GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 1-15-81

Project Title: Lanchester Modelling ~~Lancaster Modeling~~ of Small-Unit Combat

Project No: E-24-627

Project Director: Dr. L. G. Callahan

Sponsor: U. S. Army Missile Command; Redstone Arsenal, AL 35898

Agreement Period: From 12/30/80 Until 9/30/81 (Perf.) 11/30/81 (Rpts.)

Type Agreement: Delivery Order No. 0005 under Contract No. DAAH01-81-D-A003

Amount: $4,241

Reports Required: Final Technical Report

Sponsor Contact Person (s):

Technical Matters

U. S. Army Missile Command
ATTN: DRSMI-RDF
Redstone Arsenal, AL 35898

Contractual Matters
(thru OCA)

Mr. Thomas A. Bryant
ONR Resident Representative
Georgia Institute of Technology
206 O'Keefe Building
Atlanta, GA 30332

Defense Priority Rating: DO-A2 under DMS Reg. 1

Assigned to: Industrial & Systems Engineering (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
- Security Coordinator (OCA)
- ~~Reports Coordinator (OCA)~~
- Library, Technical Reports Section
- EES Information Office
- EES Reports & Procedures
- Project File (OCA)
- Project Code (GTRI)
- Other OCA Research Property Coordinator

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 6/15/82

Project Title: Lanchester Modelling ~~Lancaster Modeling~~ of Small Unit Combat

Project No: E-24-627

Project Director: Dr. L. G. Callahan

Sponsor: Redstone Arsenal

Effective Termination Date: 9/30/81

Clearance of Accounting Charges: 11/30/81

Grant/Contract Closeout Actions Remaining:

- [x] Final Invoice ~~and Closing Documents~~
- [ ] Final Fiscal Report
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

Assigned to: ISyE (School/~~Laboratory~~)

COPIES TO:

Administrative Coordinator
Research Property Management
Accounting
Procurement/EES Supply Services
Research Security Services
~~Reports Coordinator (OCA)~~
Legal Services (OCA)
Library
EES Public Relations (2)
Computer Input
Project File
Other ______

FORM OCA 10:781

E-24-627

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) "Lanchester Modelling of Small-Unit Combat"	5. TYPE OF REPORT & PERIOD COVERED Final Summary Report 12/30/80-9/30/81
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Leslie G. Callahan Jr., and Glenn Crosby	8. CONTRACT OR GRANT NUMBER(s) DAAH01-81-D-A003 Delivery Order No. 0005
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Industrial and Systems Engineering Georgia Institute of Technology Atlanta, GA 30332	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS M. M. Hallum, Tech. Monitor U.S. Army Missile Command, Redstone Arsenal Huntsville, AL 35898	12. REPORT DATE November 1981
	13. NUMBER OF PAGES 49
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release

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)

Lanchester Modelling, Hybrid Simulation, Small Unit Combat Simulation

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

Current standards in high resolution Monte Carlo type simulations of small unit combat such as CARMONETTE, require two to three hours of playing time for a fifty minute battle. Deterministic simulations such as TATS and AMSWAG require up to 200K of computer memory. The objective of this research was to investigate the feasibility of using a hybrid digital-analog computer simulation model to more accurately represent small-unit combat in a more timely and responsive manner than current digital simulations. A number of (over)

Final Summary Report
for the
United States Army Missile Command
Redstone Arsenal
Huntsville, Alabama 35898

"Lanchester Modelling of Small-Unit Combat"

Under Contract DAAH01-81-D-A003
Delivery Order No. 0005

Conducted by

The School of Industrial and Systems Engineering
Georgia Institute of Technology

Leslie G. Callahan, Jr., Project Director

Glenn Crosby, Investigator

November 1981

(unclassified)

TABLE OF CONTENTS

SUMMARY

Most high resolution digital computer simulations of small unit combat such as CARMONETTE rely heavily on stochastic Monte Carlo techniques and require two to three hours of run time for a half hour of combat, as well as a number of repetitions for parameter analysis. Deterministic digital simulations of small unit combat relying on Lanchester type models, i.e. Tank/Antitank Simulation Model (TATS) and the Army Materiel Systems Analysis Activity War Game (AMSWAG), generally have much better run times but require large computer storage capacities, and do not model many of the important factors of small unit combat. The objective of this project was to investigate the use of a hybrid digital-analog computer simulation to more effectively model small combat by including the effects of such variables as reaction times and active defense tactics in a tank-on-tank engagement using a Lanchester derived combat model.

A Systron-Donner 10/20 hybrid computer was used to provide the computational base and control of the simulation runs. In addition two COMDYNA GP-6 analog computers provided additional computational capacity. Graphs were drawn on a Hewlett-Packard 7035-3 X-Y Recorder. Bonders equation for the Expected Time to Kill for Markhov dependent fire was used, where the kill rate is the reciprocal of the Expected Time to Kill. A tactical scenario was adopted where varying numbers of Blue tanks fought from a battle position using typical active defense tactics and engaged a Red armored force closing on Blue's position.

A number of runs were conducted with varying initial strengths and closing velocities and with hybrid enhancements not included in most

small-unit combat simulations. These include variable reaction time, the target acquisition process and terrain. The results of these runs show that these factors have significant impacts on the battle outcome. In addition a search was made for a comparative digital simulation, either deterministic or Monte Carlo which closely matched the tank-on-tank scenario used on the hybrid computer. An in-house GPSS Monte Carlo simulation model development by an Army graduate student in 1980 was selected. Using the same data base and initial strengths one deterministic run was made on the hybrid and ten runs on the GPSS digital simulation. The GPSS simulation produced a wide range of battle terminations which were not consistent with the hybrid results.

It is concluded that the use of small hybrid computers for the solution of Lanchester-type models of small-unit combat offers a more realistic and timely simulation than conventional small-unit digital simulations. In addition the hybrid computer provides a convenient alternative for the development of analytical enhancements to generalized Lanchester derived models of the type proposed by Weiss and Helmbold.

CHAPTER I

INTRODUCTION

A. Description of the Problem

In the area of modeling and simulating small-unit combat, there is a lack of an adequate computerized simulation program for use by military decision makers to make quick analytical decisions or comparisons of various courses of action. The development of high speed digital computers has been a great aid in the area of war-gaming, but current programs need to be improved.

Run-time remains a significant barrier to digital computer simulation. The current standard in Monte Carlo type models, CARMONETTE, takes two to three hours of playing time for a fifty minute battle.[1] As with all Monte Carlo simulations, large numbers of repetitions are required to make reasonable comparisons between options or parameter changes. This makes the model inefficient and expensive, if not impractical in applications where timely results are required.

In addition to stochastic Monte Carlo models, a number of deterministic models are used for small-unit combat, i.e. the Tank/Antitank Simulation Model (TATS) and the Army Materiel Systems Analysis Activity War Game (AMSWAG). TATS, the less complex of the two, requires 30k words (UNIVAC 1108). It produces output on ammunition expenditure, armor loss, subresults and summary. TATS evaluates kill rates at each .25 minute

---

[1]This description of CARMONETTE was taken from the Catalog of War Gaming and Military Simulation Models, 8th Edition, 1980, SAGAM 30-80.

interval by multiplying a preprocessed single shot kill probability by the rate-of-fire for a given weapon system. This kill rate is then modified to account for over-kill using a binomial approximation[2]. AMSWAG is more complex, making time step approximations using a differential probability application of a Lanchester type combat model. Although AMSWAG has good solution times, it does require 200k in computer memory[3]. As deterministic time-step models become more complex, the logic checks at each time-step require more time and computer storage space. Presently, Lanchester type models, which were designed for and shown applicable to large scale combat, do not consider certain aspects of small-unit combat that can be critical to their outcomes. Reaction time delays and certain tactical considerations can make the simultaneous differential equation solutions an inaccurate model of the combat process. These aspects need to be more accurately modeled to develop suitable tools for the investigators involved in the analysis of small-unit combat.

B. Project Objective

The objective of this project was to investigate the feasibility of using a hybrid digital-analog computer simulation model to more accurately represent small-unit combat. Development of a simple such model would be done in order to explore the effects of such variables as reaction times and active defense tactics in comparison to more conventional simulations.

---

[2]The description of TATS is also from the Catalog of War Gaming and Military Simulation Models and from a program listing.

[3]Also from Catalog of War Gaming and Military Simulation Models.

C. Project Scope

Work on this project includes a literature search and review of Lanchester combat models and theory to determine current trends and background information. A Lanchester type combat model built on a Systron-Donner 10/20 hybrid computer is used to investigate the effects of various enhancements on modelling small-unit combat as well as the potential of the hybrid computer in combat modelling.

CHAPTER II

DETERMINISTIC AND MONTE CARLO COMBAT MODELS

Modern combat is an extremely complex process. The two approaches presently used to model this process are the Monte Carlo simulation models and the Deterministic models. Both of these models consider the randomness of certain factors of combat with the deterministic model ideally representing the mean or expected outcome of the battle. The stochastic (Monte Carlo) model, differing in its representation of time and the state space of the antagonistic forces, may be useful in interpreting the results of the deterministic model by comparison of the deterministic model's approximation of the expected outcome with the more general stochastic combat process. It must be realized, however, that due to the numerous repetitions of calculation inherent in the implementing of a stochastic model, the costs are many times larger than those of a deterministic simulation.

Monte Carlo simulations are built using discrete time and a discrete state space. By using pseudo-random numbers to approximate presumed probability distributions of such factors as hit probabilities, kill probabilities and target acquisition probabilities, these Monte Carlo simulations produce outputs readily understandable to the user. For example, the number of tanks lost on each side, the number of rounds of ammunition remaining, and the time of each kill are typical outputs of a Monte Carlo type simulation run. This type of output gives such models an impression of realism for the user. The development of better, faster and larger digital computers has encouraged the use of Monte Carlo models for small and medium size unit combat simulations.[4] Such models are easily enhanced to account for most significant variables, thereby increasing the realism of the output. In addition, making several repetitions of a simulation run with a different string of pseudo-random numbers gives the user an idea of the range and variance of the outcomes that can be expected under given model conditions. This need for repetition greatly increases the amount of computer time needed to do sensitivity analysis on various parameters if the model is to be used for decision making.

Deterministic combat models normally operate in continuous time and a continuous state space, with force levels at any given time totally dependent on the result of kill rates and replacement rates preceding that time. The derivation of these rate equations requires effective combat modelling. Most deterministic models deal with random event probabilities in an "expect value" manner. The various random variables associated with combat are combined in some function intended to give the expected value of the kill rates at any given time. Various approaches are used to determine the proper expression for these kill rates, some of which will be examined later.

Deterministic models have been criticized for lack of realism. This is partly due to the use of a continuous state space and partly due to over-simplified modelling. For example no user likes to see that he lost 2.29 tanks. Because of the intensive efforts in Monte Carlo simulations on digital computers, the art of deterministic modelling has not become

---

[4]The most commonly used being CARMONETTE which handles up to 56 weapon types and 70 weapon units.

fully developed. Many deterministic models were kept simple to allow for analytical solutions, a valuable aid to understanding the concepts involved. Many have their processes too highly aggregated for detailed analysis of tactical operations.[5]

Even with these shortcomings, the deterministic model is needed for some important applications today. Perhaps the most important advantage it has over the stochastic model is its quick solution time. The computer approximates the solution to the sets of differential equations composing a deterministic model in successive time steps. It does not have to produce or process a pseudo-random number for each modelled random event. Speed and deterministic results allow any sensitivity to parameter changes to be evaluated with only one run. This is of great advantage to the decision maker. With these advantages, the deterministic type model is used for almost all high level combat models.

---

[5]These are the firepower score type models which are difficult to disaggregate after the outcomes have been determined. TACWAR of the OJCS Studies Analysis and Gaming Agency handles conventional forces in this manner.

CHAPTER III

LANCHESTER COMBAT THEORY

Lanchester's efforts to substantiate the strategy of concentration of forces in modern warfare mathematically led to his development of differential equations now known as Lanchester equations of combat. These equations are inherently deterministic in nature, although much work has been directed toward meshing stochastic determinations with Lanchester combat theory. (The model developed in this report considers the effects of variable delays and reaction times along with variation of system parameters.) Theoretical work by Taylor, Weiss and others has extended the classical Lanchester formulation by including simple attrition factors (e.g. desertion or withdrawal), the effect of suppressing fire, battle termination rules and time-varying parameters with simple form.

Lanchester's square law is derived from these equations:

$$\frac{dx}{dt} = -ax \qquad \frac{dy}{dt} = -by \ ,$$

where

x = number of reds surviving at time t

y = number of blues surviving at time t

a = the rate at which a blue combatant kills red combatants

b = the rate at which a red combatant kills blue combatants.

This law is intended to describe combat in which each weapon is capable of engaging and concentrating its fire on any enemy weapon. This is the circumstance Lanchester termed "modern warfare." Both the square law and the linear law may be illustrated by Figure 1:

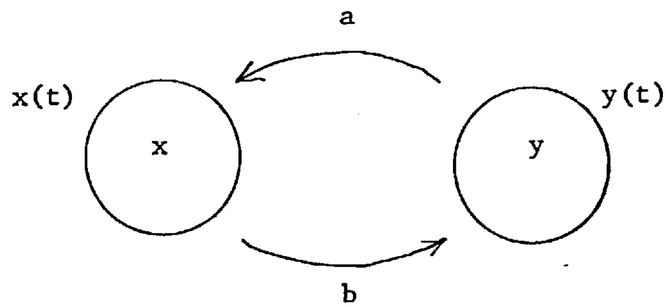


Figure 1. Lanchester Model of Warfare

Lanchester's linear law (for "ancient warfare") is formulated to model the attrition in two forces firing at enemy positions where individual targets are not known. The attrition rates are assumed to be proportional not only to the number of targets but also to the number of firers, as shown in these equations:

$$\frac{dx}{dt} = -axy \text{ , and}$$

$$\frac{dy}{dt} = -bxy \text{ .}$$

These basic equations have been the subject of various modifications and developments over the years. The Logarithmic law, developed independently by Weiss and Peterson dealt with cases of large numbers of combatants. Studies of large Civil War battles and tank combat during WWII (respectively) provided evidence that the rate of losses on each side was directly related to the number of combatants on that side. S. J. Deichman developed a guerrilla warfare model (mixed law) in exploring force ratios and the effect of their variance on Lanchester type models. F. E. Grubbs and J. H. Shuford have developed a Lanchester type model based on number random variables of time-to-kill and time-to-neutralize key opposing targets, which they treat on a probabilistic basis. The result involves the useful manipulation of the Wiebull distribution and all its concurrent advantages. Stopping rules, heterogeneous forces, command and control, intelligence, force separation, firing policies, target assignment and human performance have all been examined in the Lanchester type warfare context. Presently there is increased interest in applying Lanchester type models to complement the present generation of large-scale simulations. Interest has also developed in extending such simulations to analyze problems of replenishment, fire direction and tactical situations involving movement and both direct and indirect firing. At least twenty generically related Lanchester type models have been investigated for analytical tractability and behavior of various measures of effectiveness.

In spite of the increased development of derivations of Lanchester type models, there is growing awareness among researchers that under the "square law" theory on the theory of concentration fails to account for discontinuities of scale when there are actual operational constraints on the number of opposing forces. Some of the recent work of Weiss and Helmbold in generalizing Lanchester work permit incorporating these effects.[6] Other investigators are currently concentrating on finding better ways of arriving upon the values of attrition coefficients. Methods range from using regression techniques on the outcomes of stochastic simulation runs to an attempt at approximating the time-to-kill distributions

---

[6]The most comprehensive reference on Lanchester combat modeling is the soon to be published Lanchester-Type Models of Warfare by Dr. James G. Taylor of the Naval Postgraduate School in Monterey, California.

and using reliability theory to determine kill rates.[7] A variant of this second approach has been adopted in this study which will investigate the use of the hybrid computer in making the same type of enhancements to Lanchester models as previous analytical models.

[7] This approach is advanced by Frank E. Grubbs and John H. Shuford in their paper "A New Formulation of Lanchester Combat Theory."

CHAPTER IV

HYBRID DIGITAL-ANALOG SIMULATION

A. Capabilities of Digital Computers

Over the past three decades, there have been unbelievable developments in digital computers. The speed and memory storage improvements have made extremely complex combat simulations possible. The enhancements possible are limited only by core memory capacity and the modeler's ideas. It is these enhancements, however, that are straining the capabilities of the digital computer. The processing unit must address and execute every step of a program in sequence. This means that at every time step of a simulation, each enhancement of the model requires additional memory accessing, functional evaluations, and logic checks. This is the reason that some large wargames run slower on the computer than the actual battles would take.[8] With new advances in micro-circuitry will certainly come faster digital computers, but more enhanced combat models will certainly overtake their capabilities also.

B. Capabilities of Analog Computers

Analog computers, on the other hand, do not execute programs in sequential steps. It executes the solution to differential equations continuously, as they are written. Integration, multiplication, addition, and arbitrary functions are all represented by their analog equivalents in electronic circuitry.

---

[8] As mentioned in the Introduction, playing a fifty minute battle on CARMONETTE takes two to three hours.

Practically any mathematical expression can be expressed in equivalent analog form, but that in itself is of no significance. The real advantage of analog computation is in time scaling and sensitivity analysis. By using appropriate values for the input resistors and the capacitor in each integrator, almost any time scale can be achieved. Reasonable speeds for the most complex Lanchester type models would be at least 1000 to 1 real time to computational time ratios. Sensitivity analysis is extremely simple and quick on analog computers. Parameters can be changed with just the twist of a potentiometer, an excellent aid to interactive optimization type decision exercises.

All is not roses with analogs, or else they would be more common than digital computers. They must be programmed from a patchboard, so each new program must be wired on a patchboard rather than read from cards or tape. Logic checks are cumbersome to program, and arrays of data can only be approximated by analogous curve fitting or diode function generators set by hand. Accuracy is also limited to about three or four digits.

C. Hybrid Computer Capabilities

The hybrid digital-analog computer is still in the infancy of its development, but it is more common than most people realize. Common TV games played with "paddles" that are actually rheostats are excellent examples. Practically all the personal micro-computers sold now have digital-to-analog and analog-to-digital converters available for programming and playing games. These examples are basically digital computers with a few analog enhancements. Basically analog computers have also been enhanced with digital logic circuits such as and-gates, flip-flops, counters, clocks, and drivers. It is with this type equipment on which this paper's experimentation was done.

Use of the digital logic capabilities allows the same model enhancement possibilities as in any deterministic model executed on a purely digital computer. The advance in modeling capabilities comes in the fact that these enhancements cost no additional execution time. All functional evaluations and logic checks are done continuously and in parallel with the computations of battle attrition processes. Using the hybrid computer, even high level complex wargames could be run fast enough to make sensitivity analysis and interactive optimization possible. This allows a great improvement over basing important decisions on a single run of a Monte Carlo simulation.

D. Hierarchical Interfacing

Another important reason for developing hybrid combat models is the growing emphasis on the need for hierarchical and joint services models. It is apparent that a mammoth digital computer would be required to run small unit engagements, division, corps, and theatre level wargames concurrently. Even if such a monster computer existed, execution time would be futilely slow. This could be quickened somewhat with parallel processors at a very large cost if the interfacing could be worked out.

Hybrid computers could overcome some of these problems. The models could be built at each hierarchy in a modular form. Any variables requiring interfacing between modules are then simply connected electrically, essentially a parallel system of parallel processors.

E. Hardware Development

The hardware on which to build a new set of hybrid combat models does not exist at this time, but it is certainly within the state-of-the-art of electronics with most components available at low cost and off-the-shelf of many electronics hobby shops. If the hybrid computer were to be dedicated to the combat model, development requirements would indeed be minimal.

Development of a general purpose hybrid computer presents a larger problem, but it has been attacked. Digital computer programs have been written to write wiring diagrams of varying degrees of detail at some universities. The University of Michigan has developed a hybrid combination of the PDP-9 digital system and an AD-4 analog system connected with a switch matrix of 768 switches.[9] This small prototype allows problems to be patched and initialized under the control of the digital unit in less than 20 milliseconds. The University of Michigan system does not scale its own problems, but it does demonstrate the feasibility of time-sharing and automatic patching on a hybrid computer. Development of a full scale system of this type would expand its utility for simulations beyond combat modeling to many other systems and other engineering applications. Martin-Marietta Corporation has also built a similar type hybrid system for their own engineering applications.[9] The U.S. Army Materiel Command has been concerned to varying degrees in the planning of an Advanced Hybrid Computer System since the 1960's.[9] The hardware can be built if the military combat modelers choose to develop the programs to capitalize on the hybrid computer's capabilities in this area.

---

[9]These developments were referenced in a proposal for "An Instruction and Research Laboratory for Syndetic Digital-Analog Computation in Science and Engineering Education" by the School of Information and Computer Science at the Georgia Institute of Technology.

CHAPTER V

INVESTIGATION OF HYBRID SIMULATION TECHNIQUES

A. Background Discussion

The analog computer is an excellent tool for quickly solving all types of simultaneous differential combat models. This is true for Lanchester's Square Law, usually assumed applicable to direct fire, or for Lanchester's Linear Law, assumed applicable for area type fire. The more generalized Helmbold model, where the differential equations take the form: $\frac{dx}{dt} = -a \cdot (x/y)^c \cdot y$ and $\frac{dy}{dt} = -b \cdot (y/x)^c \cdot x$, are more useful but somewhat more difficult to model. The problem comes in the exponentiation of $(y/x)^c$ or $(x/y)^c$. Multiplier circuits used to exponentiate deal in powers of 2, so approximations to non-integer values of c could require several multiplier circuits for close approximations. For example, $x^{0.625} = x^{1/2} \cdot x^{1/4}/x^{1/8}$. Helmbold's model is very important to combat modelers since it allows the handling of the inefficiencies of scale, or overkill due to gross inequities in force ratios. These extra circuits are not necessary if a transformation is made. By setting the "Weiss parameter" W = 1-c and making the transformation of variables $p = x^W$ and $q = y^W$, Helmbold's equations become $\frac{dp}{dt} = -Waq$ and $\frac{dq}{dt} = -Wbp$. This makes the model equivalent to the familiar Force-on-Force Lanchester Square Law.

Lanchester's Square Law is in a most convenient form for study by the systems theorist, $\dot{\underline{x}} = A\underline{x}$. The system approach makes Lanchester's models expand easily into combat among heterogeneous forces. $\dot{\underline{x}} = A\underline{x}$; $\underline{x}$ and $\dot{\underline{x}}$ are vectors while A is a matrix of attrition coefficients. Finding the appropriate functions to properly describe the attrition coefficients can be as complex as the modeler wishes to make it.

For combat between large size forces, use of Lanchester models is widely accepted as being a fair approximation of combat attrition. Under varying degrees of aggregation and differing methods of parameter determination, many high level models are in use today. However, at battalion and lower level there is little faith in deterministic models. Two reasons for this attitude are evident. The first is that for smaller battles it is possible to run Monte Carlo simulations with reasonable turnaround times from the digital computer. The second reason is that for a small number of combatants, engagement outcomes may have such a high variance that an "expected value" approach does not adequately describe the situation. It is in the area of these smaller tactical engagements that this research was centered. Certain model enhancements were investigated in an attempt to capitalize on the logic capabilities of the hybrid computer to more adequately describe tactical engagements.

B. Tank-on-Tank Engagement Model

The tactical scenario that was modelled consisted of Blue tanks fighting from a battle position using typical active defense tactics and engaging a Red armored force closing on Blue's position. For simplicity, both forces are considered to be pure tank units. Blue tanks are initially in hide positions until Red tanks reach initial engagement range. Blue tanks acquire their targets while in a turret-defilade position, and then move into hull-down positions for a three round engagement. After firing three rounds, the Blue tanks back into turret defilade and move to alternate firing positions. Red tanks are moving at a rate of 12 km/hr. and fire on the move at any visible Blue forces.

Table 1 defines variables and Table 2 gives the assumed values of hit and kill probabilities which were used to build the kill rates used in the model. The numerical values are not meant to apply to any particular type of tank or ammunition, but are only reasonable values used to compare approaches. Target acquisition times are reasonable when compared to results from the Canadian Cup competition among NATO forces.[10]

C. Simulation Hardware

The hardware used in this investigation included the Systron-Donner 10/20 hybrid analog computer, which provided the computational base and control of the simulations and which is described in Appendix A. In addition two COMDYNA GP-6 analog computers provided additional computational capacity. Graphs were drawn on the Hewlett-Packard 7035-3 X-Y Recorder.

D. The Conventional Analog Diagram

Blue and Red force levels are computed on integrators with initial force levels set as an initial condition on each integrator. Range between the forces is maintained on a third integrator with an initial engagement range as an initial condition. A voltage analogous to a closing speed of 12 km/hr. is the input to the range integrator. Range dependent kill rates are set on diode function generators with the value of the range integrator as an input. Assuming applicability of Lanchester's Square Law, the output of the kill-rate function generator and the opposing force levels are fed

[10] General Franz-Joseph Schulze, former NATO commander, reported that American crews took twice as long on the average than the 2.3 seconds German crews took to identify targets in the 1979 Canadian Cup competition.

Table 1. Variables for Tank-on-Tank Model

Definition of variables:

E(T)	
P	probability of a first round hit
$P_{H/H}$	probability of a hit on a round following a hit
$P_{H/M}$	probability of a hit on a round following a miss
$P_{K/H}$	probability of a kill given the round hit
t_f	time of projectile flight in seconds
t_a	time to acquire a target in seconds
t_1	time to fire the first round given acquisition
t_h	time to fire the next round following a hit
t_m	time to fire the next round following a miss

Table 2. Assumed Data

Blue Tank Firing on Red Tank

Range (m)	P	$P_{H/H}$	$P_{H/M}$	$P_{K/H}$	t_f
3000	.03	.17	.05	.60	2.5
2500	.09	.20	.11	.63	2.1
2000	.25	.40	.30	.66	1.7
1500	.45	.60	.50	.69	1.3
1000	.75	.80	.75	.72	.8
0500	.95	.95	.95	.75	.4

$t_a = 6$ $t_1 = 6$ $t_h = 6$ $t_m = 6$

Red Tank Firing on Blue Tank

Range (m)	P	$P_{H/H}$	$P_{H/M}$	$P_{K/H}$	t_f
3000	.02	.03	.03	.58	2.0
2500	.04	.05	.04	.59	1.6
2000	.09	.10	.09	.60	1.3
1500	.18	.28	.23	.65	1.0
1000	.32	.42	.37	.70	.6
0500	.40	.50	.45	.75	.3

$t_a = 8$ $t_1 = 8$ $t_h = 8$ $t_m = 8$

into a multiplier to yield force-on-force attrition rates for input into the force level integrators. Figure 2 shows an analog simulation diagram based on the symbolism shown in Appendix B.

E. Traditional Attrition Rates

Current combat models do not incorporate active defense tactics into kill rate considerations. The TATS wargame from U.S. Army Concepts Analysis Agency uses only a weighted single shot kill probability multiplied by an assumed rate of fire to find an individual weapon system's kill rate. For the first set of kill rates, Bonder's equation for the Expected Time to Kill for Markhov dependent fire was used, where the kill rate is the reciprocal of the Expected Time to Kill.[11]

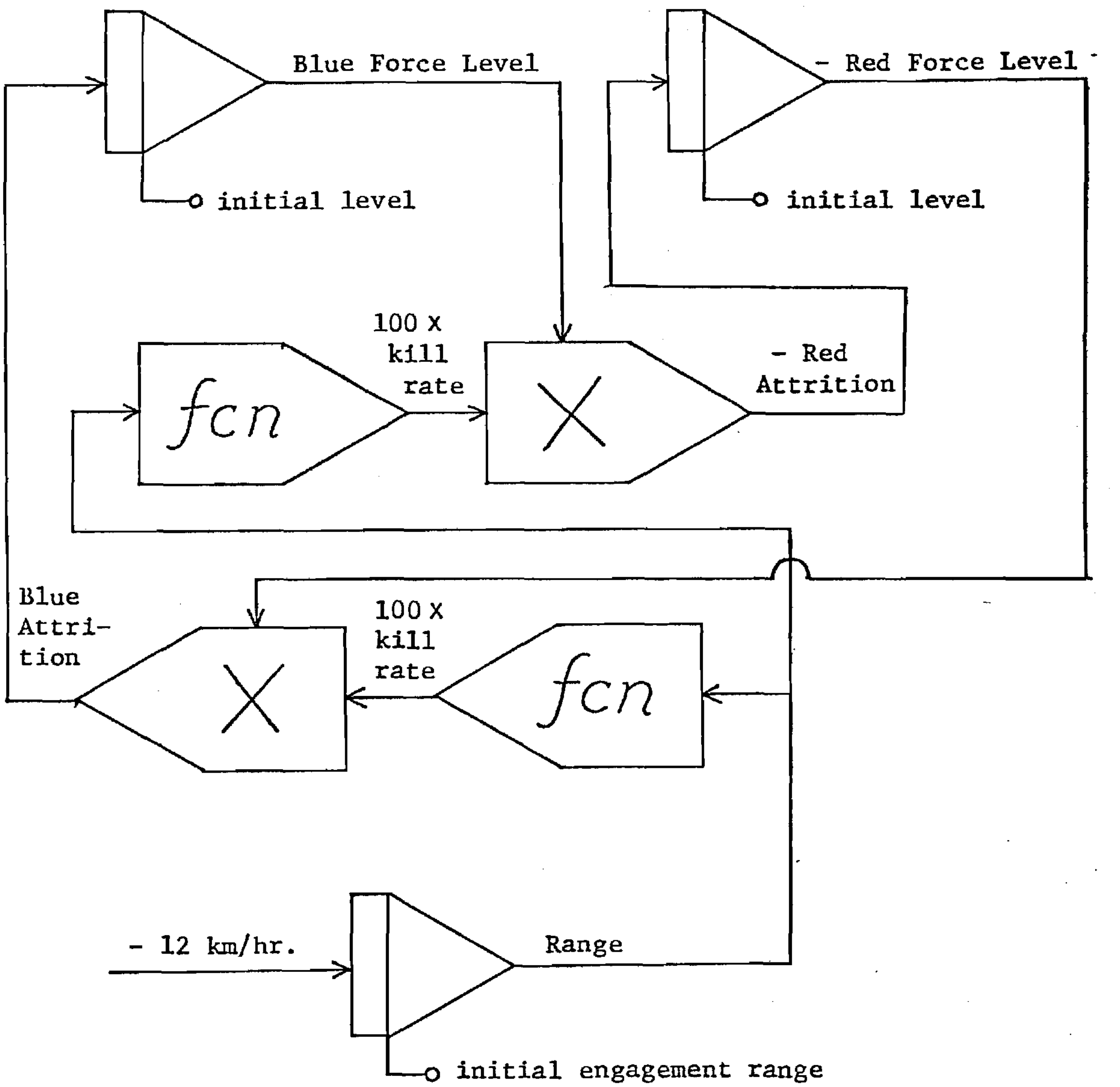
$$E(T) = t_a + t_1 - t_h + \frac{t_h + t_f}{P(K/H)} + \frac{t_m + t_f}{P(h/m)} \left\{ \frac{(1 - P(h/h))}{P(K/H)} + P(h/h) - p \right\}$$

Variables are defined as in the previous table. The kill rates for various ranges were computed using Bonder's equation and set on the computer's diode function generator with a linear approximation used between the computed ranges. The attrition rates from 500 to 3000 meters are shown in Table 3.

The results of various battle initiation ranges are shown in Figure 3. Notice that with the computer set for repetitive operation and with a given scenario modeled, a tactical decision maker could quickly determine the best range at which to initiate engagement of an energy force.

---

[11] These ideas form the conceptual basis for all attrition calculations in the Bonder/IUA computer model and are briefly described on page 50 of Taylor's MORS monograph "Force-on-Force Attrition Modelling."



Time Scale 100:1 Real:Computation

Figure 2. Analog Simulation Diagram

Table 3. Attrition Rates Using Bonder's Equation for Markhov Dependent Fire

Blue Tank Firing on Red Tank

Range(m)	E(T)	1/E(T)
3000	279.13	.0036
2500	120.46	.0083
2000	44.85	.0223
1500	27.23	.0367
1000	18.42	.0543
0500	14.98	.0667

Red Tank Firing on Blue Tank

Range(m)	E(T)	1/E(T)
3000	860.66	.0012
2500	413.11	.0024
2000	179.53	.0056
1500	69.10	.0145
1000	41.87	.0239
0500	33.21	.0301

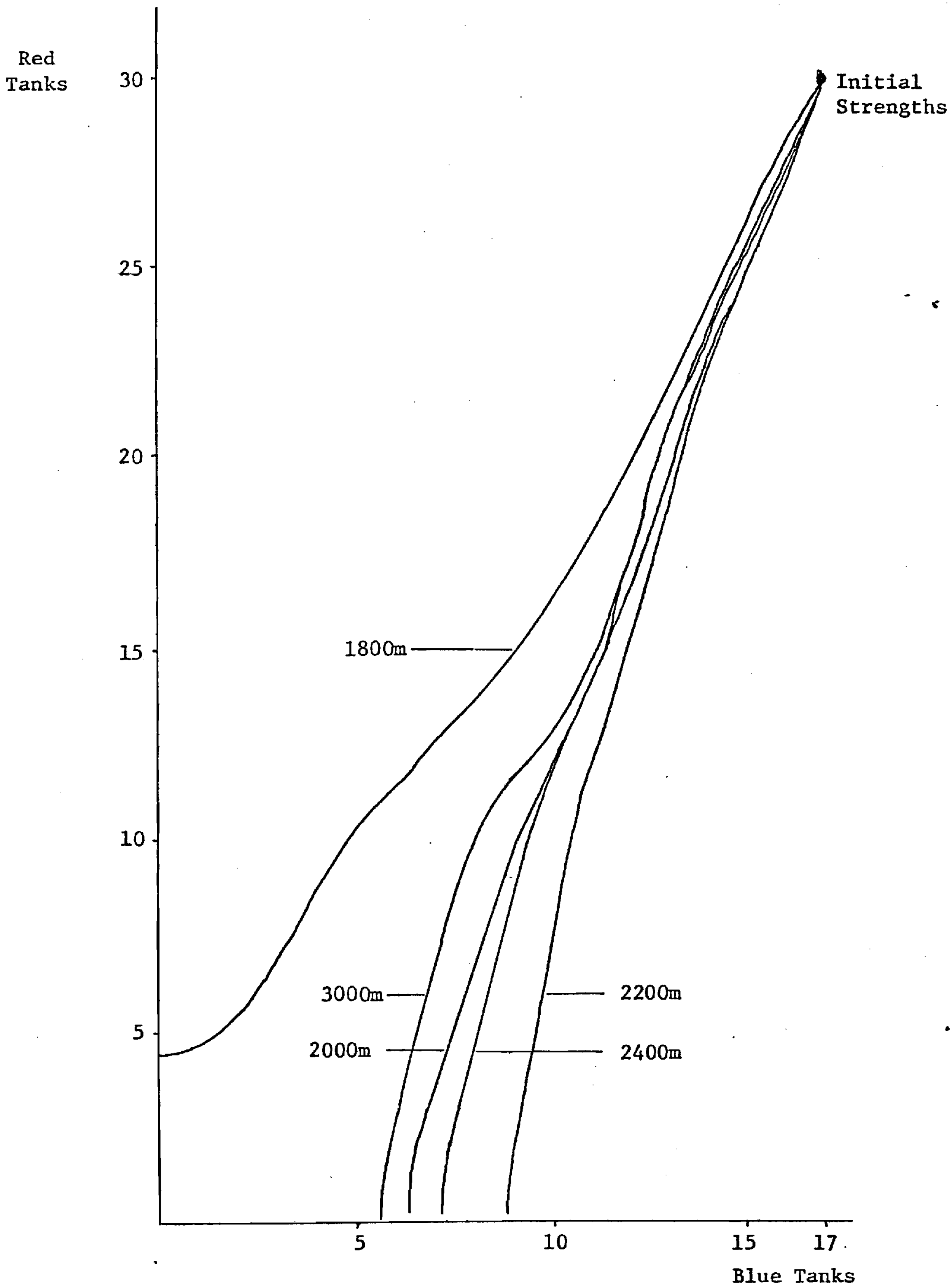


Figure 3. Comparison of Results with Varied Engagement Initiation Ranges; Kill Rates Derived from Bonder's Equation

F. Hybrid Enhancements

In this stage of the investigation, hybrid simulation techniques were developed to aid in more accurate representation of small-unit combat processes.

1. Reaction Time Delays. It has been widely accepted that in tank-on-tank combat, those that fire first usually live to tell about it. If this is so, it should be supported in combat models. Using the same attrition rates, several runs were made to demonstrate the effect of various reaction-time delays on the Red-on-Blue attrition process. Red-on-Blue attrition was disconnected from the Blue force level integrator for various time increments using a relay controlled by a digital clock. From these runs it was clear that even small delays caused by operational reaction times or induced by other tactical measures could have significant battle outcome effects. The results shown in Figure 4 indicate that more accurate modeling of engagement initiation can be critical to small-unit combat simulation.

2. Simulating the Target Acquisition Process. Most military modelers would agree that combat models are very sensitive to target acquisition parameters. Current combat models seem to have a common weakness with current tank gunnery training, inadequate target acquisition procedures. Due to the scarcity of pop-up tank gunnery targets, tank gunnery standards only consider time to a hit once the target has been acquired, usually pointed out by a controller.[12] One of the main reasons that U.S. Army crews have

---

[12] A new standard for tank crew gunnery is being tested at several posts as the tank ranges are upgraded with pop-up targets. The Crew Combat Evaluation Exercise in use at Ft. Knox and Ft. Hood has crews engage targets which pop up and "fire" a round at them. Engagement times are figured from the time the target is exposed until there is a target hit.

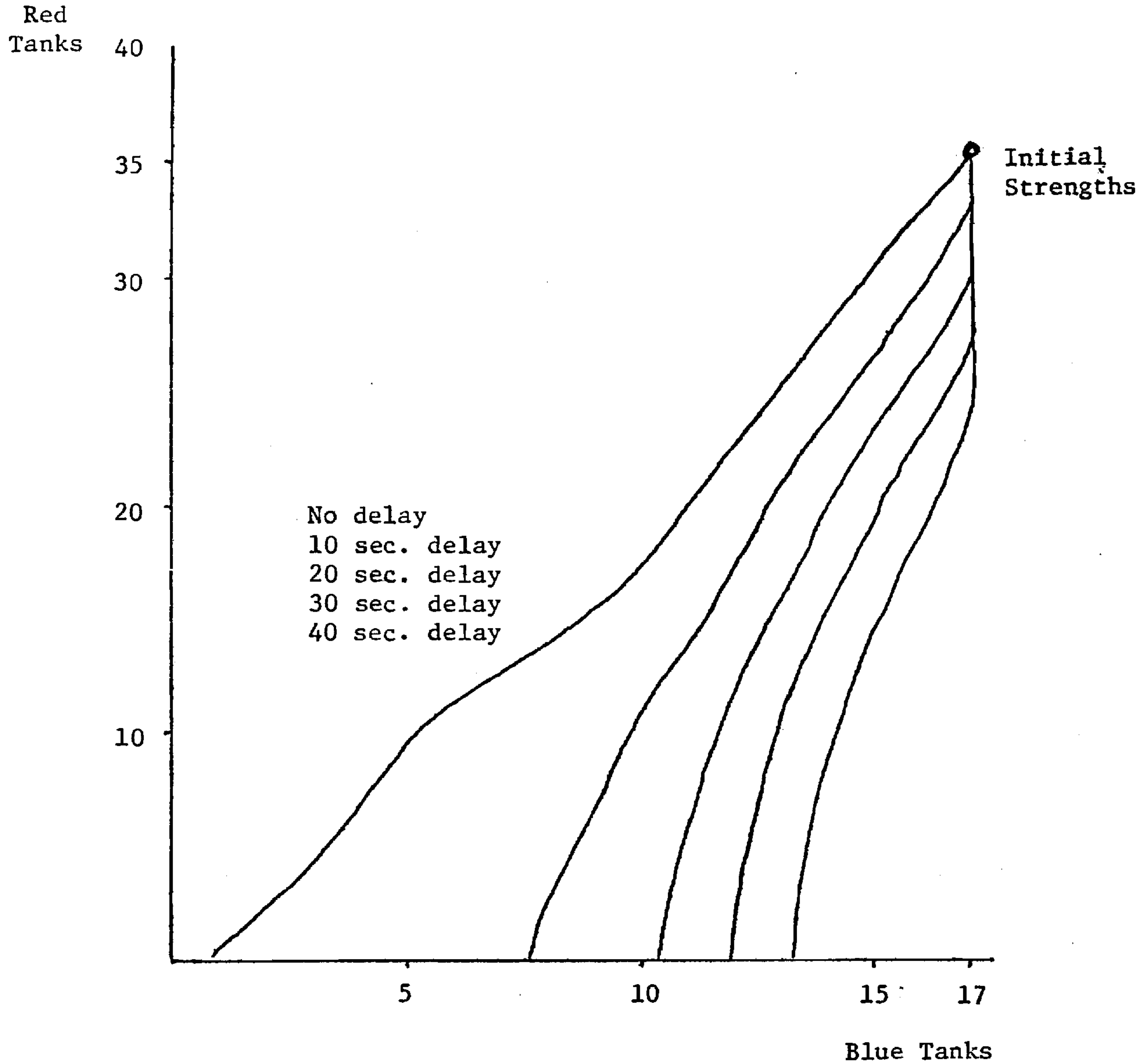


Figure 4. Reaction Time Delays
2200m Initial Engagement Range, Red-on-Blue Attrition Delayed; Kill Rates Derived from Bonder's Equation

not done well in NATO Canadian Cup competition is that they took an average of over twice as long to acquire targets as did their allied competitors.[13] Current combat models consider a probability-of-detection rather than a time-to-detection. Under ideal visibility conditions with a short mean time-to-detection then probability-of-detection would not be a bad approximation. However, as visibility is degraded, then time to detection becomes more important. It is this time delay for target acquisition that U.S. doctrine counts on to give us an advantage in the active defense. If our tanks will acquire targets from a turret down position, they should be able to move up to a hull-defilade position while laying the gun on target to fire, before an enemy tank can acquire them, lay on target, and fire. If this cannot be supported with present combat models, then either the models or the doctrine must be reexamined.

In an attempt to model the active defense type battle position tactics, the following assumptions were made. Blue tanks would acquire targets from a turret-down position. When a target was acquired, the tank would move into a hull-down position and fire, taking t_1 seconds. Over the next 20 seconds, he would fire two more rounds and move back into a turret-down position. Red tanks, on the other hand, would take $t_a + t_1$ seconds to get off the first round once the Blue tank started moving into its hull-defilade position. It would continue to fire until the Blue tank moved back down out of sight. The cycle would repeat after 34 seconds giving the Blue tank time to move into an alternate firing position and acquire new targets. This obviously calls for the computation of new attrition rates. For Blue forces this was done by computing the expected number of kills in a three

---

[13] General Franz-Joseph Schulze, former NATO commander, reported that American crews took twice as long on the average than the 2.3 seconds German crews took to identify targets in the 1979 Canadian Cup competition.

round engagement, and then dividing this value by the 20 seconds over which the impact of the three rounds would be spread. For Red forces, the familiar steady-state single shot kill probability multiplied by the rate of fire was used. These new rates were set on the diode function generator and relays controlled by a digital clock were used to connect or disconnect the attrition rates from the inputs of the force level integrators. With the previous assumptions, the Blue-on-Red attrition rates are connected to their input for 20 seconds of each minute. Red-on-Blue attrition is connected for 10 seconds of each minute initiated with a ten second delay after the Blue-on-Red attrition is connected.

The expected number of kills by Blue in its three round engagement was computed using transition probabilities. Let $\underline{A}$ be the transition matrix:

	Kill	Hit, No Kill	Miss
Kill	$P\ P_{K/H}$	$P(1 - P_{K/H})$	$1 - P$
Hit, No Kill	$P_{H/H}\ P_{K/H}$	$P_{H/H}\ (1 - P_{K/H})$	$1 - P_{H/H}$
Miss	$P_{H/M}\ P_{K/H}$	$P_{H/M}\ (1 - P_{K/H})$	$1 - P_{H/M}$

The the expected number of kills with three rounds is as follows:

$$P\ P_{K/H} + (P\ P_{K/H},\ P(1 - P_{K/H}),\ 1 - P)\ \underline{A}\ (1, 0, 0)^T + (P\ P_{K/H},\ P(1 - P_{K/H}),\ 1 - P)\ \underline{A}^2\ (1, 0, 0)^T.$$

A Red tank should not be able to fire more than two rounds at a particular target during a single exposure period, but there could be some interaction of hit probabilities while firing at different Blue tanks. Rather than assume independence, a small overestimation of Red-on-Blue kill rates was made by computing the steady-state single-shot kill probabilities and multiplying the rate-of-fire considering time-of-flight. Table 4 contains the computed kill rates for modeling active defense tactics. Figure 5 shows the output using these kill rates controlled by the clock and a digital counter. This is an enhancement possible on the hybrid computer that is not possible on the pure analog computer and which more accurately describes this aspect of small unit combat. To show that this capability is significant, a run was made with these kill rates averaged over the 60 second cycle time. This comparison is displayed in Figure 6. This type of enhancement is not an exact consideration of the distribution of the time-to-kill, but it is a better approximation than traditional Lanchester models.

3. Terrain. The modeling of terrain is important in simulating combat with direct-fire weapons because of line-of-sight considerations. If movement is along an axis of advance, then one way to handle this is to estimate the percentage of the force that has line of sight as a function of range. To demonstrate this technique with the arbitrary line-of-sight percentages shown in Figure 7, a range dependent line-of-sight function was set on another diode function generator to be multiplied by the Red force level before being input into the Blue integrator. Blue forces were considered to have identical lines-of-sight for simplicity. Graphs of this run are presented in Figure 8. Digitally stored terrain could be processed by the digital computer and the results fed into a digital-to-analog converter as an input to the line-of-sight multiplier rather than from a diode function generator if such a data base were available.

In summary, hybrid computers offer an alternative to the development of analytical enhancements to Lanchester derived models, such as the contributions of Weiss and Helmbold. Three of the enhancements selected for this investigation were the incorporation of reaction time delays, simulation of the target acquisition process and the effects of intervisibility caused by terrain mashing.

Table 4. Modeling Active Defense Engagements

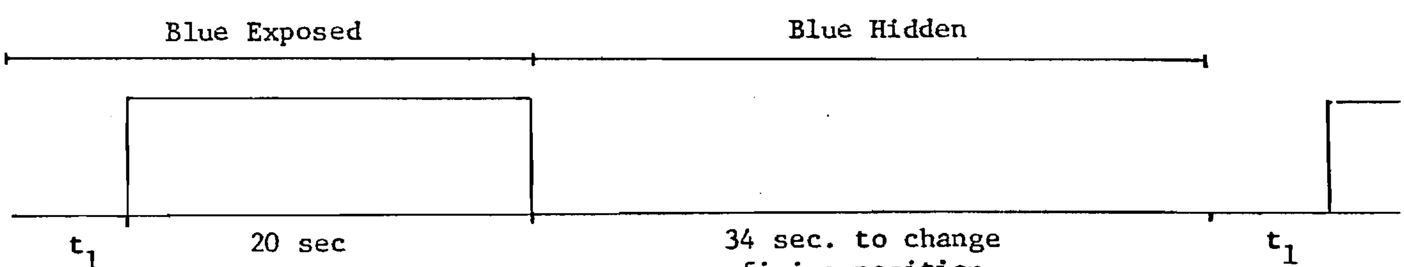
Blue Tank Firing on Red Tank

Range(m)	E(no. of kills)	(E(K))/20
3000	.07975	.0040
2500	.19793	.0099
2000	.56136	.0281
1500	.99810	.0499
1000	1.63523	.0818
0500	2.13750	.1069

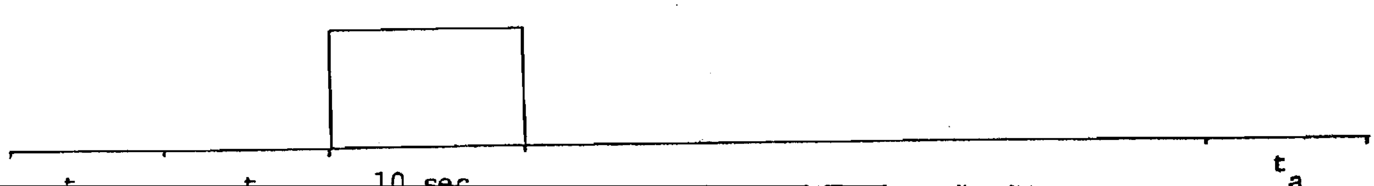
Red Tank Firing on Blue Tank

Range(m)	$S.S._{PK}$	S.S. Kill Rate
3000	.01165	.0012
2500	.02370	.0024
2000	.05422	.0058
1500	.14729	.0164
1000	.25392	.0295
0500	.32927	.0397

Blue-on-Red



Red-on-Blue



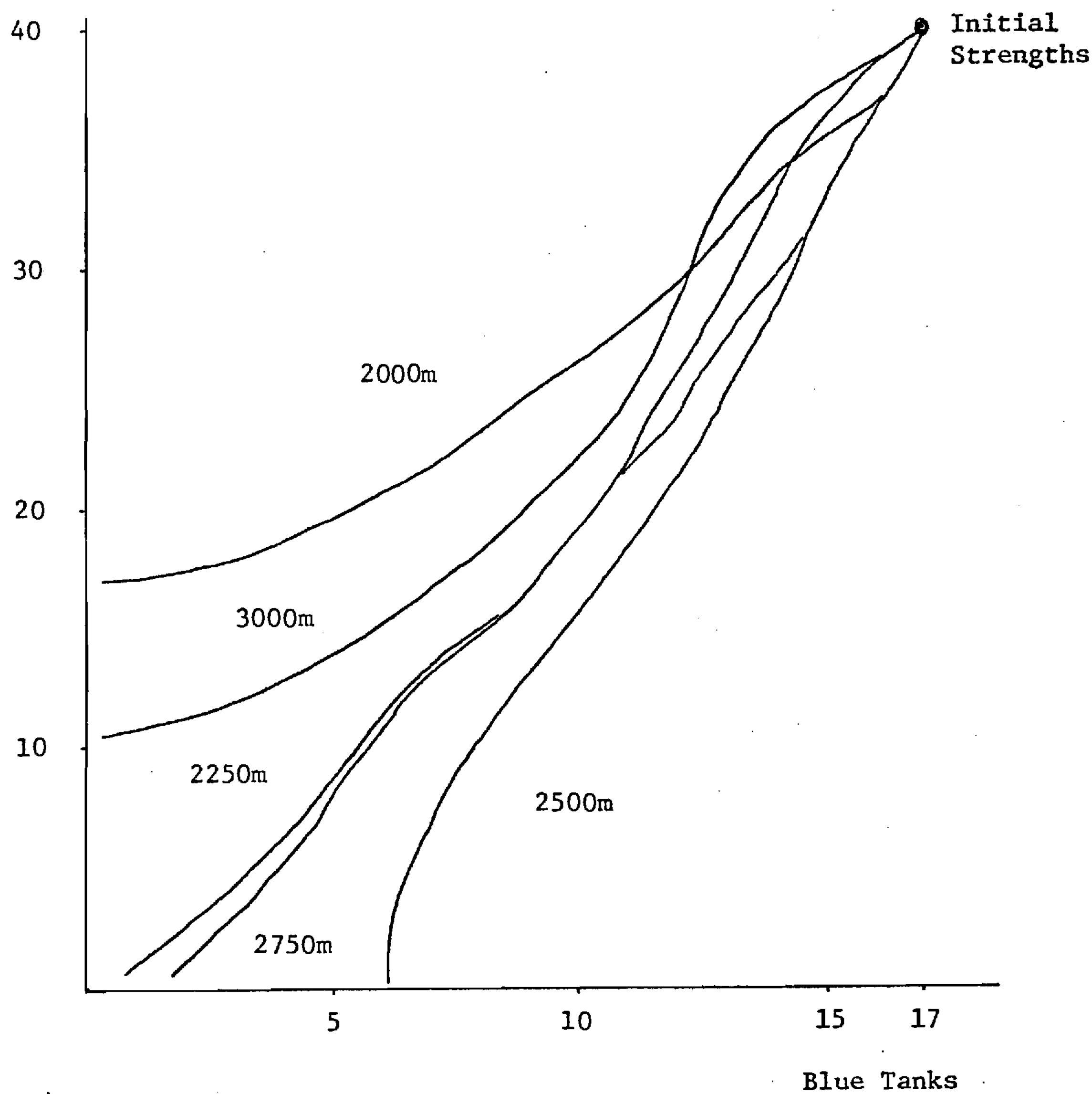


Figure 5. Explicit Modeling of Active Defense
17 Blue. vs. 40 Red

varying initial engagement ranges

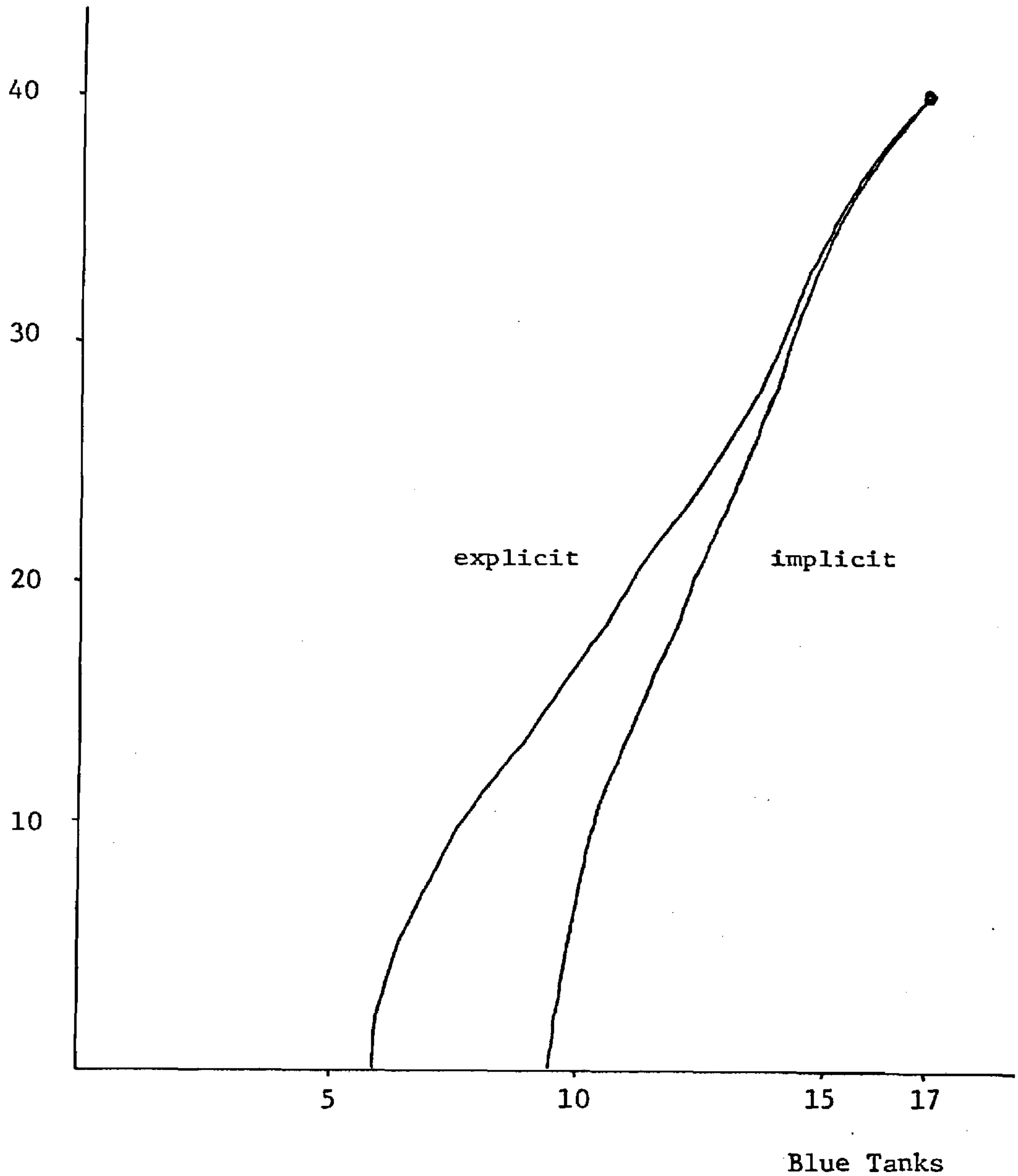


Figure 6. Implicit vs. Explicit Modeling of Active Defense
17 Blue vs. 40 Red

2500m initial engagement range

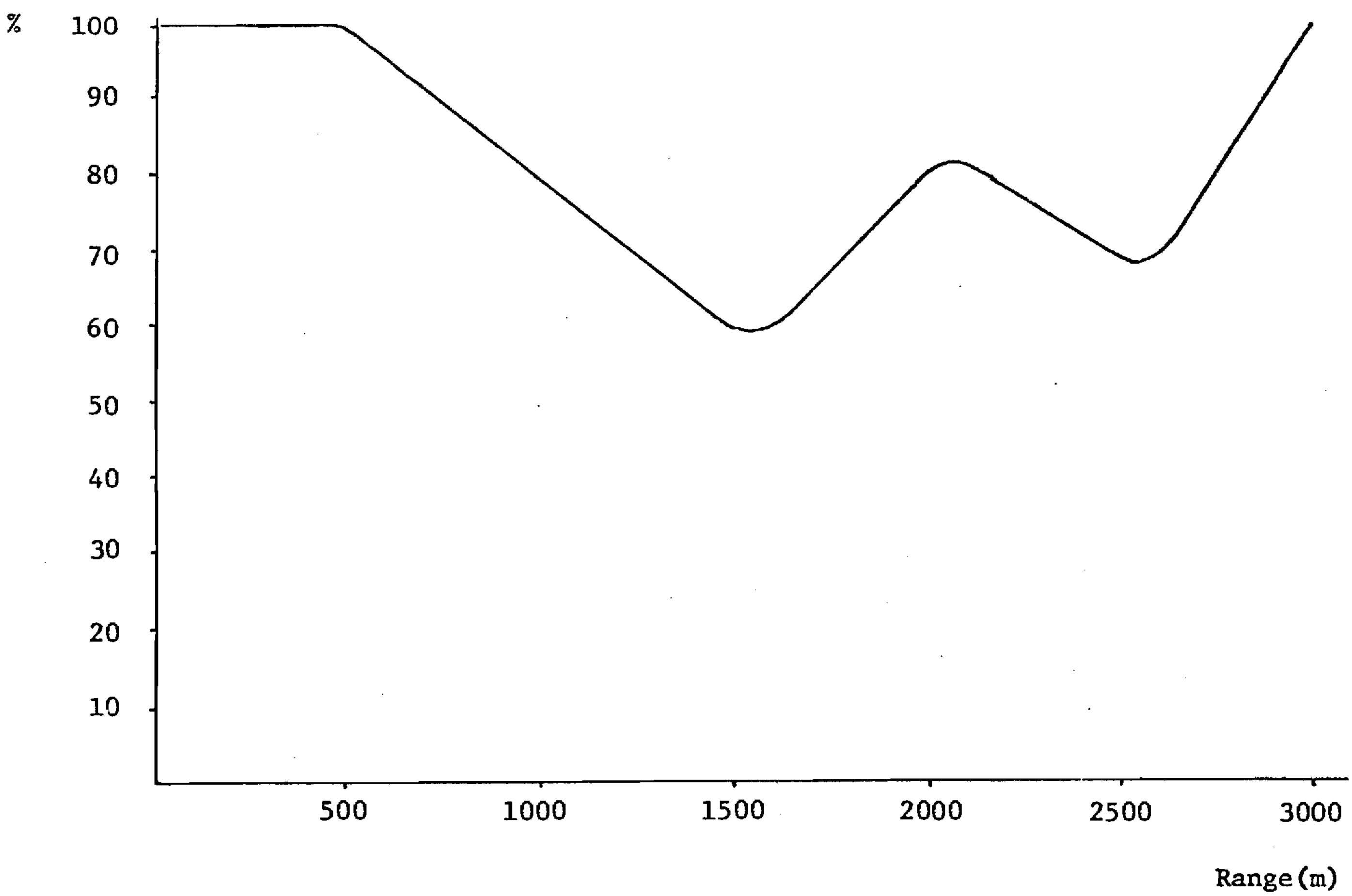


Figure 7. Percent of Red Formation Having Line-of-Sight with Blue Forces

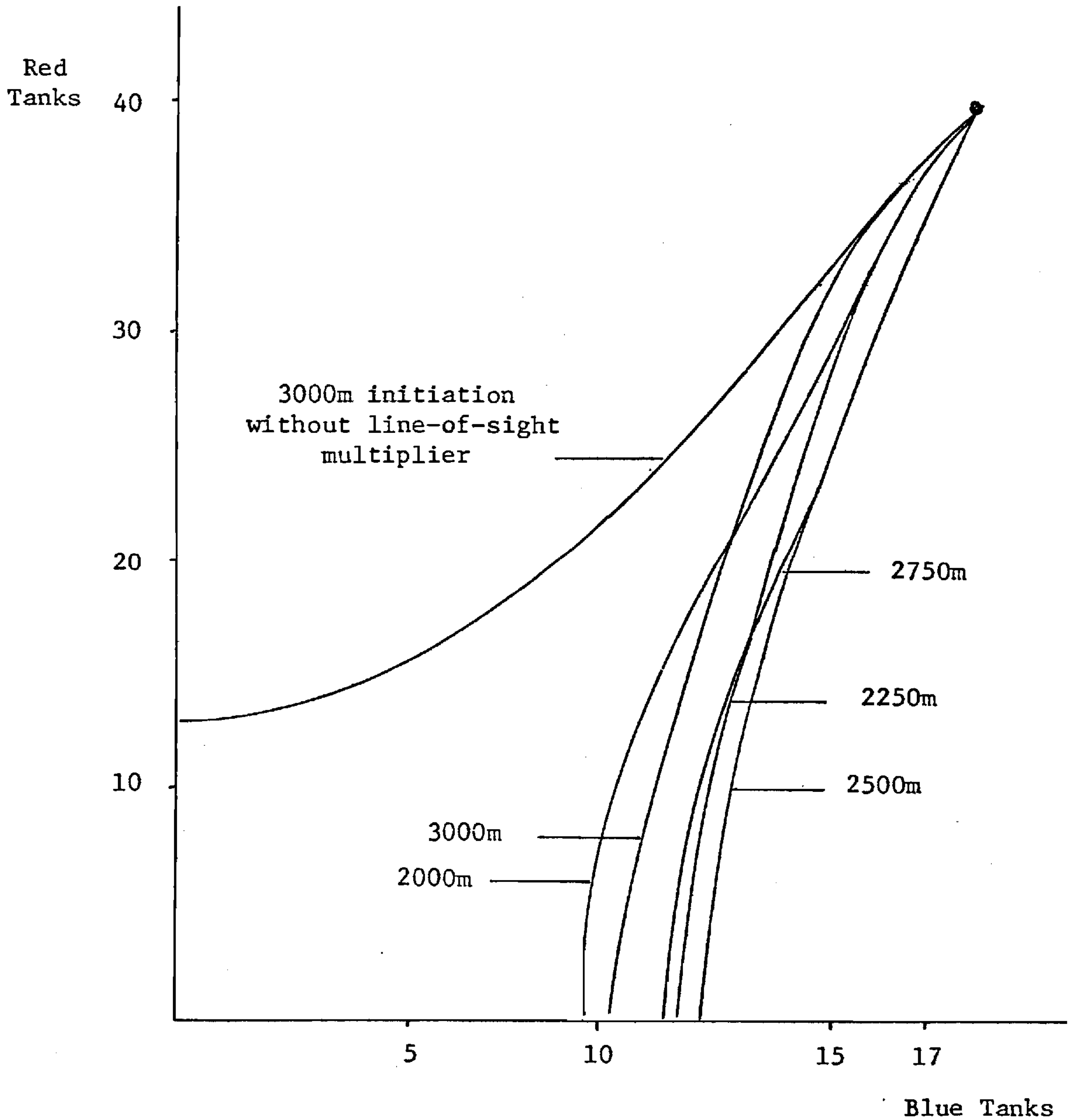


Figure 8. Impact of Line-of-Sight Multiplier on Battle Outcomes
17 Blue vs. 40 Red

varying initiation ranges

CHAPTER VI

COMPARISON WITH DIGITAL SIMULATION

A search was made for a comparative digital simulation, either deterministic or Monte Carlo, which incorporated terrain, reaction time delays, and the target acquisition time considerations inherent in tank-on-tank engagements when the defender moves between alternate firing positions on a given battle position. There are many computer simulations that play terrain-induced intervisibility problems caused by attackers moving over terrain in front of the defender, but none of those in common use was found to consider the intentional movement by the defender from one firing position into full defilade and back up into an alternate firing position. Since incorporation of these crew tactics was considered the key enhancement, an in-house Monte Carlo GPSS Land Combat Simulation Model by MAJ J. R. Wallace was modified to use for a rough comparison.[14] MAJ Wallace's program as originally written was designed to simulate a battle between a tank platoon and a reinforced motorized rifle battalion. Modifications were made to make the battle tank-on-tank, to use an exponential acquisition time rather than probability of detection, to modify parameters to bring kill probabilities in line with those used in the hybrid simulation, and to modify other parameters to align the mean times required for completion of certain actions. These modifications brought the assumptions of the two simulations into close, but admittedly not complete, agreement.

---

[14] "A GPSS Land Combat Simulation Model" submitted by Major J. R. Wallace to Dr. John Carson, School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, Georgia, 1980 (Appendix C).

Line-of-sight considerations caused by attacker movement was not considered. Ten runs were made of 5 Blue versus 15 Red with engagement initiation at 2000 meters and termination at 500 meters. The results are shown in Figure 9 with the plot of a hybrid battle with the same initial conditions.

The first thing one notices is the bias between the mean of the sample of the Monte Carlo runs and the run on the hybrid. The greatest portion of the bias is most probably due to the over-kill bias not considered in the development of attrition rates for Lanchester's Square Law. There is obviously a need for some type of modification to the attrition rates using reliability theory, binomial approximations, or the use of the more general Helmbold's equations rather than the Square Law.

The other important observation is the variance in the sample outcomes of the Monte Carlo model. The extreme spread in outcomes indicates that a large number of runs would have to be made in order to make reliable decisions regarding options or parameter changes. One can then readily see the benefit of a deterministic hybrid model in efficiently and rapidly making comparisons.

The comparison of these two simulations point out the advantages and disadvantages of both the Monte Carlo and Lanchester models where preference would depend upon the intended utilization of the models.

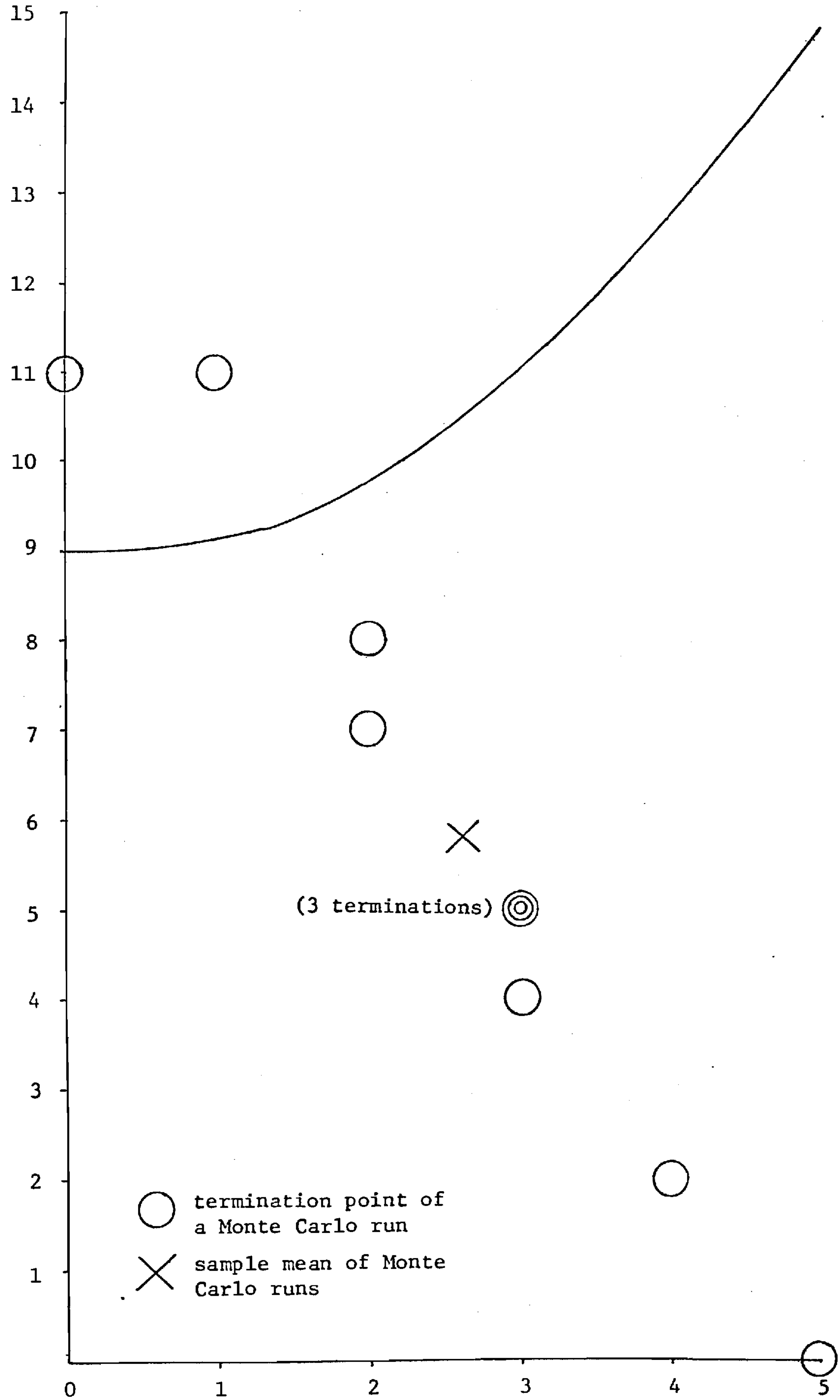


Figure 9. Comparison of Monte Carlo and Hybrid Models

CHAPTER VII

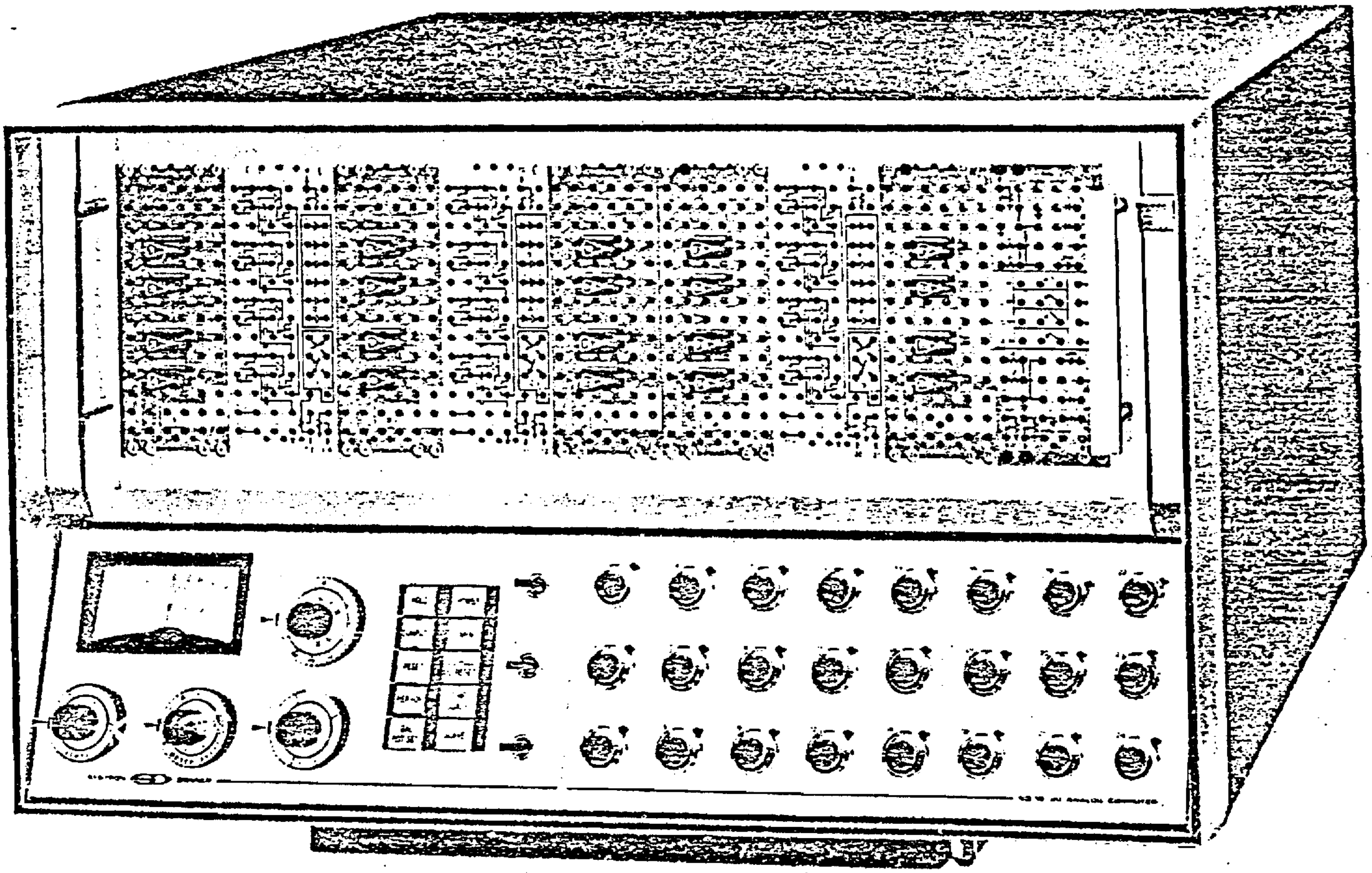
CONCLUSIONS AND RECOMMENDATIONS

The use of small hybrid computers for the solution of Lanchester-type models of small unit combat offers a more realistic and timely simulation than traditional large-scale digital simulations. In addition the hybrid computer provides a convenient alternative for the development of analytical enhancements to generalized Lanchester derived models of the type proposed by Weiss and Helmbold. This research effort extended the scope of the traditional small unit combat simulation such as TATS or AMSWAG to include reaction time delays, simulation of the target acquisition process, and the effects of intervisibility caused by terrain mashing. Actual experimental comparisons of a tank-on-tank hybrid simulation, and a similar GPSS Monte Carlo highlighted the inherent differences between deterministic and stochastic models. Selection of the best approach is highly dependent on intended use.

It is recommended that further research be conducted on the utilization of a large-scale hybrid computer for expanding the number of enhancements to make small unit combat more realistic. Finally it is recommended that the relative cost of programming and running these competitive simulation techniques be investigated using the similar scenario, and models.

Appendix

Appendix A. Systron-Donner 10/20 Hybrid Computer



MODEL 10/20 ANALOG COMPUTER

Quick Reference Selection Guide

	SD 10/20		SD 40/80		
	TYPICAL COMPLEMENT				
1 BASIC COMPUTER Cabinet with complete Control Panel, Address Selector, Potentiometer Panel, computer power supply and ±100 volt dc reference system.	Modules	Amplif.	Modules	Amplif.	PAGES
2 COMPUTING MODULES — Maximum:	9	20	42	84	
Summers:					
Dual Summer, Module 3321			13	26	(6)
Quad Summer, Module 3325	5	20	1	4	(3) (6)
Integrators:					
Dual Integrator, Module 3320			14	28	(2) (7)
Quad Integrator/Dual Multiplier/Function Relay, Module 3329	2				(3) (7)
Quad Integrator (no dual multiplier circuit)/Function Relay, Module 3329A					(7)
Non-Linear Modules:					
Dual Multiplier/Dual Inverter, Module 3323			6	12	(8)
High Accuracy Multiplier/Dual Inverter, Module 3323-1					(8)
Variable Diode Function Generator, Model 3351	4 or		15 or		(9)
High Resolution VDFG, Model 3352	4		10		(9)
Comparators:					
Dual Function Relay/Dual Inverter, Module 3322A			2	4	(10)
Quad Electronic Switch/Dual Inverter, Module 3324			3	6	(10)
3 HYBRID COMPONENTS					
Digital Logic Control Modules:					
Flip-Flops, Module 3326			3		(10)
Logic Gates, Module 3327			2		(11)
Combination Flip-Flops and Logic Gates, Module 3326A	1				(11)
Time/Event Control, Module 3328	1		1		(11)
4 POTENTIOMETER GROUP					
SD 10/20: 6 potentiometers per group, Module 3374	up to 24 pots				(12)
SD 40/80: 20 potentiometers per panel, Module 3370	up to 125 pots				(12)

5 COMPONENT UNIT TOTALS:	TYPICAL CAPACITY (*Maximum Normal Expansion)	
Operational Amplifiers	20*(32 special)	84*(120 special)
Summers/Inverters	20*	64-84*
Integrators	8-16*	20-50*
Multipliers	4-8*	10-84*
Function Relays	2	4
Electronic Switches		8
Variable Diode Function Generators — Model 3351:	4*	15*
Variable Diode Function Generators — Model 3352:	4*	10*
Function Switches	3*	5
Trunk Lines	30*	160*
Coefficient Potentiometers	24*	125*
Hybrid Components:		
Flip-Flops (12 per module)		36
Gates (12 per module)		24
Flip-Flops and Gates (6 of each per module)	6	
Timer-Counter	T/C	T/C
6 PHYSICAL SPECIFICATIONS:		
Power Consumption	150 watts	650 watts
Power Supply — Connections Provided for:	115, 220, 230, 240 and 250V ±10%, 50-400 cps	
Weight (fully expanded)	130 lbs (68 kg)	700 lbs (315 kg)
Dimensions (length x height x depth) — Inches:	24 x 15 x 25	68 x 26 x 23
Dimensions (length x height x depth) — Centimeters:	61 x 38 x 63	172 x 66 x 58

Prices available upon request. Shipment F.O.B. Concord, California

Specifications

DUAL INTEGRATOR – MODULE 3320

Feedback Capacitors (in oven) 1 μF, 0.1 μF: Trimmable to better than 0.01%.
Feedback Capacitor 0.01 μF: ±1%
Tolerance of Input Resistors and Resistors in Reset Circuit: ±0.01%
Temperature Coefficient of 0.01% Resistors: ±5 ppm/°C
Nominal Temperature in Oven: 45°C
Temperature Regulation of Oven: ±1°C
Reset and Hold Relays: Reed Relay switching speed 1 msec, differential time <500 μsec typical
Integrator Drift (R_{in} = 1M, C_{fb} = 1 μF): 50 μv/sec typical, 100 μv/sec max.
Noise at output (with C_{fb} = 1 μF): <2 mv p-p (0 to 2 kc)
Bandwidth as Summer (R_c = 1M): >13 kc (within 3 db)

DUAL SUMMER – MODULE 3321
QUAD SUMMER – MODULE 3325

Tolerance of Input and Feedback Resistors: 0.01%
Temperature Coefficient of 0.01% Resistors: ±5 ppm/°C
Bandwidth (R_{in} = R_{fb} = 100k, no capacitive loading at summing junction or output): >200 kc (within 3 db)
Bandwidth (R_{in} = R_{fb} = 1M): >50 kc (within 3 db)
Velocity limit: >3 x 10^6 volt/second
Noise at output (R_{in} = R_{fb} = 1M with R_{in} grounded): <10 mv p-p (0 to 2 kc).
Cross talk at 100 cps (R_{in} = R_{fb} = 1M): <–66 db
Phase shift at 100 cps: <0.03°

DUAL FUNCTION RELAY/COMPARATOR
MODULE 3322 & 3322A

Two Function Relays: Two Form C
Tolerance of Input and Feedback Resistors: 0.01%
Temperature Coefficient of 0.01% Resistors: ±5 ppm per °C
Bandwidth (R_{in} = R_{fb} = 100k): >200 kc (within 3 db)
Noise at Output (R_{in} = R_{fb} = 100 k): <5 mv p-p (0 - 2 kc)
Phase Shift at 100 cps: <0.03°
Pull-in Time:
  Module 3322 — 10 millisec
  Module 3322A — 1 millisec
Energizing Voltage: ±28v to ±100v.

DUAL MULTIPLIER/DUAL INVERTER
MODULE 3323

Frequency Response
  Amplitude: X = ±100, Y = 1 sin ωt. / Y = ±100, X = 1 sin ωt. } <3 db at 50 kc
  Phase Shift: <0.1° at 100 cps
Input Resistance: Multiplier mode approx. 20 kΩ (varies with input levels)
Drift: X = Y = ±100   25 mv per 2 hrs.
  X = Y = 0   5 mv per 8 hrs.
Noise: 20 mv p-p (0 to 10 kc)
Zero Offset: X = Y = 0   20 mv max.
  X or Y = 0   60 mv
Static Accuracy: 0.05%, 100 mv error typical

HIGH ACCURACY MULTIPLIER/DUAL INVERTER
MODULE 3323-1

Input Range: ±100 v max.
Output Range: ±100 v max.
Static Errors: X = 0, Y = 0   ±2 mv
  X = 0, Y = ±100 v   ±15 mv
  X = ±100 v, Y = 0   ±15 mv
  X = ±100 v, Y = ±100 v   ±30 mv
Frequency Response: –3 db point above 20 kc
Noise — Wide Band: <25 mv p-p
Multiply Mode: Inputs: X and Y, range ±100 v
  Output: 0.01 XY, range ±100 v
Divide Mode: Inputs: X range ±100 v
  Y always negative –100 v ≤ Y < 0 and |X/Y| ≤ 1
  Output: 100 X/Y, range ±100 v
Squaring Mode (two independent channels):
  Input: X, range ±100 v. Output: 0.01 $|X|^2$, range ±100 v.
  Input: Y, range ±100 v. Output: –0.01 $|Y|^2$, range ±100 v.

QUAD ELECTRONIC SWITCH
MODULE 3324

Excitation Voltage: +20 to +100 v
Excitation Current: <2 ma
Max. Current passable through Switch: 3 ma
Max. Voltage across Switch with one side grounded: ±10 volt
Impedance with switch "ON": <200Ω
Rise Time of Switch (into a resistive load): 1 μsec
Error Current: <5 x 10^{-7} amp with Switch "ON"; <10^{-9} amp with Switch "OFF."
Switch Rate: 1 kc max.
10 kΩ Resistors: Tolerance, 0.01% Temp. Coefficient, 5 ppm/°C
0.001 μF Capacitors: Tolerance, ±1%, 500 w.v.d.c.

MODEL 3351

Input Voltage: ±100 v max.
Output Voltage: Arbitrary function of input volt. within range ±100 v.
Frequency Response: 1 kc
Input Impedance: Greater than 45 kΩ (depends on function)
Output Impedance: Less than 0.1Ω (output Z of amplifier).
Function Simulation: Straight-line approximation of 12-line segments.
Line Segments: 12 breakpoints total
  6 adjustable between 0 & +100 v, 6 adjust. between 0 & –100 v.
Slopes: Each segment has a max. adjustable slope of 2.5 v/v input.
  (Larger slopes are obtainable by adding individual line segments.)
Noise: 150 mv p-p   Power Requirements: ±100 v, ±6 ma

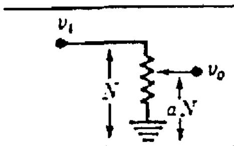
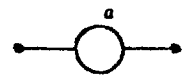
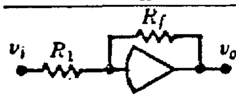
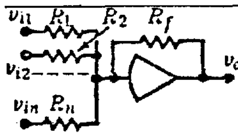
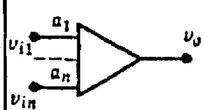
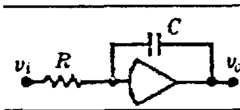
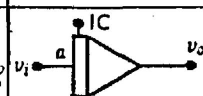
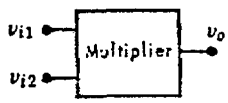
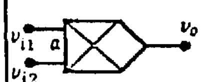
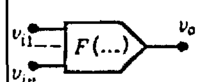
MODEL 3352

Inputs Required: ±X (±X can be common for several functions of X)
Input Voltage: ±100 v max.
Output Voltage: Arbitrary function of input volt. within range ±100 v.
Input Impedance: Greater than 39 kΩ (depends on function)
Output Impedance: Less than 0.1Ω (output Z of amplifier).
Function Simulation: Straight-line approximation with 11 segments.
Noise: 50 mv p-p (DC to 2 kc)
Linear Segment Complement:
  K_x adjustment: sets initial slope through origin of ±5 v/v max.
  Y_o adjustment: sets Y at X = 0 (between ±100 v)
  10 breakpoint-slope controls, each programmable to any of the following five combinations:

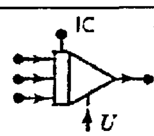
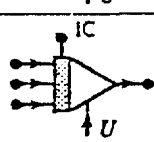
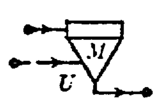
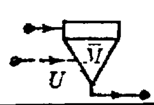
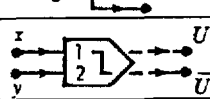
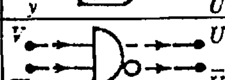
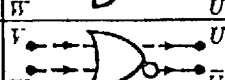
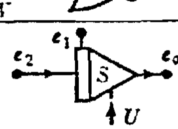
	No. 1	No. 2	No. 3	No. 4	No. 5
Breakpoint	+	–	–	+	off
Slope Change	+	–	+	–	off

Max. Slope Change per Breakpoint: 2.5 v/v, breakpoints may be stacked together for increased slope change; 22-segment function generation possible by paralleling two Model 3352 VDFG cards.

Basic analog computing elements

Circuit	*Symbol*	*Basic operation*
		$v_o = av_i$ $0 < a < 1$ N = winding turns
		$v_o = -av_i$ $a \triangleq \frac{R_f}{R_1}$
		$v_o = -\sum_{\nu=1}^{n} a_\nu v_{i\nu}$ $a_\nu \triangleq \frac{R_f}{R_\nu}$
		$v_o(t) = v_o(0) - a\int_0^t v_i\,dt$ $a \triangleq \frac{1}{RC}$
		$v_o = av_{i1}v_{i2}$
		$v_o = F(v_{i1}, \ldots, v_{in})$ (n very seldom larger than one)

A selection of hybrid components with their symbols

No	*Symbol*	*Description*
1		This integrator is placed in RESET when the control signal $U = 1$. When $U = 0$ it is placed in COMPUTE.
2		This integrator is placed in REPOP by changing U repetitively between 0 and 1, in accordance to the rules in 1. (The capacitor may be 0.1, 0.01, or 0.001 depending upon speed desired)
3		TRACK–HOLD or direct memory unit. Tracks in RESET (for $U = 1$) Holds in COMPUTE (for $U = 0$)
4		HOLD–TRACK or complementary unit Tracks for $U = 0$ (i.e., $\bar{U} = 1$) Holds for $U = 1$ (i.e., $\bar{U} = 0$)
5		Comparator If $x > y$ $U = 1$ ($\bar{U} = 0$) If $x < y$ $U = 0$ ($\bar{U} = 1$)
6		AND gate $U = 1$ only if V and W both are 1, otherwise $U = 0$
7		OR gate $U = 1$ only if V or W are 1, otherwise $U = 0$
8		Switch (obtained by replacing capacitor with resistor) when $\begin{cases} U = 1 & e_o = -e_1 \\ U = 0 & e_o = -e_2 \end{cases}$

Appendix C. GPSS Land Combat Simulation Model

The Problem:

As stated in Field Manual 100-5, Operations, the U.S. Army's primary objective is to win the land battles, whenever and wherever, this country may again find itself at war. These future battles could occur in a variety of places but the focus of this study will be on the battle in Central Europe against the Warsaw Pact. Under this circumstance, the U.S. Army would initially be fighting outnumbered against an enemy armed with modern weapons and equipment. The problem for the U.S. Army, then, is to optimize our own resources of men, weapons and equipment to produce the desired effect on this battlefield: victory.

This study will focus on a small but crucial element of this battle, the tank platoon. Specifically, it will address problems related to the defense of an American 5 tank platoon against a Soviet motorized rifle battalion, reinforced. In this situation, the U.S. forces would be outnumbered 2.8 to one in tanks and 30 to 0 in infantry vehicles. The overall ratio is approximately 9.4 Soviet armored vehicles to 1 U.S. tank. This force ratio is fairly typical of a Soviet breakthrough attempt.

Objectives of the Simulation Study

This study has two objectives:

1) To develop what is believed to be the first application of General Purpose Simulation System (GPSS) language to combat simulation modeling. The study should show if GPSS can be used to develop a

realistic, flexible and efficient model of small unit combat on the modern battlefield. The result could be simpler model building for certain classes of combat situations and less expensive simulation studies.

2) To determine the effect of the following areas on the performance of the U.S. platoon:

a) faster/slower rates of fire

b) longer/shorter exposure times

c) degradation of Soviet ability to acquire targets

d) training proficiency of tank crews

e) effect of engaging at maximum range vs. holding fire until Soviets have closed within 1500 meters.

<u>Detailed Description of the Problem</u>:

This section will describe the combat conditions assumed to exist during the simulation. Some of the assumptions and conditions may not be rigidly accurate but I believe they provide an adequate starting point for the study. Almost all the assumptions/conditions have been incorporated into the model so that they may be easily changed or modified. Therefore, the effect of these assumptions/conditions can be tested.

The U.S. tank platoon is assumed to occupy its assigned General Defensive Position (GDP). The position is prepared with several hull defilade firing points for each tank. All U.S. engagements take place from hull defilade positions. Each tank carries a basic load of 60 APFSDS rounds. All weapon systems are functioning to optimum specifications. Visibility exists to 2000 meters. Engagement sequences begin at 2000 m for both Soviet and U.S. forces. Terrain is considered typical of that in the Fulda Gap region of the West German border.

Tank gun fire and Soviet anti-tank (AT) missles are the only weapons simulated. The U.S. platoon has no infantry support nor any TOW AT missles. Soviet BMP 73 mm gun, U.S. .50 cal M85 machine gun, small arms or artillery fire are not simulated. Once Soviet vehicles close within 500 meters of the U.S. position, they are terminated from the model as having succeeded is assaulting the position.

The U.S. platoon is confronted with a major Soviet breakthrough attempt. Reconnaissance forces are ignored. The Soviet battalion is configured to be attacking with two BMP companies in the 1st echelon. Each company is preceeded by a platoon of 4 attached Soviet MBT. The 2nd echelon is comprised of the 3rd BMP company with attached tank platoon. Two ZSU-23/4's are attached. Two battalion command vehicles and the tank company commander comprise the command group. The entire attacking force consists of 13 MBT's, 30 BMP's, 2 ZSU-23/4's, and 2 battalion command vehicles for a total of 47 AFV's (Armored Fighting Vehicle).

The initial rate of advance of the Soviet battalion is 12 km/hr. This rate slows down as the unit closes on the U.S. position. At 1500 m the rate is 8 km/hr and at 1000 meters becomes 4.8 km/hr. At any given time, the Soviet force is considered to be comprised of 70% moving targets. However, all Soviet engagements are fired from the halt. The Soviets are assumed to have a .6 probability of acquiring a U.S. tank ONCE it has fired its main gun.

Engagements occur every 100 meters. That is, every 100 meters beginning at 2000 meters, each Soviet vehicle is potentially engaged and, as well, has the opportunity to engage a U.S. tank. If, however, a Soviet tank is not engaged within 20 seconds after acquisition, it automatically moves to the next 100 meter interval.

Each U.S. tank will fire a maximum of 3 rounds/target. If a Soviet target is hit on the 1st, 2nd or 3rd Rd, the U.S. tank immediately relays to another Soviet target. If all rounds miss, the U.S. tank ends the engagement of the Soviet target and proceeds to the next Soviet target. The Soviet vehicle advances to the next 100 meter interval where it is again placed in jeopardy. However, at each 100 meter interval it also has the opportunity to fire at the U.S. tanks.

U.S. tanks are exposed only for 'X' seconds and are then made unavailable for 'Y' seconds. The heavy and light sections are initially staggered so that some portion of the platoon is always engaging. U.S. priority is given to the closest Soviet MBT or ZSU-23/4. If no MBT or Z50 is available, BMP's will be engaged.

The GPSS Model of the Combat System

Overview and Basic Concepts of the GPSS Model

The basic approach to modeling this combat system was similar to one used to model customers passing through check-out counters at a supermarket. The customers in a supermarket join a line, normally the shortest, to receive a service, that is, totaling of their grocery bill. The customers in this combat model can be viewed as the Soviet vehicles. The servers are the 5 U.S. tanks. The customers (Soviets) join a queue belonging to a U.S. tank. They are serviced (hit by U.S. tank gun fire) on a probabilistic basis. If the U.S. tank services the Soviet vehicle, it achieves a hit. Otherwise, the Soviet vehicle proceeds to advance and is re-evaluated for service at 100 meter intervals. Additionally, however, means are provided for the Soviets to shoot back at the U.S. tanks.

The model has four main segments. The first creates or generates the Soviet battalion. All transactions (except control transactions) are Soviet vehicles. The second segment models the U.S. tanks engaging the Soviets with tank gun fire. The third and fourth allow the Soviet tanks and BMP's to return fire against the U.S. vehicles. Additionally, there are several smaller segments which act as controls on the amount of time the U.S. tanks expose themselves and remain hidden in defilade, ensures no U.S. tank fires when out of ammunition and "balks" any Soviet vehicle which remains in a queue for longer than 20 seconds. All of these control segments are explained in detail.

The initial portion of the model is a listing of the functions used in the model. These functions are described in detail in appendix A. Following the function listing, two INITIAL statements set the initial values of the U.S. tank's ammunition basic load (XH1-XH5) and XF1-XF4, fullword savevalues used to print certain data in the program. Their use will be explained in the appropriate program segment.

The following explanation assumes a high degree of familiarity with the GPSS language.

BIBLIOGRAPHY

Selected Methods and Models in Military Operations Research, Ed. Peter W. Zehna, Naval Postgraduate School, Monterey, California, 1971.

Force-on-Force Attrition Modelling, James G. Taylor, Military Applications Section, Operations Research Society of America, Arlington, Virginia, 1980.

Lanchester-Type Models of Warfare, James G. Taylor, Naval Postgraduate School, Monterey, California, draft 1980.

DARCOM-P 706-102 Engineering Design Handbook, Army Weapon Systems Analysis, Part Two, October 1979.

Handbook of Analog Computation, Maxwell C. Gilliland, Systron-Donner Corporation, June 1976.

A GPSS Land Combat Simulation Model, MAJ J. R. Wallace, Georgia Institute of Technology, 1980.

"Lanchester Models of Guerrilla Engagements," Marvin B. Schaffer, Operations Research, May-June 1968.

Target Selection in Lanchester Combat: Heterogeneous Forces and Time-Dependent Attrition Rate Coefficients, James G. Taylor, Naval Research Logistics Quarterly, December 1974, Vol. 21, No. 4.

Differential Models of Combat and Alternative Measures of Effectiveness, Roger F. Willis, draft 1980, White Sands Missile Range, N.M.

An Instruction and Research Laboratory for Syndetic Digital-Analog Computation in Science and Engineering Education, March 1975, School of Information and Computer Science, Georgia Institute of Technology, Atlanta, Georgia.

A New Formulation of Lanchester Combat Theory, Frank E. Grubbs, Aberdeen Proving Ground, Maryland and John H. Shyford, Fort Sill, Oklahoma.

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

Graduate Student Internal Report for Professor Jensen on Comparison of Digital and Analog Simulations, ICS 1976, Georgia Institute of Technology.