AD-A091 056 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 15/7

A SURVEY OF APPROACHES TO THE MODELING OF LAND COMBAT.(U)

JUN 80 W T FARMER

UNCLASSIFIED NL

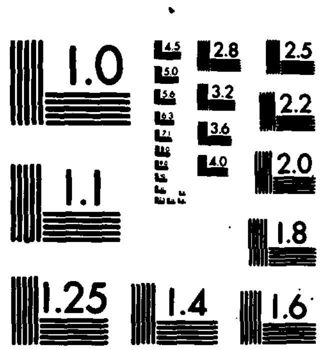
END

DATE

FILMED

12-80

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL II

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A SURVEY OF APPROACHES
TO THE MODELING
OF LAND COMBAT

by

William Ted Farmer

June 1980

Thesis Advisor: J. G. Taylor

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A091056	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Survey of Approaches to the Modeling of Land Combat		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; June 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William Ted Farmer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1980
		13. NUMBER OF PAGES 76
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Land Combat Models
Lanchester-Type Equations
Monte Carlo Simulations
Analytical Models
War Games

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This thesis surveys various methods for modeling land combat and examines the assumptions underlying each method. The users of land combat models are identified according to the nature of the problems that they are trying to solve: weapons system life-cycle management, tactical planning and doctrine, force structuring, education and training, and research and methodology. The distinction between models and the modeling

process is made and some of its consequences explored. A survey of modeling methodologies is presented: it includes high-resolution Monte Carlo simulations, Lanchester-Type models, analytical models, manual war games, firepower scores models, the hierarchy of models concept, and the Quantified Judgment Method of Analysis. Finally, a basic reading list on models is provided for the beginning military operations research analyst.

A SURVEY OF APPROACHES TO THE MODELING OF LAND COMBAT

by

William Ted Farmer
Captain, United States Army
B.A., Rice University, 1972

submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL

June 1980

Author: William Ted Farmer

Approved by: ______________________ Thesis Advisor

______________________ Second Reader

(MG SOVEREIGN)
Chairman, Department of Operations Research

____
Dean of Information and Policy Sciences

ABSTRACT

This thesis surveys various methods for modeling land combat and examines the assumptions underlying each method. The users of land combat models are identified according to the nature of the problems that they are trying to solve: weapons system life-cycle management, tactical planning and doctrine, force structuring, education and training, and research and methodology. The distinction between models and the modeling process is made and some of its consequences explored. A survey of modeling methodologies is presented: it includes high-resolution Monte Carlo simulations, Lanchester-type models, analytical models, manual war games, firepower scores models, the hierarchy of models concept, and the Quantified Judgment Method of Analysis. Finally, a basic reading list on models is provided for the beginning military operations research analyst.

TABLE OF CONTENTS

I. INTRODUCTION

This thesis was motivated by a desire to understand the complete range of quantitative tools that the Army operations research analyst may bring to the task of understanding the land combat process. For each tool there are assumptions upon which the use of the tool is predicated. One method may be known to be superior in the study of one class of problems but ineffective when applied to other problems.

A particular type of model may require the collection of enormous amounts of input data before it can be used, forcing the analyst to decide whether the cost of collecting and preparing the data is justified by the specific problem to be analyzed. If not, he must select an alternative methodology.

The analyst may be asked to participate in the construction of a new model of land combat. He will be more effective if he knows the various ways in which combat has been modeled and has learned from others' mistakes. Similarly, he needs knowledge of current methods and state-of-the-art technologies. He should bring to the group an understanding of the human enterprise of modeling in general.

The creation and use of models of land combat occur in an environment populated by professional military and civilian analysts, tactical and strategic decisionmakers, legislative and executive overseers, civilian contractors, academicians and the press. In the solution of problems involving weapons and tactics, the choices of the models to use and the results they produce must be justified. The analyst has the burden to use the most applicable model available.

This thesis was motivated by a perception that the wrong model applied to a problem may result in conclusions and decisions whose effect is worse than that of a decision made without the use of any model. This research effort was directed toward reducing that likelihood.

II. THE USERS OF LAND COMBAT MODELS AND THEIR NEEDS

A. INTRODUCTION

Land combat models are important. The military defense of the United States requires a military force strong enough to deter aggression against its interests and, failing deterrence, ready and capable enough to engage and defeat the adversary in armed combat. The resources made available to the Army, Navy and Air Force by the American people for this purpose are limited both in times of peace and war. The decisions to create new weapons systems, tailor the mix of forces to perceived threats, train the serviceman to optimally employ his tools, and create and test war plans are difficult, complex decisions whose penalty for error can be extremely costly to the country. The questions are very important; the decisions are crucial. Intuition alone is not sufficient. Models of land combat are a part of the decisionmaking process.

Dr. F. B. Kapper [1], former advisor to the Joint Chiefs of Staff, argued that special studies and analysis are a small key factor influencing the policy/decision maker. Other factors he considered more important were national strategy, objectives and priorities, politico-military judgment, budgetary/timing considerations and constraints, past experience, a sense of history, our current value system, and current intelligence and projected trends. Models then are tools and not an end in themselves.

At the national level this may be true. However for a number of problems a land combat model may be the driving element in the process of answering tough questions. Decisionmakers want to make their decisions based on the best information and judgment available at that time. Decisionmakers in complex organizations are usually removed from the people who are acquiring data, converting it into information, distilling that information into conclusions and recommendations, and briefing their results to the decisionmakers. He does not do the analysis; the analyst does the analysis and presents recommendations.

The tools that the analyst uses depends on the given problem, the resources available for analysis, and the analyst's own knowledge and skills. The users of land combat models may be divided in many ways. The author chose to distinguish among users in the way discussed in Brewer and Shubick [2]. They noted that the purpose for which a model is built drives its use. Purposes are divided into technical evaluations, force structure analysis, doctrinal evaluation, teaching and training, and research. Each purpose may require a different modeling approach and there are overlaps in the uses made of various land combat models.

B. TECHNICAL EVALUATION

Technical evaluation means evaluation of weapons systems. There is a life-cycle management process for each weapon system which commences with an idea for a weapon system to meet a perceived future military threat. Competing concepts of weapons must be evaluated for usefulness, planned cost, manpower considerations and many other factors long before even a prototype can be built. Analysts working on these problems need models which can accurately describe the physical weapon system: its lethality, rate of fire, maneuverability, survivability, and supply consumption.

C. FORCE STRUCTURE ANALYSIS

Force structure analysis means deciding how much of each weapon system and how many people to put into each unit in order to obtain the best expected effectiveness against the enemy while remaining within budgetary constraints. Such problems introduce the consideration of soldiers working as coordinated teams. The "people factor" makes the question a difficult one. For example, what is the marginal, or additional, effectiveness of adding (or subtracting) another weapon and operator to this unit? Can the unit become so large that coordination problems begin to degrade unit effectiveness? What should the assets of an Army division be and how should they be divided among subordinate commands? Such questions require their own set of models and modeling approaches.

D. DOCTRINAL EVALUATION

Doctrinal evaluation seeks to find the best employment of existing units composed of today's soldiers and weapons against the current threat. Its focus is on optimizing what is and what will be soon. The results of doctrinal evaluations are doctrine which soldiers and units study, practice and use. For the deployed small-unit, doctrinal evaluation may be the testing of alternative tactics tailored for the specific situation on the ground. A less urgent use of doctrinal evaluation may be the creation of doctrine to employ weapons systems in development but not yet fielded, as in the case of the 1986 battlefield. Practitioners in doctrinal areas have a different set of questions to ask of their models.

E. TEACHING AND TRAINING

Teaching and training models focus more on the human experiencing the model and less on the process being modeled. The goal may be to confront the subject or subject group with a new situation requiring decisions and actions which can later be critiqued. The goal may be to reinforce doctrine or previously learned lessons, as in practice to improve skills. The human factor of such models makes the principle of independent replication, so important to the scientific method in the physical sciences, very difficult. Indeed, the purpose of such models is to train.

F. RESEARCH AND METHODOLOGY

The research and methodology purpose is directed toward inventing better models, improving existing models and synthesizing results from diverse intellectual activities into new products and procedures to improve the state of modeling. Efforts in this direction may include advanced mathematical probability models or new ways to analyze the results of experiments with human subjects. The focus is on attempting something new or on refining current modeling technology without the guarantee of success. New results are published in academic and professional journals and should stand the test of the scientific method. The research and methodology purpose seeks to expand knowledge and develop better tools.

G. CONCLUSION

The variety of models is a natural consequence of the variety of questions which may be asked about land combat. According to Dr. W. B. Payne [3], former Deputy Undersecretary of the Army, the pursuit of a single, all-purpose, preferred model of any aspect of land combat is to be avoided. However, the resulting proliferation of models can give the analyst a difficult choice of which model to use and why. When approaching a model, the analyst should determine the purpose for which the model was created. Different purposes result in different types of models. The model's purpose (or purposes) help to reveal the potential usefulness of the model in solving the question in hand.

More information on the purposes, uses, costs and problems of models, simulations and games was found in Brewer and Shubick [2].

III. A SURVEY OF APPROACHES TO THE MODELING OF LAND COMBAT

A. MODELS AND THE MODELING PROCESS

According to Morris [4], modeling is an intuitive and artful process which results in objects called models. A model is an abstract representation of reality which is used for the purpose of prediction and to develop understanding about the real-world process [5]. Modeling attempts to draw out some sort of conceptual structure and order from perceptual confusion. The development of skill in modeling involves three basic hypotheses. First, one begins with very simple models and attempts to evolve toward more complex and, hopefully, more realistic models. This is the process of enrichment. Second, previously developed models with their finalized logical structures furnish reasonable starting points for the modeling process. This is the use of analogy. Third, the model must confront the data and be modified, and the assumptions of the model must be refined until a solution is possible. These two looping processes are called alternation.

The modeler proceeds from his starting points to elaborate, refine and redo his model by trial-and-error. He attempts to validate it and, if necessary, starts all over again. The modeling process is necessarily subjective [6].

When finished, he presents a completed model and a narrative containing the justification of the model. What is usually not revealed is the process of discovery which leads from start to finish, but rarely by a direct path. An excellent description of this process of discovery covering a number of years' work in creating a model is contained in Dupuy [7].

The modeling of land combat begins with one fundamental assumption: the combat processes being modeled are "regular enough" so that the model with its variables will capture the essential elements of the processes. If the combat processes are believed to be too unpredictable to model, then one has no basis upon which to construct a model. During Morris' alternation phase as the model confronts real data, the model proves to be predictable or it does not. When the model proves to be inadequate, one refines and revises. The very act of beginning to model must, however, be based on the belief that the combat processes being modeled are essentially predictable.

The analyst prefers to create and exercise a model rather than to work only with empirical data. The human mind is analog, not digital. It prefers pictures and graphs to tables of numbers. Empirical data cannot be thorough enough to answer every "what if" question which may need to be explored. The model represents a convenience to the analyst from which he hopes to extract the essence of what is being modeled. Furthermore, it is difficult if not impossible to discern from tables of numbers those factors which strongly influence the process and those which do not.

A model attempts to summarize all the data without the loss of important information. Analyzing the model rather than analyzing the empirical data provides the best path toward understanding the process being modeled.

The second part of Morris' alternation phase is profoundly important. It does the analyst little good to postulate a set of assumptions which lead to a model which cannot be solved. The model builder adds to his assumptions until he has a model which can be solved. Then he may relax an assumption and attempt to solve the resulting new model. As an example, in probability models a frequent assumption is that the occurrence of a phenomenon just observed is independent of the previous occurrences of the phenomenon. In real life that assumption is probably unrealistic, but, if one assumes dependence, the resulting model may be impossible to solve. The modeler assumes independence to make the mathematics simpler and solves his model. He still has the responsibility to explain the assumptions, caveat all results produced, and explore further methods of solving the "impossible" model. He also has the responsibility to discard the model if the independence assumption produces nonsense results.

Prior to the widespread availability of computers, models had to be solved by hand. This restricted modelers to assumptions which resulted in models which could be solved that way. The origins of western operations research lay in attempting to solve some complex military problems during the conduct of World War II. The solution techniques relied on "back of the envelope" hand calculations to solve grossly simple models. The advent of the computer and the programmable hand-held calculator permit the modeler to formulate models which cannot be solved by hand but can be solved numerically. An example of such a model is presented in Appendix B. Computer technology has expanded the freedom to relax assumptions and still solve the model.

B. A PARTITION OF LAND COMBAT MODELS

There are many models of land combat and determining a classification system was difficult. However, the author partitioned the set of combat models into two subsets: micro and macro.

A micro-model results from an attempt to model various subprocesses of the major process and then tie together, or "lash up" all the subprocesses into a model which faithfully represents the major process. Categories of models which may be considered to be micro-models are high-resolution Monte Carlo simulations, free-standing analytical models, fitted-parameter analytical models and the hierarchy of models concept. The modeler goes as deeply as he thinks is necessary into subprocesses, models them as accurately as possible, and then assembles the parts into a whole. He believes that this approach is better than others in producing models able to answer his users' questions and capable of yielding greater insight and understanding about the major process.

A macro-model results from an attempt to model the results of the major process with aggregated variables and not at the component level. Categories of models which may be considered as macro-models are manual and computer-assisted war games, Lanchester-type models, firepower scores models, and the Quantified Judgment Model. The macro-modeler is concerned with describing large systems by means of aggregated variables. For example, the "combat power" of a Russian infantry corps in World War II was described in the commercial war game "Stalingrad" as two numbers: seven when on the attack and ten when on the defense. Comparisons with the combat power number of opposing and friendly units then formed the basis for modeling attrition at the corps level. These numbers attempt to capture the relationship between large forces in a way which opposing war game players can quickly understand and manipulate.

An analogy may be drawn between this partition of land combat models and the distinction in economics between micro and macroeconomics. Microeconomists model the economic behavior of the individual and the firm. These are the building blocks or components of their process which are lashed together up to the level of the industry. Macroeconomists model the national and international process by specifying aggregate variables such as money supply, capital outlays, and the balance of payments. Based on observations and collected data, both sets of economists seek to simplify their processes into understandable, valid and solvable models.

In the discussion which follows, the author presents a survey of the categories of land combat models which focuses on the major modeling assumptions in evidence. Each model is different and unique, but within categories there are common themes which characterize the modeling approach.

C. HIGH-RESOLUTION MONTE CARLO SIMULATIONS

A simulation is a model which runs completely without human intervention [8]. The simulation is called Monte Carlo if a random sampling procedure is used for determining values of variables which may take on many possible values. Such models are stochastic: they permit the modeling of chance. The solution of a deterministic model results in the same answer every time, whereas stochastic models can, and typically do, produce different results each time they are solved.

The two high-resolution Monte Carlo simulations examined were CARMONETTE [9] and STAR, the Simulation of Tactical Alternative Responses [10, 11, 12, 13]. They are implemented on high-speed digital computers: human solution of such models is impossible. Both models reflect the micro-modeling approach to the brief intense engagement phase of land combat at the individual weapon system/vehicle level of detail. The subprocesses which are modeled may be classified as physical or behavioral.

Some examples of physical processes are weapon system effects (direct fire, indirect fire, air and air defense), terrain and line-of-sight, casualty assessment, time and movement. Some examples of behavioral processes are target selection and firing, fire control and communications, movement decision (ground and air), command and control, detection and supression.

As may be expected in the modeling of so many processes, there were a multitude of explicit and implicit rules, simplifications and assumptions. The modelers created a structure which, within explicit constraints, permitted the user to create the battle to suit his needs. The modeling of the physical processes has been extensively studied and documented [14]. The modeling of the behavioral processes has less empirical basis. The modelers required that most behavioral decisions be inputs into the model by the user. These consisted of orders and many other "if the situation is this, do that" decision rules.

Two examples of simplifying behavioral assumptions were enlightening. Both models play detection equals identification. A defender who detects a moving target at 3000 meters (1.87 miles) immediately knows the type of vehicle and whether it is friendly or hostile. One could object that this is unrealistic, to which the modeler responds, "Then tell me by how much to degrade this phenomenon, and why." Both models play target selection equals the decision to fire. World War II data compiled by General S. L. A. Marshall [15] indicated that only 25 percent of U. S. soldiers in an engagement actually fired their weapons. To the extent that such assumptions are unjustified and important, the results of such models may be biased.

Both models used the event scheduling approach to simulation modeling which permits the modeler to prepare a system description by concentrating on the moments in time when the state of the system changes [16]. Events which should occur at some time in the future, say a detection or a round's impact, are placed onto a list of pending events, and are acted upon when the simulation clock advances to coincide with the event's time. This assumes that the modelers were skillful and accurate in orchestrating this complex collection of processes. This "lash up" assumption exists in all micro-modeling efforts. The process of model verification, or proving that the mathematics in the model is behaving properly, minimizes the likelihood of "lash up" errors.

Modelers point to several advantages that simulations possess [16]. They can compress or expand time, identify and control sources of variation, eliminate real-world errors of measurement, stop, analyze and restore the state of the simulation, and replicate an experiment under tight control. They are useful research tools when systems get too large for analytical solution. They can, however, become mired in detail, thwarting clear analysis of the results.

For the analyst, the greatest advantage of a simulation may lie in the ability to "empirically" observe the interaction of several factors producing a result much greater than (or much less than) the factors acting alone could be expected to produce. This phenomenon is called synergy. For example, smoke on the battlefield does not kill, but, in conjunction with a minefield, it may result in much more effectiveness for the minefield than if the smoke were not there. Simulations may permit the quantification of such effects.

High-resolution simulations are complex. The analyst who uses one must consult available documentation and the modelers, if possible, to determine the assumptions of the model and whether he can justify to himself and his superiors its use. The modeler must document thoroughly his assumptions and techniques.

Modeling via simulation assumes that a good analytical solution is not possible or desirable. It assumes the modeler's ability to describe "well enough" the processes involved and to bring them together into a unified whole which faithfully simulates land combat.

D. LANCHESTER-TYPE MODELS OF COMBAT

In 1914 Frederick W. Lanchester postulated two sets of simple differential equations to model combat between two homogeneous forces. His purpose was to justify quantitatively the principle of concentration under "modern conditions" of warfare [17]. From then to the present, no other mathematical model of combat has been so widely studied or used. His models, as modified and extended by H. K. Weiss, R. Helmbold, H. Brackney, S. J. Deitchman and others, so dominate the field of quantified analytical modeling of land combat that the professional analyst must understand the operation of and assumptions underlying these models. Force-on-Force Attrition Modeling by James G. Taylor provides, for the first time, one book in which the basic models and extensions of Lanchester's theory are presented in a manner permitting the analyst to grasp the key ideas.

Lanchester-type models seek to describe the process of two forces attritting one another in terms of the rate at which each force is receiving casualties. Casualties are seen as a function of time (how long the battle lasts) and the casualty rate.

It was helpful to the author to consider this analogy. Suppose one were in an automobile driving at a constant rate, or velocity. The distance covered would be a function of time and the constant velocity, as in

$$\text{distance} = \text{rate} \times \text{time} .$$

Suppose now that instead there were other influences acting on the driver so that sometimes he had to accelerate or decelerate, but he did not stop or drive in reverse. Then the calculation of how far he had driven in a period of time would be more complicated but the underlying structure of distance as a function of the rate and time period would still hold.

Analytical modelers using Lanchester-type equations seek to find the best expression for the casualty rate for the scenario being modeled. In the case of the driver, it makes a difference in the rate whether he is travelling over a flat highway or through winding mountains. Similarly, direct fire "aimed" weapons have one set of casualty rates but "area" fire weapons have a different set of rate expressions. The modeler chooses that set of rate expressions which are appropriate.

These are examples of scenarios for which the "best" set of casualty rate expressions have been determined:

(1) Both sides use "aimed" fire and target-acquisition times are constant and independent of the number of enemy targets.

(2) Both sides use "area" fire against constant-density defenses.

(3) Both sides use "area" fire against constant-area defenses.

(4) Both sides use "aimed" fire with the time to detect an enemy target inversely proportional to the number of enemy targets and also much greater than the time required to kill an acquired target.

(5) Both the assaulting force and defending force use "aimed" fire but the time to acquire targets is much less for the defending force.

(6) The ambushing force uses "aimed" fire but the ambushed force, not knowing where the ambushers are, return "area" fire.

(7) Both forces use "aimed" fire but also suffer operational losses not caused by enemy action (sickness, accidents, desertions, etc.)

(8) Both forces use "aimed" fire and are supported by "area" fire support weapons not subject to attrition.

The specific casualty rate expressions for each scenario are given in Taylor [18]. Knowing the proper set of casualty rate expressions and the starting force levels of each side, the analyst can solve the resulting deterministic battle.

The equations for modeling these scenarios assume that the forces being modeled are homogeneous. This means that every unit on each side has exactly the same capability for killing enemy forces and exactly the same vulnerability to enemy action, but each unit kills opposing enemy units at different rates. This is clearly a strong simplifying assumption which for many scenarios is not reasonable. Therefore, the concept of homogeneous combat was extended to heterogeneous combat, or combat between combined-arms teams. The modeler of heterogeneous combat must specify the fraction of each weapon type which engages each opposing weapon type, or the allocation factor. To use the resulting sets of equations he assumes that the attrition effects of various different enemy weapon types against a particular friendly target type are additive (no synergistic, mutual support effects) and that the casualty rate of each weapon type is proportional to the number of enemy firers of that type [19].

These sets of equations, when given with the initial force levels, cannot be solved by hand. The analyst must resort to a computer to obtain a numerical solution. The author was concerned that perhaps heterogeneous combat models were beyond the capability of the typical military analyst and solvable only by contractors or dedicated analysis agencies using large, powerful and costly high-speed digital computers. However, the implementation of a numerical solution by discrete approximation appeared feasible. An attempt to convert this idea into a program for a Texas Instruments Programmable 59 hand-held calculator was made and the program is given in Appendix B. This means that an analyst who has values for the starting force levels, attrition rate coefficients and allocation factors can solve the resulting battle at his desk. He can postulate different values in a "what if" exploratory mode and obtain quick answers for comparison.

For example, suppose that in weapon design analysis one wanted to analyze the alternatives of increasing the probability of a round's hit by ten percent or increasing the rate of fire by ten percent. Assuming access to a supportive data base, an analyst using the methods of Appendix B could begin to explore the problem without an initial expensive outlay of computer and analysis resources. More in-depth analysis may follow, directed down paths which appear most promising based on an essentially "quick and dirty" macro-level analysis of the problem.

The two analytical modeling approaches discussed below depend upon the assumption that combat attrition, on average, follows Lanchester-type models "well enough." To use such models the analyst assumes that the discrete attrition process can be accurately approximated by a continuous Lanchester process over time. As a result the analyst is involved in real-valued and not integer-valued casualties. For larger force sizes, this approximation seems reasonable. He also assumes that attrition, like distance in the case of the automobile example, can truly be described as a function (probably complicated) of rates over time. To arrive at such a description the analyst may need to decompose the battlefield spatially or temporally. Fundamentally, he assumes that a model based on weapons and their rates captures the essential nature of the combat process being modeled.

E. FREE-STANDING ANALYTICAL MODELS

An analytical model is a set of mathematical equations which relates independent variables (inputs) to dependent variables (outputs). The equation of a straight line,

$$y = mx + b$$

describes precisely the relationship between any number x and the resulting output y. This equation is a deterministic analytical model.

An analytical model of land combat seeks to describe the process mathematically. Free-standing analytical models use the same types of inputs (i.e., weapon system characteristics, starting levels of forces, decision rules) as do a high-resolution simulations [20]. This is in contrast to fitted-parameter analytical models which take data from high-resolution simulations.

Free-standing analytical models of combat are a subset of models using Lanchester-type equations. The primary contributor to the creation and use of free-standing analytical models is Dr. Seth Bonder of Vector Research, Inc. His modeling approach was to describe mathematically the expected time for one firer to kill one passive target for each possible pair of weapon types on the battlefield under study. By making the kill rate equal to the reciprocal of the expected time to kill, one can use Lanchester-type equations of heterogeneous combat to solve the firefight being modeled [21, 22, 23].

This modeling approach led to models (BONDER-IUA, Vector family) which require large amounts of performance input data, are fast-running but which are distant from the analyst and decisionmaker because of the advanced mathematics and probability theory underlying the models. The models are deterministic.

There are several major assumptions inherent in the structure of a free-standing analytical model. The most important variable in the combat process is weapon system effectiveness. This is reasonable since "a careful study of past military history and particularly of the 'little picture' of our own infantry operations in the past war (World War II) leads to the conclusion that weapons when correctly handled in battle seldom fail to gain victory." [24] It is assumed that the parameters of the probability distribution for attrition rates are measurable capabilities of weapon systems and that the attrition-rate coefficients for Lanchester-type equations can be predicted prior to the inception of an engagement [23]. Hence there is a requirement for a large amount of performance input data. Another assumption implied in these modeling efforts is that quantifying weapon system effectiveness by examining an active firer against a passive target (a one-sided duel) is a sufficiently accurate representation. To extend the passive model to a mobile firefight requires additional assumptions about the variation of kill rates over range [22]. It is assumed that the "lash up" of individual one-on-one duels into a heterogeneous firefight is properly accomplished. Human behavior, such as detection and firing, is modeled mathematically. The empirical basis for these assumptions is not known to the author. Finally, it is assumed that Lanchester's theory of combat is essentially correct but incomplete and accounts for any synergistic effects on the battlefield.

It was evident to the author that this modeling approach depends considerably upon the second part of Morris' alternation phase: add assumptions until the mathematics is solvable. The mathematical models derived and solved represent a formidable intellectual accomplishment.

These analytical models provide the analyst with a tool in which variables may be adjusted to see the results. This facility, known as sensitivity analysis, is an important feature for the analyst. If the model can quickly answer questions such as, "If we had 3 more XM1 tanks in the blue force, how different is the battle outcome?" then the analyst has a powerful tool for exploring his problem thoroughly.

The extension of the firefight (BONDER-IUA) model to a theater-level (i.e., European) model was made in an attempt to overcome perceived difficulties with firepower scores models of large-scale war (such as ATLAS). Some documentation for VECTOR-0, a prototype of the VECTOR family of models, was examined to determine the types of assumptions made [25]. The modeling of terrain as sectors and time as discrete units, normally one day, resembled the manual war gaming approach. Forces were quantified into categories: battalion task forces, maneuver forces in reserve, artillery, attack helicopters, air defense and tactical aircraft. The assumptions underlying especially the last three categories were extensive. Also modeled were supplies, user-input tactical decision rules and seven tactical activities. The processes modeled were attrition, reorganization of forces, supply, movement, tactical decision and activity assignment. The attrition process used the same approach as the BONDER-IUA model: one-on-one duels furnish the attrition rate coefficients for a Lanchester-type heterogeneous model of combat.

The authors of VECTOR-0 acknowledged a number of important limitations on their modeling effort. Many simplifying assumptions were made in order to demonstrate the feasibility of the prototype. Only a linear or integral FEBA was modeled. None of the functions of intelligence, command, control and communications was played. Terrain classes were not modeled and only a limited number of ground combat scenarios were included. The author did not examine documentation of VECTOR-1 or VECTOR-2 to determine the extent to which these assumptions and simplifications were replaced in these production models.

The modeling of free-standing analytical models involves assumptions on the ability of the modeler to mathematically describe firefights as a complex set of one-on-one duels linked together by a heterogeneous model of combat. The analyst who uses free-standing analytical models accepts and lives with its assumptions.

F. FITTED-PARAMETER ANALYTICAL MODELS

Modelers and users of high-resolution simulations must carefully choose the scenarios they wish to explore because data collection and formatting data for input can be an expensive, time-consuming process. To achieve a degree of statistical stability the simulation must be replicated, meaning that the exact same scenario is played many times but with different random numbers [26]. The results of many replications of several scenarios are several discrete sets of outputs each representing a single scenario. However the analyst may need to know what would happen in a scenario which lay between the scenarios already simulated.

One answer to his need is to set up and simulate that new scenario, but that is expensive and incomplete. Another approach is to use a fitted-parameter analytical model. Such a model takes the observations of casualties in a simulation replication as if they were actual combat data, estimates statistically the expected time for one weapon system type to kill another weapon system type, and then uses the reciprocal of expected time as the kill-rate for a Lanchester-type heterogeneous combat model. Such models became possible in 1969 when Dr. Gordon Clark postulated and solved the COMAN model [27]. These models are also a subset of Lanchester-type models of combat.

The modeling assumptions of the fitted-parameter analytical approach are essentially two: the results of a high-resolution Monte Carlo simulation are "close" to actual combat data, and the battle data represent a sample from the Markov-chain analog to the deterministic Lanchester-type homogeneous equations of combat [28]. This effectively means that the distribution of times between casualties is modeled as being exponential and independent. Thus to all the assumptions of the simulations are added the assumption that combat attrition observed in the simulation is, in the mean or average sense, Lanchestrian.

The analytical model uses the statistical principle of maximum likelihood estimation to convert the observed times between casualties to parameters used in heterogeneous models of combat, hence the name "fitted-parameter." These estimates are characterized by their simplicity and ease of manipulation in a simple heterogeneous model.

Clark's idea of the COMAN model was adopted by Research Analysis Corporation (later part of General Research Corporation) and evolved into COMANEX (COMAN EXtended). U. S. Army TRADOC Systems Analysis Agency has used Clark's ideas to create COMANEW (COMAN nEW) to estimate attrition-rate coefficients from replications of the high-resolution simulation CARMONETTE.

The fitted-parameter analytical model provides the analog representations of reality in a size which permits manipulation and communication between players.

A war game consists of several basic components: a terrain board, playing pieces, a terrain-effects chart, an attrition-effects chart, the sequence of play, victory conditions and, if desired, a randomized decisionmaking instrument, usually a die. A computer may be used to organize the data and ease the burden of calculations, but all decisions are made by human players or by chance. Although there are a few games which play individual weapons systems and soldiers, most war games involve some amount of aggregation of weapons and organizational (logistics, command, control, communication, morale, leadership, etc.) effects into more abstract playing pieces. This level of aggregation and abstraction is fixed for the game and players do not decompose and recompose their pieces. If the game is historical, it is essentially benchmarked against real historical combat data. This benchmarking process does not ask how or why all the subprocesses converged into the historical result, but rather concentrates on the results and key elements.

An *aggregated war game is a macro-model of combat in* which the number of elements is intentionally kept small. The basic assumption involved in the use of a war game is that the modeler has correctly captured the key elements of the combat scenario being simulated. As with all modeling, this is a difficult task to accomplish. The dimensions which such an assumption can assume were made clear to the analyst with a quick-running heterogeneous model for which the attrition-rate coefficients are "benchmarked" by a complex simulation. As Clark concluded,

> Given a set of replications from the combat simulation, the COMAN model could be used in optimization or trade-off studies to evaluate a large number of alternative force structures which would be a laborious process with the combat simulation. Also, the COMAN model could be used to evaluate the outcome of small-unit engagements in a large-unit model [29].

Use of such a model implies acceptance of the assumptions underlying both simulations and Lanchester-type models of combat.

G. MANUAL WAR GAMES

Manual war games are the oldest models of land combat. The game of chess represents pre-gunpowder combat quite well, according to Mr. James Dunnigan, owner of Simulations Publications, Inc. (SPI), in guest lecture remarks at the Naval Postgraduate School. The ancient oriental game of Go, whose strategies are many times more complex than chess, models siege combat. Such games, together with the commercial historical war games, form a surprisingly large segment of recreational activity in this country. There are some 30,000 subscribers to SPI's "Strategy and Tactics" magazine and Brewer and Shubick estimated that "the number of serious amateur war gamers in the United States in 1976 was about 40,000. This population is considerably larger than that of professional war gamers." [30] Manual war games appeal to human senses of sight and touch; they are author by Dunnigan [31] in his discussion of how to design a war game. Design is guided by two cardinal principles: keep it simple and plagiarize ("use available techniques"). He identifies ten steps which are generally followed:

> The first step, and the most important one, is concept development. You must determine at the very beginning what it is that you want to do. The second step is research...The third step is what I have dubbed integration. This is where you take all of the research material and your knowledge of game mechanics and integrate it into a prototype game. The fourth step is fleshing out this prototype, coming up, in effect, with something that looks remarkably close to the finished game...The fifth step is to prepare a first draft of your rules...The sixth step is one of the more difficult ones. It is game development. This means playtesting and changing the game and rewriting the rules and taking a lot of abuse from people who would rather play than design...The seventh step is what I call blind testing. This is where you take your physical prototype and your written rules and send them out to somebody who can play the game without your presence...The eighth step occurs when all of your blind testing results have come back and have been integrated into the manuscript... The ninth step is production...There is much potential danger in this phase of game design. The tenth step is also extremely critical if you are going to design any more games. This is the feedback step. You must systematically collect feedback from those who play your game to see where you went right and where you went wrong...There is a lot more to the 10 game-designing steps than I have briefly explained. The tricks of the trade are what make these steps functional. The tricks that have been uncovered in the last 10 years could fill a few books [31].

Both Dunnigan and Morris [4] express the belief that modeling is an art acquired by active participation and trial-and-error. The modeler, since he deals with an abstraction, is always making judgments and assumptions. With an historical game, the emphasis is less on quantitative, mathematical skills and more on the ability to convert research into key elements modeled in a humanly understandable way. "Generally, the more accurate your perception regarding the critical elements in the battle, the better the game will be." [31] An example of what can go wrong in designing a war game is given in Appendix A. It also serves as an example of Dunnigan's seventh step, blind testing.

E. S. Quade, in discussing the value of games, noted that

> games fail to achieve realism in a great many respects...unless the game designer specifically guards against it, the usual assumptions are likely to lead to plans or postures that are far more efficient in their use of resources than are found in real life. However the technique of manual gaming...can do much to facilitate a policy study. Admittedly, the predictive quality of such an exercise is very clearly a function of the quality of intuitive insight provided by the experts involved. In contrast, by allowing for the introduction of judgment at every step, the game provides an opportunity to take into account intangible factors often considered completely outside the scope of analysis...Games can uncover errors or omissions in concept; it can explore assumptions and uncover the implicit ones; it can check coordination measures; it can develop the contingencies on which a plan depends; it can draw out divided opinions; it can examine the feasibility of an operational concept...But, of course, it can give very limited indication of failure or success of particular strategies [32].

The author feels that the primary advantage of gaming lies in the active participation of human decisionmaking. The mind, in its mysterious way, integrates pictures, symbols, concepts, stresses and goals into a plan and behavior pattern which may not be mathematically optimal but is human and real. To the criticism that games are too variable to quantify for analysis, the author suggests research into the concept of an "expected value" game between pairs of opponents as explained in Appendix A as a possible methodology. This concept is also similar to the solution of games by fictitious play [33].

H. FIREPOWER SCORES MODELS

Firepower scores models seek to represent the combat potential of heterogeneous forces by an index-number. This approach is similar to attrition modeling in war games in which all the attack factors of one side are summed into one attack number and the defense factors of the other side are summed into one defense number for each battle. Combat is resolved and casualties assessed based on the ratio of these two numbers. The scores and indices may be known as firepower score/index of combat effectiveness (FS/ICE), firepower potential/unit firepower potential (FP/UFP), firepower potential score/index of firepower potential (FPS/IFP), weapon effectiveness index/weighted unit value (WEI/WUV), weapon effectiveness value (WEV) and other names [34].

The modeler determines the relative combat power of each weapon in a unit, assigns a value of one to the least effective weapon (usually a rifle) and assigns higher scores to more potent weapon systems. The unit index is the sum over all weapon systems of the number of weapons present times its score, and it represents the aggregation of heterogeneous forces into a single homogeneous force. The reader should note that this is in contrast to the design of a war game since blind testing feedback allows the war game designer to tinker with the indices empirically and not have to make an explicit computation.

This system of indices has been used by force planners since World War II. It reflects an attempt to find a general theory of aggregating and disaggregating forces apart from a specific historical scenario which a war gamer may model. A widely-used firepower scores model, A Tactical, Logistical and Air Simulation (ATLAS), began its life as QUICK GAME, a "two-sided, open, semirigidly assessed, grossly aggregated, manually operated war game for feasibility testing of plans and exercises, and for gross evaluation of force capabilities." [35] The success of QUICK GAME led to computerized QUICK GAME, in which the rules became more rigid and replication became less costly. After revisions and expansions it became ATLAS. A fine history of the evolution of operational gaming as practiced at Research Analysis Corporation is given by Hausrath [35].

Firepower scores models represent a macro-model of combat grossly based on the count of weapons systems, tons of supplies and air resources. An attempt is made to calibrate casualties, movement of the front and supply consumption to historical data, usually from World War II. There can be data problems, as discussed in a recent General Accounting Office report [36]. A more serious assumption is the modeler's ability to correctly aggregate and disaggregate. Bode [37] emphasized the information reducing nature of aggregation and the difficulty, if not impossibility, of recreating the details later. If the essence of the scenario being modeled depended on details that were aggregated, then the analyst could reach incorrect conclusions. For example, did ten percent attrition at the corps level mean complete destruction of one battalion, or partial destruction of three battalions, or minor casualties to all battalions? If the analyst needs these answers, then he should probably ask his questions of a different type of model.

I. HIERARCHY OF MODELS CONCEPT

The Army Models Review Committee of 1971 defined the hierarchy of models as "a set of models in which the outputs of one element in the set become inputs to another element in the set." [38] For example, the division or brigade may be the basic elements in a theater-level model, the battalion the basic component of a division-level model and the individual weapon system or soldier the basic component of the high-resolution model.

The hierarchy of models concept seeks to link models designed for these various levels together in a two-way linkage. The first is from high-resolution to highly aggregated models in order to feed information about combat up. The second is from top to bottom for the purpose of defining the scenarios for investigation by the high-resolution models. In theory, any set of micro-models of combat could be "lashed together" into any aggregated model.

One operational model based on this concept is a theater-level model developed by the British Defence Operational Analysis Establishment (DOAE). As described by Dare [39], it consists of a high-resolution Battle Group Model using Army officers to game the scenarios and Lanchester-type equations for attrition modeling. This model feeds the Corps Model whose piston-like sectors resemble those in ATLAS. It uses an extended form of Lanchester-type equations. The output of the Corps Model becomes input to the Central Front Game, a computer-assisted war game of sectors. Also deriving input from the Corps Model is the NATO Deployment Model, a linear programming model which provides "an optimum allocation of the defenders' forces to the deployment zones to meet the set of threats as well as an estimate of the length of time for which the final phase line can be held against the most difficult threats." [39]

Section F discusses another family of models which fits the hierarchy of models concept: the COMAN, COMANEX, COMANEW fitted-parameter analytical models. They use outputs of high-resolution Monte Carlo simulations to calculate the attrition coefficients for Lanchester-type models.

This modeling approach attempts to substitute model outputs for actual combat data from wars of the future, perhaps using weapons not yet produced or deployed. The analyst using such a model accepts the set of assumptions underlying each component model. He also accepts that the information passed between models was the important information and that the transmission of information was undistorted. He assumes that the "lash up" of component models was done well.

J. QUANTIFIED JUDGMENT METHOD OF ANALYSIS

The last model of land combat considered was the Quantified Judgment Method of Analysis (QJMA) as developed by Colonel T. N. Dupuy [7] and his associates at the Historical Evaluation and Research Organization (HERO). The model began in 1964 with the study of weapons effectiveness and evolved over a decade of historical research and empirical modelbuilding.

The model is essentially a firepower scores model elaborately modified by the variables of combat and a battle outcome model. To compute the Theoretical Lethality Index (TLI), the modeler examines twelve factors ranging from rate of fire to fire control and ammunition supply effects. The TLI is then converted into the Operational Lethality Index (OLI) which is the firepower scores building block.

The basic OLI's are then adjusted by 73 variables of combat which are divided into the eleven categories of weapon, mobility and tactical air effects, terrain, weather, season, air superiority, posture and vulnerability factors, other combat processes and intangible factors. Dupuy maintains that

> No two battles are alike. No matter how similar two combat situations may appear to be, there are inevitably many differences, no matter how slight, in circumstances, and in the composition of the opposing forces. Anything that may change between battles, or during battle, may be

> termed a variable of combat, no matter what the reason for change or difference may be. HERO has identified 73 separate Combat Variables...This list is almost certainly incomplete--but it is close to including all currently identifiable variables that affect combat outcomes [40].

Of these variables, most are always calculable, two (logistics and combat effectiveness) are sometimes calculable, eight are probably calculable but not yet calculated, and eight are intangible and probably individually incalculable.

QJMA is best described in its author's own words.

> The QJMA is a method of comparing the relative combat effectiveness of two opposing forces in historical combat, by determining the influence of environmental and operational variables upon the force strengths of the two opponents. The heart of the QJMA is a model of historical combat called the Quantified Judgment Model (QJM). The model is applied to statistics of selected historical engagements and produces values for the Combat Power Potentials of the two opposing forces under the circumstances of the engagement, and a Combat Power Ratio to ascertain which of the opposing sides--on the basis of data available in the records--should theoretically have been successful in the engagement, and by what margin.
>
> This Combat Power Ratio is next compared to a quantification of the actual outcome of the battle. This outcome value, derived from consulting the records, represents...the comparative performance of the opposing forces in terms of (1) their accomplishment of their respective missions, (2) their ability to gain or hold ground, and (3) their efficiency in terms of casualties incurred. If the Combat Power Ratio of Force A with respect to Force B is greater than 1, then the Result Value for Force A should be greater than that for Force B. In the event of a different relationship between Combat Power Ratio and Result Values, or if the Result Value differential is not consistent with "normal" relationships of Combat Power Ratios and Result Values, further exploration is necessary to explain the discrepancy, which is usually due to behavioral considerations...
>
> When they are not consistent we can be certain that the inconsistency is due to some exceptional combat phenomenon, which is usually explicable after further study and analysis. In fact, it has been through the exploration of the causes of such inconsistencies that the value of the QJMA as an analytical tool has been greatest [41].

Two of the results from analyzing inconsistencies were the quantification of surprise and a national overall combat effectiveness value for one soldier [42]. The results on the factor of surprise were published in "Army" magazine [43] and a discussion of German versus Russian combat effectiveness is contained in Appendix A.

Having developed the historical QJMA by 1973, Dupuy sought to test it against modern combat. He obtained information from both sides of the October 1973 Arab-Israeli War and successfully analyzed the war. He found that "there was a major methodological conclusion. The value of the QJM was reaffirmed as a unique tool for combat experience analysis, as a coherent, comprehensive theory of combat, and as a valid simulation of modern combat with modern weapons." [44]

HERO also analyzed the relationship between its firepower scores as modified and Lanchester's theory of combat. Dr. Janice Fain's analysis led to the conclusion that

> the Lanchester Equations provide reliable casualty rates only when combat power values for opposing forces reflect the variables of combat, as formulated by HERO's QJM...It shows an interesting convergence between these two very different approaches to a representation of combat, one theoretical and one empirical. Above all, it demonstrates the significance of considering the variables of combat when attempting to analyze anything like a force ratio [45].

The author noted with interest that the apparent inadequacy of Lanchester's theory led both Bonder and Dupuy to elaborate the theory in quite different ways. Neither concluded that combat was too variable to be analyzed or predicted.

In summation, Dupuy offered a clear contrast between his QJMA and other methods presented earlier.

> It is in its concept of variables, and their application, that the methodology described in this book differs most radically from other modern models, or simulations of combat. We believe that the concept of variable factors, representing environmental and operational effects upon the readily calculable firepower effects of weapons, is a reasonable, logical approach to representing the actual battlefield influence and effects of such weapons. It is not necessarily the only approach which can be reasonable and logical but at this time it is the only approach that we know of that makes consistent military sense [46].

The analyst using QJMA makes some important assumptions. He assumes that the subjective judgment used by the historian to convert primary, secondary and tertiary historical research into properly quantified data was essentially correct. He accepts an evolutionary view of combat which seeks to extend and modify past lessons into answers to today's and tomorrow's questions. Dupuy explained

> Nor do many [analysts] see--without historical perspective--that the tremendous changes in weaponry and equipment which they observe today are (with the possible exception of nuclear weapons) hardly any more startling than other technological and weapons developments since the dawn of the Industrial Revolution...The reason for this is that the principal weapon of war is, and always has been, man himself. Thus the nature of warfare has changed only in its details (sometimes dramatically, but always relatively slowly) as man adapts himself and his thinking to new weapons and technology...In our time there could be no more striking demonstration of this truism than the 1973 October War [47].

The analyst assumes, as does the war game designer, that history has aggregated for him the myriad of subprocesses in combat into the key variables. Finally, the analyst accepts the many mathematical formula for fusing together the variables into two firepower scores.

IV. CONCLUSION

The author found no one model of combat unconditionally preferred to another, although his undergraduate training in mathematics and history and his recreational war gaming led him to a perhaps unpopular bias in favor of Dupuy's QJMA and its theory of combat. Although only Dupuy's model specifically uses the word "judgment," the survey of methods for modeling land combat demonstrated that every model contains enough of the modeler's judgment to make a decisionmaker (or at least the author) a bit skeptical about the entire process of attempting to model land combat as if it were a part of a physical science.

The survey also demonstrated that the analyst need not be constrained methodologically to only one approach. Although the user's needs are varied and complex, for both the firefight and the theater-level war there are micro- and macro-models which may be applied to the problem.

Two phenomena observed during the research for this thesis appear to bode well for the future of land combat analysis. One is the wide interest in war gaming. As Dupuy observed,

> Let me also remind both historians and operations researchers that some of the most serious analyses of historical conflict are appearing in the periodicals of the wargames-for-entertainment community. Not least is the fact that at least one commercial manufacturer of such games has, as a result of the sophistication of its

products, preformed consulting and developmental services for the US armed forces [48].

The analyst should remain in touch with this supportive community's activities.

The second promising note is sounded by the tremendous (and increasing) power of programmable hand-held calculators. The program in Appendix B was only one simple example of what could be done to give the analyst more freedom to use a variety of tools. The author was confident that the QJMA could also be so programmed.

Finally, this survey led the author to the conclusion that four books form a core of knowledge about the methods of modeling land combat. They are Taylor's Force-on-Force Attrition Modelling, Colonna's CARMONETTE. Volume I. General Description, Dunnigan's The Complete Wargames Handbook, and Dupuy's Numbers, Predictions and War. Their inclusion in the education of U. S. Army officers and especially operations research analysts could aid in the pursuit of better answers to the difficult questions of land combat.

APPENDIX A. MODIFYING THE MANUAL WARGAME "STALINGRAD" TO REFLECT HISTORICAL ANALYSIS

1. INTRODUCTION

The German invasion of Russia in June 1941 was a long-shot gamble that almost succeeded. The ensuing four years of offensives, sieges and counter-offensives were unmatched for their size, duration and scope of heroism. For military historians this period holds a special fascination. It was therefore fitting that one of the first commercially available manual wargames was "Stalingrad" by Avalon Hill, Inc. Their sales brochure correctly extols this game: "The perennial favorite at wargaming conventions, this 'classic' wargame has passed the text of time. For simplicity of play and excitement level, this 'starter' game has no equal say knowledgeable aficionados who cut their teeth on this game way back when..." [1]

In college the author began playing "Stalingrad" and can attest to that appraisal. Over a period of ten years the author has played a total of over twenty games against several opponents and knows the rules, terrain and likely scenarios well. The best opponent, Captain Chris North, so thoroughly triumphed initially that the author studied it intensely, playing solitaire games to gain insight, and eventually attained near parity with him. It is from these experiences that "Stalingrad" was examined in the light of historical combat data in an attempt to validate the underlying assumptions of the model.

The historical information was taken from War in the East, The Russon-German Conflict, 1941-45 by the Staff of Strategy and Tactics Magazine. The contributors were James F. Dunnigan, Colonel Trevor Dupuy, David C. Isby, Edward C. McCarthy and Stephen B. Patrick. Some of the articles appeared first in the magazine in the early 1970's.

The method of analysis was to compare the actual course of the war with an "expected value" game between two equal and competent players. That game existed only in the author's mind, so the conclusions were subjective. Despite this, the exercise acted to highlight several key factors in the modeling of land combat.

Since the game of monthly turns ends in May 1943, the analysis was restricted to that historical period. That was a reasonable point for game termination since it corresponded roughly with the Battle of Kursk, the greatest tank battle in history, after which the Soviets never lost the offensive. Significant rule changes would be needed to model the improved Russian effectiveness and large quantity Lend-Lease and domestically produced supplies, but those were beyond the scope of this analysis. Rather, the period during which the Germans had a fighting chance was considered.

2. A SUMMARY OF THE WAR TO MAY 1943

The attack by German forces against the Soviets at 0300 hours, 22 June 1941, caught the Russian command completely by surprise. The advances by Army Group North toward Leningrad and Army Group Center past Minsk toward Smolensk were devastating and swift beyond belief. In one month's time the Germans were to the Luga River. While Army Group South had a slower, tougher fight, it succeeded in taking Kiev in late September and crossed the Dnepr River. By December, Army Group Center was exhausted in front of the gates of Moscow, Army Group North had Leningrad under siege, and Army Group South had taken Rostov, Stalino, Kharkov and Kursk, extending to the headwaters of the Don River. The enormity of the German success was staggering [2, 3].

From December to May 1942, the Soviets counterattacked the overextended Germans in the center and south. Rostov was retaken and advances were made in the center, relieving the pressure on Moscow. The weather, as much as the Russian combat effectiveness, began to take its toll. "The Germans had taken some serious blows in the winter but the overall picture at this time was not a bad one." [4]

The German Offensive, "Fall Blau," ran from May to November. It retook only a portion of the center in front of Moscow and Tula, made no advance on the Leningrad siege, but scored great success in the south. The Russians were pushed back to the Don River, lost nine-tenths of

Stalingrad, and were pushed to the Caucasus Mountains. However, the German 6th Army in Stalingrad was overextended.

The south then collapsed. From November through March 1943, the Soviets' counteroffensive led to the surrender of the Germans in Stalingrad and pushed beyond Kursk, Kharkov and Rostov. The Germans then retook Kharkov but lost some ground near Leningrad. "Although the Soviet winter offensive of 1942-43 began with disaster and the Germans had lost vast areas of ground, the tactical skill of von Manstein had salvaged more than just some holding positions in the south...They had shortened their lines to more defensible ones and were still able to beat off anything like a Soviet force of equal size." [5] In the spring the Germans concentrated on preparing to retake the Kursk salient. The actual battle began on 5 July against tremendous Soviet defenses, achieved penetration but died when Hitler pulled tank corps out of the campaign for transfer to Orel to counter a Soviet penetration. From this time on, the Soviets had the offensive all the way into Germany.

3. THAT WHICH IS MODELED CORRECTLY

Of the major components of the game, only the Combat Results Table (CRT) and initial setup of forces in June 1941 appeared to need modification to bring the game into historical reality. The omission of air power could have been incorporated into the CRT and the naval conflict was, for the scope of this analysis, inconsequential. The possibility of aid to either side from liberated partisans, primarily in the Ukraine, was not played although they were a factor working against the Germans in the war. This omission was not serious and, like air power, could be factored into the CRT if desired.

The terrain board accurately reflected the area of operations. It was in hexes, incorporating rail lines, rivers, marshes, mountains, seas and lakes. Key cities such as Warsaw, Kiev, Smolensk, Moscow, Leningrad, Kharkov, Kursk, Rostov and Stalingrad were highlighted. Defenders in the cities were probably correctly doubled in effectiveness. Lakes and rivers around and north of Leningrad froze in the winter, permitting the type of attacks across the ice which actually occurred. Other terrain effects appeared correctly modeled: defenders' effectiveness was doubled when in mountains or behind a river; only three units (corps) could aggregate in a hex; Hungary was off-limits to the Germans in the initial invasion; the Pripyat marshes split the invasion forces into two thrusts.

The modeling of movement was realistic with the exception of rail movement which none of the authors directly addressed. The effect of the seasons in Russia upon movement were pronounced: snow upon all combatants and mud upon the motorized forces. The rule of halving all movement in snow and mud months was realistic. The ten hex rail movement rule was unverified as was the reduction to five hexes in snow. It certainly contributed to a rapid

German advance in parallel to the actual invasion campaign. One nuance which could be added would require the opposing force to travel at regular movement rate over the railroad when taking it from his enemy. Thereafter it would be available to him at the full rail movement rate. This would simulate the engineering required to convert Russian railroads to German guage and back.

Weather was fixed as clear or snow for all months except October, Novenber, March and April. For these months, the German player rolled a die to determine the weather (and movements rules) for that month's turn. This was a good rule. Combat effectiveness was not degraded on either side due to mud or snow. However, a case could be made that the weather's effect was greater on the German forces than on the Russian.

Two entire chapters on the order of battle discussed in detail the size and nature of the forces of both sides. The sixty-five Axis unit counters and thirty-four Russian unit counters appeared to represent roughly the number and size of the various corps-size units. All Russian units were fifty percent more effective on defense that on offense--a figure supported by Colonel Dupuy [6]. Armor had a higher combat power than infantry in proportion to their "firepower" indices. The translation from paper organization charts to combat indices on unit counters appeared adequate for the level of aggregation played in the wargame.

None of the authors discussed the Finnish campaign by the Russians so the appropriateness of the Finnish rules could not be evaluated. There was a question, though, about the complete discretion of the Russian player in placing forces near Leningrad to restrain and destroy the Finns. This question was related to the initial setup of forces to be discussed below.

The rules for conducting combat were related to zones of control exerted by a unit counter and the ability of a side to mass against one unit while making inferior attacks against other enemy units in the same or adjoining hexes. This was a profound insight made by the game's designers, reflecting the conclusion of F. W. Lanchester's law of modern warfare: concentration of modern firepower can be devastating. In the conduct of the game, each player must weigh both side's ability to mass and destroy key units or seize key terrain, thereby rendering the front substantially weaker than a simple numerical comparison of total attacker to defender firepower scores. In Russia the vastness of the land gave new definition to the concept of "the front." It could best be considered as a line of fortified outposts [7]. The zone of control rule ably modeled this expansive front concept.

Rapid German advances required the wholesale destruction-in-place of enemy units and subsequent penetration. In this game there was no movement after battle. Given the size of units, one month turns and the size of a hex, the rule made sense.

The modeling of replacement unit counters for the German was accurate. It was a constant rate of four attack factors per month. There were no extra counters, so that the German could never have more forces on the playing board that that with which he began [8].

The modeling of Soviet replacements was less certain. The increase of replacement factors from zero to four to six to eight reflected the relocation of industry beyond the front and the seemingly endless supply of manpower in Russia. The timing of the increases was accurate but the size of the replacements was in question. It was related to the CRT and is discussed below.

4. THAT WHICH IS MODELED POORLY

Given the above historical scenario, is it likely that an "expected value" game of "Stalingrad" among equally competent players would result in a similar scenario and outcome? The answer is a resounding no! The German player simply can not expect to achieve penetrations and advances comparable to the historical scale. The two key weaknesses of the game were the Combat Results Table and the initial setup of forces. The two factors were related.

While the order of battle analysis had correctly sized the competing forces into corps unit counters with appropriate firepower indices, the CRT failed to incorporate the key factor which made the Germans grossly more effective than the Russians during this two-year period. "The prime advantage the Germans had over the Russians lay in the quality of the German leadership and training and in the adaptability of their manpower." [9] In summarizing the war, Colonel Dupuy highlighted two key factors: "the superb conbat performance of the German Army, with battlefield accomplishments probably exceeding the best of any other army in military history...(and)... the seemingly inexhaustable supply of manpower at the disposal of the outclassed Soviet commanders." [10]

The Russians could not attack as well as the Germans. "When the Red Army finally turned to the offensive, commanders were reluctant to concentrate forces for a penetration...The depth of a single thrust was further limited by the inadequacy of Soviet control and supply systems." [11] Another part of this Soviet ineptitude was revealed in the distinctions between the 1939 and 1943-45 divisions. "Man for man, the December 1942 rifle division had 64 percent more firepower than the September 1939 division." [12] There was no indication that "Stalingrad's" designers took these intangible factors into account in the design of the CRT.

The Germans pioneered in the "combined arms" concept and achieved unexpected successes due to the synergy of the team and their skill in execution. The artillery was a key part of this team. "On paper, the 1943 Soviet rifle battalion was about equal to the German 1944 battalion in firepower...What gave the Germans an edge was their numerous divisional artillery, which was accustomed to working closely with the divisional infantry battalions. This was not the case with the numerous non-divisional artillery which often worked with Soviet rifle battalions." [13] Colonel Dupuy, founder and Executive Director of the Historical Evaluation and Research Organization (HERO), concluded that "100 German soldiers were the combat equivalent of 264 Russian troops! For 1943 alone the average German superiority was 148 percent greater than that of the Russians." [14] Dunnigan confirmed this conclusion qualitatively: "As infantry alone, the Russian infantry was much respected by the Germans from the very start of the war. But as part of a combined arms-team, they never really got the upper hand over the Germans." [15]

The "Stalingrad" CRT underrewarded the German player on offense, forced him to take too many casualties in proportion to his monthly replacement rate, and, barring exceptional luck with the die, doomed the German cause. The most likely explanation for this failure was the confusion of similar paper combat organizations with equal combat effectiveness. "At a glance the German organization doesn't look much different from that used by its opponents, particularly the Western Allies. By 1944, this would have been a valid assessment. But before that, appearances were deceiving. Other armies had organization which looked somewhat like the German one but in performance was quite inferior. The critical factors here were training and, to a lesser extent, equipment and weapons." [16]

The second serious flaw in "Stalingrad" which prevented the German player from achieving the initial incredible thrusts lay in the rules governing the initial setup of forces. An experienced Russian player could deploy his forces to bottle up the initial German attacks in the north, center and south. He hid behind rivers, in mountains, and sacrificed small units to both slow the advances and exacted precious casualties until replacements began arriving. By the time the German had broken through Minsk, Smolensk, Kiev and Riga and was onto the flat, open terrain, he was behind schedule, bloodied beyond hope of replacement to his initial strength level and facing a constantly growing Russian opponent.

5. CHANGES TO THE GAME TO REFLECT HISTORICAL DATA

Two adjustments to the rules of "Stalingrad" were needed to permit the "expected value" of the game to more closely parallel history. These two rule changes were selected from among many possible combinations because they seemed to be the most likely to achieve this purpose. The first was to change the CRT as follows: the German attacks at a ratio of one greater than the force ratio would indicate, the Russian attacks at the normal ratios and the die outcomes in the CRT remain the same. Thus, if the Germans had 42 attack factors against 14 Russian defense factors, the battle was a 4-1 instead of a 3-1.

The second was to initially deny the Russian player one of his 7-10-4 infantry corps and two cavalry corps--the 6-9-6 and 5-7-6. Their losses would substantially weaken the initial Russian deployment and, coupled with the CRT change, would open up the game to the quick advantages the German should make. These big units, sitting in key cities and behind key rivers, were the foundation of the bottling up of Axis forces in the game. These unit counters could be placed in Finland but could not be released until the Finns were overcome.

Neither of these rule changes was tried in actual wargaming since the author had yet to find any opponents. However, one rule change was routinely played: reducing the Soviet replacement rate from 4-6-8 defensive factors per month per city down to 4-5-6. This acted to equalize the forces and prolonged the German player's agony. Another rule change which the author had played was to give the German an initial "surprise" advantage by adding one to the force ratio, as proposed above. This occurred only on the first turn but, coupled with the modified replacement rate, made for a long, toughly fought game. However, the rapid initial advance still did not occur.

The changes, then, were to increase German combat effectiveness, restrict Russian initial force deployment, and continue the replacement rate of 4-6-8.

6. CONCLUSIONS

A careful analysis of campaign information and battle results can give the military analyst sources by which rough coefficients of unit combat effectiveness can be derived. Deviations from parity, as in the dramatic case of German versus Russian combined arms teams, force closer examination of the factors contributing to effectiveness and ineffectiveness. At the micro-level of combat analysis, the analyst is hard pressed to place a number on intangibles such as morale, espirit, training, equipment, timeliness of replacements, level of supplies and maintenance, and so forth. How much is one more measure of morale worth? Furthermore, how is the synergy of the combined arms team to be measured and modeled? Frankly, the author doubted that any answer could be given at the micro-level of combat analysis.

The insights to be gained from the macro-level of campaign analysis at such a super-aggregated level as in "Stalingrad" might be applied to smaller unit battles if desired. The coefficients for Lanchester-type models of combat, reflecting relative combat effectiveness, could be applied (with reservations, of course) to the combat of smaller units. This top-down solution would not yeild specific numbers for the intangibles listed above, but may give a measure to their combination. As such, the use of historical campaign analysis could aid in our understanding and modeling of the synergistic and intangible parts of combat.

LIST OF REFERENCES

1. Commerical brochure, Avalon Hill, Inc., 1976.

2. "Stalingrad" Battle Manual, Avalon Hill, Inc., pp. 2-3.

3. Patrick, Stephen B., "The Russo-German Conflict," in War in the East, The Russo-German Conflict, 1941-45, pp. 20-52, Simulations Publications, 1977.

4. Patrick, ibid., p. 34.

5. Patrick, ibid., p. 48.

6. Dupuy, Trevor N., "An Analysis of the War," in War in the East, p. 101.

7. Dupuy, ibid., p. 130.

8. Dupuy, ibid., p. 138.

9. Dunnigan, James F., "Organization of German Ground Forces," in War in the East, p. 131.

10. Dupuy, ibid., p. 87.

11. Dupuy, p. 99.

12. Dunnigan, "Organization of Soviet Ground Forces," in War in the East, p. 118.

13. Dunnigan, "Soviet Ground Forces," p. 119.

14. Dupuy, ibid., p. 101.

15. Dunnigan, "Soviet Ground Forces," p. 109.

16. Dunnigan, "German Ground Forces," p. 128.

APPENDIX B. A SIMPLE HETEROGENEOUS FORCE MODEL PROGRAM

1. INTRODUCTION

The program models a red force of two weapon types attacking a blue force of two weapon types. It is implemented on a Texas Instruments Programmable 59 calculator and PC-100C Printer. The user provides the initial force levels, aggregated attrition-rate coefficients, forward step-time unit, battle termination time and printer time increment for printing the force levels periodically throughout the battle.

This linear model of heterogeneous combat is based upon equation (6.6.6) of Taylor [49].

$$\frac{dx_i}{dt} = -\sum_{j=1}^{n} A(ij)Y(j) \quad \text{with } X_i(0) = X(i0) \quad \text{for } i = 1,2,\ldots,m$$

$$\frac{dy_i}{dt} = -\sum_{j=1}^{m} B(ij)X(j) \quad \text{with } Y_i(0) = Y(i0) \quad \text{for } i = 1,2,\ldots n$$

Here the allocation factor, or fraction of a weapon type which engaged an opposing weapon type, is combined with the constant attrition-rate coefficient into one coefficient: A(ij) or B(ij). When a weapon type is annihilated, its strength is set to zero automatically and the battle continues. The program uses the forward finite-difference approximation method.

2. USER INSTRUCTIONS

Insert the program into calculator memory. Storing the program on both sides of one magnetic card is recommended. Press GTO, LNX, and key in the initial force level of blue's first weapon system X(10) and press R/S. Repeat the process of keying in the proper number and pressing R/S in the following sequence: X(20), Y(10), Y(20), A(11), A(12), A(21), A(22), B(11), B(12), B(21), B(22), step-time, stop-time, and the number of step-times between each print cycle. The data has now been entered.

To initialize or reinitialize the calculator, press GTO, CE, R/S. To execute the program and print the results, press GTO, 1/X, R/S. The program will stop when stop-time is reached. The smaller the step-time, the longer the calculator will spend in execution.

3. DATA REGISTERS

00	X(10)	INITIAL FORCE LEVEL - FIRST BLUE WEAPON
01	X(20)	INITIAL FORCE LEVEL - SECOND BLUE WEAPON
02	Y(10)	INITIAL FORCE LEVEL - FIRST RED WEAPON
03	Y(20)	INITIAL FORCE LEVEL - SECOND RED WEAPON

04	A(11)	COEFFICIENT - BLUE ONE VS RED ONE
05	A(12)	COEFFICIENT - BLUE ONE VS RED TWO
06	A(21)	COEFFICIENT - BLUE TWO VS RED ONE
07	A(22)	COEFFICIENT - BLUE TWO VS RED TWO
14	B(11)	COEFFICIENT - RED ONE VS BLUE ONE
15	B(12)	COEFFICIENT - RED ONE VS BLUE TWO
16	B(21)	COEFFICIENT - RED TWO VS BLUE ONE
17	B(22)	COEFFICIENT - RED TWO VS BLUE TWO
08	STEP-TIME	
18	STOP-TIME	
30	NUMBER OF STEP-TIMES BETWEEN PRINT CYCLES	

09-13, 19-29, 31 ARE WORK REGISTERS

4. PROGRAM LISTING

000	76	LBL	001	23	LNX	002	91	R/S	003	42	STO
004	00	00	005	91	R/S	006	42	STO	007	01	01
008	91	R/S	009	42	STO	010	02	02	011	91	R/S
012	42	STO	013	03	03	014	91	R/S	015	42	STO
016	04	04	017	91	R/S	018	42	STO	019	05	05
020	91	R/S	021	42	STO	022	06	06	023	91	R/S
024	42	STO	025	07	07	026	91	R/S	027	42	STO
028	14	14	029	91	R/S	030	42	STO	031	15	15
032	91	R/S	033	42	STO	034	16	16	035	91	R/S
036	42	STO	037	17	17	038	91	R/S	039	42	STO
040	08	08	041	91	R/S	042	42	STO	043	18	18
044	91	R/S	045	42	STO	046	30	30	047	91	R/S
048	76	LBL	049	24	CE	050	43	RCL	051	00	00

052	42	STO	053	10	10	054	43	RCL	055	01	01
056	42	STO	057	11	11	058	43	RCL	059	02	02
060	42	STO	061	12	12	062	43	RCL	063	03	03
064	42	STO	065	13	13	066	43	RCL	067	08	08
068	42	STO	069	29	29	070	42	STO	071	31	31
072	43	RCL	073	30	30	074	42	STO	075	09	09
076	91	R/S	077	76	LBL	078	35	1/X	079	43	RCL
080	10	10	081	42	STO	082	24	24	083	43	RCL
084	12	12	085	42	STO	086	26	26	087	43	RCL
088	13	13	089	42	STO	090	28	28	091	43	RCL
092	04	04	093	42	STO	094	25	25	095	43	RCL
096	05	05	097	42	STO	098	27	27	099	71	SBR
100	52	EE	101	43	RCL	102	19	19	103	42	STO
104	20	20	105	43	RCL	106	11	11	107	42	STO
108	24	24	109	43	RCL	110	06	06	111	42	STO
112	25	25	113	43	RCL	114	07	07	115	42	STO
116	27	27	117	71	SBR	118	52	EE	119	43	RCL
120	19	19	121	42	STO	122	21	21	123	43	RCL
124	12	12	125	42	STO	126	24	24	127	43	RCL
128	10	10	129	42	STO	130	26	26	131	43	RCL
132	11	11	133	42	STO	134	28	28	135	43	RCL
136	14	14	137	42	STO	138	25	25	139	43	RCL
140	15	15	141	42	STO	142	27	27	143	71	SBR
144	52	EE	145	43	RCL	146	19	19	147	42	STO
148	22	22	149	43	RCL	150	13	13	151	42	STO
152	24	24	153	43	RCL	154	16	16	155	42	STO
156	25	25	157	43	RCL	158	17	17	159	42	STO
160	27	27	161	71	SBR	162	52	EE	163	43	RCL

164	19	19	165	42	STO	166	23	23	167	43	RCL
168	20	20	169	42	STO	170	10	10	171	43	RCL
172	21	21	173	42	STO	174	11	11	175	43	RCL
176	22	22	177	42	STO	178	12	12	179	43	RCL
180	23	23	181	42	STO	182	13	13	183	43	RCL
184	31	31	185	32	X-T	186	43	RCL	187	18	18
188	77	GE	189	34	X*.5	190	91	R/S	191	76	LBL
192	34	X*.5	193	00	0	194	32	X-T	195	43	RCL
196	08	08	197	44	SUM	198	31	31	199	97	DSZ
200	09	09	201	35	1/X	202	61	GTO	203	45	Y X
204	76	LBL	205	52	EE	206	53	(	207	43	RCL
208	24	24	209	75	-	210	43	RCL	211	25	25
212	65	X	213	43	RCL	214	26	26	215	65	X
216	43	RCL	217	29	29	218	75	-	219	43	RCL
220	27	27	221	65	X	22	43	RCL	223	28	28
224	65	X	225	43	RCL	226	29	29	227	54	)
228	42	STO	229	19	19	230	77	GE	231	94	+/-
232	00	0	233	42	STO	234	19	19	235	76	LBL
236	94	+/-	237	92	RTN	238	76	LBL	239	45	Y X
240	43	RCL	241	10	10	242	99	PRT	243	43	RCL
244	11	11	245	99	PRT	246	43	RCL	247	12	12
248	99	PRT	249	43	RCL	250	13	13	251	99	PRT
252	43	RCL	253	31	31	254	99	PRT	255	98	ADV
256	43	RCL	257	30	30	258	42	STO	259	09	09
260	61	GTO	261	35	1/X						

LIST OF REFERENCES

1. Kapper, F. B., "Theater-Level Gaming in the Formulation of Plans and Policies (JCS)," in Theater-Level Gaming and Analysis Workshop for Force Planning, Volume I-Proceedings, pp. 19-21, Office of Naval Research, 1977.

2. Brewer, Gary D. and Shubick, Martin, The War Game, A Critique of Military Problem Solving, pp. 160-180, Harvard University Press, 1979.

3. Payne, W. B., "Keynote Address," in Military Strategy and Tactics, Computer Modeling of Land War Problems, edited by Huber, R. K., Jones, L. F. and Reine, E., pp. 9-12, Plenum Press, 1975.

4. Morris, William T., "On the Art of Modeling," Management Science 13, pp. B707-B717, August 1967.

5. Honig, J., et al, Review of Selected Army Models, p. I-B-4, U. S. Army Models Review Committee, May 1971.

6. Brewer and Shubick, ibid., p. 148.

7. Dupuy, T. N., Numbers, Predictions and War: Using History to Evaluate Combat Factors and Predict the Outcomes of Battles, Bobbs-Merrill, 1979.

8. Honig, ibid., p. I-B-6.

9. Colonna, Gary S., et al, CARMONETTE.Volume I.General Description, General Research Corporation, 1974.

10. Wallace, William S. and Hagewood, Eugene G., Simulation of Tactical Alternative Responses (STAR), M. S. Thesis, Naval Postgraduate School, Monterey, California, 1978.

11. Caldwell, William J. and Meiers, William D., An Air to Ground and Ground to Air Combined Arms Combat Simulation (STAR-AIR), M. S. Thesis, Naval Postgraduate School, Monterey, California, 1979.

12. Naval Postgraduate School Technical Report NPS55-79-018, Parametric Terrain and Line of Sight Modelling in the STAR Combat Model, by James K. Hartman, August 1979.

13. Parry, Samuel H., "STAR: Simulation of Tactical Alternative Responses," 1978 Winter Simulation Conference Proceedings, pp.563-69, Institute of Electrical and Electronic Engineers, December 1978.

14. U. S. Army Material Development and Readiness Command, DARCOM Pamphlet 706-101. Engineering Design Handbook, Army Weapon Systems Analysis, Part One, November 1977.

15. Marshall, S. L. A., Men Against Fire, The Problem of Battle Command in Future War, p. 50, William Morrow, 1947.

16. Fishman, George S., Principles of Discrete Event Simulation, pp. 4-7, John Wiley, 1978.

17. Taylor, James G., Lanchester-Type Models of Warfare, Chapter 2, Office of Naval Research, to be published.

18. Taylor, James G., Force-on-Force Attrition Modeling, pp. 23-35, Operations Research of America, 1979.

19. Taylor, Force-on-Force Attrition Modeling, pp. 75-82.

20. Bonder, Seth, "An Overview of Land Battle Modeling in the U. S.," pp. 73-88, Proceedings of the Thirteenth Annual U. S. Army Operations Research Symposium, Fort Lee, Virginia, 1974.

21. Bonder, Seth, "Combat Model," Chapter 2 in The Tank Weapon System, Report No. RF 573 AR 64-1 (U), Systems Research Group, The Ohio State University, Columbus, Ohio, June 1964.

22. Bonder, Seth, "A Theory for Weapon System Analysis," pp. 111-128, Proceedings of the Fourth Annual U. S. Army Operations Research Symposium, Redstone Arsenal, Alabama, 1965.

23. Bonder, Seth, "The Lanchester Attrition-Rate Coefficient," Operations Research, v. 15, pp. 221-232, 1967.

24. Marshall, ibid., p. 39.

25. Weapons Systems Evaluation Group Report WSEG-2, VECTOR-0, The Battle Model Prototype: Summary and Description, Arlington, Virginia, 1973.

26. Fishman, ibid, pp. 120-122.

27. Clark, Gordon M., The Combat Analysis Model, Ph. D. thesis, The Ohio State University, Columbus, Ohio, 1969.

28. Taylor, James G., Lanchester-Type Models, p. 5.15-2.

29. Clark, ibid., p. 238.

30. Brewer and Shubick, ibid., p. 39.

31. Dunnigan, James F., "Part 8. Designing Games (Plus a Complete Wargame--The Drivs on Metz: 1944)," The Complete Wargames Handbook, to be published.

32. Quade, E. S., Analysis for Public Decisions, pp. 199-211, Elsevier, 1975.

33. Owen, Guillermo, Game Theory, p. 31, W. B. Saunders, 1968.

34. Taylor, Force-on-Force Attrition Modeling, p. 9.

35. Hausrath, Alfred H., Venture Simulation in War, Business, and Politics, pp. 152-187, McGraw-Hill, 1971.

36. General Accounting Office, Models, Data and War: A Critique of the Foundation for Defense Analyses, pp. 120-130, Government Printing Office, 1980.

37. Bode, John, "Problems of Aggregation and Resolution in Theater-Level Models," in Theater-Level Gaming, pp. 61-72.

38. Honig, ibid., p. I-8-3.

39. Dare, David P., "On a Hierarchy of Models," in Operationsanalytische Spiel fur die Verteidigung, pp. 285-307, Huber, R. K., Niemeyer, K., and Hofmann, H. W. editors, Oldenbourg Verlag, Munchen, 1979.

40. Dupuy, ibid., p. 32.

41. Dupuy, ibid., pp. 50, 56.

42. Dupuy, ibid., pp. 95-110.

43. Dupuy, T. N., "Predicting the Element of Surprise in Combat," Army, pp. 44-51, May 1977.

44. Dupuy, Numbers, p. 139.

45. Dupuy, Numbers, p. 150.

46. Dupuy, Numbers, p. 39.

47. Dupuy, Numbers, p. 142.

48. Dupuy, Numbers, p. 183.

49. Taylor, Force-on-Force Attrition Modeling, p. 79.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 55 Department of Operations Research Naval Postgraduate School Monterey, California 93940	1
4.	Professor James G. Taylor, Code 55Tw Department of Operations Research Naval Postgraduate School Monterey, California 93940	50
5.	Captain William Ted Farmer 201 Glenwood Circle, Apt. 8-C Monterey, California 93940	2
6.	Professor James K. Hartman, Code 55Hh Department of Operations Research Naval Postgraduate School Monterey, California 93940	10
7.	Professor S. H. Parry, Code 55Py Department of Operations Research Naval Postgraduate School Monterey, California 93940	10
8.	LTC Edward P. Kelleher, Code 55Ka Department of Operations Research Naval Postgraduate School Monterey, California 93940	10
9.	Professor Arthur L. Schoenstadt, Code 53Zh Department of Mathematics Naval Postgraduate School Monterey, California 93940	1
10.	Office of the Commanding General U. S. Army TRADOC ATTN: General Donn A. Starry Ft. Monroe, Virginia 23651	1
11.	Headquarters U. S. Army Training & Doctrine Command ATTN: ATCG-T (Col. Scribner) Ft. Monroe, Virginia 23651	1

12. Headquarters 1
U. S. Army Training & Doctrine Command
ATTN: Director, Analysis Directorate
Combat Developments (MAJ Chris Needels)
Ft. Monroe, Virginia 23651

13. Headquarters 1
U. S. Army Training & Doctrine Command
ATTN: Director, Maneuver Directorate
Combat Developments (Col. Fred Franks)
Ft. Monroe, Virginia 23651

14. Mr. David Hardison 1
Deputy Under Secretary of the Army
(Operations Research)
Department of the Army, The Pentagon
Washington, D. C. 20310

15. LTG William Richardson 1
Commanding General
U. S. Army Combined Arms Center
Ft. Leavenworth, Kansas 66027

16. Director 1
Combined Arms Combat Development Activity
ATTN: Col. Reed
Ft. Leavenworth, Kansas 66027

17. Director, BSSD 1
Combined Arms Training Development Actiivity
ATTN: ATZLCA-DS
Ft. Leavenworth, Kansas 66027

18. Director 1
Combat Analysis Office
ATTN: Mr. Kent Pickett
U. S. Army Combined Arms Center
Ft. Leavenworth, Kansas 66027

19. Command and General Staff College 1
ATTN: Education Advisor
Room 123, Bell Hall
Ft. Leavenworth, Kansas 66027

20. Dr. Wilbur Payne, Director 1
U. S. Army TRADOC Systems Analysis Activity
White Sands Missile Range, New Mexico 88002

21. Headquarters, Department of the Army 1
Office of the Deputy Chief of Staff
for Operations and Plans
ATTN: DAMO-2D
Washington, D. C. 20310

22. Commander 1
U. S. Army Concepts Analysis Agency
8120 Woodmont Avenue
ATTN: MOCA-SMS (CPT Steve Shupack)
Bethesda, Maryland 20014

23. Commander 1
U. S. Army Concepts Analysis Agency
ATTN: MOCA-WG (LTC Earl Darden)
8120 Woodmont Avenue
Bethesda, Maryland 20014

24. Director 1
U. S. Army Night Vision & Electro-optical Lab.
ATTN: DEL-NV-VI-Mr. Bob Hermes
Ft. Belvoir, Virginia 22060

25. Director 1
U. S. Army Material Sustems Analysis Activity
ATTN: Mr. Will Brooks
Aberdeen Proving Grounds, Maryland 21005

26. Director 1
Combat Developments Experimentation Command
ATTN: CPT William J. Caldwell
Ft. Ord, California 93941

27. Director 1
Armored Combat Vehicle Technology Program
ATTN: Col. Fitzmorris
U. S. Army Armor Center
Ft. Knox, Kentucky 40121

28. Col. Frank Day 1
TRADOC Systems Manager - XM1
U. S. Army Armor Center
Ft. Knox, Kentucky 40121

29. Director 1
Combat Developments, Studies Division
ATTN: MAJ W. Scott Wallace
U. S. Army Armor Agency
Ft. Knox, Kentucky 40121

30. Commandant 1
U. S. Army Field Artillery School
ATTN: ATSF-MBT (CPT Steve Starner)
Ft. Sill, Oklahoma 73503

31. Director, Combat Developments 1
ATTN: Col. Clark Burnett
U. S. Army Aviation Agency
Ft. Rucker, Alabama 36362

32. Director 1
Combat Developments
U. S. Army Infantry School
Ft. Benning, Georgia 31905

33. Commander, MICOM 1
ATTN: DRSMI-YC (CPT Hagewood)
Redstone Arsenal, Alabama 35809

34. Director 1
Combat Developments
ATTN: CPT William D. Meiers
U. S. Army Air Defense Agency
Ft. Bliss, Texas 79905

35. Commander 1
U. S. Army Logistics Center
ATTN: ATCL-OS-Mr. Cammeron/CPT Schuessler
Ft. Lee, Virginia 23801

36. Commander, USAMMCS 1
ATTN: ATSK-CD-CS-Mr. Lee/Mr. Marmon
Redstone Arsenal, Alabama 35809

37. Commander 1
U. S. Army Combined Arms Center
ATTN: ATZL-CA-CAT (R. E. DeKinder, Jr.)
Ft. Leavenworth, Kansas 66027

38. Director 1
U. S. Army AMSAA
ATTN: DRXSY-AA (Mr. Tom Coyle)
Aberdeen Proving Grounds, Maryland 21005

39. R. Stampfel, Code 55 1
Department of Operations Research
Naval Postgraduate School
Monterey, California 93940

40. Mr. James F. Dunnigan 1
Simulations Publications, Inc.
257 Park Avenue South
New York, New York 10010

41. Colonel T. N. Dupuy 1
Historical Evaluation and Research Organization
P. O. Box 157
Dunn Loring, Virginia 22027

42. Professor Ira Gruber 1
History Department
Rice University
Houston, Texas 77001

43. Director 15
TRADOC Research Element Monterey
Naval Postgraduate School
Monterey, California 93940

44. CAPT Wayne P. Hughes, Jr., Code 55Hl 15
Department of Operations Research
Naval Postgraduate School
Monterey, California 93940

45. President 1
Center for Naval Analyses
2000 Beauregard St.
Alexandria, Virginia 22311

46. Director 2
Center for Advanced Research
U. S. Naval War College
Newport, Rhode Island 02850

47. Director 2
Center for War Gaming
U. S. Naval War College
Newpost, Rhode Island 02850

48. Chairman 1
History Department
U. S. Naval Academy
Annapolis, Maryland 21402