYMENT AND EFFECTS — CONVENTIONAL	AIR TO AIR	◕	○	◒ / ◕	◒	○
	WEAPONS EMPLOYMENT AND EFFECTS — NUCLEAR — RADIATION, THERMAL AND BLAST EFFECTS	TAC AIR DELIVERED	◒	●	○ / ●	○	◒
	WEAPONS EMPLOYMENT AND EFFECTS — NUCLEAR — RADIATION, THERMAL AND BLAST EFFECTS	ARTILLERY	◕	●	○ / ●	○	◕
	WEAPONS EMPLOYMENT AND EFFECTS — NUCLEAR — RADIATION, THERMAL AND BLAST EFFECTS	SSM	◕	●	○ / ●	○	◕
	WEAPONS EMPLOYMENT AND EFFECTS — NUCLEAR — RADIATION, THERMAL AND BLAST EFFECTS	ADM	○	●	○ / ●	○	○



LEGEND:

○ NOT INCLUDED

◒ NOMINALLY INCLUDED; MODELED TO A LIMITED DEGREE

◓ INCLUDED; MODELED IN AN AGGREGATED WAY BUT ACCOUNTS FOR MOST OF THE MAJOR ASPECTS

● INCLUDED; MODELED IN CONSIDERABLE DETAIL. ACCOUNTS FOR ALMOST ALL OF THE MAJOR ASPECTS

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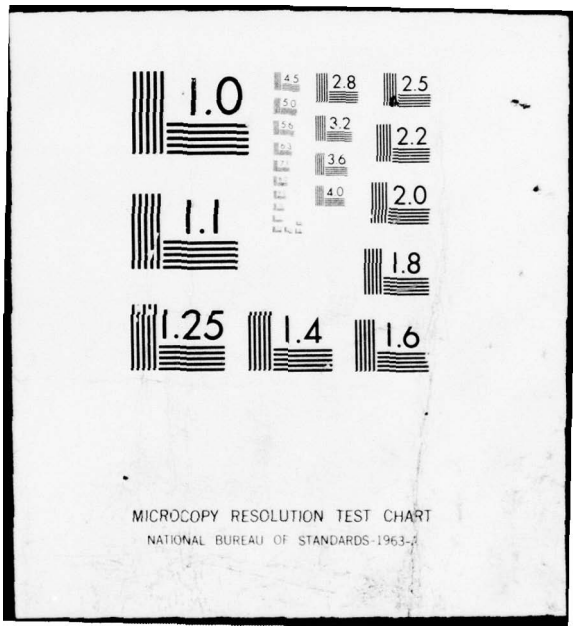
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MICROCOPY RESOLUTION TEST CHART
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APPENDIX A. COMBAT II

COMBAT II is a theater-level combat model developed recently by the BDM Corporation. It simulates simultaneous ground/air combat which is supported by a choice of various conventional and tactical nuclear weapons. The objective in developing this simulation was to provide analysts with a tool that would allow them to identify and examine the key variables which heavily influence the outcome of such combat and to analyze how they change as a function of time. In developing this model, two constraining design criteria were established: the resulting digital-computer program would be relatively simple in terms of its required inputs, and the program should be fast running and hence economical to use in parametric analyses and tradeoff studies.

The COMBAT II model has the capability to examine in an aggregated manner the interactions among the ground and air combined-arms forces engaged in conventional, tactical nuclear or mixed conflict. It is completely two-sided with no built-in asymmetries. If inputs for the two sides are reversed, the results will be complete mirror images. Ground combat and support elements are aggregated into representative size force supply and reserve while aircraft, airbases, nuclear weapons, etc., are specified in terms of numbers and functions. Geometric relationships among the forces are implicit in terms of the simulated interactions occurring at the fronts, or rear, or in the air. The FEBA of each of three sectors (which can be about 300 km wide and 30 km deep), can move independently or can have a functional relationship with other sectors at the option of the user. However because of this abstract geometric representation there is no mechanism for simulating "flank attacks," local breakthroughs or the like.

The mathematical methodology employed for ease and speed of program operation is that of a deterministic differential equation flow-rate model. In this type of simulation, the key parameters and events are modeled using a set of inter-related ordinary differential equations that are solved simultaneously. Each equation defines the time rate of change of some variable of state such as the number of ground troops, interceptor aircraft, or surface-to-surface missiles, all of which change as a function of time due to their interactions with other components. For example, the time rate of change of the number of ground troops at a front is expressed as a function of their losses to each of the various weapon systems plus the net flow of reserve troops from the rear. In such equations, each of these individual terms is defined mathematically in terms of acquisition, attrition and other factors associated with the operation of a particular weapon or support system. All of the major subprocesses of combat are related to each other through these coupled equations which determine the relative contribution of each variable of state to the final outcome and provide a means of examining the evolution of the battle over time. A group of approximately one hundred such equations is numerically integrated over time to generate the evolution of the battle and calculate the attrition.

The model has been designed so as to provide the analyst both with an overview of theater-level mixed combat and with detailed time-histories of all the components modeled. The simulation is geared for investigating force mixes, ground and air force employment strategies, and nuclear weapon employment and timing in a parametric fashion, and for determining the driving factors. Emphasis is placed on giving the analyst the ability to readily investigate the contributions and interactions of the particular major weapon systems and strategies to the outcome of the battle.

As indicated in the model matrix, a majority of the environmental and force elements, weapon systems and events are modeled in a highly aggregated manner or simulated to a limited degree. Environmental characteristics such as weather and terrain are not modeled explicitly within the program but are nominally accounted for indirectly through user inputs concerning target acquisition factors and maximum movement rates of the FEBA and resupply units.

The combat system associated with each of the three fronts include aggregated ground force units (with their share of conventional artillery), nuclear artillery, tactical missiles, supplies and nuclear warheads. In the rear are reserve forces and supplies, airbases, aircraft, centrally controlled surface-to-surface missiles, and nuclear storage sites. The aircraft may be designated as interceptors which engage enemy aircraft or nuclear-capable aircraft, which may be specifically allocated to either ground support or long-range attack and interdiction.

Logistics is simulated in that troops and supplies flow from the rear to the fronts and vice versa. The program permits moving these resources from one front to another by withdrawing and reallocating them. Based on user input allocations and options, the model's doctrine provides for conventional and/or nuclear exchanges, including ground-to-ground duels, tactical missile exchange, aircraft air-to-air battles and ground attacks.

Using inputs concerning target acquisition factors, weapon kill factors, allocation factors, and maximum expenditure and flow rates, the program evaluates the interactions between various weapon systems by solving its set of simultaneous

differential equations. For those combat systems defined as being at one of the three fronts, interchanges are permitted only between opposing ground force units and include both conventional and nuclear artillery. However, surface-to-surface missiles are able to attack all opposing elements within the front. All aircraft are located at airbases in the rear area, but only the long-range nuclear-attack aircraft are based beyond the range of enemy surface-to-surface missiles. The air battle simulation involves both interceptors and nuclear-capable aircraft. Of those aircraft which survive air combat, those interceptors not allocated to ground support return to base. The remaining interceptors and nuclear-capable aircraft continue on to attack their targets where they are subjected to area and terminal air defenses.

Naturally in any simulated combat extending for more than a few hours, the time-dependent results must include not only force draw downs and weapon system attrition, but also the movement of ground forces. In this model, the FEBA movement is modeled heuristically so as to range from zero, when the opposing forces approximate parity, to a maximum unopposed rate, which is input by the user. The particular functional relationship employed is based on extending the Lanchester Equations so as to represent the total attrition of ground forces due to all causes. The calculations of FEBA movement are performed independently of the integration of the simultaneous differential equations. The flow of reserves and resupplies from the rear to the fronts is controlled by response equations which reconcile the maximum allowable densities, the actual and commanded FEBA advance rates, and the maximum flow rates specified to define the resulting flow rates used in the set of differential equations.

Because of the designer's aims and methodology, this model could probably be readily implemented by other users. It is programmed in FORTRAN and requires 100K of storage plus two on-line disk or tape files. These disk or tape files are used to store the time histories of the approximately 1100 variables of state used within the program. This tape can be input to a post processor program to obtain printer output and time-history plots of any of these parameters of interest, as well as summary tables displaying the composition and distribution of each of the combat systems throughout the battle. Acquiring the data base and structuring the inputs can usually be completed in one to two weeks.

As indicated above, the types of inputs required for this kind of model include allocation, acquisition and kill factors, and maximum expenditure and flow rates. The initial disposition of forces and weapon systems is specified in terms of the numbers and distribution of men, weapons and supplies at each of the three fronts and in the rear, and thereby defines an aggregated order of battle for the two sides. Other inputs such as acquisition and kill factors, and maximum expenditure and force and supply movement rates represent average values associated with the various systems and their interactions. These factors determine values for the coupling coefficients used in the differential equations to interrelate the various combat systems. Naturally, the selection of approximate values by the analyst can be extremely important to the outcome of the battle, especially when different magnitudes are used for the two sides. Therefore, these factors are usually chosen on the basis of a combination of other model results, available combat data, military judgments and estimates and tempered with the particular analysis of tradeoff study being performed.

Because of the nature of the inputs, program preparation time even for a completely new case is relatively short (usually on the order of 1 to 2 weeks). The model's computational time is also very fast, typically less than 2 CPU minutes (on a CDC 6000-7000 computer system) for a 10-day war. In keeping with this philosophy, summary data and time-history plots are generated by the program to enable the analyst to evaluate the results readily, typically in less than a day. The model has been developed and exercised by BDM over the past two years. However it became available to the analytic community in August 1975 and consequently has not yet been used by others.

It must be recognized that BDM's basic philosophy and objectives of producing a model that would be easy to implement and employ in a parametric fashion were achieved by adopting an "outside-in" design approach. As is shown in the matrix, many components and facets of combat are accounted for in only a nominal fashion, while others considered to be of less direct importance to the type of analysis the model was intended for are omitted entirely. The mathematical methodologies and implicit geometric representation of space used in the model are commensurate with this level of detail and contribute to the program's rapid running time on the computer. However, this type of geometric representation opposes a realistic assessment of civilian collateral damage or delayed casualties, and hence these aspects of tactical nuclear combat are not included.

Elements concerned with ground combat and air defense are represented as aggregated combined units and are simulated to a limited degree. Because the designers were particularly interested in investigating the options and strategies related

to the employment of tactical nuclear weapons, these associated weapon systems and events are identified as separate entities and are modeled in more detail. As is seen from the matrix, the elements, events and functions involved with the command, control, communications, intelligence and decision-making aspects of combat are omitted entirely in the model. Although these are extremely important facets of any combat, most do not readily lend themselves to an aggregated representation that is useful and can account for their impact on the course of the combat in a meaningful way. In the analysis of mixed combat involving both conventional and tactical nuclear weapons, the consequences of the timing of the initial employment of the nuclear weapons are of particular interest. In COMBAT II this time (in hours) is specified as a program input, and thus it is possible for the analyst to investigate in a parametric fashion the criticality of the timeliness of the overall combat assessment/decision-making process with respect to nuclear weapon employment.

The developers have emphasized that COMBAT II is not intended to be used to generate absolute quantitative answers. It is intended to provide an analyst with a very convenient tool for comparing the effects of various options, strategies and weapons in a relative way, and to identify some of the major drivers of the combat results and how they vary with time.

APPENDIX B. DWEEPS

The DWEEPS model, developed by Lawrence Livermore Laboratory (LLL), is a one-sided, asymmetrical, user-assisted simulation designed to assess the effects of employing nuclear weapons in a land combat conflict. In essence, the model simulates the acquisition of enemy ground forces and the employment and effects of using tactical nuclear weapons against a predetermined moving target array. It does not model the conventional conflict or the interaction of forces, but instead simulates a one-sided nuclear-attack, as selected by the user, on a predefined advance of enemy ground units.

The model is nominally configured for a one to two division land battle along a 30-km front, with the minimum size of unit that is resolved being a platoon (tank platoon, infantry platoon, etc). The movement of the enemy forces (units), the times at which they are acquired, and the times at which the nuclear weapons are called for are determined using a time-step simulation increment of five minutes over a period of several hours of combat. However, the actual number and location of enemy units acquired and the actual arrival time and detonation location of each nuclear weapon are determined by a Monte Carlo process. As a result, each individual computer run represents a single possible outcome, and a number of runs must be made for the same situation to determine the expected value.

The model's data base includes the positional time history of each enemy unit, as obtained from some other source, e.g., from another model or a map exercise. This is defined in terms of the unit's coordinates on the battlefield, the geographic space it occupies (approximated by a square of

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specified size) and the times at which it arrives at and departs from that location. Up to 1000 units of any aggregation can be specified. The expected location of these forces at anytime is determined by interpolating between known locations (or extrapolating if need be), and thus the model can reflect different movement rates. Therefore, if the user chooses to input a detailed target array history, he can account for terrain, road networks, and natural obstacles in a nominal way.

The second portion of this target data base consists of the civilian population centers. Each city in the battle zone is represented geographically as one or more rectangles of appropriate size and proportions. For a previous LLL study this included all communities that could be identified from a 1:50,000 scale map. Input data included the coordinates specifying the center of the city as well as its population, and the model can handle up to 1000 individual locations.

As noted above, DWEEPS is a one-sided model simulating the employment of tactical nuclear weapons on enemy forces. Therefore, information presented in the matrix concerning combat participants, functions, and events define characteristics for only one of the two sides. The matrix descriptors identifying combat participants and support refer to those defined in the model's military force target data base described above. The format of the data base provides for each unit to be described in terms of the number of personnel, vehicles and weapons and to be identified as to the unit's disposition and function (AAA, tank unit, command post, etc.). Hence, ground combat and air defense elements can be described in the data base in some detail; however, no provision is made for accounting for the enemy's tactical air elements.

Because of the purpose and structure of the model, none of the friendly forces are simulated and the employment plan for their nuclear weapons is specified by user inputs.

The portion of the matrix describing the combat functions and events refers in general to those facets of the simulation that are applicable to the side employing the tactical nuclear weapons.* As is shown on the matrix, this program models the employment and effects only of nuclear weapons. The specific form of the attack is defined by the user through inputs and is developed as follows. The data base defining the moving enemy forces is processed by the program, which decides which targets are acquired and identified, as a function of time. The probability that an enemy unit will be acquired is a function of the unit's distance from the FEBA, the type of unit and the unit's motion.

This target intelligence information is presented to the user together with a menu of the nuclear weapons available to him (number, type, yield, delivery CEP). Based on his particular military objectives, employment constraints and doctrine, the user selects targets for his nuclear weapons and defines the nuclear attack in terms of weapon types, aimpoints and the times of employment.

Upon inputting this weapons employment plan, the model then simulates the nuclear attack and calculates the enemy troops and equipment losses, and the civilian casualties and

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*Once exception is the action of the enemy ground forces as a result of the nuclear attack. The interactive video-graphics version of the model does stop movement of individual units when their attrition exceeds specified levels.

and damage. The targets killed or damaged may or may not be those targeted, depending on the movement rates of the forces, the size of the target acquisition errors, the delivery accuracy, and the delay in delivery time, as determined by Monte Carlo processes. The specific forces destroyed or damaged are those that are inside the weapon's effective range at the time of detonation, and thus may include enemy forces that had not been acquired.

The model assesses the nuclear attack in terms of military and civilian casualties, and losses and damage to enemy weapons and support resources due to prompt nuclear radiation, thermal radiation, and blast. The damage calculations account for multiple weapons effects where applicable, and the results are presented for various yield levels and hence can be used to forecast delayed casualties.

The individual enemy units at the forward edge of the advancing force define an irregularly shaped FEBA of uneven movement. The videographics version of DWEEPS alters the input enemy force movements as a function of the strength of the nuclear attack; if 30 percent of the units in a battalion are destroyed, the battalion will cease to advance and thus the FEBA will remain stationary in that area.

The DWEEPS model currently exists in two forms at LLL: The CDC-7600 version for normal batch processing with hard copy input and output, and the interactive time-sharing version designed to run on the XDS Sigma-7 computer. This latter version requires peripheral equipment including a user-terminal consisting of a keyboard, CRT display screen, function box and light pen. The acquired target array is displayed on the CRT, and the user defines his weapons

employment plan by designating weapon types, detonation points and times with the light pen. Thus the user-time required to complete this portion of program inputs is reduced from several hours (for the CDC-7600 version) to a few minutes. Both versions of the model require several days to several weeks for preparation of the military and civilian data bases, depending on the size and nature of the target data array required.

LLL has used the program extensively to investigate relationships among military effects, collateral damage, weapon system characteristics, and employment doctrine. Thus there exists a substantial data base including a detailed target array drawn from the report Legal Mix III Optimum Mix of Artillery Units 1971-1975, by the U.S. Army Combat Development Command Institute of Nuclear Studies. It appears that DWEEPS could also be an effective tool in conventional combat. It could be used to evaluate the impact of the initial employment of tactical nuclear weapons on the course of the conventional conflict, and to investigate the timing and level of employment required to stop the enemy's advance.

APPENDIX C. JEREMIAH

JEREMIAH is an entirely new land combat model that is now under development at Lawrence Livermore Laboratory (LLL). As a completely new model that will ultimately simulate both conventional and tactical nuclear combat in a very detailed way, its characteristics and potential applications are of current interest. Therefore it is included on the matrix, even though at this stage of model development its more detailed characteristics are not necessarily finalized.

To distinguish between the model's current and projected capabilities, as perceived by the designers, the model is described on the matrix for both a near- and far-term version. "Prototype" refers to the model configuration which is currently being completed to test methodologies, sensitivities, etc.; "under development" pertains to the model as the designers envision it in its completed form at some future date.*

In contrast to many of the combined-arms conventional/tactical nuclear models, which aggregate actions and events to simulate theater combat, JEREMIAH is a high-resolution, Monte Carlo model that simulates the interactions of small units (squads) and major weapon systems (individual tanks, antitank weapons) within a battalion-size area over a short period of time. The program has no built-in asymmetries and is two-sided; the developers state that it could be expanded to be multi-sided if required. Time is advanced

*For complete and up-to-date information on this model the reader should contact Mr. Ken Froeschner at LLL.

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in the simulation using a 10-sec time step, and the model is being structured so that it can be operated in several modes, e.g., as a batch job, user-assisted, or at a future date, in a highly interactive manner.

As a first step towards developing an interactive videographic capability, the simulations generated by the prototype model have been displayed on a multi-color videographics terminal. In addition there is currently under construction at LLL a "conflict simulation laboratory" for JEREMIAH, which includes development of both hardware and software. This will provide the analyst with the capability to have real-time scene simulation in full color with multiple consoles for on-line interaction with the program.

In keeping with the designer's objectives of producing a model capable of simulating the interactions of elements and events at a fine-grained level, geometry is represented in the model in a very detailed manner. The terrain is divided into a grid consisting of rectangles of arbitrary dimensions. Each of these "cells" is characterized in terms of its altitude at a corner, the fractional cover available, its fractional impassibility, and the fractional absorption of optical energy of the air. These characteristics are used in the program to calculate the speed and path of each element and the probability of acquisition of targets.

As is evident from the manner in which the battlefield is represented, the model is configured so that it can (or will) take into account most of the facets of environment in a very explicit manner if desired. This can include road networks and civilian population centers as well as military support systems such as command, control and communications.

At its current stage of development, the prototype is limited to simulating engagements between forces in contact which employ direct fire conventional weapons. However, as the methodologies developed to model these elements and events are checked-out, these procedures and techniques will be extended to include other components (e.g., artillery and tactical nuclear weapons) and their actions.

The overall modeling philosophy or procedure used in this model is analogous to that employed in a hydrocode in which the individual actions of many small units are integrated to obtain the sum total effect. The premise of the developers of JEREMIAH is that by simulating the actions and interactions of small units and individual major weapons using very short computing periods (10 sec), and summing up or "integrating" their effects in the proper fashion, one can obtain a valid simulation of the combat extending over a period of time (hours). The "behavior" of these forces, and consequently of the individual units, is naturally scenario-dependent and is a function of many factors. To achieve a balance between scenario flexibility and simulation efficiency, the designers have configured the model as follows: scenario-type information defining overall directives and objectives for the force components and their units are set by the user; the detailed actions of each unit and major weapon during each computing cycle are determined automatically by internal program logic using a "fire-maneuver" algorithm.

The specification of mission doctrine is in the form of scenario files input by the user that define each unit's type, location, mission (e.g., reach a certain location, follow another unit), its actions upon completing its mission, and what its alternate objective may be. The designers intend

to expand and improve the current syntax used to input these data with an advanced command language that will employ "standard" packages of commands to define the most detailed level of troop movement or doctrine.

The manner in which these directives are carried out and the extent to which they are completed during the course of the simulation is determined in part by the "fire-maneuver" algorithm that defines the actions of the individual units for each computing cycle. The basic form of the methodology employed is as follows. At the beginning of each computing cycle, the program determines for each element the cumulative probability that it will survive the cycle. This is a function of the probability of its being acquired, shot at, and killed by the opposing enemy units. The program also calculates the probability that the unit can hit and kill each target it perceives and its priority.

Based on these two probabilities (P_s and P_k) the unit then employs an algorithm to select one of three "micro-tactical" options as to what actions it should undertake during the cycle. The three options are as follows: (1) to move in a direction that will avoid contact with the enemy, (2) to pass, i.e., ignore the enemy and continue towards the objective defined by the doctrine, or (3) to engage the enemy. If the unit's P_s for the cycle is low, then it will move in a direction so as to avoid the enemy. If its P_s is high (the current lower bound value used is 0.994) but the probability of killing the enemy is low, then it will not move to engage but will pass and continue towards its specified objective. However, if its P_s is high and its P_k against the enemy is high, then it will elect to engage.

The prototype model is being used to investigate and refine this basic methodology to ensure that the force actions simulated conform to sound military judgment and tactics. The designers expect that this "micro-tactical" option logic should result in simulations of combat that include breakthroughs, open-flanks, encirclements, etc. Thus, in contrast to most models no artificial FEBA line is established or used within the program. It should be noted also that at this level the model reflects a limited-type of optimization in that a unit's specified directives may be temporarily disregarded to enhance its probability of survival.

At this stage of development many of the practical considerations concerning the implementation and use of JEREMIAH are not established. Nevertheless, it is evident that this type of detailed simulation will require a lot of computing power. In its fully interactive mode with user terminals and real-time displays of simulations, it will employ custom-designed computer hardware and software; thus in its most advanced and flexible form, the model will probably be limited to being used at LLL.

The developers are attempting to configure the model's data base so that the required input data can be readily structured. For example, their representation of the terrain is configured to interface easily with data provided by the Defense Mapping Agency's Topographic Center.

The development of this model is currently being funded by LLL. As can be seen from the matrix the designer's long-term objectives are ambitious both in terms of the model's eventual scope and level of detail. Clearly, the model's growth will be an evolutionary process and will involve striking a balance

between the desire for completeness of simulation and the practical constraints imposed by the computer, and the desire for responsive interactive capability.

APPENDIX D. LULEJIAN I

LULEJIAN I developed by Lulejian and Associates, Inc., is a deterministic, theater-level tactical combat model designed to assess the combat capabilities of one conventional theater force structure against another. To this end it models in a completely symmetrical manner each force by composition, including unit and weapon types and numbers for both sides. Most of the possible interactions and interdependencies between all opposing elements and weapon systems are simulated but at an aggregated level of detail, and the inclusion of the logistics elements provides for a more realistic determination of force drawdowns for combats extending over a period of weeks. The model recognizes and can keep a status track on as many as six national participants on each side, which may be distributed over 10 sectors to make up a theater force structure. A feature that sets Lulejian I apart from other models is an option for employing an algorithm which distributes certain allocatable resources in a nearly optimal manner for both sides. This is done in an effort to achieve a simulation outcome that is independent of either side's "general-ship" abilities. Results, therefore, are considered to be an unbiased comparison of the originally specified forces and their combat capabilities against each other.

In the model, the combat resources of each side's force structure are divided into three major categories: the ground forces in the theater available for combat (including the air defense elements); the tactical air combat elements; and the logistics support systems for moving personnel and materiel into and through the theater supply network. Each of these can be managed in a near optimal manner by the model in terms of a specified payoff function (usually FEBA movement) over

a user-specified time period. The dynamic relationships among these combat participants and support elements are established by five basic submodels: Ground Combat Assessment, Tactical Air, Logistics, Ground Forces Management, and Resource Allocation Algorithm.

The Ground Combat Assessment model simulates combat interactions between all units and weapon systems using a time step increment of one day of combat. A forward edge of the battle area (FEBA) is assumed. Infantry, mechanized infantry, and armor maneuver units are modeled as distributed along fairly well defined lines on either side of the FEBA. The effects of support fire from artillery, helicopter, and tactical aircraft are replicated. Losses of personnel and equipment and associated losses of combat capability are addressed and used to modify each side's ability to fight the following combat day. Central to LULEJIAN I is the concept of each side trading territory for survivability and having a "threshold" attrition rate. (This threshold loss rate can be thought of as a measure of each combatant's attitude towards maintaining or acquiring territory. It may also be termed "resolve.")

Maneuver units contact and localize the opposition in order to bring effective direct fire to bear. Both the ability to localize targets and the effectiveness of direct fire weapons degrade with increasing separation distance. Therefore, a major component of the loss rate one side experiences can be reduced by increasing the separation distance between its maneuver units and those of the opposition. Accordingly, one side advances on the other only when it is able to inflict a loss rate in excess of the opposition's threshold, while simultaneously sustaining a loss rate below its own threshold. The FEBA moves as one side moves to increase separation distance while the other moves to decrease it.

The Ground Force Management submodel does not perform the initial allocation of maneuver units, but it does determine all subsequent allocations, based upon the current status of the forces and the previous combat results. Its functions include the allocation of the available maneuver units to line or reserve status among all the combat sectors for the next day, and the determination of which of three postures (attack, hold, delay) is to be employed in each sector the following day. The posture selected is a function of the prior day's posture in that sector and the previous FEBA movement.

In addition, this submodel assesses a combat unit's threshold attrition rate (resolve) for the next day. These resolves are recalculated daily based on a maneuver unit's accumulated losses. If total losses reach a specified fraction, the unit is defined as "fought-out." It is then removed from combat and held out for a length of time while it is refitted with personnel and equipment. When this process is completed, the unit is again available for allocation to a reserve or combat status.

The Tactical Air submodel simulates the results of aircraft missions for each of two air regions within the theater. The tactical aircraft that are in the theater and available for combat at a given time are also managed by the Resource Allocation Algorithm. This allows the questions of sortie/mission mix to be addressed. Five types of aircraft can be allocated to each of six major missions, which include air defense, airbase attack, interdiction of logistics targets, close combat air support, escort/CAP, and air defense suppression. All aircraft attrition is simulated within the Tactical Air model. Those aircraft on interdiction and combat

air support missions which are not attrited are evaluated by the Logistics and Ground Combat Assessment submodels, respectively, as to the effects of their attacks.

The Logistics model is a highly aggregated, single pipeline simulation of men and materiel flow throughout the theater. It consists of an entry "port" of given input capacity. A fraction of the theater's input capacity is specified by the user to be devoted to scheduled deployment of individual and unit replacements for combat elements. This includes personnel, tanks, three types of maneuver battalions, tactical aircraft, attack helicopters, and air defense artillery. The remainder of the port capacity is managed by the Resource Allocation Algorithm. This portion is devoted to three logistical categories: (1) general supplies, such as food, fuel, and ammunition; (2) vehicles, such as trucks which can be used to expand transport capacity; and (3) engineering supplies, such as bridges, to be used for restoring or expanding the intratheater logistics network. The Logistics model also simulates the effects of aircraft interdiction strikes on network capacity.

The initial deployment of the ground forces that are present in the theater at the time of the beginning of the conflict is established by the Resource Allocation Algorithm. This algorithm implements the basic premise of LULEJIAN I which is that the ultimate objective of tactical war is to acquire (or defend) territory and that both sides will allocate resources to them as possible under the existing circumstances. By means of these dynamic game-like allocation procedures, the model works to the end that the predicted outcome of the "war" be in agreement with what would occur if both sides exercised highly intelligent generalship over their choices.

Accordingly, the danger of biasing the outcome by attributing poor allocation of resources to either friendly or enemy forces is removed.

To employ this optimizational procedure the user must specify the length of combat to be simulated and the decision points for which allocation strategies are to be assessed. Then, the algorithm allocates (at these decision points) the previously mentioned portion of the Logistics model port capacity consisting of general supplies, vehicles to expand transport capacity, and engineering supplies to expand the logistics network. The other portion of each side's resources which is allocated at these specified decision points is their tactical aircraft. All available sorties are assigned to possible missions and the effect of any assignment is examined in light of its payoff.

An automated search process is used over all combinations of these resource allocations. Each allocation strategy is composed of a set of allocations (one for each decision point) through the specified end of the game. The payoff used to assess strategies is the territory controlled at the end of the game (i.e., FEBA movement, given the width of the combat area does not change much).

The algorithm identifies near optimal allocations (in a min/max sense) of each side's resources over the specified time period. The significant feature of the Resource Allocation Algorithm is that it permits the identification of an outcome of a postulated force interaction which is attainable by one of the opponents. The outcome identified is attainable because it is assumed that the opposition is knowledgeable of each of the allocation decisions as they are made and responds optimally.

Although this algorithm can, in principle, be used for engagements of any complexity (a number of different types of resources and number of relocation decision points in the war), the computational requirements grow rapidly with complexity. As a consequence LULEJIAN I places emphasis on simplicity of engagement equations and description of theater geography.

As is indicated in the model utility section of the matrix, even though the FORTRAN code for this simulation is quite large, the program storage requirements are relatively modest. This is because the program has been structured so that it can be run in three consecutive segments. It should be noted that typical running times for the program can vary from 1.5 to 60 CPU seconds for one combat day, depending on whether or not the optimal allocation option is employed. Although the time requirement for acquiring and structuring the input data is substantial, this task is facilitated through the use of a separate preprocessor program. This factor, coupled with the program's extensive documentation and previous use by nondevelopers, suggests that its implementation by other users should proceed relatively smoothly.

APPENDIX E. L&A TAC NUC

The L&A TAC NUC model, recently developed by Lulejian & Associates, Inc., was designed primarily to investigate the battlefield employment of tactical nuclear weapons. It is a modified and expanded version of the ground combat portion of Lulejian's theater-level model of conventional land combat and is capable of handling a mixture of both nuclear and conventional ordnance employed by either or both sides. Unlike its predecessor, it is not a theater-level model, but is limited to simulating one sector of the battlefront, typically a corps zone of about 60 km in width.

The model simulates the interactions among friendly and enemy combined-arms combat forces and assesses the outcome of the battle in terms of the forces lost by each side and the movement of the FEBA. However, the doctrine built into the model limits it to simulating a situation in which one side is the attacker and the other is the defender. Thus, although the representation of the conflict is two-sided, it is asymmetrical and the model does not allow counterattacks and reversals in the direction of FEBA movement during a simulation.

For most of the aspects of combat simulated within the model, the basic ground force unit used is an average-sized maneuver battalion. The area covered by this battalion is set by defining representative relative positions and distances among the companies, platoons and squads that comprise a nominal battalion, based on typical deployment concepts. However, this deployment array can be modified to account for massing or dispersal as appropriate for battlefield force deployment tactics in a conventional or nuclear environment. It should be noted however that the simulation processes

concerning target acquisition are defined in terms of individual squads. Consequently, on the matrix, the smallest element resolved is specified to be the squad.

Basically, the L&A TAC NUC model is a deterministic, expected-value digital computer model using as its time-step increment, one combat day. That is, the losses and FEBA movement for a full day are determined as a function of the number and disposition of the forces at the beginning of the day, and the number of targets acquired and weapons used, etc., for that particular day. The values of force losses and FEBA movement for a given day are determined simultaneously by employing an iterative technique to obtain a solution to a set of algebraic equations, derived from an extension of Lanchester theory, which represent the interactions among the various force components, and relate the FEBA movement and force loss equations. The basic form of the equation that relates the FEBA movement to the losses is:

$$\begin{matrix}\text{FEBA} \\ \text{movement} \\ \text{rate}\end{matrix} = \left(\begin{matrix}\text{Unopposed} \\ \text{rate}\end{matrix}\right)\left(1 - \frac{\text{actual losses}}{\text{threshold level}}\right)$$

where the unopposed rate and threshold level are input values. These losses are calculated as a function of the types and number of forces involved, the separation distances between them, and the appropriate effectiveness parameters (acquisition and kill probabilities, which are determined by the separation distances). FEBA movement is then calculated based on the losses sustained by each side's tanks and infantry. There are four such FEBA movement equations: two for tanks (friendly and enemy) and two for infantry. At each computing interval the program adjusts these four associated separation distances (e.g., enemy tanks to friendly infantry, enemy tanks to friendly tanks, etc.)

and the corresponding losses on both sides so that each equation yields the same FEBA movement.

Although geometric representation of space within the program is implicit, within the battlefield area it is simulated with a moderate degree of realism. As discussed above, the relative positioning of ground forces is defined in terms of nominal battalion units and their components. The positioning of these battalions relative to the FEBA is controlled through a combination of program inputs and algorithms within the model. These define and relate the number of battalions deployed on line and in reserve, the depth to which they are deployed, the attacker's degree of "resolve" to hold or acquire territory, and the defender's willingness to trade space for survivability. Because of the conceptual representation of space, environmental characteristics are not simulated in a detailed geometric manner. However, the effects of a typical terrain and weather can be nominally accounted for by changing the inputs for target acquisition probabilities and unopposed force movement rates accordingly.

As is seen from the matrix, although the simulation accounts for most of the ground combat elements in an aggregated way, it does not model most of the tactical air forces or any of the air defense elements. Only the close air support (CAS) mission is simulated; CAS sorties are specified through program inputs and their impact on the evolution of the ground battle is determined. However, other tactical air missions such as deep strike, combat air patrol (CAP) and fighter sweeps are not included in the model, nor are any aspects (SAMs, AAA or aircraft) of air defense simulated. In addition none of the components defining the support systems of logistics and command, control and communications are explicitly included within the model.

As is apparent from this brief review of the array of combat participants simulated, the emphasis within the model is on the elements and actions occurring in the battlefield area. This is also reflected in the section of the matrix defining combat functions and events. Items concerned with actions and weapons in the battlefield, although simulated in an aggregated fashion, are modeled in a manner that accounts for most of their major effects or characteristics. These events include the deployment of forces, the acquisition of enemy targets (through various types of visual sensors, counterbattery radars), the engagement of enemy ground forces, the firing of conventional and nuclear ordnance, the maneuvering of these forces (based on doctrine of acceptable losses), and the allocation of reserve froces and nuclear weapons.

The commitment of reserve maneuver battalions during the course of the battle is determined in the program in one of two ways, as preselected by the user. Under one option, the deployment strategy (e.g., attack, hold, defend) for committing reserves to the front line area is prespecified for the duration of the conflict. If the alternate method is selected, the program employs a dynamic algorithm in which the strategy and therefore the commitment of reserve forces is adjusted daily according to the battle outcome to date and the desired outcome for the next day's battle. Because of this logic the decision process concerning ground force actions is specified on the matrix as being aggregated but accounting for most of the major facets. However, it must be recognized that there exists in this context the overriding model restriction discussed previously, i.e., the asymmetrical representation of the conflict. The internal program logic is such that the initial designation of one side as the attacker and the other as the defender cannot be subsequently altered so that the

two roles are completely reversed as the simulation progresses. Although none of the components of the logistics and C^3 support systems are simulated, two aspects of their processes are accounted for in the program in a nominal way. The model provides for reinforcements to be supplied to the battlefield area at a specified constant rate, and the resulting timing of tactical nuclear weapons employment is treated in a probabilistic manner.

As would be expected, the aspects of combat modeled most completely in the program involve those facets related to the use of tactical nuclear weapons. The employment of these weapons may be based on an allocation that is fixed and independent of the battle's outcome, or is a function of one or more parameters describing the cumulative outcome of the battle to date or for the outcome of the most recent day's combat. Currently, the program is configured to handle data concerning two sets (yields) of nuclear effects, and thus can simulate in a single run the employment of any two of the three nuclear weapon systems (tactical aircraft, artillery, and SSMs) indicated on the matrix. The nuclear damage assessment calculations take into account the losses resulting from blast, thermal and radiation effects in an aggregated manner. Both prompt and delayed casualties are determined, based on the initial and cumulative radiation doses received by personnel from multiple exposures. Collateral military damage is assessed in terms of the cumulative ground area that is subjected to various levels of blast, thermal and nuclear radiation; however, the model does not provide for a civilian data base, and hence there is no estimate of the associated civilian casualties resulting from nuclear detonations.

Although many of the aspects of combat included in this program are modeled in a manner that accounts for most of their major facets, it is clear from the manner in which the conflict area is represented and the small size of the program (number of FORTRAN statements and computer core requirements) that most of these features are treated in an aggregated way, in terms of average functions. Required inputs to the program total about 300 and consist primarily of those defining initial numbers and disposition of forces for both sides, target acquisition and kill factors, and limits on force movement rates and acceptable attrition levels. The initial disposition of the forces is specified in terms of the number of battalions, the area covered by each side's "average" maneuver battalion, and the density of battalions, i.e., the width and depth of deployment and fraction committed on line. Kill factors for weapons employed are specified in terms of the mean area of effectiveness (MAE), circular error probability (CEP), and/or probability of kill against a particular type target. An additional important program input is the number and rate of CAS sorties employed by each side.

The primary outputs which are used to evaluate the course of the battle as a function of time include the distance and rate of FEBA movement, and the size and combat effectiveness of the forces on each side. The size of the forces remaining is a measure of the attritions sustained; the fraction of these forces (troops) that are ineffective is a function of the prompt and delayed effects of nuclear radiation as well as the casualties sustained due to conventional weapons.

The program was employed by Lulejian to simulate a portion of the Barbarossa II scenario for AEC/ISA. This involved simulating a short ten-day battle between Pact and NATO

divisions of differing force size. The combat situation investigated was that of Pact forces massing a number of divisions against a single U.S. division in a 60-km-wide sector with NATO employing only hold and block tactics against the Pact attack. The model has also been used by Lulejian for a study comparing the effect of using advanced precision-guided munitions with tactical nuclear weapons near the FEBA. Thus, even though this program has certain limitations due to its omission of tactical air (except CAS) and air defense forces, it appears that under certain conditions it can be used for sensitivity analysis of land combat involving conventional and nuclear weapons. The model is particularly applicable for investigating the initial phases of a sector-level conflict before the deep strike missions have any pronounced effect on the development of the ground war. Within this context, the number and rate of CAS sorties specified should be commensurate with the expected losses to enemy air defenses in the forward battle area during this period.

Although it models only a single sector of an entire front, the program could be used in a parallel fashion to simulate combat on several adjacent battlefields (sectors), each having different forces, force ratios, terrain, etc. In this manner, uneven force deployments and FEBA movements (i.e., bulges in the line) could be simulated. However, in this mode of model usage, the question of "open flanks" would have to be addressed and taken into account externally.

APPENDIX F. OTHER CANDIDATE MODELS

This appendix describes briefly five land combat models that are currently being used within the analytic community to investigate various aspects of combat involving both conventional and tactical nuclear weapons.

F.1 CASCADE III

CASCADE III (Computerized Air Strike and Counter Air Defense Evaluation) Model was developed for the National Military Command System Support Center by the U.S. Army Strategy and Tactics Analyses Group for use by the Joint War Games Agency. Development and documentation of the latest version of this model (III) was completed in 1970. CASCADE III models the detailed air operations of a two-sided comprehensive land, sea, and air theater-level war. It does not model the complete combined arms land or sea battle. It is a computerized stochastic model which simulates conventional and/or nuclear tactical air operations, air defense forces, and nuclear surface-to-surface missile (SSM) forces. Tactical air and SSM strikes are conducted against counter-air type targets (e.g., SSM bases, airfields, ships, task forces, surface-to-air missile sites, antiaircraft artillery sites, air defense employment areas to which air defense sites are assigned for command and control purposes, early warning radar sites, ground controlled intercept radar sites, and air defense direction centers to which airfields are assigned for command and control purposes). The location and duration of the conflict, the ground and air orders of battle, the weapon systems characteristics, the air mission assignments, and the surface-to-air firing doctrines are all described in input data that must be furnished by the user. The results of each simulation are presented in the form of attack flight histories, intercept flight histories, ground damage assessment reports, air defense engagement reports, and status reports on all units.

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The basic mathematical procedure employed is an event-stepped Monte Carlo process. The minimum unit size represented in the model is a single aircraft, missile, or site. CASCADE III is a relatively large computer model (220 K), is programmed for use on an IBM-360 system, requires a minimum of one to two weeks to structure the data in model input format, and requires a considerable amount of computer time for each model cycle (∿20 minutes to three hours of CPU, depending on the force size).

F.2 DIVWAG

DIVWAG (Division War Game) is a highly detailed, two-sided, computer-assisted combat model designed to investigate mid- and high-intensity nuclear and conventional conflicts between a Blue force of division size and a Red force of three divisions. Maneuver force resolution is generally at the battalion level, but can be manipulated to the company level in special cases; support elements are resolved to the company/battery or individual aircraft, sensor, etc., as appropriate.

Based upon game orders to the units, the model simulates movement of ground units, aircraft and logistics, ground combat between opposing forces, artillery, armed helicopter, target acquisition, replacement of supplies equipment and personnel, etc. Nuclear weapons of various yields can be delivered by atomic demolition, cannon, rocket, missiles or air delivered bombs. Prompt blast, thermal, and radiation effects are assessed, as well as delayed casualties and induced radiation hazards (barriers), but nuclear fallout is not modeled. Thus the model accounts for most of the key elements and events important to the simulation combined arms combat. However airborne operations, air-to-air combat, C^3 and electronic warfare are not included or modeled explicitly. Delays in reporting and response times are introduced by the

user through inputs and interactions during the course of the simulation.

Program inputs include unit locations and mission assignments, weapons and equipment characteristics, consumption rates, unit TO&E's, weapons effects data, decision tables for defining priorities for levels of attack, and terrain and weather data. Each of the up to 30,000 terrain cells (2km/side) is coded for roughness, vegetation, trafficability, elevation, and a maximum of nine individually homogeneous weather zones can be defined, with hourly changes in temperature, precipitation, visability, etc. Up to a 1000 resolution units can be specified as a total for both forces and up to 200 types of equipment, supplies, weapons, etc., can be played for each side.

Because of the level of detail of this model, the time, manpower, and computer power requirements to use it are prodigious. The model is maintained and operated by the War Games Division at CACDA (U.S. Army Combined Arms Combat Developments Activity) at Fort Leavenworth, Kansas. It employes both FORTRAN and COMPASS programming languages and is run on a CDC 6500 computer. A minimum of 3 million words of storage are required, plus 1 disc drive and 3 tape drives, as well as the standard card reader and printer. CACDA estimates that approximately three months are required for acquiring and structuring the data base, and about 60 calendar days for playing 48 hours of continuous combat. The ratio of simulated time to real time is about 1 to 3. Although automatic play of the game can be set for any length of time (up to about 14 hours), it has been found that about two hours of game time is the practical maximum limit. For intense combat it is recommended that this time limit for user intervention and review should drop to about one half hour. Preliminary analysis of the detailed program outputs at the end of the dynamic play can require one to two months.

F.3 MAFIA

The TRW/MAFIA model is a modified version of a model originally developed by Operations Research Inc. for the U.S. Army Combat Developments Command. Initially, the model was named MAFIA V, an acronym for Maneuver and Fire Analyzer. Two different versions of it are known to be operational today. One, called DACOTAH, is being used by AMSAA at Aberdeen Proving Ground, Maryland. The second, TRW/MAFIA, is being used by TRW Systems at Redondo Beach, California.

The TRW version has been modified to make it a player-assisted interactive simulation as opposed to the original MAFIA V model which is a fully computerized closed-form computer model. In the TRW version, the player-analyst acts as a pseudo-commander with full command/control capability over all fire and maneuver units (both Red and Blue) in the simulation scenario. The analyst, in effect, exercises "direction" and "coordination" of the scenario-defined units. It is important to note that recent modifications to the program logic and current data-set have been made to incorporate simulation of low-yield, tube-launched, nuclear weapons. Thus, the model can simulate combined conventional/nuclear operations.

The model is a deterministic, time step model, programmed in FORTRAN IV and was designed to analyze in detail close combat between opposing forces of brigade size or smaller during short battles lasting from several minutes to several hours. For a typical brigade simulation, the analyst would normally construct a scenario by defining the maneuver units (mechanized infantry and armor) at company level or platoon level (with a corresponding increase in resolution) and by defining the support fire artillery units at battery level. Smaller than brigade size scenarios can easily be simulated by restructuring the data base with an

attendant increase in resolution. In a like manner, division scenarios can be constructed; however, there is a resultant loss in resolution.

In using the model, it is possible to prescribe, with considerable flexibility, the types and number of units involved, their respective missions, their scheme of maneuver, and the employment of fire-support weapons and close air support. Tactical decision rules can be supplied to the model by initial input as well as by on-line interactive input. Target acquisition capabilities of surveillance systems and the suppressive effects of high casualties or heavy volumes of fire are also inputs to the model. Intelligence system effectiveness can be gamed explicitly by allowing the user analyst to have more or less intelligence about each opposing force.

Specific inputs are types, numbers, and location of units (personnel, equipment, weapons, etc.), maximum effective range of weapons, target acquisition/detection probabilities, weapons effects data, target priorities for artillery, criteria for automatically making command decisions, unit movement orders and data indicative of fire suppression effects. The major model outputs are time histories of unit movement, allocations of direct and indirect fire, personnel and equipment casualties, and status of each unit. These outputs can be either in the form of a printer plot or a display on a suitable CRT device (e.g., a pseudo-commander's tactical situation display). Some of the primary limitations of the model are: the effects of terrain and cover are treated statistically rather than in terms of particular terrain features, the elements in each unit are assumed to be randomly distributed within the area occupied by the unit, no service support and resupply is accounted for, only prompt radiation effects from tube-launched nuclear weapons

are considered, no air defense weapons or their effects on Tac Air or Army helicopter close-air support are simulated, and no automatic simulation of communications are taken into account (these must be gamed explicitly through the model interactive equipment).

It should be noted that a nonnuclear version of this model has been incorporated into TRW's Combined Arms Tactical Training Simulator (CATTS), a two-sided, player-interaction, real-time full simulation of the command, control, and communications functions associated with a combined arms land combat. The CATTS simulator includes the use of real C^3 equipment (actual radios, etc.) along with realistic effects of enemy ECM on this equipment and the effects of combat noise on the operators of the simulator (field commanders and their personnel). CATTS was developed by TRW primarily as a training simulator for U.S. Army C^3 personnel; however, it could also be used as a war gaming tool. It includes a realistic representation of a particular battlefield environment in considerable detail; computer tapes which have the terrain contours, types of vegetation, and weather data are used in the target acquisition modeling required for all direct fire weapons. Missions, doctrine, strategy and tactics are input by the operators of the simulator. The CATTS simulator was developed for and is currently in operation at the Command and General Staff College at Fort Leavenworth, Kansas.

F.4 TANREM

TANREM (Tactical Nuclear Requirements Methodology) is a model developed in 1974-1975 by the Army's Concepts Analysis Agency to assist them in determining tactical nuclear weapons requirements to support limited nuclear options. The model is a

player-interactive war game which embodies two separate computer codes, a data base of conventional combat results and loss rates (assembled from previous studies employing other combat simulation models*) and a large number of player-initiated policies and decisions. The first of these two codes is NUREX (Nuclear Requirements Extrapolator). This computer code is a two-sided deterministic model which simulates theater-wide combat within multiple sectors (usually corps) on a time-stepped daily basis. Starting with a theater scenario, data concerning opposing forces in each sector are input. This includes information on: committed and noncommitted forces; Red division replacement criteria; Red/Blue personnel and equipment replacement rates; nuclear delivery systems to be played; delayed casualty criteria and decay factors; and the combat posture (probe, attack, delay, etc.) for each side for the current day.

The NUREX code computes conventional firepower potentials for each side in each sector, using a selected algorithm. All committed conventional ground elements are included at this point. Loss rates due to conventional fire and estimates of force movements are then determined by reference to the data base of conventional combat results, which are parameterized, based on each side's relative strength and chosen posture. Loss rates to ground forces due to air support are also estimated but no air combat or air defense is simulated. The losses due to conventional combat are calculated on a daily basis in each sector; player interactions at the start of each day adjust inputs to insure that they are within realistic limits and best serve each side's goals.

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*This data base of conventional battle results is a compilation of simulated outcomes determined by other models of conventional-only land combat such as the CAA TARTARUS model.

At some point, when it is decided by either side to escalate to tactical nuclear weapons, the currently active forces (down to company/battery size) in the sectors to be attacked are deployed in static, stylized arrays according to their chosen posture, the terrain, and the relative locations of the cities. These arrays of potential targets are part of the input data for the second code called NUFAM (Nuclear Fire Planning and Assessment Model).

NUFAM is a code with some Monte Carlo features designed to perform tactical nuclear fire planning in one sector at a time (allowing player interaction) and then assess the results of the fire plan execution over time throughout a 24-hour period. Simulation time advances on an event-store basis within the day. That is, the model has a dynamic aspect in that each side schedules a nuclear fire plan (event is scheduled and stored) with available resources; however a particular nuclear delivery system may be destroyed by an enemy nuclear weapon prior to its scheduled firing (stored events occur only if criteria concerning previous events are met).

In performing tactical nuclear fire planning, NUFAM utilizes the static target arrays previously described and input information concerning: percent-of-knowledge target acquisition data as a function of target type, distance from the FEBA, and target location error (TLE); a "flee-time" distribution by target type and distance from the FEBA which accounts for loss of acquisition; the number, type, yields, CEP, etc., of nuclear delivery systems available to be played; a distribution of time delays for each delivery system type which accounts for the total C^3 time between target acquisition and weapon firing; and a desired level of damage to each target type.

Target damage assessments are determined by calculating the amount of overlap obtained between the prescribed radiation levels (circles) and the target deployment configurations (rectangles). Actual ground zero (AGZ) for each weapon is determined by sampling the CEP and TLE normal distributions. Collateral damage in the form of civilian casualties is also assessed against the input city array. The cumulative effects of exposure to multiple bursts are not accounted for. Once nuclear casualties have been assessed, the user evaluates the results and modifies the inputs as appropriate to simulate the next day using NUREX.

Typical simulations of a 10- to 15-day battle usually require about three calendar months to process. This includes at least three repetitions of each Monte Carlo portion of the study. The greatest portion of the effort is, of course, manpower time to acquire and structure inputs (including player interactions). NUREX uses only one CPU second per 24-hour day, and NUFAM uses 30 minutes of CPU time to plan and assess the outcome of 500 nuclear fires over 6000 targets.

F.5 UNICORN

UNICORN, developed by Scientific Applications, Inc., is a weapon-allocator model designed to investigate employment capabilities and options for both conventional or nuclear indirect fire weapons. The model is essentially one-sided, in that it allocates weapons against a user-specified array of point and area targets. The program's main objective is to select the optimum mix of weapons to maximize the total expected damage to the target system, subject to any allocation constraints that are specified by the user. Conventional and nuclear weapons are traded off simultaneously, and the target array can range in size from less than division through theater.

Program inputs include weapon types and deployments (in terms of grid locations), target types and locations, minimum and maximum weapon system range limitations, range-dependent CEPs, the lethal radii of conventional weapon types against various target types, the yields of various nuclear weapons and target acquisition capabilities. For nuclear attacks, blast or radiation kill criteria can be specified and the user can also stipulate an upper limit for these levels. In addition to specifying the maximum allowable collateral damages, the user defines the minimum required levels of target damage for various target categories. The program also provides for a variety of allocation constraint controls to be designated by the user, such as the minimum fraction of targets in a given category to be attacked, the fraction of defense suppression targets which must be suppressed, etc.

Based upon weapon characteristics, range constraints, stockpile limitations, defenses, etc., the model employes a generalized linear programming technique to determine an optimal weapon deployment against a target array, consistent with the user's specified levels of target damage and allocation constraints. The model can be used to determine weapon effectiveness drawdowns, and will take into account factors such as weapon systems rates of fire limitations, target acquisition, weapon survivability, nuclear release delay times, and weapon response times. However, allocation and damage assessments are made based on treating each target in the array independently. Moreover, as an essentially one-sided model, it does not explicity and dynamically account for opponent responses to the allocation process.

The current version of the model is configured to be used on the MULTICS computer facilitys of Office of Assist. Secretary

of Defense (Program Analysis and Evaluation) in an interactive mode. Program implemention time for this operating system is minimal: the data base can be acquired and structured for input within a day, computer running time for a case is typically less than a minute CPU time, and analysis and evaluation of the results can be completed within a day. The model is constantly being revised and expanded and documentation is updated periodically.

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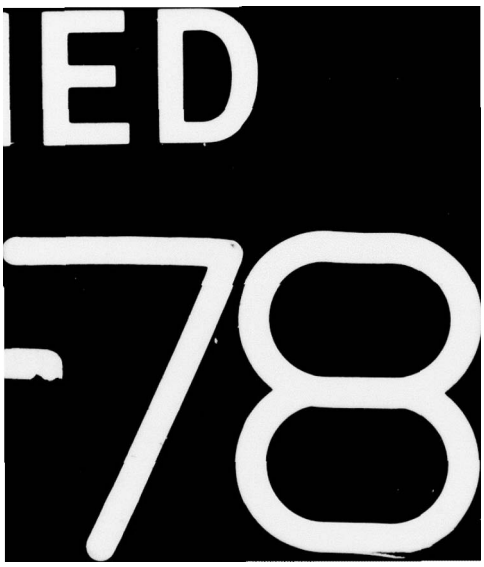
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