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PARAMETRIC ANALYSIS OF AIRLAND COMBAT
MODEL IN HIGH RESOLUTION

by

Jae Yeong Lee

September 1988

Thesis Advisor:

Samuel H. Parry

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Parametric Analysis of Airland Combat Model in High Resolution

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Submitted in partial fulfillment of the
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ABSTRACT

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TABLE OF CONTENTS

I. INTRODUCTION	1
A. BACKGROUND	1
B. PURPOSE AND GOAL	1
C. METHODOLOGY	2
II. MODEL DEVELOPMENT	3
A. SCENARIO	3
1. General	3
2. Assumptions	3
B. ALGORITHM	7
1. Basic model	7
2. Units casualties	10
a. Indirect fire	10
b. Minefield packages.	13
c. Direct fire	13
3. Unit speed	19
a. Indirect fire and Minefields	19
b. Direct fire	20
4. Advanced model	21
III. MODEL OUTPUT ANALYSIS	25
A. OVERVIEW	25
B. MEASURES OF EFFECTIVENESS (MOES)	28
C. COMPARISON BETWEEN BATTLE1 AND BATTLE2	31
D. UTILITY THEORY	35
1. General	35
2. Application	35
a. Linear Utility	35
b. Squared Utility	36
c. Square root Utility	37
E. GAME THEORY	38

1. General	38
2. Application	39
a. MOE-1 (Red casualties)	39
b. MOE-2 (Blue survivors)	41
c. MOE-3 and MOE-4	41
F. USE OF UTILITY VS GAME THEORY FOR THE ANALYST	43
IV. SENSITIVITY ANALYSIS	44
A. GENERAL	44
B. FORCE SIZE	44
C. ATTRITION RATE COEFFICIENTS	46
1. Sensitivity for attrition rate coefficients.	46
2. ANalysis Of VAriance (ANOVA).	49
D. WEISS PARAMETER	54
E. COUNTERMEASURES	59
F. MODEL ENRICHMENT	64
V. SUMMARY AND FUTURE DIRECTIONS	68
A. SUMMARY	68
B. FUTURE DIRECTIONS	69
APPENDIX A. MODELS INPUT DATA	70
APPENDIX B. BASIC MODEL	71
APPENDIX C. EXEC FOR BASIC MODEL	86
APPENDIX D. ADVANCED MODEL	87
APPENDIX E. EXEC FOR ADVANCED MODEL	114
LIST OF REFERENCES	115
BIBLIOGRAPHY	116

INITIAL DISTRIBUTION LIST	117
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LIST OF TABLES

Table 1.	INITIAL FORCE ELEMENTS	3
Table 2.	THE MATRIX OF RED AND BLUE OPTIONS	9
Table 3.	THE RELATIVE LETHAL AREAS FOR A 155MM HOWITZER ..	12
Table 4.	COMPARISON OF MOES BETWEEN BATTLE1 AND BATTLE2 ..	31
Table 5.	SENSITIVITIES OF MOES FOR ATTRITION RATE COEFFI- CIENTS.	48
Table 6.	RESULTS OF ONE-WAY ANOVA TEST WHEN THE MAXIMUM ATTRITION RATE COEFFICIENTS ARE CHANGED.	54
Table 7.	RESULTS OF ONE-WAY ANOVA TEST WHEN THE WEISS PA- RAMETER BLUE ENGAGING RED ARE CHANGED.	57
Table 8.	PAYOFF MATRIX FOR RED AND BLUE COURSE OF ACTIONS (MOE-1 MOE-2).	61

LIST OF FIGURES

Figure 1.	Map of area used in the scenario	4
Figure 2.	Network representation of the battle area	5
Figure 3.	Flow chart of computer program for the basic model	8
Figure 4.	The output of the Basic model (BATTLE2 case)	10
Figure 5.	Relation between the defender's casualty rate and the attacker/defender force ratio.	14
Figure 6.	Relation between the attacker's casualty rate and the attacker/defender force ratio.	15
Figure 7.	Relationship between range and attrition coefficient	17
Figure 8.	Battle case when a Blue is threatred from two directions	18
Figure 9.	Speed of attacking force versus their attrition coefficient	20
Figure 10.	Flow chart of the advanced model	22
Figure 11.	The output of the advanced model	24
Figure 12.	Red and Blue force sizes over time	26
Figure 13.	The Red casualties by different types of Blue weapons	27
Figure 14.	Distance between Red and Blue forces over time.	28
Figure 15.	Speed of Red force on each avenue over time.	29
Figure 16.	The MOE values for each options of Red and Blue (BATTLE2)	30
Figure 17.	Ratio of MOEs in BATTLE1 types based on BATTLE2 type.	32
Figure 18.	MOEs for each options of Red and Blue (BATTLE1 with Avenue-21) .	33
Figure 19.	MOEs for each options of Red and Blue (BATTLE1 with Avenue-22) .	34
Figure 20.	Three different utility distribution functions.	36
Figure 21.	Weighted utility values for each function.	38
Figure 22.	Initial matrix and reduced matrix for MOE-1	41
Figure 23.	Solution for Value of the Game (MOE-1)	42
Figure 24.	Red and Blue force sizes over time when the Blue ambush point is rein- forced.	45
Figure 25.	Comparison of MOEs when the Blue forces are reinforced.	46
Figure 26.	Change of MOE values based on different maximum attrition rate coef- ficients, a_0 and b_0	47
Figure 27.	Ratio of change for MOE values based on different a_0 and b_0	47

Figure 28. Fitting the Red casualties (MOE-1) of the Advanced model output to Normal Distribution.	50
Figure 29. Fitting the Blue survivors (MOE-2) of the Advanced model output to Normal Distribution.	51
Figure 30. MOE outputs for both battle cases; original battle, and both a_0 and b_0 increased by 10 percent.	52
Figure 31. Change of Basic model output (MOE-1 and MOE-2) based on Weiss parameter for Blue engaging Red.	55
Figure 32. Change of Basic model output (Red to Blue casualty ratio and force ratio) based on Weiss parameter for Blue engaging Red.	55
Figure 33. Change of the Basic model output (MOE-1 and MOE-2) when Weiss parameters for both Red and Blue approach the same value.	56
Figure 34. Change of Red Blue casualty and force ratio in Basic model when Weiss parameters for both Red and Blue approach the same value.	56
Figure 35. 3-Dimensional view of payoff matrix for Red casualties.	62
Figure 36. 3-Dimensional view of payoff matrix for Blue survivors.	62
Figure 37. 3-Dimensional view of payoff matrix for the Red to Blue casualty ratio.	63
Figure 38. 3-Dimensional view of payoff matrix for the Red to Blue force ratio.	63
Figure 39. Two different functions for minimum speed.	65
Figure 40. Comparison of RED BLUE casualty ratio (MOE-3) between Basic and Enriched model.	66
Figure 41. Comparison of duration of battle (MOE-4) between Basic and Enriched model.	66

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I. INTRODUCTION

A. BACKGROUND

Since the Korean War (1950-1953), the Republic of Korea (ROK) has invested a significant amount of money to defend against the threat posed by North Korea and to maintain a peaceful atmosphere on the Korean Peninsula. As industry and the economy have developed, it has become necessary for the ROK Department of Defense to apply more efficient methods to operate and control the huge defense system. For the Army, one major source of defense expenditure has been in developing different combat simulation models which can be used in ROK's terrain conditions. Unlike the North Atlantic Treaty Organization (NATO) terrain, the Korean peninsula is very complex geographically having many small streams, mountains, hills, and reservoirs. This means it is relatively easy to channalize the enemy's avenues of approach when they attack. Therefore, when the ROK develops an airland combat simulation model, it more precisely and realistically describes the Korean geography than other models. Based on this concept, it is hoped that this thesis will be an useful addition in helping to develop better combat simulation models.

B. PURPOSE AND GOAL

The purpose of this thesis is to analyze the parameters which are heavily used in high resolution airland combat models. As the deterministic model is developed, a common scenario is used to approach this goal. In this scenario, Red (enemy force) attacks Blue (friendly force) through an arbitrary terrain network giving Red a number of different routing options. It is assumed that Red can take limited avenues of approach since the maneuverability of Red is restricted to certain arcs (routes) due to destroyed bridges or a strong probability of ambush.

Specifically, the goal of this thesis is to suggest the best courses of action for the Blue commander based upon various types of airland battle situations and to demonstrate several decision methods from an analytic viewpoint. The model developed here can be easily modified and applied to test other battle situations if one has more precise terrain data.

C. METHODOLOGY

To build a scenario, an area in ROK near the Demilitarized Zone (DMZ) was selected and a network was developed having several possible paths for Red forces based upon the road conditions of that actual terrain area. Generally, Red attempts to attack Blue's fortified positions through the shortest distance path or shortest time path. There are several methodologies available to find these paths. This effort will incorporate methodologies previously explored by the AirLand Reach Model (ALARM) at the Naval Postgraduate School. The use of network methodology to model terrain was developed by Craig [Ref. 1] and McLaughlin [Ref. 2]. The determination of network attributes from a high resolution terrain data base was developed by Choi [Ref. 3 : p. 27].

Regard each intersection of the roads as a node and the road between the nodes as an arc, and add the speed, distance, and width to estimate the trafficability of each arc. This information is to be used as inputs for the models. In this deterministic model, single round lethality of Firing Theory is adopted for artillery fire in the beginning of the battle, Lanchester's Linear Law is used for casualties in the minefields, Hembold equations are used for direct fire as well as range dependency and ambush attack. It is also assumed that the speed of the Red force depends on their attrition rate coefficient caused by the Blue force. In other words, Red's speed is a function of Blue's attrition rate coefficient on Red, since the maneuverability of the Red force will decrease as they get closer to the Blue positions. This will be explained in more detail in Chapter 2.

Based on the several options available to each side, the battle situations are changed to derive the different outputs. If the Red force has M options and Blue has N options, the output can be described by an M by N matrix of each specific value which can be compared and analyzed. These matrices could be Red casualties, Blue survivors, time of the battle, or the ratio of Red and Blue casualties. Because these values are very significant factors of the battle, they are defined as the values of Measures Of Effectiveness (MOEs). After generating the required matrices of MOEs, they were analyzed using the techniques of Utility Theory and Game Theory. Additionally, sensitivity analysis was also conducted for selected parameters.

II. MODEL DEVELOPMENT

A. SCENARIO

1. General

The Red regiment has three infantry battalions and one reserve company and the Blue battalion has three infantry companies and one reconnaissance platoon. Blue commander can employ its reconnaissance platoon for a special mission. In the model, the reconnaissance platoon of Blue will ambush Red on the most important avenue of approach and Blue will defend from two well fortified positions (Node-27, Node-28 in Figure 2). The battle will terminate if one of the Red forces reaches either of these two nodes. Only infantry forces were considered in the initial runs of the model. Initial force elements of both sides are shown in Table 1.

Table 1. INITIAL FORCE ELEMENTS

Red force		Blue force	
	3 battalions : 1500		3 companies : 510
	1 reserve co.: 150		1 recon. pltn. : 40
Total	1650		550
• unit = infantryman.			

The battle area in this scenario is taken from one of the ROK Army divisions' assigned sectors. This area is relatively flat except for one large mountain, Geumhag San, which is located in the west central part of the battle area. One small river, Daegyo Cheon, which flows from the northwest to the southeast, poses no significant problem to the Red force when attacking with either mounted or dismounted units. The map of this terrain area is shown in Figure 1 and a representation of the network in terms of arcs and nodes is shown in Figure 2.

2. Assumptions

The assumptions and description of the scenario are as follows:

1. There are three major avenues of approach for the Red force.
2. The Red force on the second avenue (center) will be divided at node-14, with two equal forces and attack to nodes 27 and 28, respectively (This assumption could

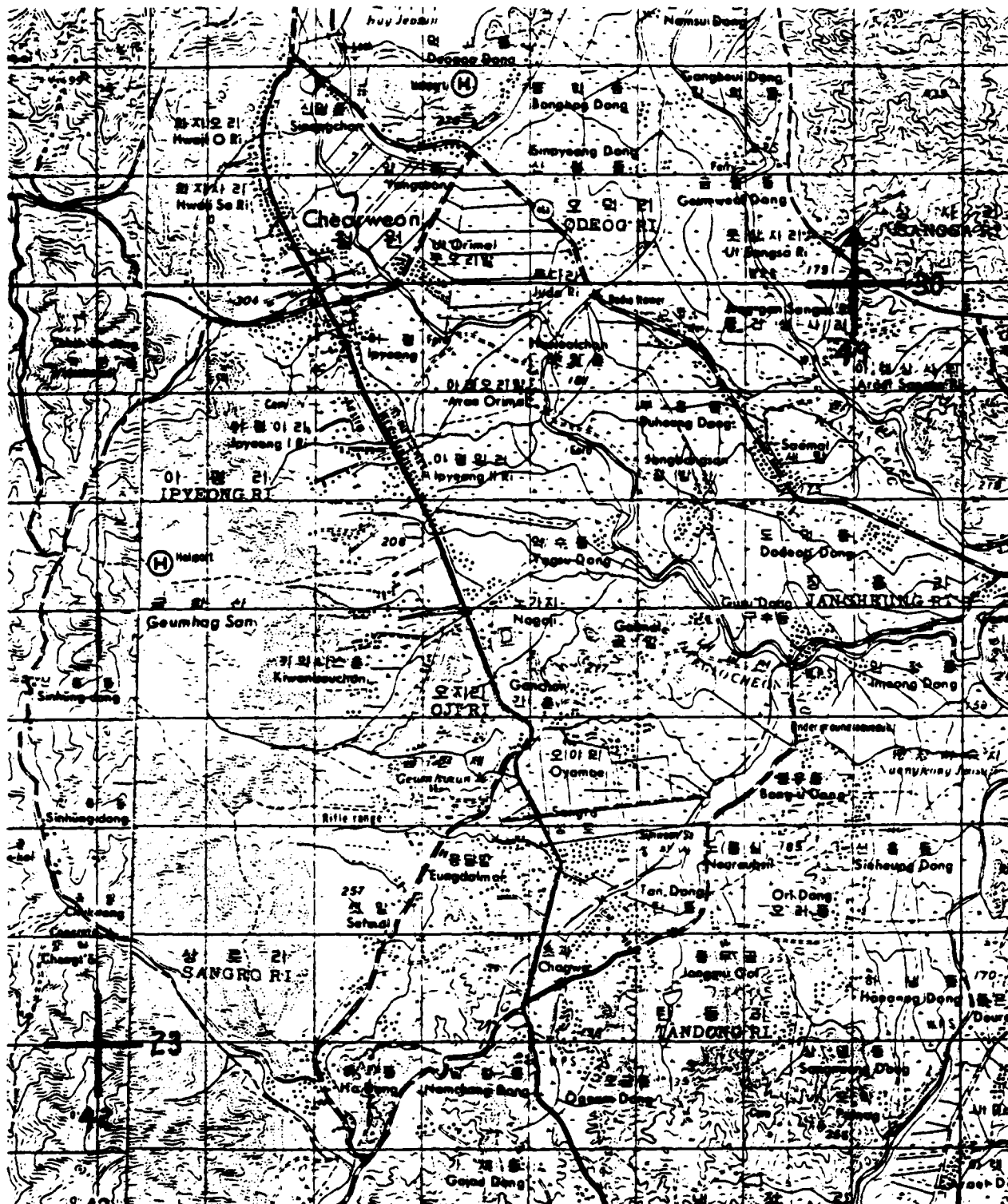


Figure 1. Map of area used in the scenario

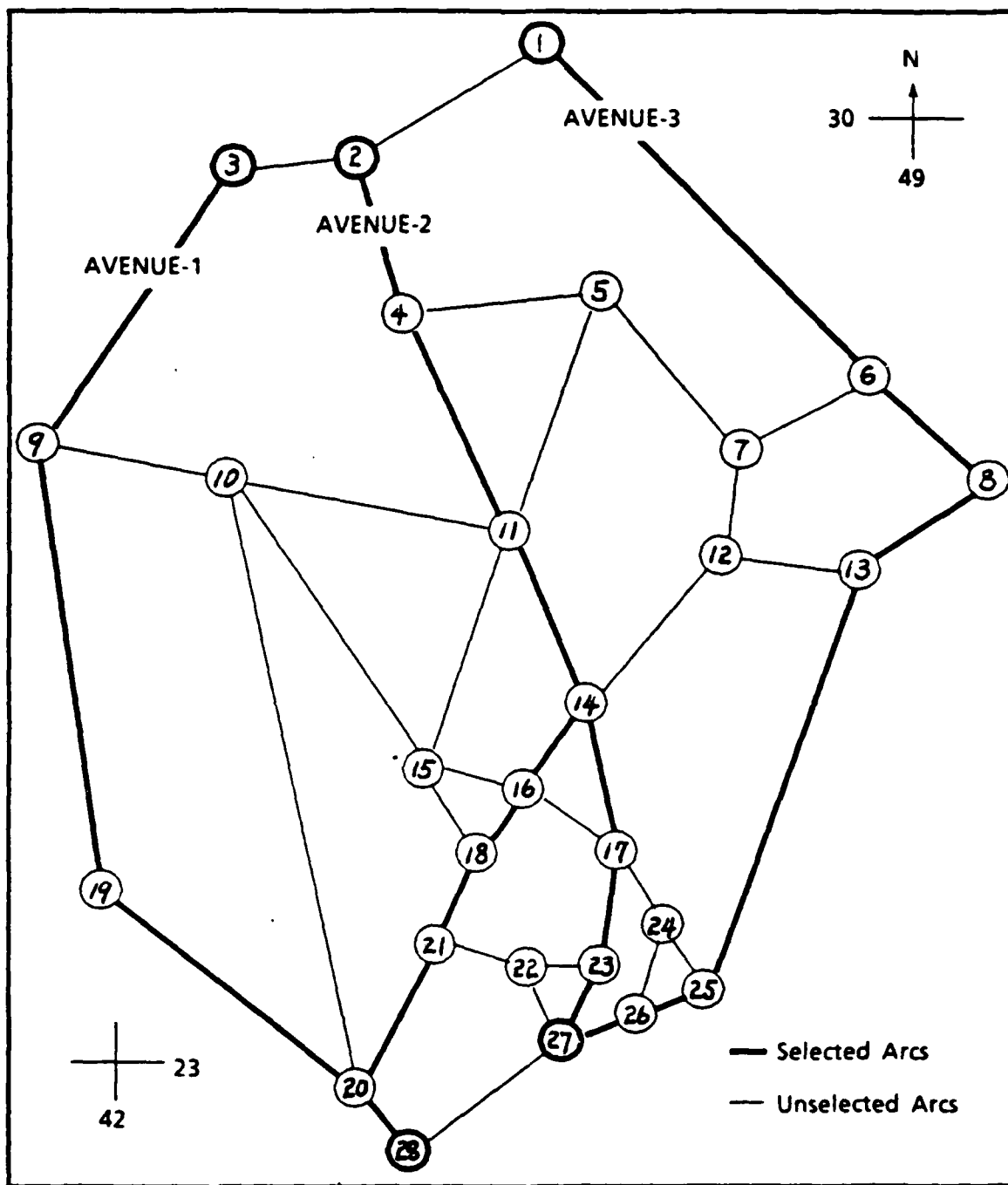


Figure 2. Network representation of the battle area

be changed so that the Red force on the second avenue will attack only one of two Blue positions as described in Chapter 3). Therefore, denote Avenue-21 used by Red attacking to node-28 and Avenue-22 used by Red attacking to node-27.

3. Red force initiates maneuver from their boundary at the same time (from nodes 1,2,3).
4. Red force has four options to allocate their units (battalions) for each avenue of approach, where attacker (Red) actions are treated as states of nature, as follows:

Option	Avenue-1	Avenue-2	Avenue-3
1.	1 Bn.	1 Bn.	1 Bn.
2.	0 Bn.	2 Bn.	1 Bn.
3.	0 Bn.	1 Bn.	2 Bn.
4.	0 Bn.	3 Bn.	0 Bn.

5. Blue force has two options to allocate their units (companies) for each fortified defense positions as follows:

Option	Fort-1(node 27)	Fort-2(node 28)
1.	1 Co.	2 Co.
2.	2 Co.	1 Co.

6. Blue force has four options for how to allocate the three scatterable mine packages they currently possess. Those options are as follows:

Option	Avenue-1	Avenue-2	Avenue-3
1.	1 Pkg.	1 Pkg.	1 Pkg.
2.	0 Pkg.	2 Pkg.	1 Pkg.
3.	0 Pkg.	1 Pkg.	2 Pkg.
4.	0 Pkg.	3 Pkg.	0 Pkg.

7. The number of Red units (battalions) affect the speed of attacking Red forces on each avenue. This implies that Red moves with reduced speed when there are multiple units on one of the avenues of approach. The Red forces also become more dense in a given area when multiple units are on one avenue.
8. Whenever the Red force reaches a minefield, it takes more time to bypass than to break through. Therefore, the Red force will choose to break through.
9. The only artillery weapon system that supports the Blue force is the 155 millimeter howitzer (towed).
10. Red indirect fire weapons are not represented.
11. Blue has two types of minefield packages: preinstalled and scatterable.
12. The maximum range for infantry direct-fire weapons is 1.1 km (M60 machine gun).
13. There are no Close Air Support (CAS) aircraft or chemical weapons employed in this scenario.

As described above, Red has four options and Blue has eight options. Therefore, there are 32 battle cases in this scenario.

B. ALGORITHM

1. Basic model

The rule for representing the battle is based on discrete time steps. The battle clock will begin when the Red force attacks from their original locations, which are nodes 1, 2, and 3 in the network representation of Figure 2. The time step interval is one minute.

The basic model is only one of the possible battle cases in this scenario, that is, one option for Red and one option for Blue which represent one element out of the 4 by 8 matrix. These options may be entered interactively. The basic model steps are described below:

- **Input** : Characteristics of the network terrain model which include source node (tail node), sink node (head node), arc number, distance and speed on each arc, location of minefield, and amount of time for indirect fire. An example of input format is included in Appendix A.
- **Output** : Characteristics of battle results which include casualties and survivors for both sides, the length of battle, proportion of casualties based on weapon types (indirect fire, minefield, direct fire), avenues of approach, and positions (nodes) of the the Blue forces.

Step 1 : Read the input data and initialize the forces, time, location etc..

Step 2 : Set the battle clock to the next time step

Step 3 : Detect the weapon type such as indirect fire, minefield and direct fire.

Step 4 : Compute the casualties and survivors for each weapon type based on Step 3.

Step 5 : Determine the speed of the attacking force and compute the distance it moved during that time step. It is assumed that the speed of Red forces is affected by indirect fire, minefields, and direct fire.

Step 6 : Consider battle termination conditions and decide whether the battle will continue or not. If the battle does not terminate, go to Step 2. If the battle terminates, print the output.

All these steps occur independently and simultaneously on each avenue.

The flowchart of the basic model is given in Figure 3, and the following definitions apply:

IF = Indirect Fire battle

MF = Minefield acquisition

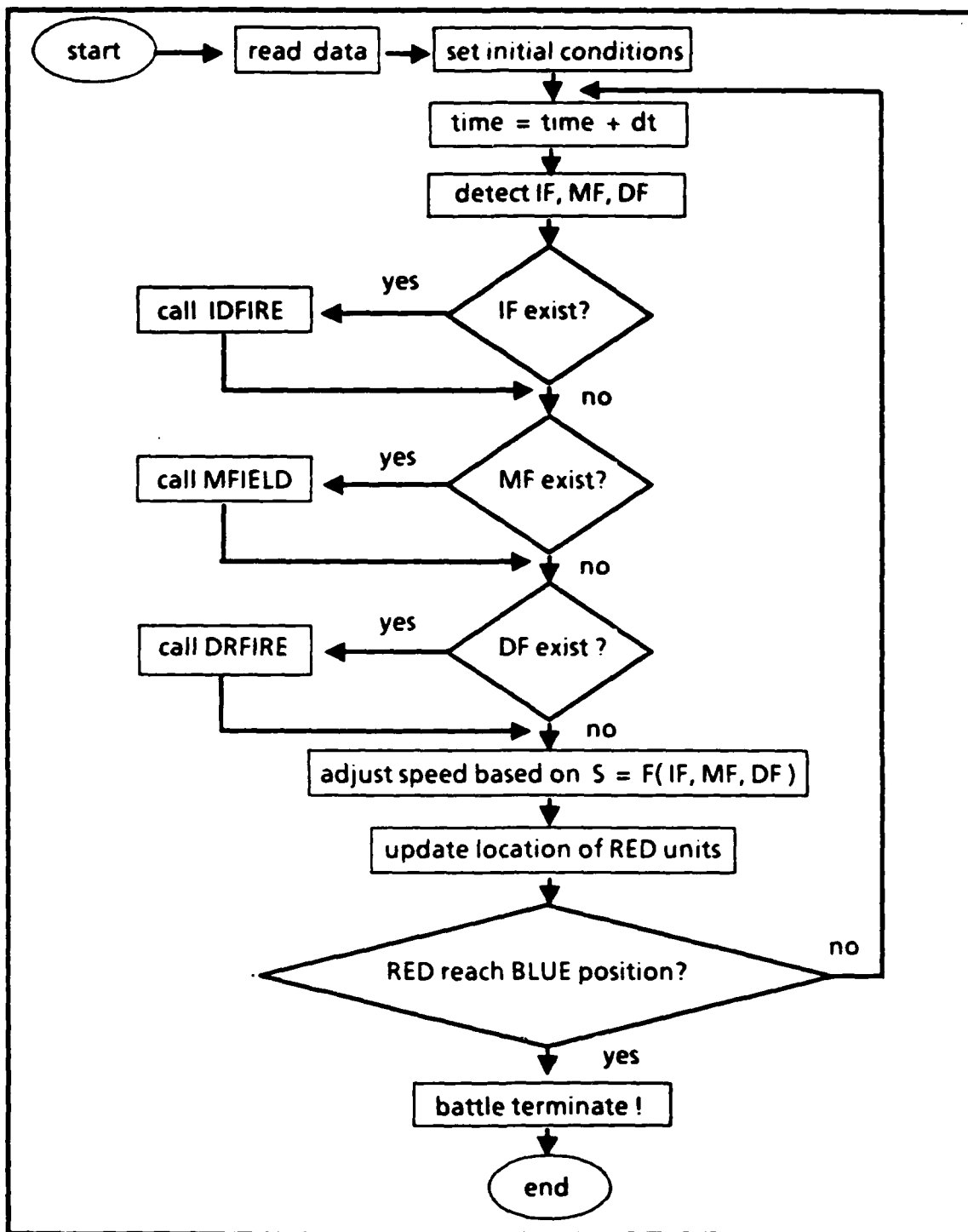


Figure 3. Flow chart of computer program for the basic model

DF = Direct Fire battle

IDFIRE = subroutine for computing the casualties by indirect fire.

MFIELD = subroutine for computing the casualties by minefield.

DRFIRE = subroutine for computing the casualties by direct fire.

The table for Red and Blue options can be represented as a 4 by 8 matrix (see Table 2).

Table 2. THE MATRIX OF RED AND BLUE OPTIONS

Options			Red's unit allocation on each avenue			
			1 1 1	0 2 1	0 1 2	0 3 0
Blue's unit allocation (1 2)	Scatterable mine allocation on each avenue	1 1 1	O_{11}	O_{12}	O_{13}	O_{14}
		0 2 1	O_{21}	O_{22}	O_{23}	O_{24}
		0 1 2	O_{31}	O_{32}	O_{33}	O_{34}
		0 3 0	O_{41}	O_{42}	O_{43}	O_{44}
Blue's unit allocation (2 1)	Scatterable mine allocation on each avenue	1 1 1	O_{51}	O_{52}	O_{53}	O_{54}
		0 2 1	O_{61}	O_{62}	O_{63}	O_{64}
		0 1 2	O_{71}	O_{72}	O_{73}	O_{74}
		0 3 0	O_{81}	O_{82}	O_{83}	O_{84}

As presented in Table 2, the Red force has four options based on its unit allocation, and the Blue force has eight options which represent all possible combinations of unit allocation with scatterable mine allocation (see assumptions 4, 5, and 6 previously discussed). Based on the Blue commander's tactical viewpoint and considering the geographical situations, the O_{22} (option-2 for Red and option-2 for Blue) battle case could be expected to occur in a real battle situation with higher probability than the other cases. Thus, O_{22} case was executed as an example output of the basic model and the results are shown in Figure 4.

In Figure 4, the numeric values corresponding to the Red and Blue options are the number of troop units or minefield packages (i.e., Bn, Co, Pkg) each allocates to each avenue of approach or position. These values remind the user of what he has entered interactively. In fact, this output shows precisely how the battle terminated and what the results are for each Blue position. A computer program of the basic model is provided in Appendix B.

RED OPTION ==> 0 2 1

BLUE OPTION

* SCATERABLE MINEFIELD ==> 0 2 1
(LOCATED ON ARCS) ==> 30 34 42

* FORCE ALLOCATION ==> 1 2

RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE END !
(BATTLE TIME ==> 225 MINUTES)

<<< RED CASUALTIES BY EACH TYPE OF BLUE FORCE >>>

	INDIRECT-FIRE	MINE-FIELD	DIRECT-FIRE
AVENUE#1	0.0	0.0	0.0
AVENUE#21	23.4	47.1	163.0
AVENUE#22	23.4	47.0	406.2
AVENUE#3	0.0	22.2	19.4
	46.8	116.3	588.6

<<< BLUE FORCE CASUALTIES FOR EACH POSITION >>>

	CASUALTIES	SURVIVORS
POSITION-1	55.7	134.3
POSITION-2	186.7	173.3

<<< TOTAL CASUALTIES AND SURVIVORS >>>

	INITIAL FORCE	CASUALTIES	SURVIVORS
RED	1650.0	751.7	898.3
BLUE	550.0	242.4	307.6

Figure 4. The output of the Basic model (BATTLE2 case)

2. Units casualties

a. Indirect fire

Casualties caused by indirect fire weapons are computed using single round lethalty and weapon firing rates. Target density is a major factor in computing casualties

and is defined as the distance between adjacent soldiers. The dispersion between troops decreases as Red allocates more than one unit (battalion) to one avenue. In other words, the number of Red infantrymen in a given area will increase. Also, in this model, the targets are represented as two dimensional, which means that an artillery projectile is represented as detonating on the ground, not in the air. A target under attack by artillery could consist of many personnel performing various functions of combat, and such consideration is taken into account in the computation of lethality. Lethal areas are computed for single conditions such as prone personnel. The definition of lethal area A_L is given by equation (2.1).

$$A_L = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} p(x,y|H) dx dy \quad (2.1)$$

where $p(x,y|H)$ is the conditional probability that a hit on a target element located at the point (x,y) on the ground results in an incapacitation for given height of burst H ($H=0$ in this model) [Ref. 4 : p. 14-9].

Using the Gaussian Lethality Function $p(x,y|H) = e^{-(x^2+y^2)/2a^2}$, and transforming into polar coordinates, equation (2.1) becomes equation (2.2).

$$\begin{aligned} A_L &= \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} e^{-(x^2+y^2)/2a^2} dx dy \\ &= \int_0^{2\pi} \int_0^{+\infty} e^{-r^2/2a^2} r dr d\theta = 2\pi a^2 \quad \text{where } r^2 = \sqrt{x^2 + y^2} \end{aligned} \quad (2.2)$$

A Red infantryman is assumed to be killed if he is within the lethal area. Thus, the probability of kill is the probability of hitting the lethal area multiplied by the proportion of lethal area of the entire target area, given in equation (2.3).

$$P(kill) = P(hit) \times Prop(lethal) \quad (2.3)$$

The $Prop(lethal)$ is calculated by dividing the total area of the Red force by the total lethal area per unit time from equation (2.4), and $P(hit)$ is computed for a two-dimensional target by equation (2.5).

$$Prop(lethal) = \frac{R_f \times A_L}{Row_{sp} \times Col_{sp} \times RF_c} \quad (2.4)$$

where

R_f : rate of fire per unit time

A_L : lethal area of each round

Row_{sp} : row spacing of each unit (infantrymen)

Col_{sp} : column spacing of each unit (infantrymen)

RF_c : current Red force size

$$P(hit) = \frac{a^2}{[(a^2 + \sigma_x^2)(a^2 + \sigma_y^2)]^{1/2}} \exp \left[-\frac{1}{2} \left\{ \left(\frac{\mu_x^2}{a^2 + \sigma_x^2} \right)^2 + \left(\frac{\mu_y^2}{a^2 + \sigma_y^2} \right)^2 \right\} \right] \quad (2.5)$$

where

a : lethality constant for each round type (where $Total A_L = 2\pi a^2$)

μ_x : mean distance of deflection error

μ_y : mean distance of range error

σ_x : standard deviation of deflection error

σ_y : standard deviation of range error

Finally, the casualties by indirect fire per unit time (IF_{cas}) are computed by equation (2.6) based on equations (2.3) through (2.5).

$$IF_{cas} = P(kill) \times RF_c \quad (2.6)$$

Table 3. THE RELATIVE LETHAL AREAS FOR A 155MM HOWITZER

Weapon and Caliber	Projectile	Area for Personnel (Open Woods : m ²)		
		Standing	Prone	Foxhole
M109A1 155-mm	M107	103.42.5	70.8 22.3	6.67/2.0
	M483	981/580	508.308	14.2/9.5
	M549	100.44.8	82.2 26.0	1.50 0.83

The source for 155 milimeter howitzer lethality data is [Ref. 4 : p. 43-9] which is shown in Table 3 for a range of 14km. For example, the value of a single round lethal area,

70.8m², is used when the Red force is in the prone position and is subjected to Blue indirect fire attack in the open.

b. Minefield packages.

It is assumed that the Blue force has five preinstalled minefield packages: one on Avenue-1, three on Avenue-2, and one on Avenue-3. Scatterable minefield packages are also employed by the Blue commander. The area fire assumptions of the "Lanchester Linear Law" are generally applied to indirect fire patterns of artillery. Minefields also exhibit these same patterns, and therefore the Lanchester Linear Law equations are appropriate for assuming minefield attrition. The equation for preinstalled minefield casualties is given in equation (2.7).

$$PMF_{cas} = P_{coef} \times N_{red} \times NP_{mine} \times T_p \quad (2.7)$$

The equation for scatterable minefield casualties is shown in equation (2.8).

$$SMF_{cas} = S_{coef} \times N_{red} \times NS_{mine} \times T_s \quad (2.8)$$

where

PMF_{cas} : number of casualties by preinstalled minefield

SMF_{cas} : number of casualties by scatterable minefield

P_{coef} : attrition coefficient of preinstalled minefield

S_{coef} : attrition coefficient of scatterable minefield

NP_{mine} : number of mines in one preinstalled minefield

NS_{mine} : number of mines in one scatterable minefield

T_p : time to traverse a preinstalled minefield

T_s : time to traverse a scatterable minefield

N_{red} : number of infantrymen traversing the minefield

The time to traverse each minefield is a constant value. When the Red force moves on an arc that has a minefield, Red's traversing time on that arc is increased by the amount of time needed to traverse the minefield. However, Red's speed on that arc decreases based upon the time to traverse the minefield, which will be discussed in detail in section 3.

c. Direct fire

Based on consideration of historical combat data, Helmbold has proposed a modification of Lanchester's equation for "modern warfare" to account for inefficien-

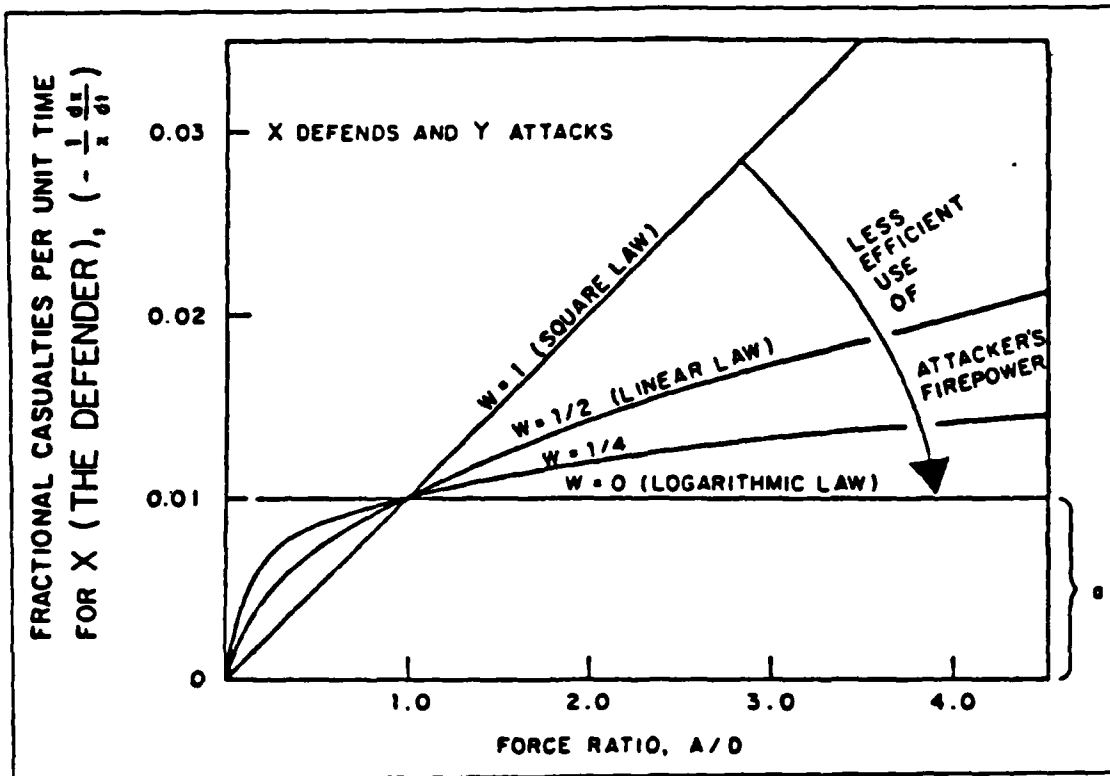


Figure 5. Relation between the defender's casualty rate and the attacker/defender force ratio. [NOTE: In the above figure, A denotes the attacker's force level, and D denotes that of the defender].

cies of scale for the larger force when force sizes are grossly unequal. His basic idea is to modify the relative force attrition (or fire effectiveness) capability by a multiplicative factor depending on only the force ratio. Helmbold considered the special case in which the fire effectiveness modification factor is a power function. In this case, the casualty rates of X and Y are

$$\frac{dx}{dt} = -a(t) \left(\frac{x}{y} \right)^{1-w} y \quad \text{with } x(0) = x_0 \quad (2.9)$$

$$\frac{dy}{dt} = -b(t) \left(\frac{y}{x} \right)^{1-w} x \quad \text{with } y(0) = y_0 \quad (2.10)$$

where w is called the *Weiss parameter*, and equations (2.9) and (2.10) are called the *equations for Helmbold type combat*.

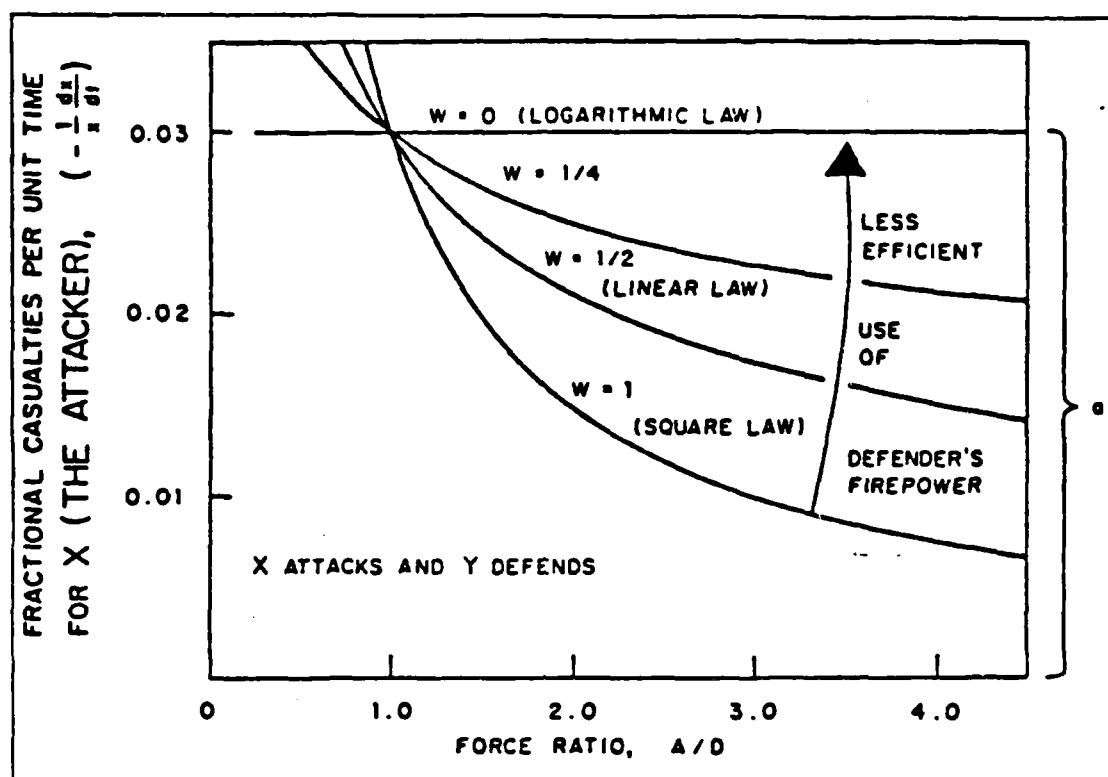


Figure 6. Relation between the attacker's casualty rate and the attacker/defender force ratio.

These equations are particularly significant because a simple generalization of them gives a much better fit to casualty rate curves used in several important contemporary large scale combat models than does Lanchester's classic model of modern warfare. As for the case of constant attrition rate coefficients (i.e., " $a(t)$ " and " $b(t)$ " from equations (2.9) and (2.10) become " a " and " b "), the equations for Helmbold type combat yield the Square Law when $w = 1$, the Linear Law when $w = 1/2$, and the Logarithmic Law when $w = 0$.

Figure 5 shows the relation between the defender's casualty rate (expressed as a fraction of his current force level, $x(t)$) and the attacker/defender force ratio for the model $dx/dt = -a(x/y)^{1-w} y$ with X defending. Figure 5 is X's fractional casualties plotted per unit time versus the force ratio y/x (denoted in the figure as A/D) for the case in which Y attacks and X defends. In Figure 5, $w = 1$ corresponds to the case in which X's casualty rate is proportional only to the number of enemy firers, and (in the sym-

metric case in which Y's casualty rate has the same functional form) consequently the corresponding attrition model is given by Lanchester's Square Law equation. We observe that in this case (i.e., $w=1$) X's fractional casualties per unit time are directly proportional to the force ratio A/D when Y attacks and X defends. Referring to equation (2.9), we see that $w=w_1$ corresponds to a more efficient use of the attacker's firepower for force ratios $A/D = y/x > 1$ than does $w=w_2$ when $1 \geq w_1 > w_2$, since the attacker's fire effectiveness modification factor for $w=w_1$ (i.e., $(x/y)^{1-w_1}$) is greater than that for $w=w_2$ when $y/x > 1$ [Ref. 5 : p. 299]. The following is a numerical example for Figure 5.

<EXAMPLE>

Let $a = 0.010$

$b = 0.020$

$x = 10$ (defender force size)

$y = 30$ (attacker force size)

hence, attacker to defender force ratio $A/D = y/x = 3.0$

Using equation (2.9), fractional casualties per unit time for X (the defender) are as follows:

	$w=1$	$w=1/2$	$w=1/4$	$w=0$
$-dx/dt$	0.300	0.173	0.132	0.100
$-(1/x)(dx/dt)$	0.030	0.0173	0.0132	0.010

Figure 6 shows the same type of plot when X is the attacker and Y is the defender. In this case, the casualty-rate curve corresponding to the Square Law is a hyperbola. Note, the smaller the value w ($0 \leq w \leq 1$), less efficient use of defender's firepower is made when attacker to defender force ratio (A/D) is greater than 1.0. However, the reverse phenomenon occurs when A/D is less than 1.0.

The strength of the equations for Helmbold type combat is that it easily incorporates either area fire or aimed fire with the Weiss parameter, " w ". These

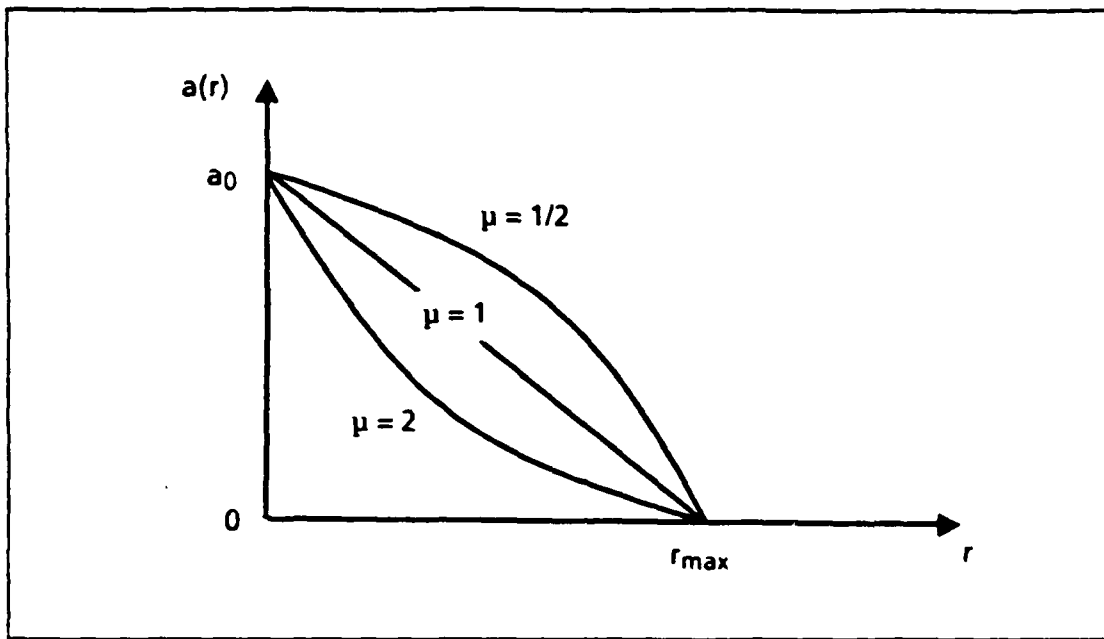


Figure 7. Relationship between range and attrition coefficient

equations are based on the perception that limitations in space, terrain masking and target engagement opportunities prevent a large force from using its full firepower. This deterministic model uses these Helmbold type combat equations for direct fire from fortified Blue positions (node 27 and 28), and the Lanchester's Mixed Law (which is the special case of Helmbold type combat where $w = 1$ for one side and $w = 1/2$ for the other) is utilized for ambushes on arc-19 of the second avenue of approach. The ambush point is determined by the Blue commander. The ambushes will terminate when the Red forces reach the Blue ambush point, and Blue survivors will retreat to join their main forces at node-27 or node-28.

The range dependency is considered for both cases (at nodes 27 and 28, and the ambush point). This implies that attrition rate coefficients for each side increase as the Red force approaches the Blue position. Plotting attrition rate coefficients as a function of range shows how different values of μ (power factor based on different weapon types) affect battle outcomes. Figure 7 shows the relationship between range and attrition coefficients.

A common tactic that is employed to counter multiple Red forces approaching a Blue position is discussed next. Each Blue position has two possible ave-

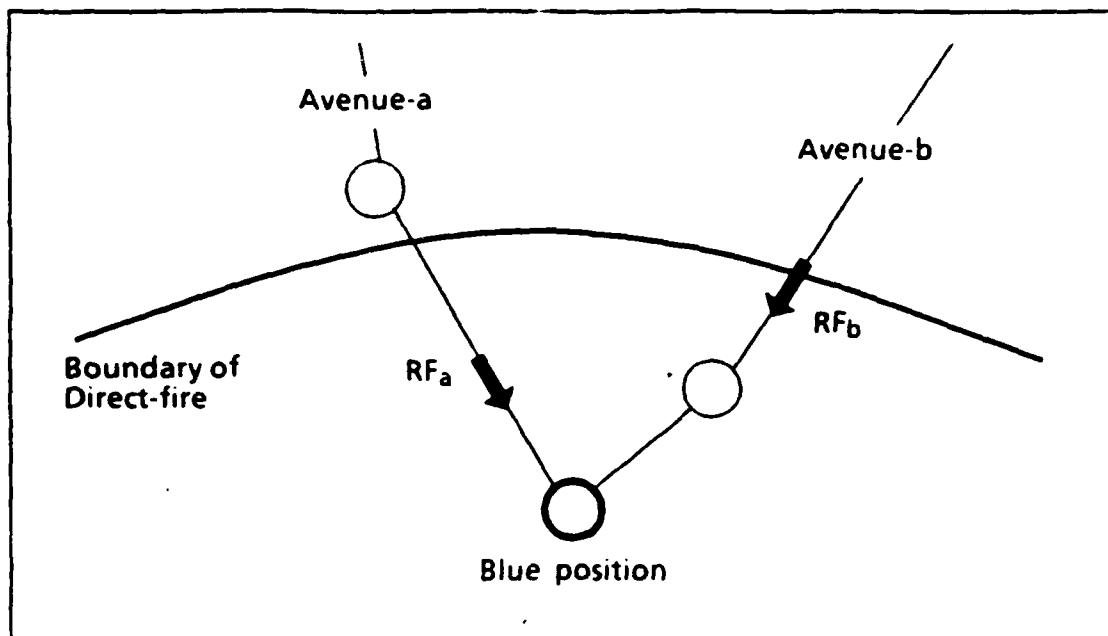


Figure 8. Battle case when a Blue is threatened from two directions

nues of approach: Avenue-1 and Avenue-21 for node-28, and Avenue-22 and Avenue-3 for node-27. If a Blue position is threatened simultaneously from both avenues of approach within its direct fire region, Blue allocates firepower based on the proportion of Red forces on that avenue of approach. The number of Blue forces firing on Avenue-a are given by equation (2.11)

$$BF_a = BF_0 \times \frac{RF_a}{RF_a + RF_b} \quad (2.11)$$

The number of Blue forces firing on Avenue-b are given by equation (2.12)

$$BF_b = BF_0 \times \frac{RF_b}{RF_a + RF_b} \quad (2.12)$$

where

- BF_a : Blue forces firing into Avenue-a
- BF_b : Blue forces firing into Avenue-b
- RF_a : Red forces attacking from Avenue-a
- RF_b : Red forces attacking from Avenue-b

BF_0 : Blue forces at the moment two Red forces engage a Blue position.

Once the Blue force allocates its firepower, it continues at a steady rate until battle termination. Figure 8 depicts a Blue position being attacked by Red units on two avenues of approach.

The following equations used in this deterministic model represent both range dependency and the Weiss parameter.

$$\frac{dx}{dt} = -a_0 \left(1 - \frac{r_c}{r_{\max}}\right)^{\mu_y} \left(\frac{x}{y}\right)^{1-\omega_y y} \quad (2.13)$$

$$\frac{dy}{dt} = -b_0 \left(1 - \frac{r_c}{r_{\max}}\right)^{\mu_x} \left(\frac{y}{x}\right)^{1-\omega_x x} \quad (2.14)$$

where

x : Red force size

y : Blue force size

a_0 : maximum attrition rate coefficient to Red from Blue

b_0 : maximum attrition rate coefficient to Blue from Red

r_c : current range between Red force and Blue force

$r_{\max}$: maximum range between the Red force and the Blue force (1.1 Km by assumption).

μ_y : power factor, based on Blue weapon types

μ_x : power factor, based on Red weapon types

ω_y : measure of efficiency which the Blue force engages the Red force.

ω_x : measure of efficiency which the Red force engages the Blue force.

Equation (2.13) is used for Red casualties while equation (2.14) is used for Blue casualties during a specific time step. Note that different values of μ and ω are used for the Red and the Blue force.

3. Unit speed

a. Indirect fire and Minefields

When Red forces move over the arcs which have indirect fire or minefields, they are delayed for a specified amount of time. If the delay time is denoted by DT, the updated speed is computed by equation (2.15).

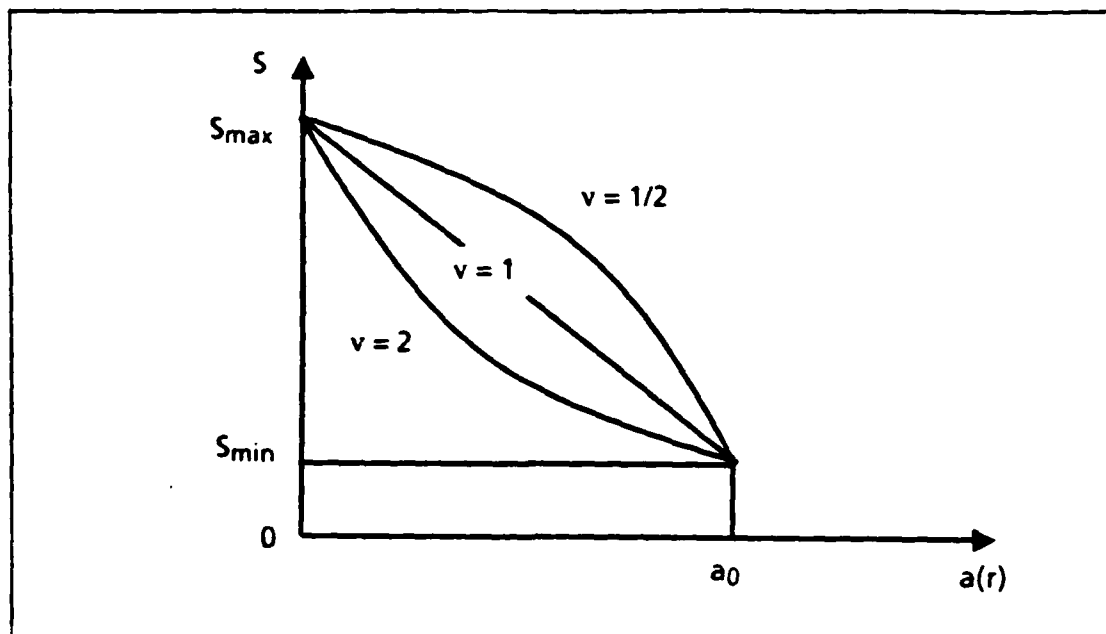


Figure 9. Speed of attacking force versus their attrition coefficient [S vs $a(r)$].

$$S_{new} = \frac{DIST(arc_i)}{TIME(arc_i) + DT_i} \quad i = a, b, c \quad (2.15)$$

where

$DIST(arc_i)$: distance of arc,

$TIME(arc_i)$: amount of time to transit arc,

DT_i : delay time on arc,

arc_a : arcs which are being subjected to indirect fire

arc_b : arcs which have preinstalled minefields

arc_c : arcs which have scatterable minefields

b. Direct fire

To update the location of the Red force in the direct fire region, equation (2.16) is used to calculate the Red force speed during each time step. The equation shows that unit speed decreases as the range between opposing forces decreases, but gets no smaller than a specified minimum speed (S_{min}).

$$S_{new} = S_{old} \times (1 - \frac{a_c}{a_0})^v + S_{min} \quad (2.16)$$

where

v : power factor, based on different weapon types

S_{new} : updated speed of attacking force

S_{old} : speed of attacking force for past time step

S_{min} : minimum speed for the attacking force

a_c : current attrition coefficient

a_0 : maximum attrition coefficient

Equation (2.16) is portrayed graphically in Figure 9. Actual model results are discussed in Chapter 3

4. Advanced model

To obtain the required data for analysis, the basic model is expanded. The advanced model uses the basic model as a submodel and produces two output matrices (see Figure 11). The upper portion of the figure is the output matrix of four selected MOE values for use in Table 2, which is a 4 by 8 matrix for the Red and Blue options for each MOE. MOE-1 through MOE-4 represent Red casualties, Blue survivors, duration of battle, and Red to Blue casualty ratio, respectively. The lower part of the figure contains utility values for three different utility functions (Linear, Squared, and Square Root) versus Blue options for MOE-2 values (Blue survivors). The utility values are based upon the way the Blue commander weighs the Red options. The characteristics of each utility function and weighted utility values are discussed in Chapter 3.

In the advanced model, the user can decide whether the attacking Red forces through Avenue-2 are equally divided at node-14 (BATTLE2 case), or continue to attack to only one of the Blue positions (BATTLE1 case). The computer program of the advanced model is listed in Appendix D. The flow chart of the advanced model is in Figure 10, and the following definitions apply:

BATTLE1 = basic model which has three avenues of approach (Red force on Avenue-2 will choose only one of two objectives to attack).

BATTLE2 = basic model which starts with three avenues of approach but divides into four because the Red force on Avenue-2 will be divided equally at node-14 and attacks toward each objective, respectively.

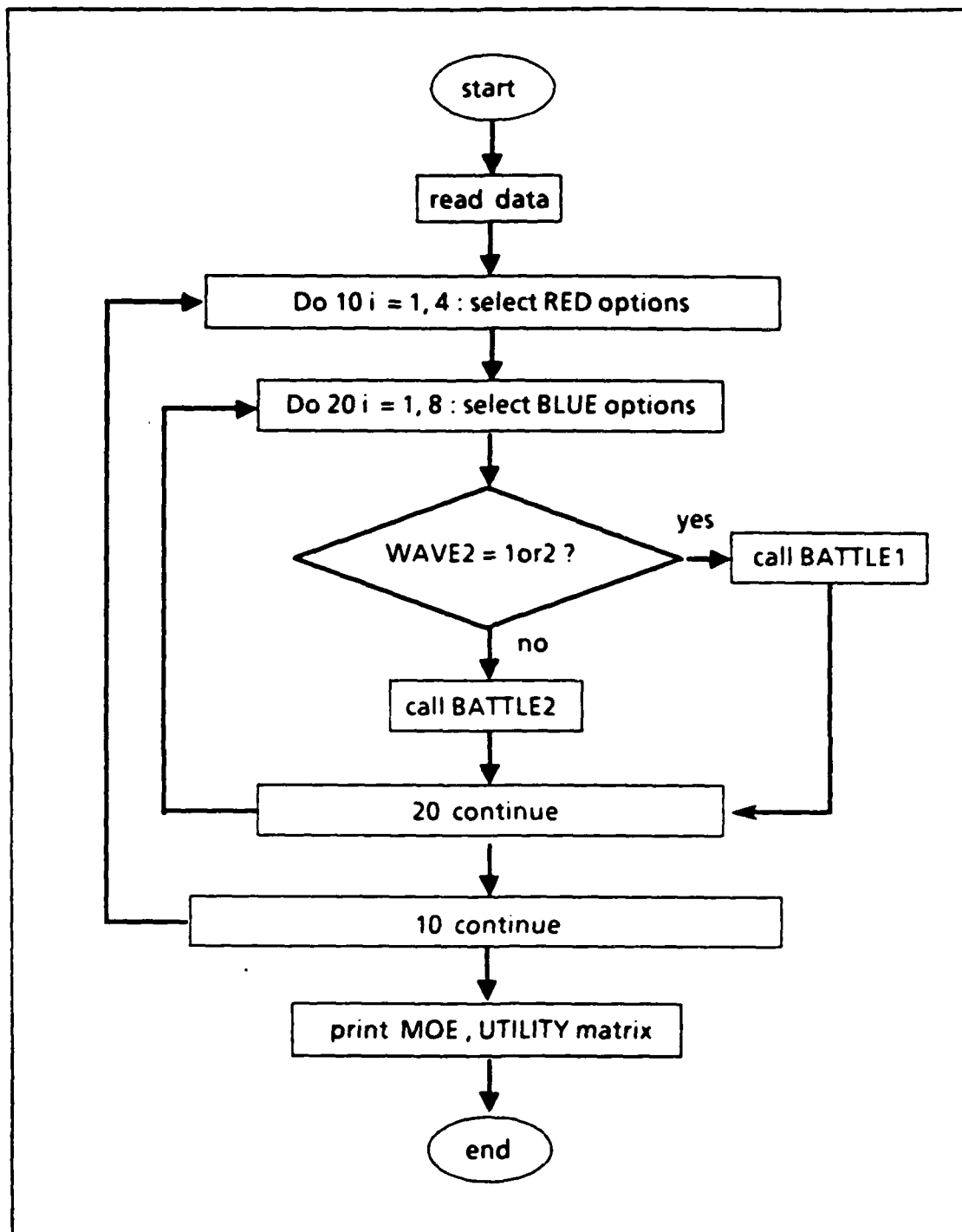


Figure 10. Flow chart of the advanced model

WAVE2 = numeric value (1, 2, or 12) which is supposed to be given by the model user ; if WAVE2=1, it will be a BATTLE1 case, and all Red forces on Avenue-2 attack to node-28 ; if WAVE2=2, it will also be a BATTLE1 case, but all Red forces on Avenue-2 attack to node-27 ; if WAVE2=12, it will be a BATTLE2 case.

These outputs will be analyzed in more detail in the next chapter. The example output of the advanced model is shown in Figure 11.

<< MOE VALUES BASED ON THE RED AND BLUE OPTIONS >>					
BLUE	RED	1	2	3	4
1	759.6	802.3	949.2	828.5	<== MOE-1
1	349.9	278.1	219.9	230.1	<== MOE-2
1	215.0	225.0	290.0	229.0	<== MOE-3
1	3.80	2.95	2.88	2.59	<== MOE-4
2	795.2	751.7	951.3	783.0	
2	321.1	307.6	220.0	268.9	
2	224.0	225.0	290.0	229.0	
2	3.47	3.10	2.88	2.79	
3	786.9	795.4	967.3	817.1	
3	321.7	278.4	241.6	230.4	
3	223.0	225.0	283.0	229.0	
3	3.45	2.93	3.14	2.56	
4	771.0	752.0	923.0	787.0	
4	345.5	297.3	224.4	271.0	
4	215.0	225.0	280.0	229.0	
4	3.77	2.98	2.83	2.82	
5	768.6	747.8	810.1	733.7	
5	336.3	298.7	297.5	251.1	
5	215.0	225.0	290.0	229.0	
5	3.60	2.98	3.21	2.45	
6	813.9	639.9	808.9	630.5	
6	316.5	346.3	297.9	305.0	
6	224.0	225.0	290.0	229.0	
6	3.49	3.14	3.21	2.57	
7	803.5	737.4	847.3	722.1	
7	305.7	299.1	307.1	251.4	
7	223.0	225.0	283.0	229.0	
7	3.29	2.94	3.49	2.42	
8	773.9	632.4	787.7	631.3	
8	345.5	342.3	300.4	308.0	
8	215.0	225.0	280.0	229.0	
8	3.79	3.05	3.16	2.61	
<< WEIGHTED UTILITY VALUES USING MOE-2 >>					
	LINEAR U(X)	SQUARED U(X)	SQUARE ROOT U(X)		
1	44.56	24.24	69.87		
2	48.47	29.19	73.32		
3	44.05	24.14	69.90		
4	48.10	28.14	72.67		
5	47.63	28.17	72.70		
6	61.69	37.05	77.92		
7	47.51	28.00	72.62		
8	62.09	36.87	77.86		

Figure 11. The output of the advanced model

III. MODEL OUTPUT ANALYSIS

A. OVERVIEW

As mentioned in Chapter 1, the purpose of this thesis is to analyze the key variables of air-land combat models in high resolution and provide some analytical methodologies. This chapter focuses on several methods of analysis of model output while the following chapter explores various sensitivity analyses.

Since this model is sequenced by time steps, the user can easily visualize the battle situation as the battle progresses. For example, if the Blue force places a certain size minefield on a certain arc of the network terrain model, the output will show how the minefield affects the casualties and speed of the Red force. The next four figures (Figure 12-15) provide more displays of battle situations which occur on each avenue. Figures 12-15 are created based on sample output of the basic model in the previous chapter. In this battle case, the Red force is assumed to take option-2 (allocation of two battalions on Avenue-2, one battalion on Avenue-3, and no unit allocation on Avenue-1). The Blue force is assumed to employ option-2, which locates one company on position-1 (node-28) and two companies on position-2 (node-27), etc. (see O_{22} of Table 2 in Chapter 2).

Figure 12 shows how the Red and Blue force sizes are decreasing on each avenue. Note that the Red forces attacking on Avenue-22 are severely attrited and end up with approximately one third of the initial forces even though they were reinforced by a reserve company (150 infantrymen). The unit reinforcement is supposed to occur if the Red forces are less than the Blue forces after they are engaged in the direct fire battle. On Avenue-22 of Figure 12, Red on that avenue is reinforced at battle time 160 which appears to be the beginning of the direct fire battle. The Blue force lost more than half of the initial forces in combat on position-2. The approximate number of casualties caused by the indirect fire and ambush attack can also be observed. Note, in Figure 12, that the Red casualties on Avenue-22 are much more than those on the other avenues of approach. In other words, the intensity of the battle between Red forces on Avenue-22 and Blue force on position-2 was very high. There are no forces on Avenue-1 because the Red force did not allocate any forces there.

Figure 13 depicts the size or proportion of Red casualties in relation to each weapon employed by the Blue force, such as indirect fire, mines, and direct fire. For example,

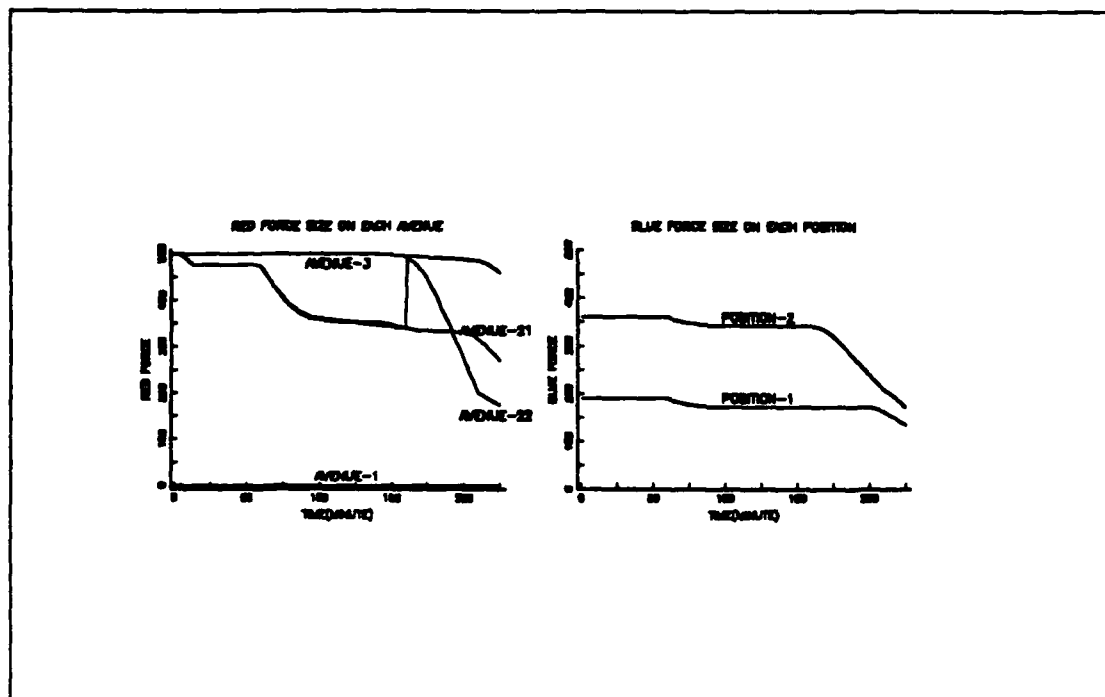


Figure 12. Red and Blue force sizes over time

on Avenue-22, a high proportion of the Red casualties were due to direct fire. Another item depicted is that the time when the Red force engaged in direct fire is based on the slope of the curve (i.e., the point that the slope of curve changes abruptly). An ambush attack occurred from approximately 55 to 90 on the battle clock (for 35 minutes) on Avenue-2 (actually this happened before the Red was divided onto Avenue-21 and Avenue-22 at node-14). The Red force on Avenue-21 entered the direct fire region at about 205 battle clock time, and at about 160 on Avenue-22, and at about 210 on Avenue-3. So, after 210 minutes, the Blue position-2 started to be threatened from two directions which were from Avenue-22 and Avenue-3. Note, even though the range of Avenue-21 (9.45Km : initial distance between Red and Blue force when the battle clock equaled 0) was much shorter than that of Avenue-3 (13.55Km), the Red forces on Avenue-21 and Avenue-3 were engaged in direct fire with the Blue force for a shorter period of time (between 205 and 210 minutes). That was because the Red forces on Avenue-21 were attrited more by Blue forces and their obstacles than those on Avenue-3.

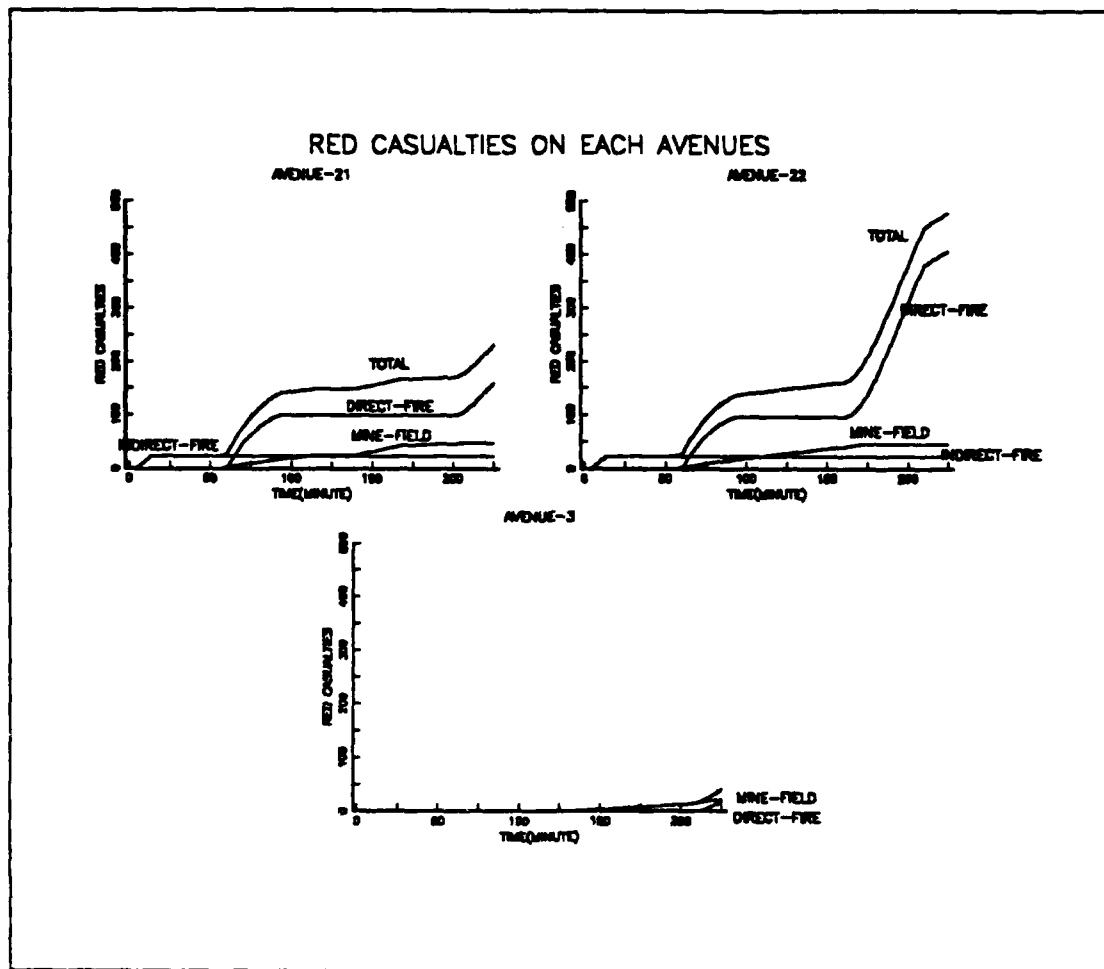


Figure 13. The Red casualties by different types of Blue weapons

The Blue commander may want to know where the Red forces are at certain times and the distance from which they are attacking. Figure 14 shows not only when the battle terminates but also who reached one of the Blue positions first. The Red force from Avenue-22 took the Blue position first in this battle case. In Figure 14, the slope of each curve represents the speed of the Red forces. For example, Avenue-3 has a constant speed from 0 to 130 battle clock time which means there is no attrition during that time, and Avenue-21 and Avenue-22 have very small slopes (low speed) during an ambush attack by Blue forces (from 55 to 90 battle clock time).

The speed of Red force is another important factor which can cause different Blue responses. Sometimes, the Blue forces need to know when the Red forces will reach their

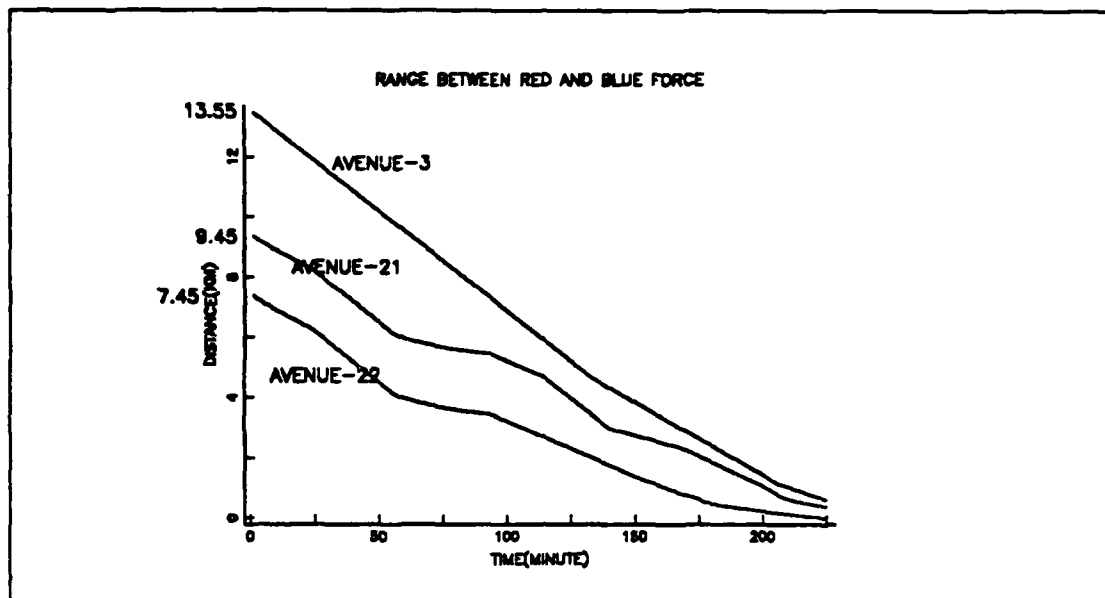


Figure 14. Distance between Red and Blue forces over time.

positions in order to prepare and decide on an effective course of action. The average speed of the attacker can be calculated from Figure 14.

Figure 15 also shows how fast the Red force moves and how their maneuverability is reduced by indirect fire, minefields, and the direct fire of the Blue force on each avenue. In the direct fire region, the Red forces are forced to slow their movement depicted by exponential shaped curve. Note how the curve changes during the ambush battle (at 55-90 battle clock).

B. MEASURES OF EFFECTIVENESS (MOES)

After considering the battle situations, four MOE values were selected to estimate how they changed in each of the time steps. The four MOEs are as follows:

- MOE-1 : number of Red casualties
- MOE-2 : number of Blue survivors
- MOE-3 : duration of battle
- MOE-4 : ratio of Red and Blue casualties (Loss exchange rates)

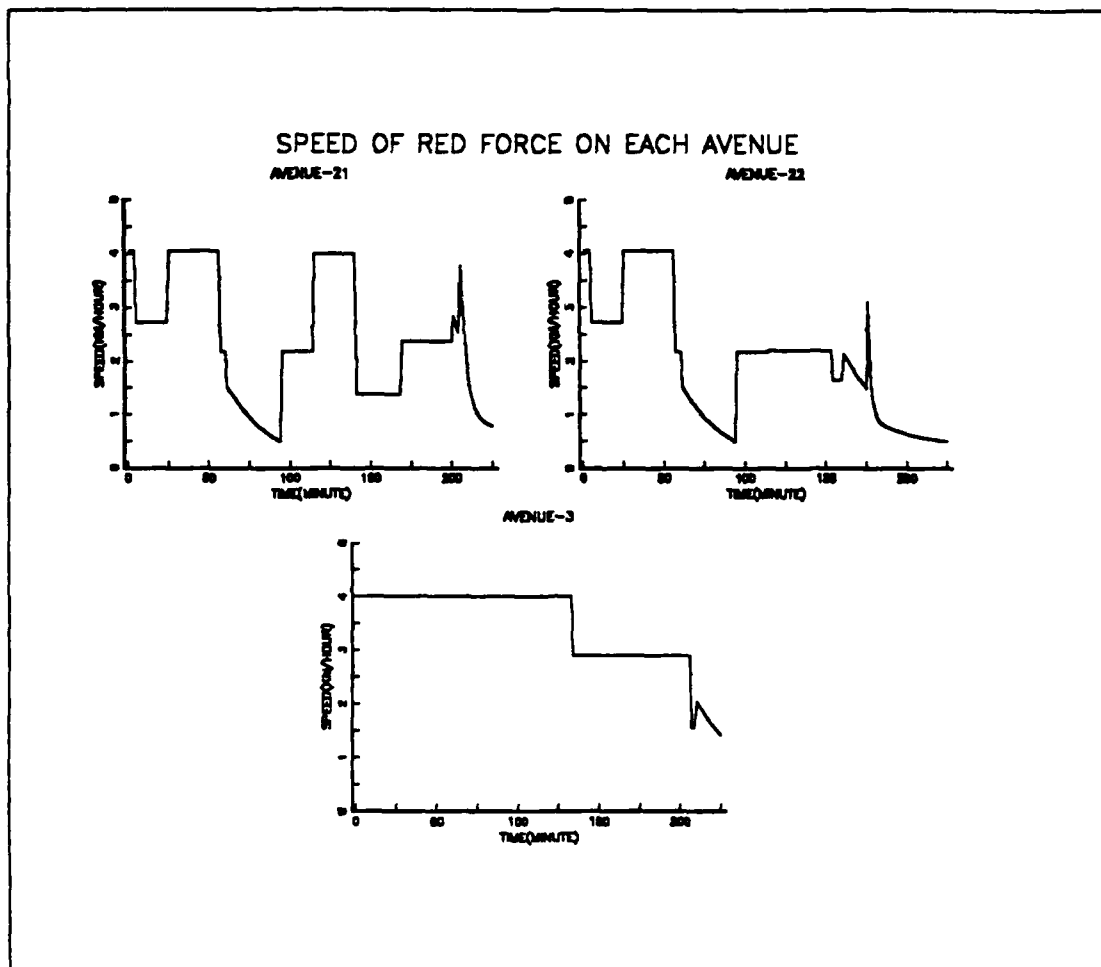


Figure 15. Speed of Red force on each avenue over time.

Larger MOE values are better for the Blue forces in all cases. The characteristics of all the MOEs' for this scenario are shown on Figure 16. For the particular option of Red and Blue, refer to Table 2 in Chapter 2.

For MOE-1, if the Red chose option-2, then the Blue force should select option-1, because the Blue force wants to maximize Red casualties (MOE-1). Blue has no large differences among its options for Red option-1. Note that Red options 2 and 4 show approximately the same tendency and this also happens for MOE-3. This implies that there is some relation between MOE-1 and MOE-3. In other words, Red casualties depend on how long the battle lasts.

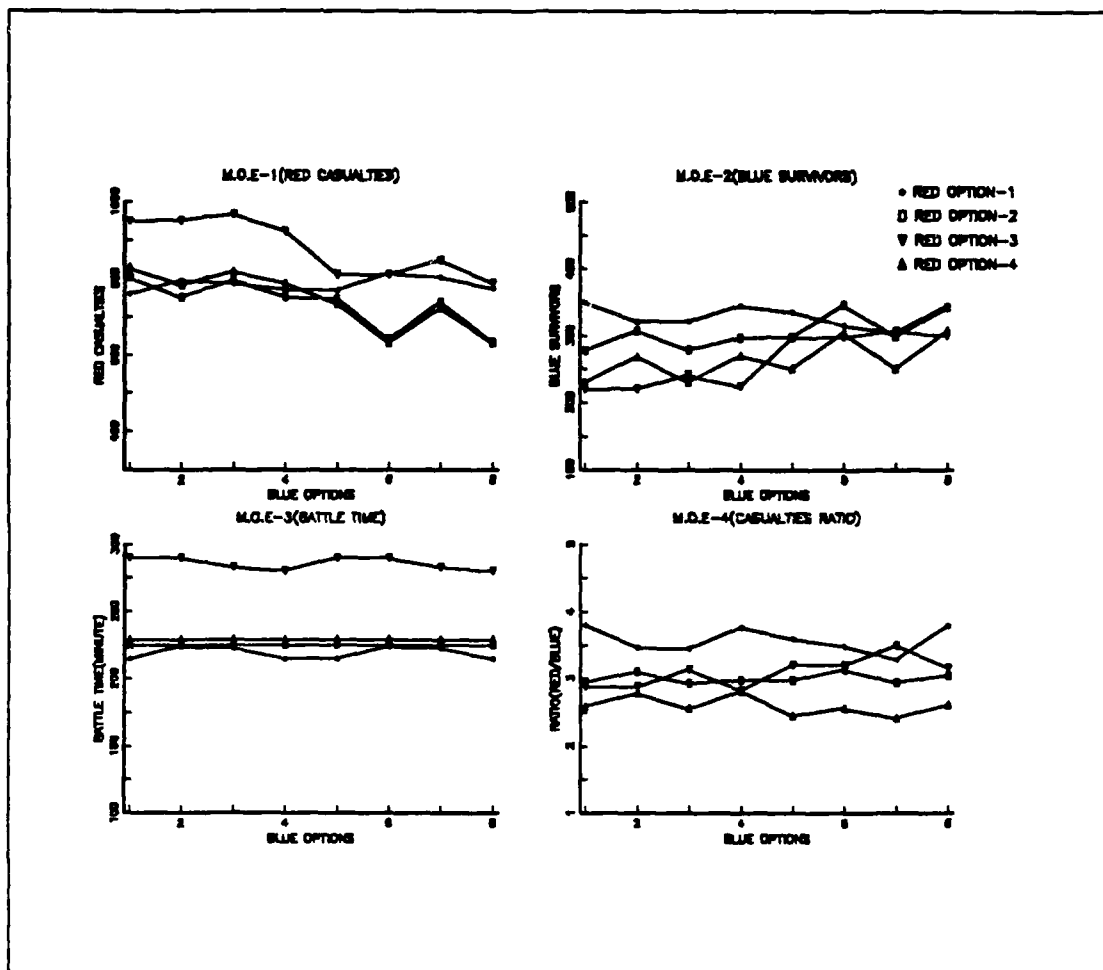


Figure 16. The MOE values for each options of Red and Blue (BATTLE2)

For MOE-2, the Blue forces are affected by the Red options in Blue option 1 through 5 but they are not severely affected in Blue option 6, 7, and 8. Note that Red option 2 and 4 of MOE-2 show almost reverse trends against those of MOE-1. This implies that the Red casualties have a negative correlation with the Blue survivors which agrees with the theoretical battle concept.

For MOE-3, Red option-3 has a longer battle time than any other options. The reason this occurs is that Red's main forces (two battalions) attack to the Blue positions over the Avenue-3 which is the longest among the three major avenues of approach. If the Red forces choose option 2 or 4, MOE-3 has constant values of 225 and 229, re-

spectively. In other words, when the Red force allocates more than two units (battalions) on Avenue-2, the duration of battle will be same regardless of Blue's options.

MOE-4 seems to have some relationship with MOE-2, but the relationship is not entirely clear except for the Red option-1. It would require more analysis to verify the relationship between them such as a coefficient of correlation (ρ).

To summarize the MOEs, it is difficult to pick the best option which is the most beneficial for all MOEs for the Blue force. The course of action is strongly based on how Blue's decision maker wants to drive the battle according to his tactical courses of action.

C. COMPARISON BETWEEN BATTLE1 AND BATTLE2

This section will discuss differences between the results of BATTLE1 and BATTLE2. BATTLE1 has two approaches which the Red force can take on Avenue-2. So, in total, three battle types are compared. For a description of BATTLE1 and BATTLE2, refer to the last part of Chapter 2. The output of BATTLE1 came from the same battle which was discussed in Chapter 2 (Red's second option with Blue's second option). The differences are given in Table 4.

Table 4. COMPARISON OF MOES BETWEEN BATTLE1 AND BATTLE2

value names	BATTLE1		BATTLE2
	with Avenue-21	with Avenue-22	
MOE-1	763.3	609.3	751.7
MOE-2	158.6	242.8	307.6
MOE-3	264.0	228.0	225.0
MOE-4	1.95	1.98	3.10
Who reaches Where first?	Red on Avenue-3 to Node 27	Red on Avenue-22 to Node 27	Red on Avenue-22 to Node 27

From the Red force's viewpoint, it is better to choose Avenue-22 over Avenue-21 based on Red casualties (MOE-1) and duration of battle (MOE-3) since $609.3 < 763.3$ and $228 < 264$ [Note, the smaller MOE values is better for the Red force]. Compared with BATTLE2, if the Red force chooses Avenue-22 in BATTLE1, it can reduce its casualties and kill more Blue forces, even though the duration of battle increases by three minutes. The Red Blue casualty ratio (MOE-4) is indifferent as to whether the Red force

chooses Avenue-21 or Avenue-22 in BATTLE1 (1.95 and 1.98). In BATTLE2, MOE-4 is much larger.

When the Red force chooses Avenue-21 in BATTLE1, the duration of battle increases to its greatest value, because the Red forces attacking through the longest path (Avenue-3) reached the Blue position (node-27) first and battle was terminated. From Blue's viewpoint, if the Blue force attempts to prolong the battle, it will attempt to channelize Red forces on Avenue-2 into Avenue-21 (because the duration of battle for BATTLE1 with Avenue-21 is the highest; 264 minutes in Table 4). Installing more mines and obstacles or conducting ambushes on Avenue-2 should be considered by the Blue force. As shown in Figure 17, Blue is at a disadvantage if Red chooses Avenue-22 in BATTLE1 (i.e., the best way for Red). Since Figure 17 was drawn with MOE ratios based on BATTLE2 battle type, it clearly shows the relative proportion of changes among the three battle types. Figure 17 also shows that the attacking force usually has the advantage in concentrating its forces on one objective, which is a well-known tactical concept of war.

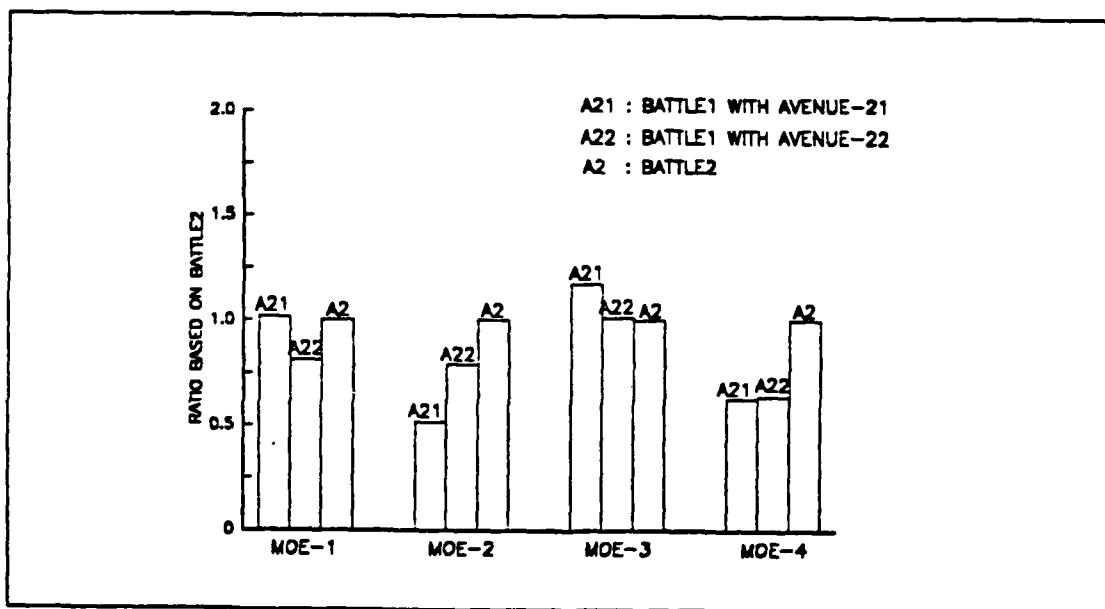


Figure 17. Ratio of MOEs in BATTLE1 types based on BATTLE2 type.

Figure 18 describes how all the battle case MOE's change when the Red forces that are on Avenue-2 choose Avenue-21. Compared with BATTLE2 (Figure 16), Red casualties (MOE-1) and the ratio of Red to Blue casualties (MOE-4) are relatively small, and

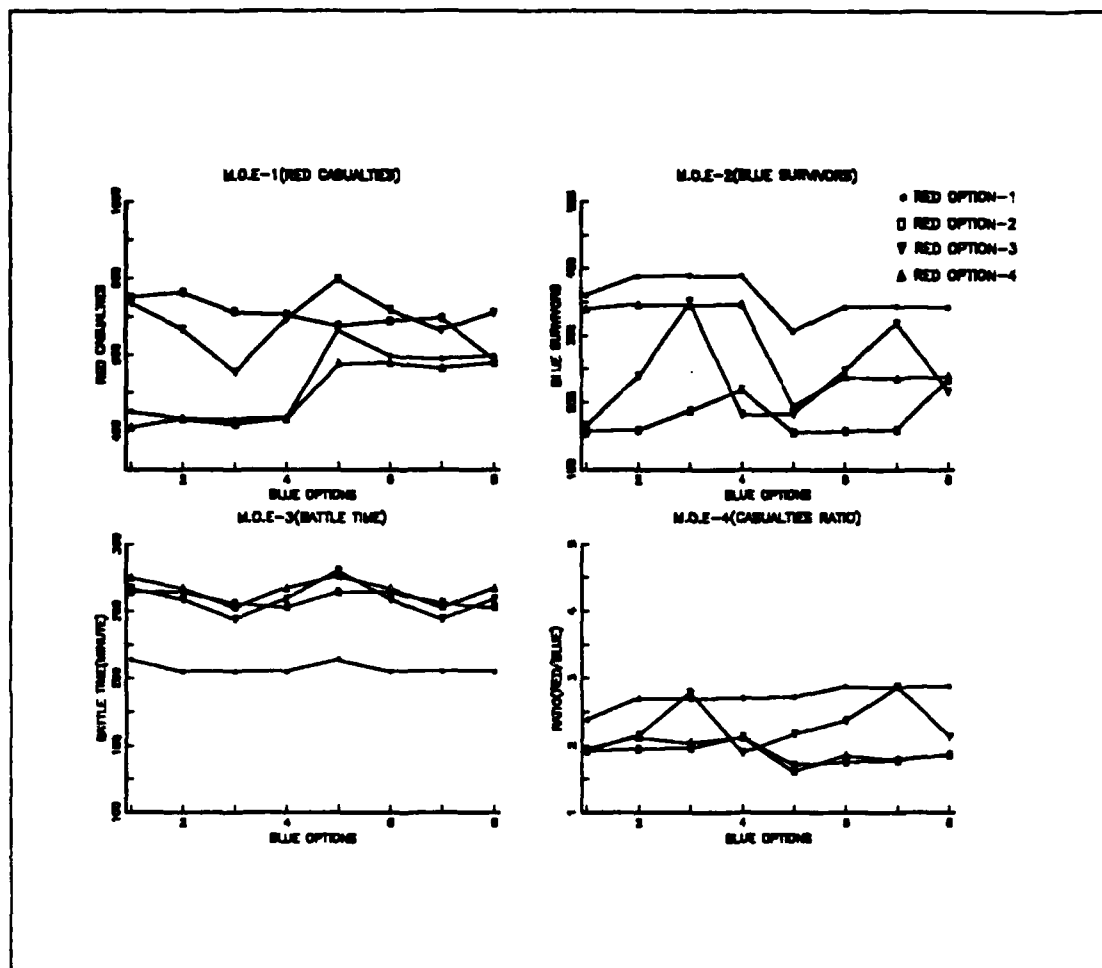


Figure 18. MOEs for each options of Red and Blue (BATTLE1 with Avenue-21)

the variance of Blue survivors (MOE-2) based on the Red options is large. Generally, the duration of battle (MOE-3) increases in BATTLE1 on Avenue-21, though Red casualties decrease (i.e., rate of killing per time is decreased). This fact implies that the number of units (infantrymen) engaging in direct fire in BATTLE1 on Avenue-21 is smaller than that of BATTLE2. In other words, the troop density in BATTLE1 on Avenue-21 is small.

Figure 19 shows how all battle MOEs change when Red forces on Avenue-2 choose Avenue-22. In this battle, Red casualties (MOE-1) are the smallest among all three battle types. For MOE-1, there is a interesting phenomena which is that Red option-1 case has a reverse shape from all other Red option cases with respect to the Blue

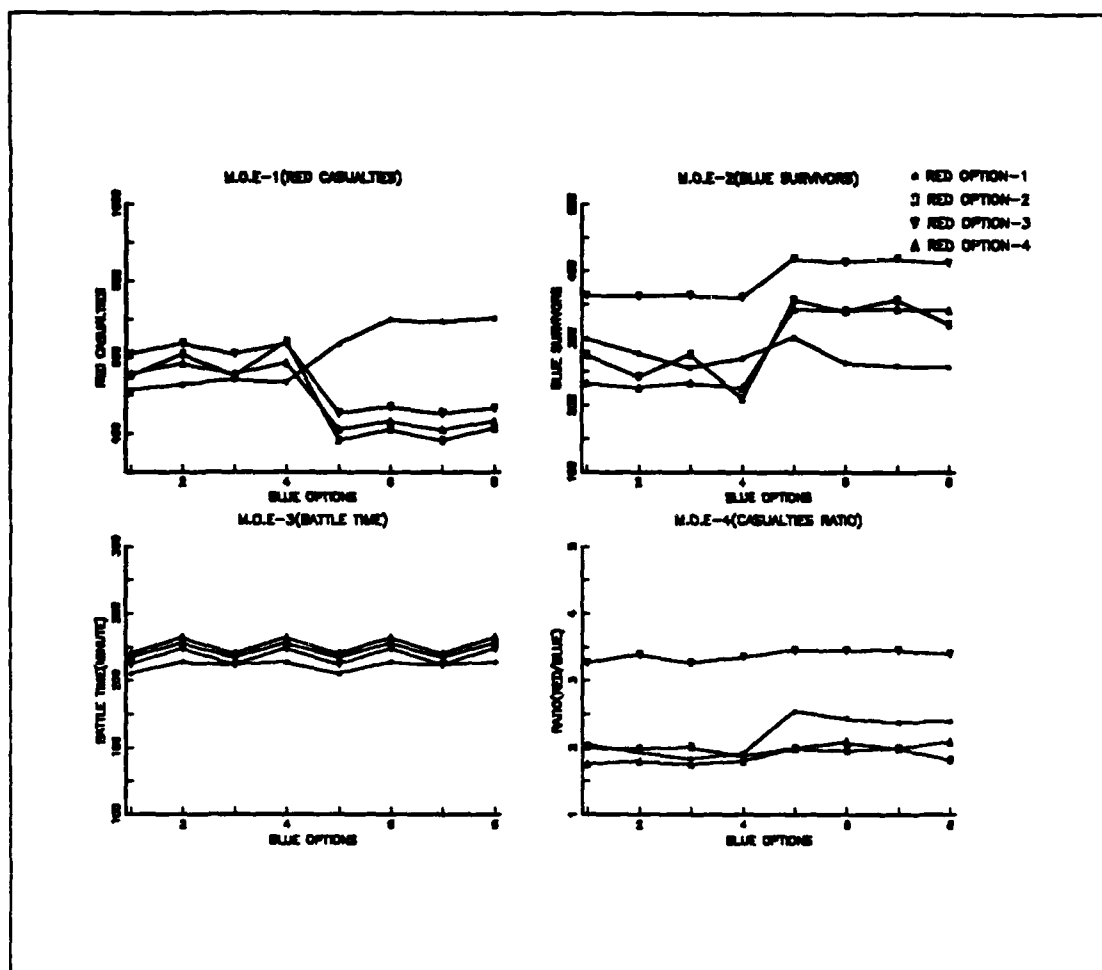


Figure 19. MOEs for each options of Red and Blue (BATTLE1 with Avenue-22)

options. For the duration of battle (MOE-3), there are no large differences among the Red options. All MOE-3 values are between 205 and 235 minutes of battle time, because all 32 battle cases (four Red options with eight Blue options) are terminated by the Red forces on Avenue-22. Therefore, this deterministic model shows that the Blue force needs other courses of actions in order to hold its positions for more than 4 hours. Blue survivors (MOE-2) and ratio of Red to Blue casualties (MOE-4), values are relatively constant for each Red option based on Blue options.

In summary, the assumption that the Red force will choose BATTLE1 on Avenue-22 forces Blue to consider other courses of action against Red.

D. UTILITY THEORY

1. General

Individuals (or Decision Makers) frequently must choose among alternatives that differ, among other things, in the degree of risk to which the individual will be subjected. The clearest examples are provided by insurance and gambling. An individual who buys fire insurance on a house he owns is accepting the certain loss of a small sum (the insurance premium) in preference to the combination of a small chance of a much larger loss (the value of the house) and a large chance of no loss. That is, he is choosing certainty in preference to uncertainty. An individual who buys a lottery ticket is subjecting himself to a large chance of losing a small amount (the price of lottery ticket) plus a small chance of winning a large amount (a prize) in preference to avoiding both risks. He is choosing uncertainty in preference to certainty. [Ref. 6 : p. 234].

In order to develop a means to rank probability distributions we must resort to the theory of "Utility". This provides a consistent way in which to combine different figures of merits or sub-MOE's, subjective and judgemental factors, and probabilistic aspects of outcomes (i.e., risk factors) into an overall MOE appropriate for the level in the hierarchy in which each decision maker must function. [Ref. 7 : p. 9].

2. Application

Three different utility functions are proposed to compare each battle situation by using MOE-2, which is the number of Blue survivors. These utility functions are represented as linear, squared, and square root, and are depicted in Figure 20. The utility curves reflect the decision maker's judgement.

a. Linear Utility

Using the fact that the utility functions are arbitrary up to a positive linear transformation, for convenience we define:

$$U(550 \text{ survivors, i.e., no losses}) = 100$$

$$U(0 \text{ survivors, i.e., all losses}) = 0$$

As a Blue decision maker, it is assumed that if the number of survivors decrease to less than 340, which is the size of two companies (i.e., if they lost one company out of three), the utility value of the Blue force drops with a 10 percent step change. The appropriate function for linear utility is given by equation (3.1).

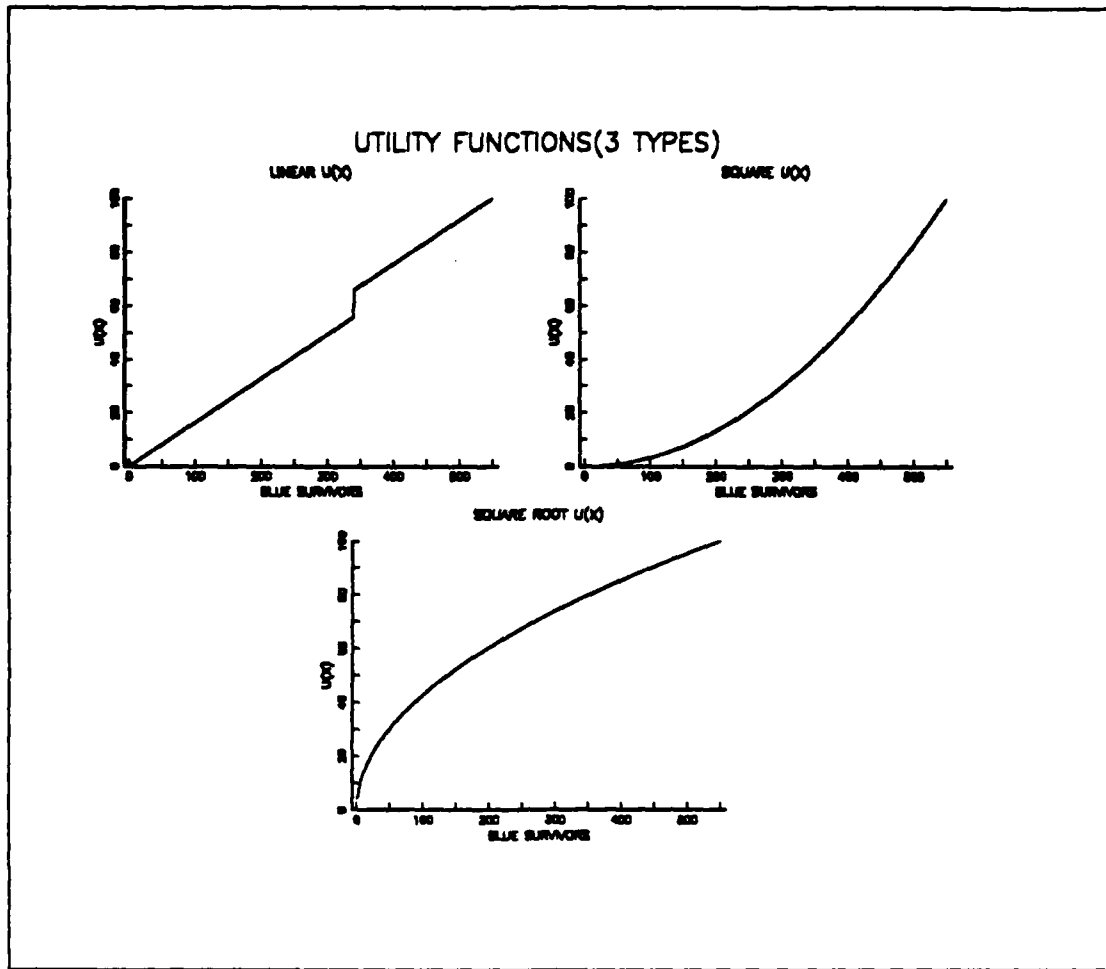


Figure 20. Three different utility distribution functions.

$$\begin{aligned}
 U(x) &= \frac{9}{55}x, & x < 340 \\
 &= \frac{9}{55}x + 10, & x \geq 340 \\
 &= 0, & \text{otherwise}
 \end{aligned} \tag{3.1}$$

b. Squared Utility

This is concave upward function which will result in a *risk preferring* decision. The appropriate function for squared utility is given by equation (3.2).

$$U(x) = \frac{1}{3025} x^2, \quad x > 0$$

$$0, \quad \text{otherwise}$$
(3.2)

c. Square root Utility

This utility curve is concave downward. It generally represent the *risk averse* case; most individuals and organizations generally are risk averse with respect to most decisions. The appropriate function for square root utility is given by equation (3.3).

$$U(x) = 4.264 \sqrt{x}, \quad x > 0$$

$$0, \quad \text{otherwise}$$
(3.3)

If it is assumed that Red's options are weighted as w_1, w_2, w_3, w_4 for each option, then weighted utility values can be calculated by equation (3.4).

$$U(x) = w_1 U_1(x) + w_2 U_2(x) + w_3 U_3(x) + w_4 U_4(x)$$
(3.4)

where

$U(x)$: weighted utility value

w_i : proportion of weight for i-th Red option. $0 \leq w_i \leq 1 \quad i = 1, 2, 3, 4$

$U_i(x)$: utility value of i-th Red option. $i = 1, 2, 3, 4$

As an example, with given values of w_i (0.05, 0.70, 0.05, 0.20), the weighted utility values for each function are shown in Figure 21. This figure represent the characteristics of MOE-2 for the Red option-2 well, because the Blue decision maker puts large weight (0.70) on the Red option-2 (see Figure 16 for MOE-2). Note, in the Linear Utility case, Blue options 6 and 8 are emphasized because their MOE-2 values are greater than 340 (i.e., Blue survives with more than two companies) while the others are not.

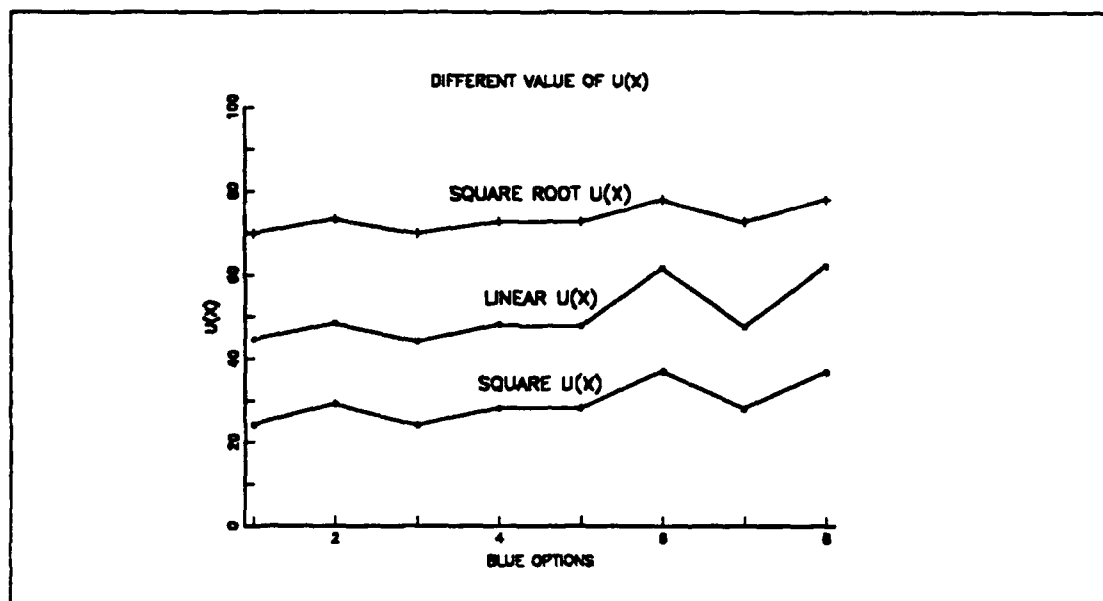


Figure 21. Weighted utility values for each function.

E. GAME THEORY

1. General

In game theory, the word "strategy" has a very definite meaning, namely, "a complete rule for decision making". [Ref. 8 : p. 2]. By the assumptions, all initial MOE values consist of a 4 by 8 matrix and the values for each MOE matrix come from the output of the advanced model (Figure 11 in Chapter 2). A strategy is a particular Blue option paired with a particular Red option. In order to study the characteristic properties of games of strategy and find an optimal strategy for the two players (Red and Blue), the 4 by 8 "Rectangular Game" is utilized. Two theorems are also used to compute the *value of the game*. [Ref. 9 : p. 34 and 39].

Theorem 1. : Let

$$A = \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ a_{m1} & \dots & a_{mn} \end{bmatrix}$$

be any matrix, with m rows n columns, and let the expectation function $E(X,Y)$, for any $X = ||x_1 \dots x_m ||$ and $Y = ||y_1 \dots y_n ||$ that are members of S_m and S_n , respectively, be defined as follows:

$$E(X,Y) = \sum_{i=1}^m \sum_{j=1}^n a_{ij} x_i y_j \quad (3.5)$$

Then the expressions

$$\max_{X \in S_m} \min_{Y \in S_n} E(X,Y) \quad (3.6)$$

and

$$\min_{Y \in S_n} \max_{X \in S_m} E(X,Y) \quad (3.7)$$

exist and are equal. Where;

S_m : close subset of whole space (E_m) which have elements, $x_1, \dots, x_m$.

S_n : close subset of whole space (E_n) which have elements, $y_1, \dots, y_n$.

Theorem 2. : Let E be the expectation function for an $m \times n$ rectangular game, let v be a real number, and let X^* and Y^* be members of S_m and S_n , respectively. Then a necessary and sufficient condition that v be the value of the game and that X^* and Y^* be optimal strategies for P_1 and P_2 , respectively, is that, for $1 \leq i \leq m$ and $1 \leq j \leq n$,

$$E(i, Y^*) \leq v \leq E(X^*, j).$$

2. Application

a. MOE-1 (Red casualties)

The initial 4 by 8 matrix is reduced to a 3 by 5 matrix which results in a Mixed Strategy¹ solution (see Figure 22). The relations of dominance are as follows:

Column 3 dominate column 4 = = = > eliminate column 3

Row 3 dominate row 4 = = = > eliminate row 4

¹ Rectangular game whose matrix has no saddle point, that is, Red could determine optimal way with probabilities $P_1, P_2, \dots, P_c$ for each column of matrix, and Blue could determine optimal way with probabilities $P_1, P_2, \dots, P_r$ for each row of matrix. For more explanation in detail, refer [Ref. 9 : p. 21].

Row 3 dominate row 5 == => eliminate row 5

Row 7 dominate row 8 == => eliminate row 8

By Theorem 2, the reduced matrix suffices to find numbers $x_1, x_2, x_4, y_1, y_2, y_3, y_6, y_7$, and v which satisfy the following conditions:

$$x_1 + x_2 + x_4 = 1$$

$$y_1 + y_2 + y_3 + y_6 + y_7 = 1$$

$$0 \leq x_i, y_j \leq 1 \quad i=1,2,4 \text{ and } j=1,2,3,6,7$$

$$759.6x_1 + 802.3x_2 + 828.5x_4 \leq v$$

$$795.2x_1 + 751.7x_2 + 783.0x_4 \leq v$$

$$786.9x_1 + 795.4x_2 + 817.1x_4 \leq v$$

$$813.9x_1 + 639.9x_2 + 630.5x_4 \leq v$$

$$803.5x_1 + 737.4x_2 + 722.1x_4 \leq v$$

$$759.6y_1 + 795.2y_2 + 786.9y_4 + 813.9y_6 + 803.5y_7 \geq v$$

$$802.3y_1 + 751.7y_2 + 795.4y_3 + 639.9y_6 + 737.4y_7 \geq v$$

$$828.5y_1 + 783.0y_2 + 817.1y_3 + 630.5y_6 + 722.1y_7 \geq v$$

From Theorem 1, we know that there exists a solution to the system. These conditions were solved by using Linear, Interactive, Discrete Optimizer (LINDO) [Ref. 10] which utilizes a Linear Program to find the optimum solution (see Figure 23 for the equations and results). In this solution, the objective equation is set to find a maximum value of v . If the objective equation is set to find a minimum value of v , the result will be the same. Note, that if there is a negative element in the matrix of Mixed Strategy, the Linear Program method can not be used.

Based on the solution in Figure 23, an optimal way for Red to play this game is to choose options 1, 2, and 4 with respective probabilities 0, 0.78, and 0.22; and an optimal way for Blue to play is to choose options 1, 2, 3, 6, and 7 with respective probabilities 0, 0, 0.89, 0, and 0.11. The *value of the game* is 788.8; i.e., Red can play in such a way as to make sure of not losing more than 788.8 Red casualties, and Blue can play in such a way as to make certain that Red will lose at least 788.8.

<< Initial matrix (4 × 8) >>				
	1	2	3	4
1	759.6	802.3	949.2	828.5
2	795.2	751.7	951.3	783.0
3	786.9	795.4	967.3	817.1
4	771.0	752.0	923.0	787.0
5	768.6	747.8	810.1	733.7
6	813.9	639.9	808.9	630.5
7	803.5	737.4	847.3	722.1
8	773.9	632.4	787.7	631.3

<< Reduced matrix (3 × 5) >>			
	1	2	4
1	759.6	802.3	828.5
2	795.2	751.7	783.0
3	786.9	795.4	817.1
6	813.9	639.9	630.5
7	803.5	737.4	722.1

Figure 22. Initial matrix and reduced matrix for MOE-1

b. MOE-2 (Blue survivors)

A similar method as the MOE-1 case was used for MOE-2. After eliminating the redundant rows and columns by relations of dominance, the following 2 by 2 Mixed Strategy matrix is left.

Blue Red	3	4
7	307.1	251.4
8	300.4	308.0

This implies that the Red favors its option 3 and 4, and the Blue favors its option 7 and 8. Since a 2 by 2 matrix is simple to solve, familiar methods of elementary algebra were used. An optimal strategy for Red is $||0.89, 0.11||$, an optimal strategy for Blue is $||0.12, 0.88||$; and the *value of the game* is 301.2 Blue survivors. So, not more than two Blue companies (340 infantry men) may survive during the battle.

c. MOE-3 and MOE-4

MOE-3 and MOE-4 do not have a mixed strategy, but have a unique strategy which can be easily found by inspection. For MOE-3 (duration of battle), the Red option-1 is dominated by its option 2,3, and 4 so that the Red will choose its option-1. Thus, an optimal strategy is that Red choose its option-1 with probability 1

<< EQUATIONS FOR LINEAR PROGRAM >>

MAX V
SUBJECT TO
2) $X_1 + X_2 + X_4 = 1$
3) $Y_1 + Y_2 + Y_3 + Y_6 + Y_7 = 1$
4) $-V + 759.6 X_1 + 802.3 X_2 + 828.5 X_4 \leq 0$
5) $-V + 795.2 X_1 + 751.7 X_2 + 783.0 X_4 \leq 0$
6) $-V + 786.9 X_1 + 795.4 X_2 + 817.1 X_4 \leq 0$
7) $-V + 813.9 X_1 + 639.9 X_2 + 630.5 X_4 \leq 0$
8) $-V + 803.5 X_1 + 737.4 X_2 + 722.1 X_4 \leq 0$
9) $-V + 759.6 Y_1 + 795.2 Y_2 + 786.9 Y_3 + 813.9 Y_6 + 803.5 Y_7 \geq 0$
10) $-V + 802.3 Y_1 + 751.7 Y_2 + 795.4 Y_3 + 639.9 Y_6 + 737.4 Y_7 \geq 0$
11) $-V + 828.5 Y_1 + 783.0 Y_2 + 817.1 Y_3 + 630.5 Y_6 + 722.1 Y_7 \geq 0$
END

<< OUTPUT OF LINEAR PROGRAM >>

LP OPTIMUM FOUND AT STEP 12

OBJECTIVE FUNCTION VALUE

1) 788.791260

VARIABLE	VALUE	REDUCED COST
V	788.791260	0.0
X1	0.777479	0.0
X2	0.222521	0.0
X4	0.0	0.0
Y1	0.0	19.689911
Y2	0.0	3.271210
Y3	0.886059	0.0
Y6	0.0	13.610260
Y7	0.113941	0.0

Figure 23. Solution for Value of the Game (MOE-1)

and Blue choose its option-6 with probability 1. The *value of the game* is 224 minutes which means that the Blue forces can hold their positions at least 3 hours and 44 minutes. From a tactical viewpoint, the Blue forces have to be reinforced before 224 minutes of battle time if Blue does not want to lose their positions.

For MOE-4 (ratio of Red and Blue casualties), the Red option-4 is dominated by its option 1, 2, and 3 so that the Red will choose its option-4 to minimize the Red/Blue casualty ratio. Thus, an optimal strategy is that Red choose its option-4 with

probability 1 and Blue choose its option-4 with probability 1. The *value of the game* is 2.82 Red casualties per Blue casualty which means that one Blue force unit can kill 2.82 Red units in the battle.

F. USE OF UTILITY VS GAME THEORY FOR THE ANALYST

The choice of technique depends on how the analyst desires to view the enemy force. For the Utility approach, the *states of nature*, with appropriate probabilities, would be assigned by the analyst. If intelligence reports are available, these could be used to determine the most likely Red option (i.e., unit mix on various avenues).

For Game theory, we are assuming that both Red and Blue forces are using the same payoff matrix, and that Red and Blue are making strategy decisions according to the max(min) and min(max) criteria, respectively. In the analyses, Red is being treated as an intelligent player as opposed to *states of nature*. Results from this analysis can be used to determine the frequency with which Red will choose his various options.

IV. SENSITIVITY ANALYSIS

A. GENERAL

The previous chapters have considered, using the deterministic model and its output, analysis based on a given scenario. In all cases, the analysis was based on a fixed force size and a given set of weapon parameters. This chapter examines the numerical sensitivity of the methodologies and the effect on the model output interpretation as it pertains to Red and Blue options. The Analysis of Variance (ANOVA) and Two Sample t-Test are applied to support the sensitivity analysis. Some introductory analytical techniques to evaluate countermeasures are also covered, and an example of model enrichment is considered.

The deterministic model developed in this thesis has used many parameters which may possibly be changed based on real battle situations. For example, attrition rate coefficients may be affected if Red uses "Smoke" while they attack, since smoke will restrict the firepower of opposing forces. This would also occur in the night battle case. If Red uses a "Mine-plow" when it traverses the minefield, attrition rate coefficients for mines should also be decreased. From the Blue force's viewpoint, installing more mines in the minefield or increasing the amount of indirect fire may be used as countermeasures against the Red force. These key parameters are varied in turn to determine their effects on outputs of the model. Those parameters which are shown to have little or no effect on the results may be treated as constants and the model simplified accordingly. Those showing large sensitivity should be examined in detail, since these will affect model performance to the greatest degree.

B. FORCE SIZE

The force size is one of the major factor to affect the battle output. In this section, the Blue forces are considered to be reinforced by one additional platoon (40 infantrymen). Two methods of reinforcement are compared with the basic battle case which has no reinforcement, and the basic battle also has Blue option-2 and Red option-2 (referred to as O_{22} of Table 2 in Chapter 2). These battle cases' results have been discussed in detail in Figure 12-15 in Chapter 3 as an example of the basic model output.

Figure 24 shows Red and Blue force sizes over time when the Blue ambush point is reinforced with one more platoon. Compared with Figure 12 in Chapter 3, the rate of

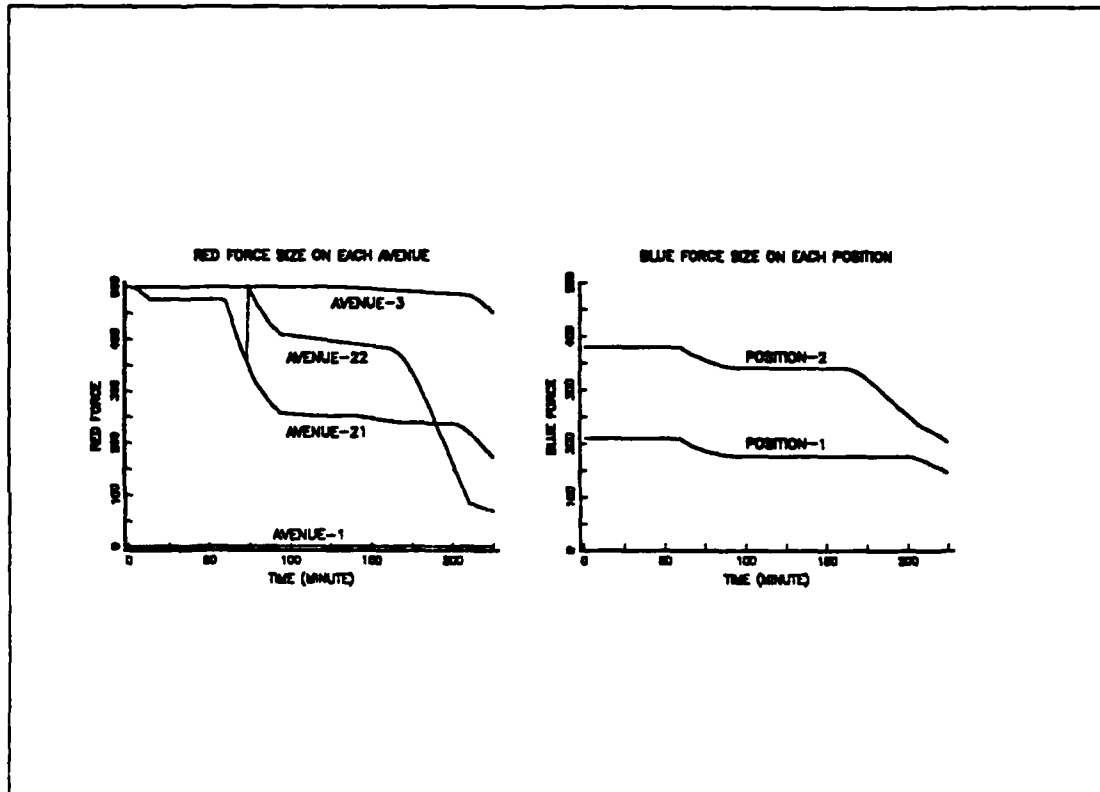


Figure 24. Red and Blue force sizes over time when the Blue ambush point is reinforced.

decreasing Red forces is very steep at the ambush battle region (for battle time 55-90 minutes). Since the Red force on Avenue-22 is reinforced during the ambush battle (about time 70), this implies that the Red force size on Avenue-22 is reduced to the same as that of the Blue force based on the model assumption (the unit reinforcement is supposed to occur if the Red forces are less than the Blue forces). The shape of the Blue force size curve looks similar compared with Figure 12 in Chapter 3 except that the slope of the curve during the ambush battle region is somewhat steeper than those in Figure 12.

Figure 25 provides significant information if the Blue commander wants to know the difference depending on whether he reinforces a given platoon at the ambush point or at the main forces areas on node 27 and 28. The Red casualties (MOE-1) are the highest when the ambush point is reinforced while there is no large difference with respect to the Blue survivors (MOE-2) between the two reinforcement methods (R1 and R2 in Figure

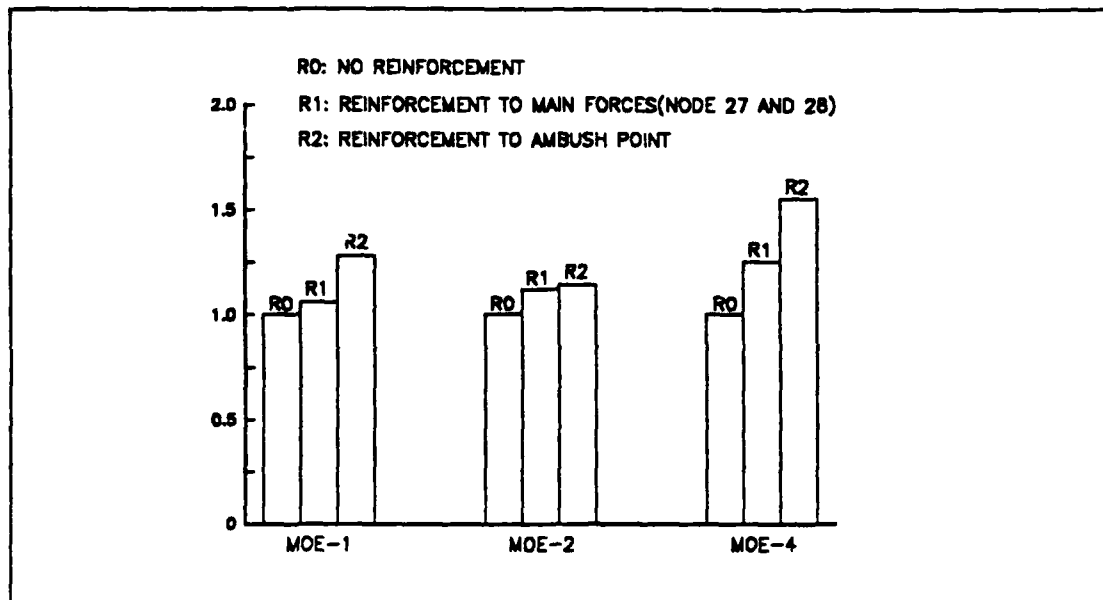


Figure 25. Comparison of MOEs when the Blue forces are reinforced.

25). The Red to Blue casualty ratio (MOE-4) linearly increases from the R0 to R2 case in Figure 25. Based on Figure 25, reinforcing a platoon at the ambush point appears to be a better course of action for the Blue commander. However, the following conditions should be considered before the final decision of whether a Blue platoon is reinforced at the main forces areas or ambush point.

- Availability of well-fortified battle space for one more platoon to fight at the ambush point.
- Probability of being detected by Red when Blue ambush force size is increased (i.e., the more forces there are, the easier they are to be detected).

C. ATTRITION RATE COEFFICIENTS

1. Sensitivity for attrition rate coefficients.

The attrition rate coefficients are another important factor in the deterministic model. The maximum attrition rate coefficients, which are given by equations (2.13) and (2.14) in Chapter 2, can be varied. The " a_0 " in equation (2.13) is the maximum rate at which Red forces are attrited by Blue, or the number of Red forces lost per unit of time. The " b_0 " in equation (2.14) is the maximum rate at which Blue forces are attrited by Red, or the number of Blue forces lost per unit of time.

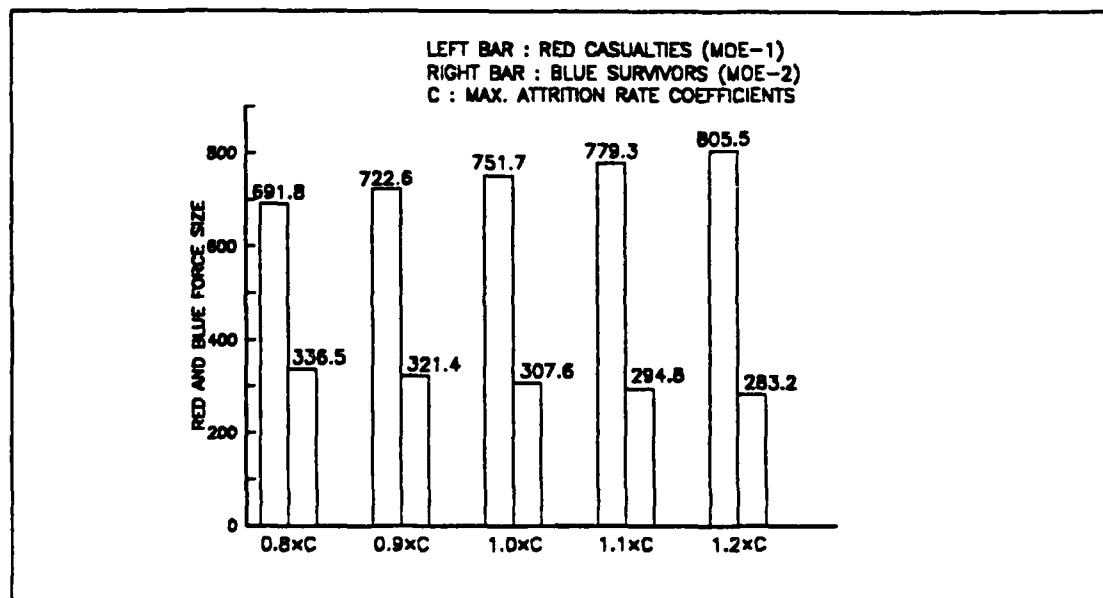


Figure 26. Change of MOE values based on different maximum attrition rate coefficients, a_0 and b_0

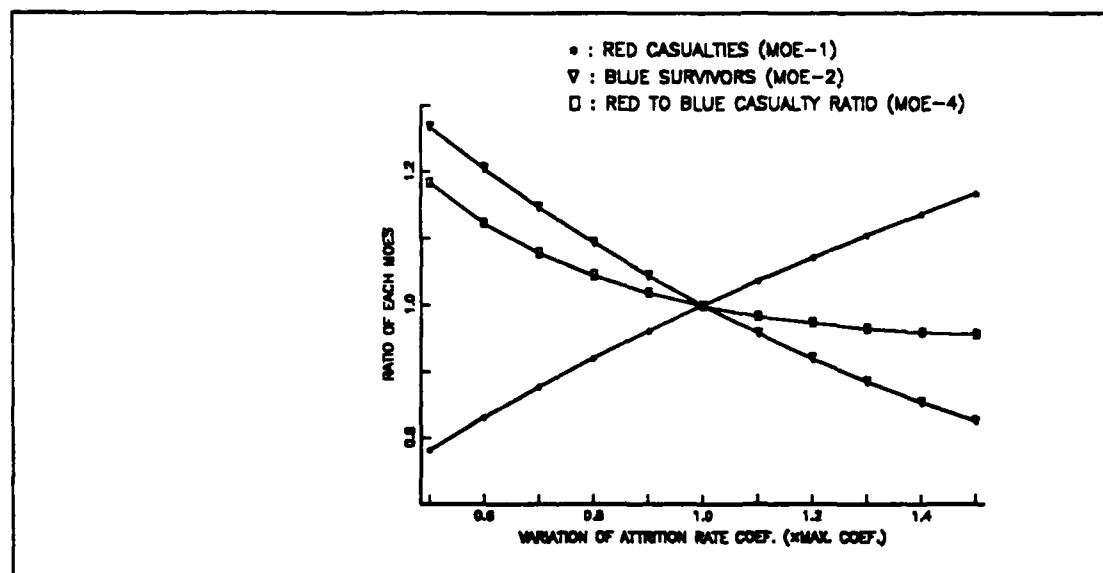


Figure 27. Ratio of change for MOE values based on different a_0 and b_0

Figure 26 is created with the MOE outputs of the basic model, which were discussed in a previous section, when both maximum attrition rate coefficients (a_0 and b_0) are changed to between 80% and 120% of original values in the basic model. Red casualties (MOE-1) increase linearly while Blue survivors (MOE-2) decrease linearly as a_0 and b_0 increase.

Figure 27 is the plotted ratio of MOE values with decreased or increased attrition rate coefficients to the basic model's MOE outputs with no changes of attrition rate coefficients. In this figure, unlike Figure 26, attrition rate coefficients (a_0 and b_0) are altered between 50% and 150% of original values. Figure 27 shows that the ratio of change for Red casualties (MOE-1) increases with a weak concave downward shape curve, which means that the rate of change for MOE-1 slightly decreases as the attrition rate coefficients get larger. The figure also depicts that the ratio of change for MOE-2 and MOE-4 decreases with a concave upward shape, which implies that the rates of change for Blue survivors (MOE-2) and Red to Blue casualty ratio (MOE-4) decrease as the attrition rate coefficients increases. In other words, as a_0 and b_0 increase, fire-power effectiveness (or loss rate exchange) of the Blue force will be gradually reduced.

At this time, only one of the maximum attrition rate coefficients, either a_0 or b_0 , is changed and compared. The differences are given in Table 5. The numerical values in parentheses represent the percentage of MOE value change when compared with those of the basic case (no changes of attrition rate coefficients).

Table 5. SENSITIVITIES OF MOES FOR ATTRITION RATE COEFFICIENTS.

a_0	$0.9 \times a_0$	a_0	$1.1 \times a_0$
MOE-1	712.4 (94.8%)	751.7 (100%)	790.8 (105.2%)
MOE-2	302.4 (98.3%)	307.6 (100%)	313.0 (101.8%)
b_0	$1.1 \times b_0$	b_0	$0.9 \times b_0$
MOE-1	740.9 (98.6%)	751.7 (100%)	762.6 (101.5%)
MOE-2	289.2 (94.0%)	307.6 (100%)	326.4 (106.1%)

Based on Table 5, when the constant rate at which Red forces are attrited by Blue forces (a_0) decreases by 10%, MOE-1 decreases 5.2% and MOE-2 decreases 1.7%. When a_0 increases 10%, MOE-1 increases 5.2% and MOE-2 increases 1.8%. For the constant rate at which Blue forces are attrited by Red forces (b_0), when b_0 increases by

10%, MOE-1 decreases 1.4% and MOE-2 decreases 6.0%, and when b_0 decreases 10%, MOE-1 increases 1.5% and MOE-2 increases 6.1%. If the same amount of effort or cost are required to either increase a_0 by 10% or decrease b_0 by 10% for the Blue force, increasing a_0 is more efficient for improving Red casualties (MOE-1) than decreasing b_0 . On the contrary, decreasing b_0 is more efficient for improving Blue survivors (MOE-2) than increasing a_0 .

2. Analysis Of Variance (ANOVA).

In this section, an analysis tool known as the *analysis of variance*, abbreviated ANOVA, is considered. The use of ANOVA requires some basic assumptions, such as; the observations that are obtained are independent and normally distributed; all the observations have the same variance; and the mean of each observation can be represented as a linear combination of certain unknown parameters. [Ref. 11 : p. 644]. The One-way Layout (One-way ANOVA) will be discussed here.

It is assumed that the output of each Basic model run (a cell of the output matrix produced by the Advanced model in Chapter 2) is an independent battle result, and eight observations (based on 8 Blue options) on each column (based on each Red option) have the same variances. With these assumptions, the actual output of the Advanced model is fitted to the normal distribution. Figure 28 and 29 show how Red casualties (MOE-1) and Blue survivors (MOE-2) fit the normal distribution. In each figure, all four graphs (histogram and normal density function, normal cumulative distribution function, normal probability plot, and normal likelihood surface) verify that these observations are normally distributed. [Note: all 32 observations are within the 95% K-S bound² on normal probability plot (the third graph in Figures 28 and 29)]. It is also verified that Red to Blue casualty ratio (MOE-4) fits the normal distribution by using the same methods for MOE-1 and MOE-2.

To apply an AVOVA test, the maximum attrition rate coefficients, a_0 and b_0 , are multiplied by 1.1, respectively (i.e., both maximum attrition rate coefficients are increased by 10%). The problem is to compare the mean values of each MOE output for the different Red options between the two battle cases; original outputs of the Advanced model without any changes, and when both a_0 and b_0 are multiplied by 1.1. Each Red option has eight independent MOE outputs based on eight different Blue options. The results for both battle cases are given in Figure 30.

² Kolmogorov-Smirnov bound [Ref. 11 : p. 552].

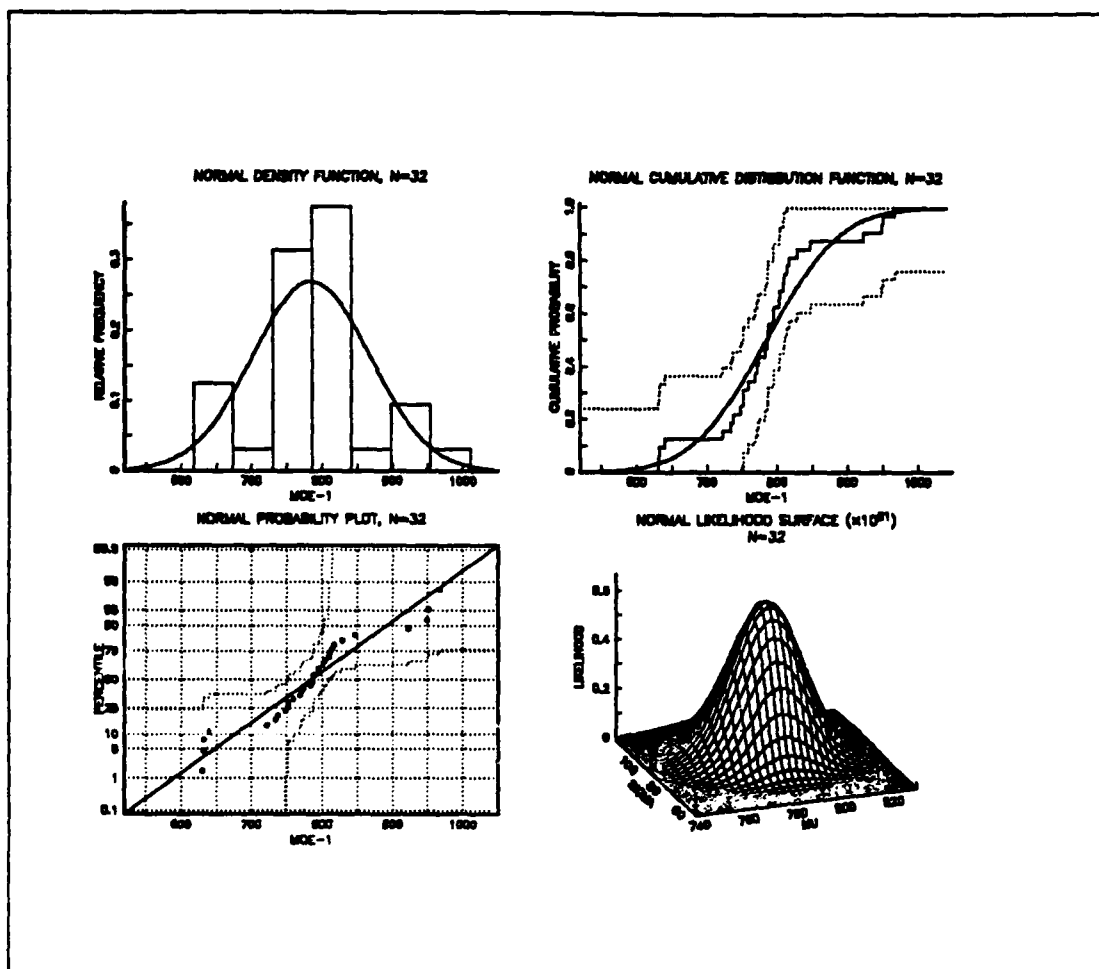


Figure 28. Fitting the Red casualties (MOE-1) of the Advanced model output to Normal Distribution.

In Figure 30, ROW represents the eight different Blue options, columns 1 through 12 (C1-C12) represent the original Advanced model outputs without any modifications, and columns 21 through 32 (C21-C32) represent modified Advanced model outputs with increased maximum attrition rate coefficients. Also, C1 and C21 represent Red option-1, C2 and C22 for Red option-2, C3 and C23 for Red option-3, C4 and C24 for Red option-4, etc. The MINITAB computer software [Ref. 12] was used to compute the *value of F-Ratio* for the One-Way AVOVA test. The following example shows the MINITAB output for the One-Way ANOVA test. The example compares the mean difference between C1 and C21.

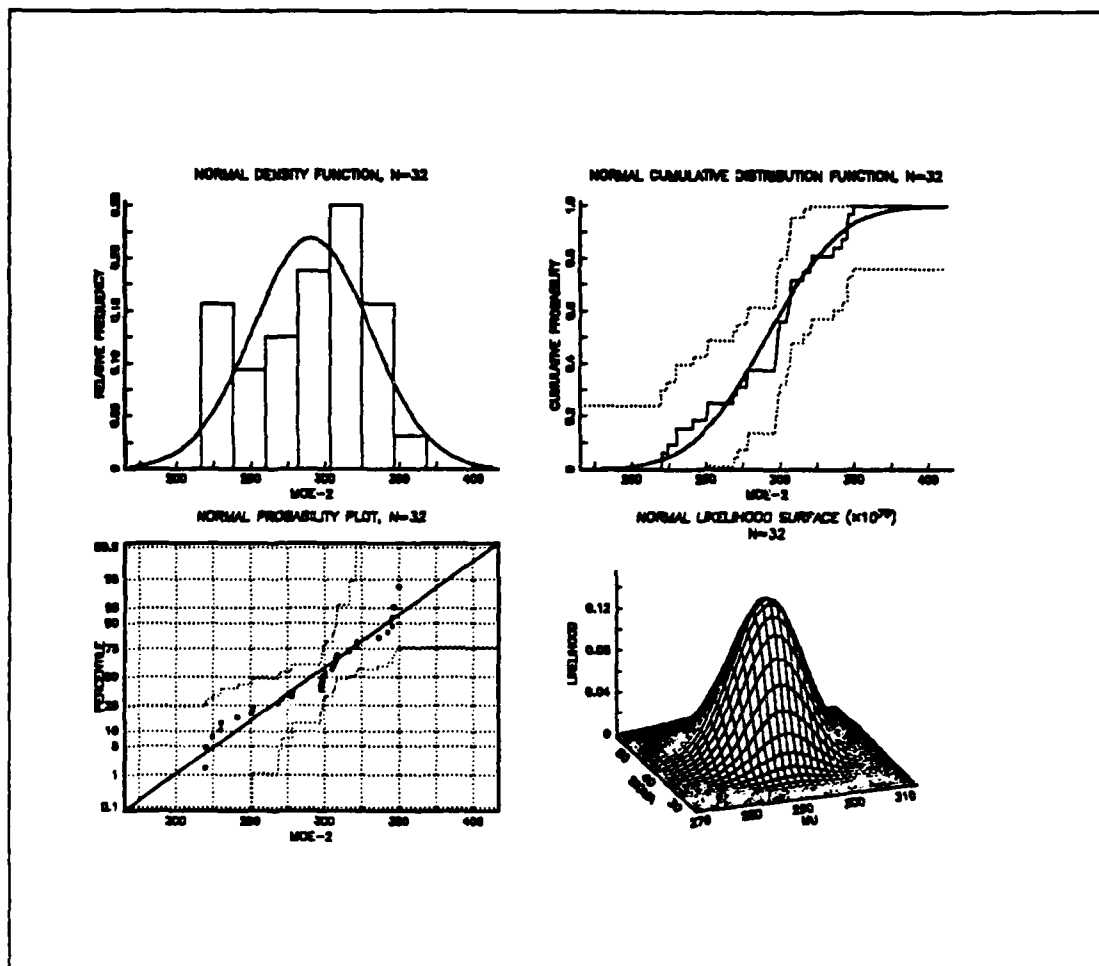


Figure 29. Fitting the Blue survivors (MOE-2) of the Advanced model output to Normal Distribution.

A. RED CASUALTIES (MOE-1)

ROW	C1	C2	C3	C4	C21	C22	C23	C24
1	759.6	802.3	949.2	828.5	769.3	832.8	961.9	857.7
2	795.2	751.7	951.3	783.0	807.1	779.3	959.9	810.6
3	786.9	795.4	967.3	817.1	798.2	825.8	977.4	846.3
4	771.0	752.0	923.0	787.0	782.3	779.9	936.0	814.4
5	768.6	747.8	810.1	733.7	791.7	775.7	814.2	756.0
6	813.9	639.9	808.9	630.5	839.8	660.8	814.7	646.4
7	803.5	737.4	847.3	722.1	828.4	765.4	845.6	744.4
8	773.9	632.4	787.7	631.3	798.2	652.5	791.9	646.8

B. BLUE SURVIVORS (MOE-2)

ROW	C5	C6	C7	C8	C25	C26	C27	C28
1	349.9	278.1	219.9	230.1	341.5	263.5	206.9	212.1
2	321.1	307.6	220.0	268.9	311.4	294.8	207.1	253.3
3	321.7	278.4	241.6	230.4	312.1	263.8	228.3	212.4
4	345.5	297.3	224.4	271.0	336.6	283.6	211.2	255.6
5	336.3	298.7	297.5	251.1	324.7	284.0	293.0	234.2
6	316.5	346.3	297.9	305.0	304.8	334.3	293.3	291.5
7	305.7	299.1	307.1	251.4	292.7	284.4	300.7	234.5
8	345.5	342.3	300.4	308.0	335.0	330.2	295.3	294.7

B. RED TO BLUE CASUALTIES (MOE-4)

ROW	C9	C10	C11	C12	C29	C30	C31	C32
1	3.80	2.95	2.88	2.59	3.69	2.91	2.80	2.54
2	3.47	3.10	2.88	2.79	3.38	3.05	2.80	2.73
3	3.45	2.93	3.14	2.56	3.36	2.89	3.04	2.51
4	3.77	2.98	2.83	2.82	3.67	2.93	2.76	2.77
5	3.60	2.98	3.21	2.45	3.51	2.92	3.17	2.39
6	3.49	3.14	3.21	2.57	3.42	3.06	3.17	2.50
7	3.29	2.94	3.49	2.42	3.22	2.88	3.39	2.36
8	3.79	3.05	3.16	2.61	3.71	2.97	3.11	2.53

Figure 30. MOE outputs for both battle cases; original battle, and both a_0 and b_0 increased by 10 percent.

< EXAMPLE >

ANOVA-ONEWAY on C1 C21

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	1	1267	1267	2.84
ERROR	14	6256	447	
TOTAL	15	7523		

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	
C1	8	784.07	18.94	(-----*-----)
C21	8	801.87	23.13	(-----*-----)
				-----+-----+-----+-----
POOLED STDEV =		21.14	770	784 798 812

The example compares column 1 and column 21 (C1 and C21), which are Red casualties (MOE-1) of Red option-1 for both battle cases. The *value of F-Ratio* 2.84, in this example, is compared with the table value for the $F_{1,14}$ (F-Distribution with degrees of freedom 1 and 14). If the significant level, α , is 0.05, the table value for $F_{1,14}$ is 4.60. Consequently, because the *value of F-Ratio* is less than the table value for $F_{1,14}$ ($2.84 < 4.60$), the difference for mean of Red casualties (MOE-1) on Red option-1 between above two battle cases is not significant at the 0.05 significance level.

All results for the One-Way ANOVA test between C1-C12 and C21-C32 are given in Table 6. Like the example, no results are significant with a significance level of 0.05. This implies that increasing both a_0 and b_0 by 10% do not make any differences at 0.05 significance level for all possible battle cases in this given scenario.

Table 6. RESULTS OF ONE-WAY ANOVA TEST WHEN THE MAXIMUM ATTRITION RATE COEFFICIENTS ARE CHANGED.

Red options	MOE-1	MOE-2	MOE-4
Red option-1	2.84	1.55	0.92
Red option-2	0.66	1.07	2.40
Red option-3	0.03	0.18	0.39
Red option-4	0.35	1.06	0.70

D. WEISS PARAMETER

In Chapter 2, the *Weiss parameter* was discussed by showing how the attacker's (or defender's) casualty rate per time changes by attacker to defender force ratio (see Figures 5 and 6 in Chapter 2). At that time, it was also shown how the attacker's (or defender's) casualty rate per time changes different when w (Weiss parameter) is changed from 0 to 1.0. In this section, two approaches for sensitivity analysis of w will be applied.

First, only w_b (Weiss parameter Blue engaging Red) varies from 1.0 to 0.6, which implies that the type of fire for the Blue force changes to area-fire from aimed-fire. Figure 31 shows that both Red casualties (MOE-1) and Blue survivors (MOE-2) increase as w_b decreases. In other words, fractional casualties per unit time for Red (attacker) increase as w_b decreases, and fractional casualties per unit time for Blue (defender) increase as w_b decreases. This fact can be verified from Figures 5 and 6 in Chapter 2. [NOTE : Red to Blue force size ratio ($A/D = \text{Red/Blue}$) is between 2.92 and 2.66 in Figure 32 while w_b varies from 1.0 to 0.6, and fractional casualties per unit time for each w (when $w = 0, 1/4, 1/2$, and 1.0) consistently varies between 2.92 and 2.66 in Figures 5 and 6 in Chapter 2]. Figure 31 also depicts that the increasing rate of MOE-1 is greater than that of MOE-2. In other words, Red casualties are more sensitive to the parameter, w_b . Figure 32 is compared for Red to Blue casualty ratio and Red to Blue force ratio. Red to Blue casualty ratio increases as w_b varies from 1.0 to 0.6, while Red to Blue force ratio decreases as w_b varies. This is a reasonable tendency in theoretical battle situations.

Second, outcomes are analyzed as if the w_b (Weiss parameter Blue engaging Red) and w_r (Weiss parameter Red engaging Blue) approach the same value. In other words, the type of fire for the Blue force turns to area-fire from aimed-fire, and type of fire for the Red force turns to aimed-fire from area-fire. Figure 33 shows that Red casualties

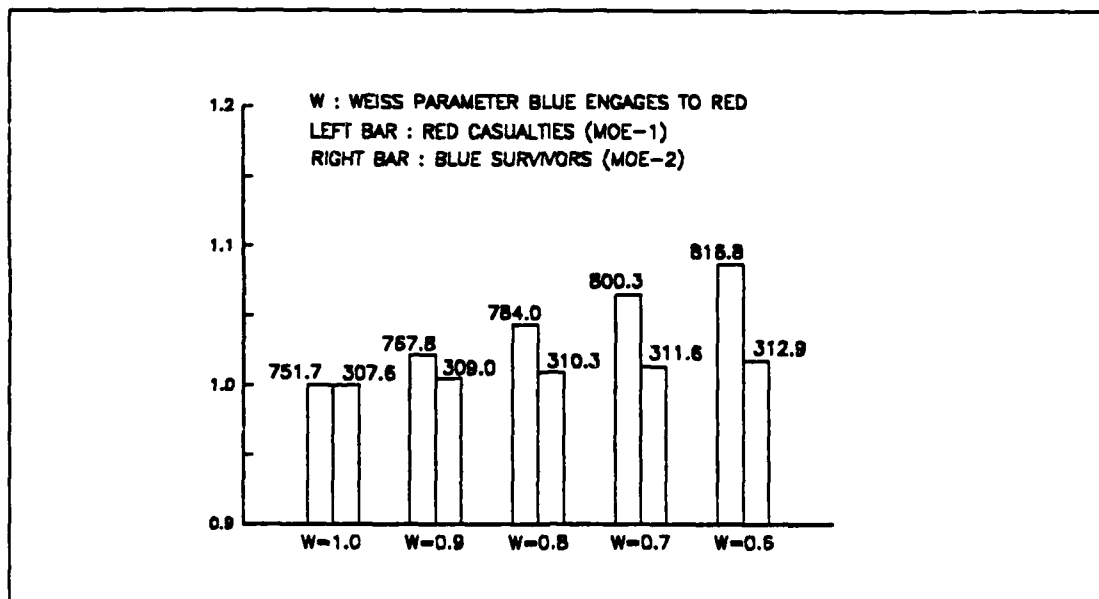


Figure 31. Change of Basic model output (MOE-1 and MOE-2) based on Weiss parameter for Blue engaging Red.

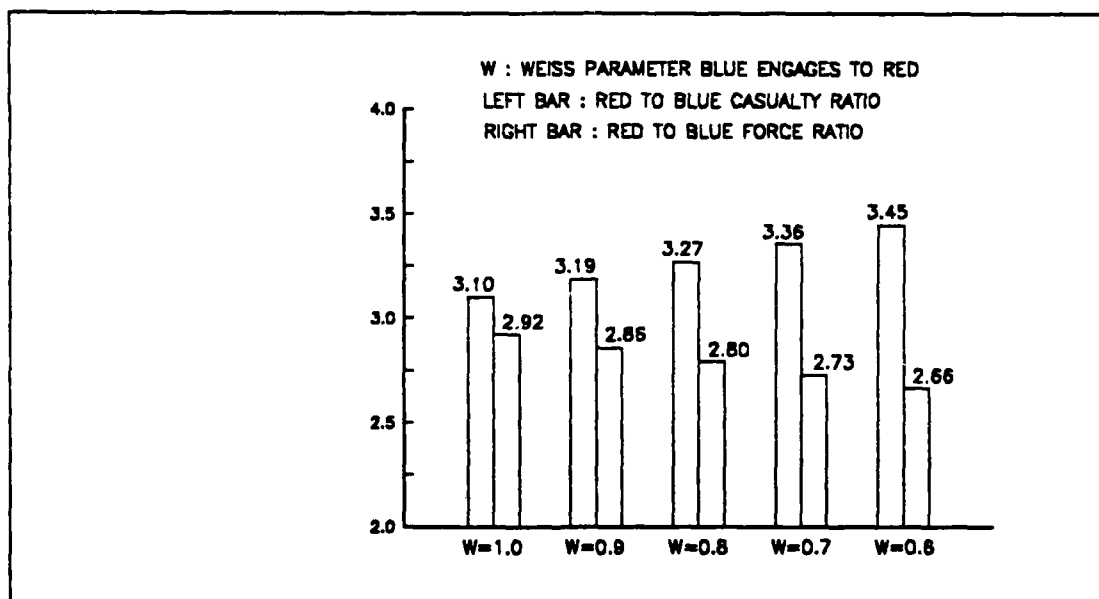


Figure 32. Change of Basic model output (Red to Blue casualty ratio and force ratio) based on Weiss parameter for Blue engaging Red.

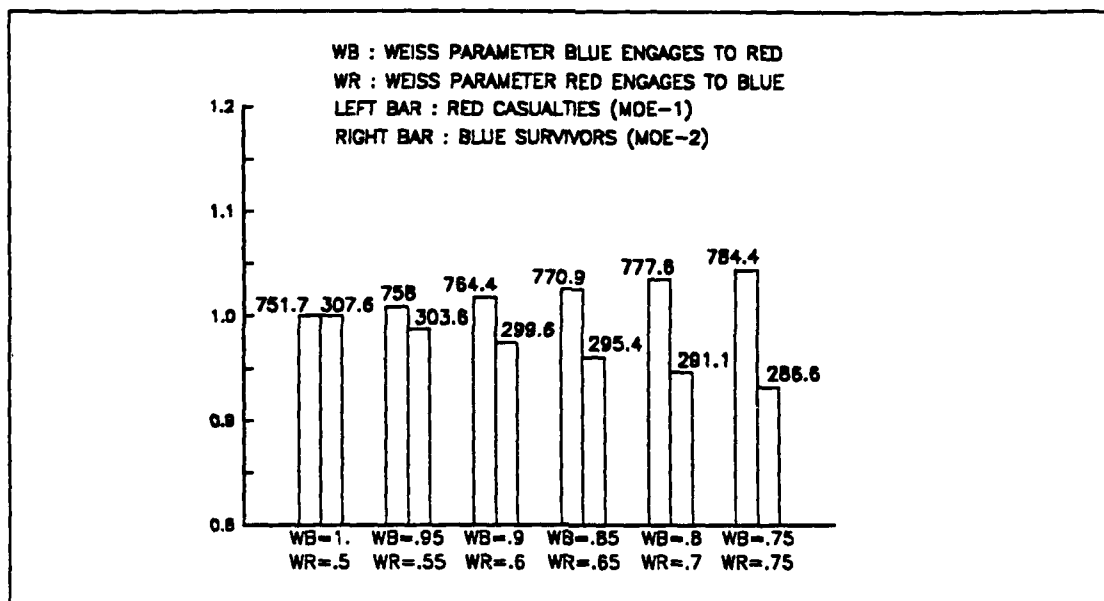


Figure 33. Change of the Basic model output (MOE-1 and MOE-2) when Weiss parameters for both Red and Blue approach the same value.

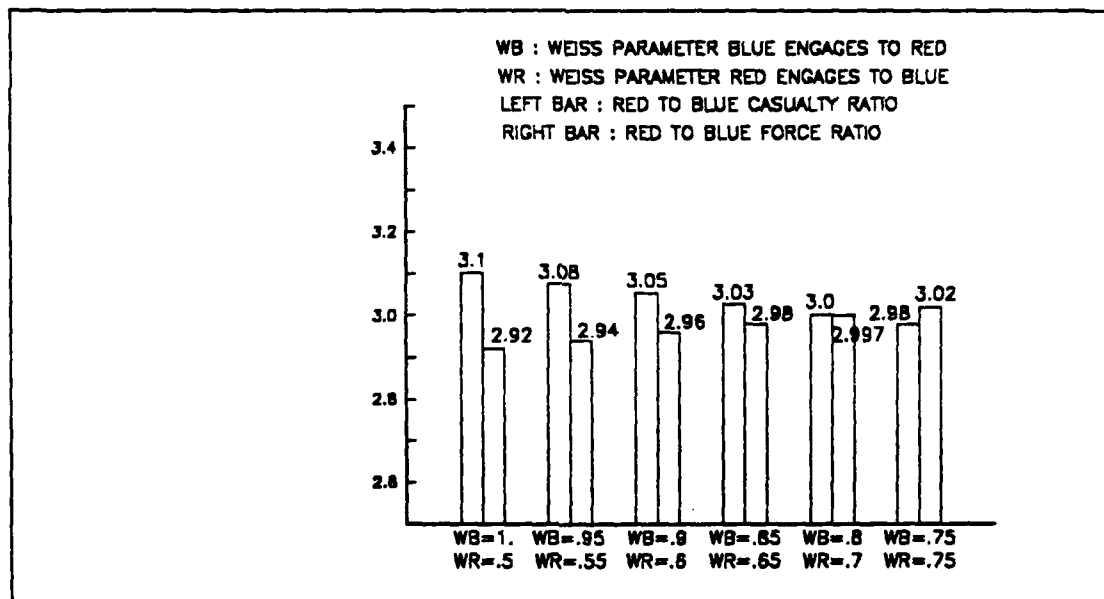


Figure 34. Change of Red/Blue casualty and force ratio in Basic model when Weiss parameters for both Red and Blue approach the same value.

(MOE-1) increase linearly as w_1 and w_2 get closer in value, while Blue survivors (MOE-2) decrease linearly. Figure 34 depicts the differences between Red to Blue casualty ratio and force ratio. The Red to Blue casualty ratio decreases as w_1 and w_2 get closer to each other, while Red to Blue force ratio increases. Note that Red to Blue casualty and force ratio are almost equal when w_1 is 0.8 and w_2 is 0.7, and the Red to Blue force ratio becomes greater than the casualty ratio thereafter.

Finally, the One-Way ANOVA test is also applied in the sensitivity analysis of the first case above. The test compares the original basic model output and the output when Weiss parameter for Blue engaging Red is changed to 0.9 from 1.0. All value of *F-Ratio* results for the test are given in Table 7.

Table 7. RESULTS OF ONE-WAY ANOVA TEST WHEN THE WEISS PARAMETER BLUE ENGAGING RED ARE CHANGED.

Red options	MOE-1	MOE-2	MOE-4
Red option-1	4.79	0.12	0.31
Red option-2	0.36	0.01	5.60
Red option-3	0.68	0.05	0.29
Red option-4	0.69	0.02	3.88

Since the compared values (MOE-1, MOE-2, and MOE-4) and the number of observations are same as those shown in the previous section (see Figure 30), $F_{1,14}$ (F-Distribution with degree of freedom 1 and 14) is utilized. If the significant level, α , is 0.05, the table value for $F_{1,14}$ is 4.60. There exist two values which are larger than 4.60 in Table 7 (4.79 and 5.60), which are MOE-1 in Red option-1 and MOE-4 in Red option-2. This implies that the mean number of Red casualties of eight Blue options (i.e., eight observations) with Red option-1 changes significantly if w_1 (Weiss parameter Blue engaging Red) decreases from 1.0 to 0.9. The same result occurs for the mean of Red to Blue casualty ratio of eight Blue options with Red option-2.

To confirm these results, *Two Sample t-Test*³ was applied for both cases. The t-Test can be employed because it was assumed and verified that comparing two 8 observations have same variances and each observation (each battle output : MOE values) is a random sample from a normal distribution as explained in the previous section. The above

³ Page 506. Morris H. DeGroot, *Probability and Statistics (Second Edition)*, by Addison-Wesley Publishing Company, Inc. 1986.

two significant cases are tested as examples. The following examples show the results of the two sample t-test with null hypothesis and alternative hypothesis in case of the two-tail test.

Example (Case 1)

Let $\bar{X}$ be the mean number of Red casualties of eight Blue options with Red option-1 in original Basic model output.

Let $\bar{Y}$ be the mean number of Red casualties of eight Blue options with Red option-1 after changing w_x to 0.9 from 1.0.

Test the following hypothesis with a significant level $\alpha = 0.05$.

$$H_0 : \bar{X} = \bar{Y}$$

$$H_a : \bar{X} \neq \bar{Y}$$

Let S_X^2 and S_Y^2 be the sums of squares as follows:

$$S_X^2 = \sum_{i=0}^m (X_i - \bar{X}_m)^2 \quad S_Y^2 = \sum_{i=0}^n (Y_i - \bar{Y}_n)^2 \quad (4.1)$$

Also let the statistic U be defined by the following relation:

$$U = \frac{(m+n-2)^{1/2}(\bar{X}_m - \bar{Y}_n)}{(\frac{1}{m} + \frac{1}{n})^{1/2}(S_X^2 + S_Y^2)^{1/2}} \quad (4.2)$$

Since the alternative hypothesis is two-sided, the test procedure would reject H_0 if either $U < c_1$ or $U > c_2$, where the constants c_1 and c_2 are chosen so that when H_0 is true,

$$\Pr(U < c_1) + \Pr(U > c_2) = \alpha.$$

In this example, the sample sizes are $m=8$ and $n=8$, and the value of the statistic U defined by equation (4.2) is 2.18. Also, by use of a table of the t distribution with 14 degrees of freedom ($m+n-2$), c_1 and c_2 are -2.145 and 2.145, respectively. Since the value of the statistic U is greater than 2.145 ($U > c_2$), the null hypothesis is rejected for the given specified level of significance, $\alpha = 0.05$.

Example (Case 2)

Let $\bar{X}$ be the mean Red to Blue casualty ratio of eight Blue options with Red option-2 in original Basic model output.

Let $\bar{Y}$ be the mean Red to Blue casualty ratio of eight Blue options with Red option-2 after changing w_x to 0.9 from 1.0.

In this example, the sample sizes are $m=8$ and $n=8$, and the value of the statistic U defined by equation (4.2) is 2.37. Also, as in the previous example, since the value of the statistic U is greater than 2.145 ($U > c_2$), the null hypothesis is rejected for the given specified level of significance, $\alpha = 0.05$.

These examples verify the results from the One-Way ANOVA test which is shown in Table 8. Recall, from Table 8, there were only two significant cases (4.79 and 5.60) which were greater than 4.60 (table value for F-distribution with degree of freedom 1 and 14).

E. COUNTERMEASURES

The practicing weapon systems analyst must be well acquainted with the more general principles of countermeasures. for his task is often that of evaluating the potential of proposed countermeasures. Also, countermeasures are often likely to improve survivability, especially for defenders. Indeed, the battle is often based on "see-sawing" advantages. While it is usually impossible to anticipate enemy reactions to an initiative, there is a rather satisfactory or useful mode of approach to this problem. The tank was the countermeasure to the machinegun, while antitank mines and shaped charge warheads are countermeasures to the tank threat.

In this model, two Blue courses of action are considered against two Red courses of action. It is assumed that the Blue force can increase indirect fire by expanding the firing time of the Blue artillery weapons and can also increase mine density in a given minefield, while the Red force may use a mine-plow to break through a Blue minefield and may also use smoke for restricting the firepower of the Blue force's direct fire. It is also assumed that Red smoke does not affect its own direct fire.

The quantitative amounts of effects for the different parameters, depending on which course of action is employed, are defined as follows:

- If the Red forces use mine-plows : decrease by 70% the attrition rate coefficient for minefields.
- If the Red forces use smoke : decrease by 10% the attrition rate coefficient to Red force from Blue force.
- If the Blue forces increase indirect fire : expand firing time of Blue artillery to 20 minutes from 10 minutes.
- If the Blue forces increase mine density : increase the number of mines in a given minefield by 100%.

Table 8 provides payoff matrices for Red and Blue courses of action, which shows both Red casualties and Blue survivors (MOE-1 and MOE-2). Based on Table 8, if the Blue force can use only one of two courses of action, increasing its indirect fire is better than increasing mine density (MOE-1 : $722.8 > 705.1$, MOE-2 : $305.9 > 303.1$) when the Red forces use the mine-plows. Recall that the larger MOE values are better for the Blue force. However, when the Red forces use smoke, increasing mine density is better for Blue than increasing indirect fire for the Blue force (MOE-1 : $822.6 > 774.4$, MOE-2 : $316.4 > 313.1$). From the above facts, the Blue commander can perceive that the number of mines in a minefield do not have much effect on Red's mine-plows, so that Blue may need another course of action to attrite Red mine-plows. Table 8 also shows that if Red and Blue forces employ all their available courses of action, the Red force will have larger advantages than the Blue force (see Table 8, MOE-1 : $718.8 < 751.7$, MOE-2 : $305.0 < 307.6$).

Figures 35 and 36 depict how Red casualties (MOE-1) and Blue survivors (MOE-2) change based on each course of action. For example, in Figure 35, there is a small difference in Red casualties for Blue courses of action 2 and 3 (B2 and B3) if the Red force selects its course of action 3 or 4 (R3 or R4). These two figures also show a quantitative difference of MOE values for each course of action, so the reader can easily tell the differences by the height of each pillar.

Figures 37 and 38 show how Red to Blue casualty ratio and force ratio change based on Red and Blue's respective course of action. From these figures, the reader can see the trend of the change of Red to Blue casualty ratio and force ratio for each Red and Blue courses of action. Figure 38 has almost the reverse shape of that of Figure 37, which implies that the Red to Blue casualty ratio and the Red to Blue force ratio have negative correlation.

Table 8. PAYOFF MATRIX FOR RED AND BLUE COURSE OF ACTIONS (MOE-1/MOE-2).

Courses of action				RED Force			
				use Mine-plow		do not use Mine-plow	
				use Smoke		use Smoke	
				YES	NO	YES	NO
BLUE Force	increase Indirect fire	increase Mine density	YES	718.8/305.0	758.1/310.3	888.3/330.0	927.5/336.6
			NO	683.5/300.7	722.8/305.9	774.4/313.1	813.7/318.8
	do not increase Indirect fire	increase Mine density	YES	655.9/298.3	705.1/303.1	822.6/316.4	862.0/322.2
			NO	631.6/296.3	670.2/300.4	712.4/302.4	751.7/307.6

In Figures 35 and 36, the following abbreviations apply:

- R1 = Red force uses both Mine-plow and Smoke.
- R2 = Red force uses only Mine-plow.
- R3 = Red force uses only Smoke.
- R4 = Red force does NOT use either Mine-plow or Smoke.

- B1 = Blue force increases both Indirect-fire and Mine density.
- B2 = Blue force increases only Indirect-fire.
- B3 = Blue force increases only Mine density.
- B4 = Blue force does NOT increase either Indirect-fire or Mine density.

In Figures 37 and 38, the following abbreviations apply:

- 1 on Red courses of action = R1 in Figures 35 and 36
- 2 on Red courses of action = R2 in Figures 35 and 36
- 3 on Red courses of action = R3 in Figures 35 and 36
- 4 on Red courses of action = R4 in Figures 35 and 36

- 1 on Blue courses of action = B1 in Figures 35 and 36
- 2 on Blue courses of action = B2 in Figures 35 and 36
- 3 on Blue courses of action = B3 in Figures 35 and 36
- 4 on Blue courses of action = B4 in Figures 35 and 36

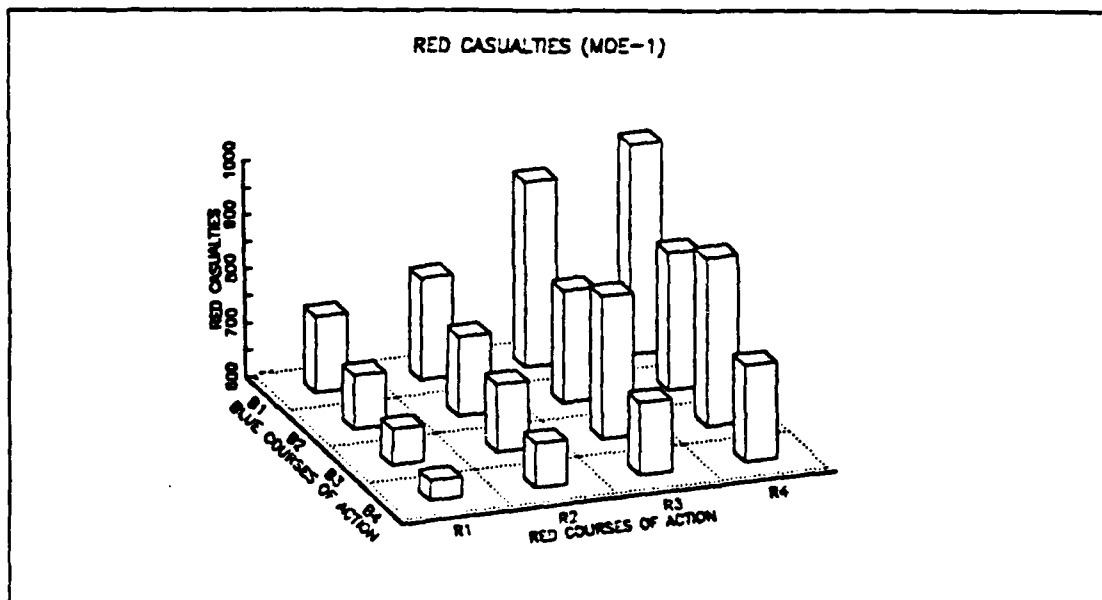


Figure 35. 3-Dimensional view of payoff matrix for Red casualties.

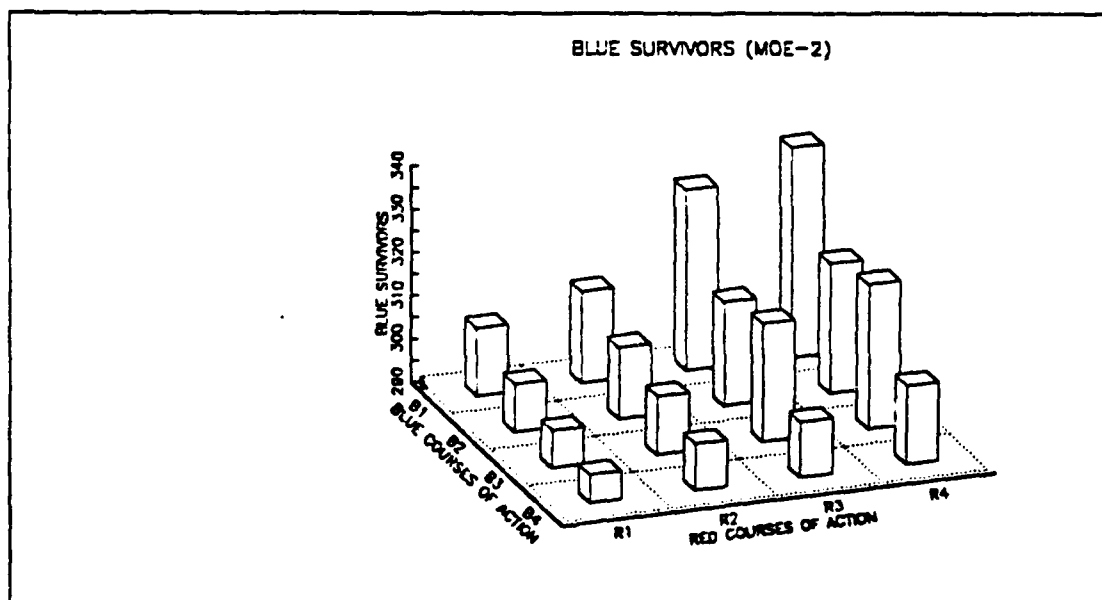


Figure 36. 3-Dimensional view of payoff matrix for Blue survivors.

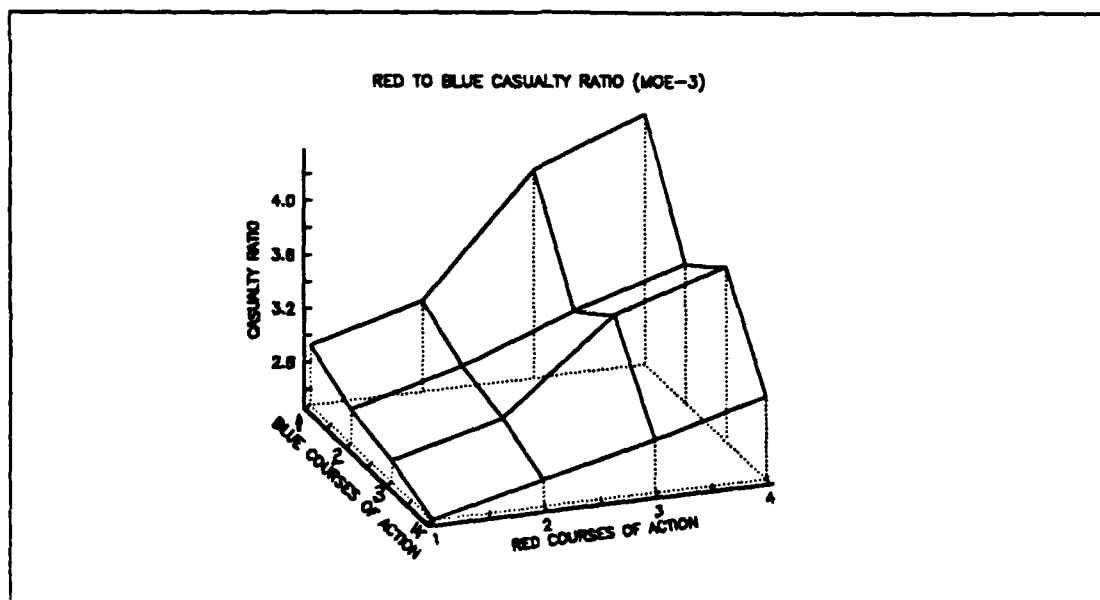


Figure 37. 3-Dimensional view of payoff matrix for the Red to Blue casualty ratio.

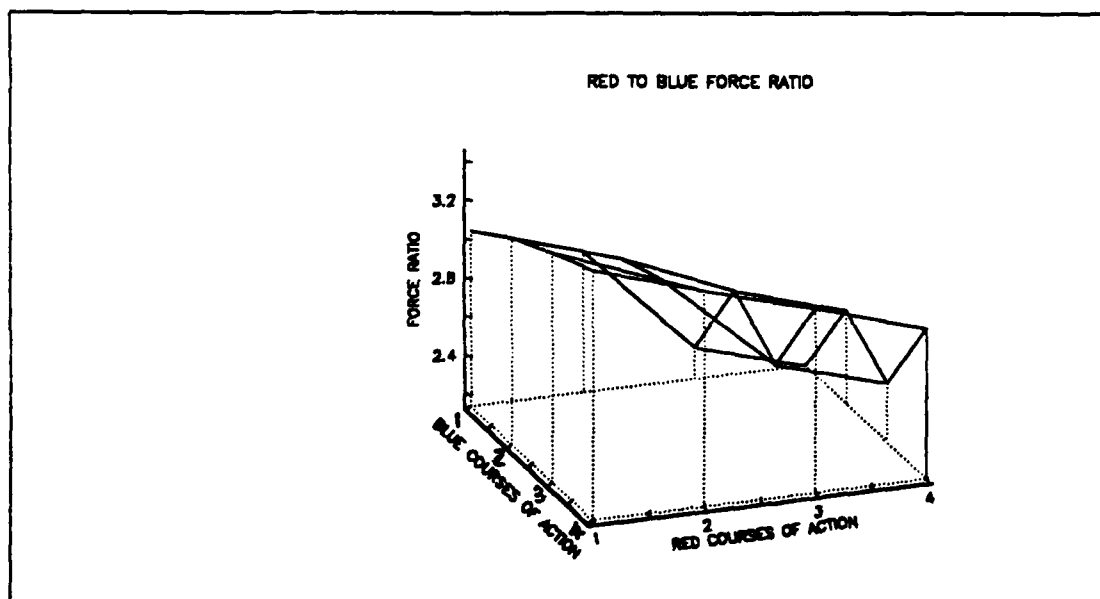


Figure 38. 3-Dimensional view of payoff matrix for the Red to Blue force ratio.

F. MODEL ENRICHMENT

The important question answered in this chapter is "Is this deterministic model performing in a reasonable fashion?" To support this question, this section will provide answers to the following questions, "Can a Red and Blue force size ratio affect the attacking force's speed?" (i.e., Is it better for the Red force to move fast when the Red to Blue force ratio is large versus when the Red to Blue force ratio is small?). If the answer is "yes" for this question then "How are they related?" and "How does it affect the duration of battle (MOE-4)?" These questions arise because the duration of battle in the Basic model did not vary by changing any of the parameters during the sensitivity analyses in previous sections.

In order to solve these problems, equation (2.16) in Chapter 2 was modified as given by equation (4.3).

$$S_{new} = S_{old} \times (1 - \frac{a_c}{a_0})^v + S_{min} \quad \text{where} \quad S_{min} = 0.3 \times (\frac{RF_c}{BF_c}) \quad (4.3)$$

where

v : power factor, based on different weapon types

S_{new} : updated speed of attacking force

S_{old} : speed of attacking force for previous time step

S_{min} : minimum speed for the attacking force

a_c : current attrition coefficient

a_0 : maximum attrition coefficient

RF_c : current Red force size

BF_c : current Blue force size

In equation (4.3), it is assumed that Red to Blue force ratio affects the minimum speed of Red (attacker) force. In other words, the Red force's minimum speed is proportional to the Red to Blue force ratio ($S_{min} \propto RF_c/BF_c$). It is also assumed the Red to Blue force ratio is greater than one. The 0.3 is a constant value under the assumption that the Red force can maneuver at least 0.3km per hour regardless of the Red to Blue force ratio value. The linear function for the minimum speed is shown in left portion of Figure 39. The function shown in right portion of Figure 39 represents the case when the attacker's minimum speed is not a linear function of Red Blue force ratio. In this chapter, the

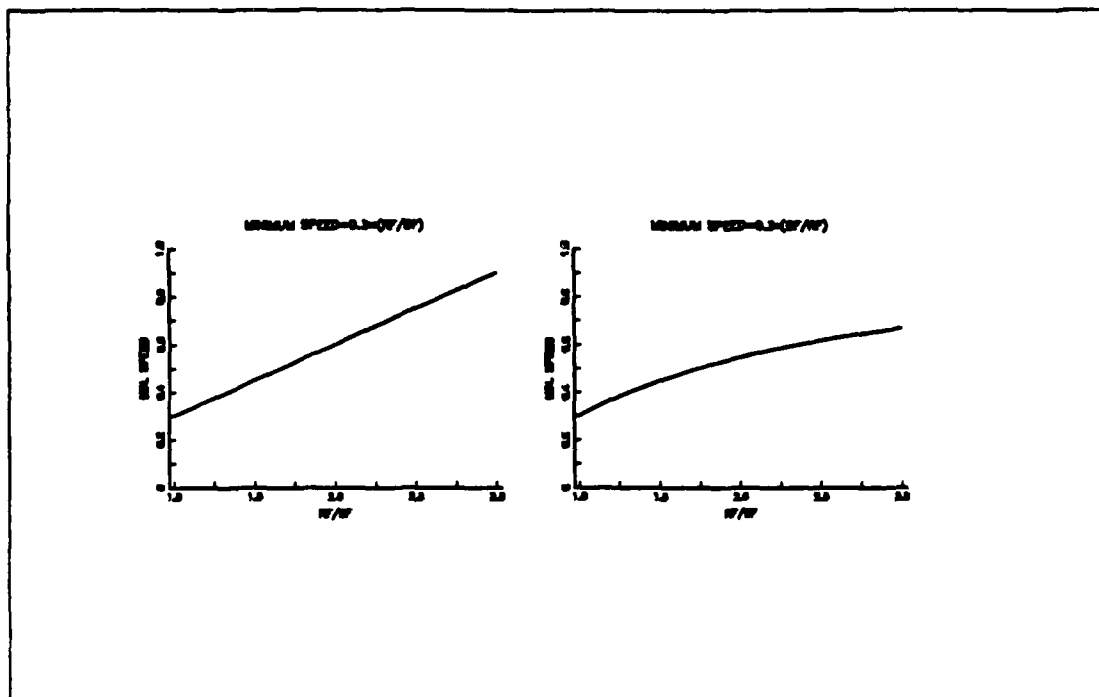


Figure 39. Two different functions for minimum speed.

linear function case, given in left portion of Figure 39, is applied to the basic model and analyzed in Figures 40 and 41.

Figure 40 shows differences of the Red to Blue casualty ratio (MOE-3) between the Basic model (which has constant minimum speed) and the Enriched model (which regards the attacker's minimum speed as a linear function of Red Blue force ratio) when each parameter is altered as follows:

NO CHANGE : no parameters are changed

↑ MD : Blue increases the Mine density.

↑ IF : Blue increases the Indirect fire.

USE MP : Red uses Mine-plow.

USE SM : Red uses Smoke.

Figure 40 illustrates that as the mine density and indirect fire increase for both models so do Red/Blue casualty ratios. When mine-plow and smoke are employed for both models, Red Blue casualty ratios decrease. These results are reasonable from a military standpoint. Even though there exist somewhat differences in increasing or decreasing

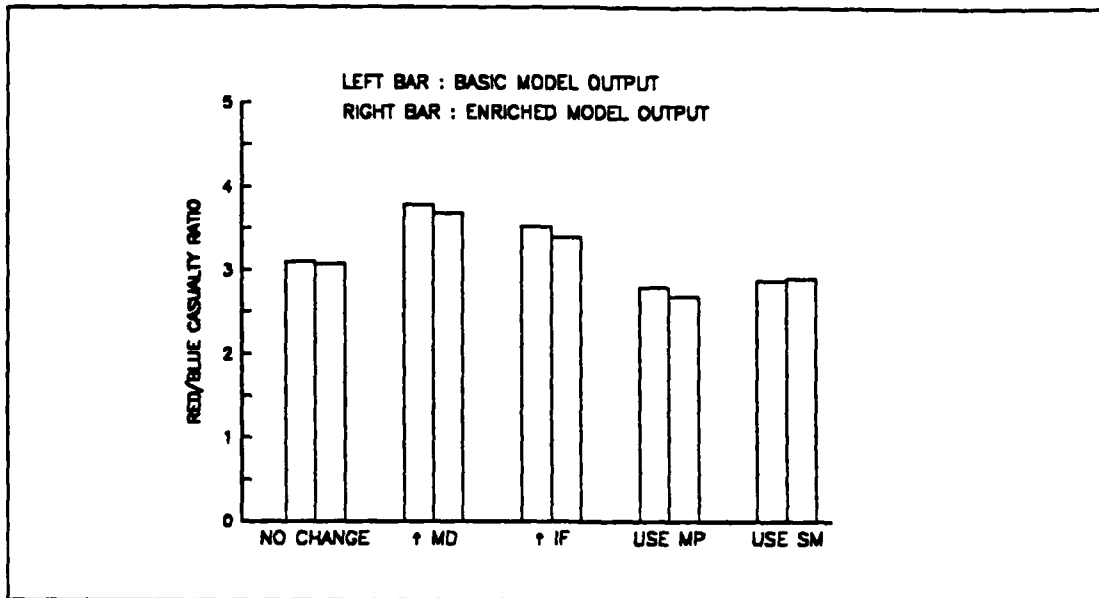


Figure 40. Comparison of RED/BLUE casualty ratio (MOE-3) between Basic and Enriched model.

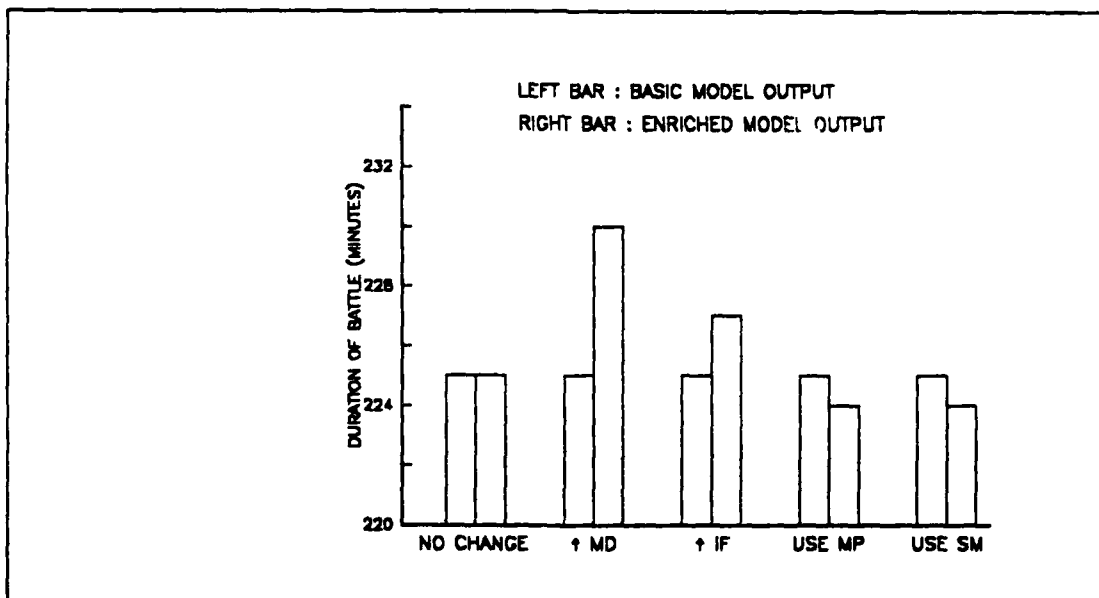


Figure 41. Comparison of duration of battle (MOE-4) between Basic and Enriched model.

Red Blue casualty ratio between Basic and Advanced model, both models change with a similar tendency based on alteration of each parameter.

Figure 41 shows differences of duration of battle (MOE-4) between the Basic model and the Enriched model. As expected, battle time is longer when Blue increases its mine density or indirect fire, and battle time is shorter when Red uses its mine-plow or smoke. Based on the above analysis with both Figures 40 and 41, the Enriched model appears to produce more reasonable results than the Basic model.

V. SUMMARY AND FUTURE DIRECTIONS

A. SUMMARY

This thesis has developed a deterministic air-land combat model using network attribute terrain data. Even though the model utilized terrain data for battalions and regiments, it may accept terrain data for larger sized forces. The model was run under a given scenario of specific battle conditions using an assigned battle area in the Republic of Korea. Three avenues of approach were employed in the model for the attacking force to reach the defending force. Based on the disposition of the forces (personnel, minefields, indirect fire, and so forth), the model outputs (MOEs) provide the military planner with information on preparing better defensive plans.

The primary focus of the thesis was to demonstrate various methods for analyzing model outputs. In this respect, the model provided sufficient data for analysis, which was performed in Chapters 3 and 4. In Chapter 4, sensitivity analysis varying specific parameters produced reasonable results, and also determined those parameters which were most volatile to change. The important results from sensitivity analyses are as follows:

1. If Blue has proper conditions (discussed in Chapter 4) on ambush points, reinforcing an additional platoon at the ambush point is better than at the main force areas.
2. As both maximum attrition rate coefficients (a_0 and b_0) increase, firepower effectiveness (or loss rate exchange) of Blue force is gradually reduced.
3. Both Red casualties and Blue survivors increase as w_1 (Weiss parameter for Blue engaging Red) decrease, but Red casualties are more sensitive to w_1 than Blue survivors.
4. When Weiss parameters for both Red and Blue approach the same value, both Red and Blue casualties decrease and the Red/Blue casualty ratio also decreases, which implies that firepower effectiveness of Red force increases.
5. The number of mines in Blue minefields do not have much effect on Red's mine-plows.
6. If Red uses smoke, increasing the number of mines in Blue minefields is better than increasing Blue indirect fire.

In addition to the above results, the model pointed out that Blue needs to consider new courses of action for attrition to Red on Avenue-22 in the BATTLE1 case which was

discussed in section C of Chapter 3. The model was enriched by using a modified equation for computing the attacking units' speed.

B. FUTURE DIRECTIONS

The deterministic model developed in this thesis is neither a complete nor perfect model. The author focused his efforts on analyzing the model outputs with various methodologies. Additional research is needed for improving the model. Other analytical methodologies, not covered in this thesis, should be explored. A limitation of this deterministic model is how to specify and determine more realistic attrition rate coefficient for each weapon system, to be used in Lanchester's Linear and Square law. However, simulation methods may be a possible approach to find more accurate attrition rate coefficients for weapon systems.

There are numerous factors which affect a battalion or regimental size battle. Therefore, the model developed in this thesis can be expanded by adding more combat types such as Close Air Support (CAS) and other newly developed weapon systems. The inclusion of these factors makes the model more complicated, yet allows for more realistic outputs. As for one way of dealing with new weapon systems, different value of μ (power factor based on different weapon types in Figure 7 of Chapter 2) could be used.

If the battle area has many terrain features (such as small hills, streams, bridges, resevoirs, and so forth) in small battle areas, some attrition rate coefficients may need to be changed. In order to deal with these factors, different analytical approaches are required. Simulations may help to obtain data outputs for comparison to real world data. Verification and evaluation with historical data is necessary before this model is used to test actual combat plans or scenarios.

It is recommended that the deterministic nature of the model be retained, as opposed to applying stochastic processes, because the purpose of this model is to generate battle outcomes traceable to specific input parameters. In other words, it is not suggested that stochastic variables be treated by a Monte Carlo process. Rather, the parameters are varied for different runs to maintain audit trail control for the purposes of analysis.

Finally, because only dismounted units (infantry forces) were considered in this model as an initial run, mounted units (vehicles such as tanks, APCs, and trucks) also should be considered for future runs. This requires some modifications to the model to incorporate different parameters based on vehicle types.

APPENDIX A. MODELS INPUT DATA

This is a formation of the input data for both models (Basic and Advanced) for dismounted (Infantry) unit cases.

Arc No.	Nodes (tail-head)		Passing time(min)	Distance	Width	Speed
1	1	2	31.5	2.1	0.006	4.
2	1	6	67.5	4.5	0.356	4.
3	2	3	16.5	1.1	0.506	4.
4	2	4	15.33	1.15	0.358	4.5
5	3	9	41.25	2.75	0.011	4.
6	4	5	32.57	1.9	0.254	3.5
7	4	11	28.67	2.15	0.558	4.5
8	5	7	40.29	2.35	0.004	3.5
9	5	11	60.0	3.	0.112	3.
10	6	7	21.43	1.25	0.554	3.5
11	6	8	31.5	2.1	0.106	4.
12	7	12	19.71	1.15	0.004	3.5
13	8	13	33.75	2.25	0.006	4.
14	9	10	25.0	1.25	0.002	3.
15	9	19	54.0	3.6	0.026	4.
16	10	11	65.0	3.25	0.002	3.
17	10	15	75.0	3.75	0.002	3.
18	10	20	107.0	5.35	0.002	3.
19	11	14	18.67	1.4	0.098	4.5
20	11	15	34.29	2.0	0.054	3.5
21	12	13	19.71	1.15	0.154	3.5
22	12	14	27.43	1.6	0.049	3.5
23	13	25	52.5	3.5	0.406	4.
24	14	16	11.25	0.75	0.066	4.
25	14	17	19.33	1.45	0.258	4.5
26	15	16	26.0	1.3	0.152	3.
27	15	18	15.43	0.9	0.204	3.5
28	16	17	17.14	1.0	0.084	3.5
29	16	18	14.25	0.95	0.076	4.
30	17	23	8.67	0.65	0.328	4.5
31	17	24	12.86	0.75	0.354	3.5
32	18	21	10.5	0.7	0.256	4.
33	19	20	51.43	3.0	0.049	3.5
34	20	21	21.75	1.45	0.176	4.
35	20	28	13.5	0.9	0.506	4.
36	21	22	18.86	1.1	0.224	3.5
37	22	23	9.43	0.55	0.704	3.5
38	22	27	12.0	0.7	0.454	3.5
39	23	27	8.67	0.65	0.678	4.5
40	24	25	8.57	0.5	0.574	3.5
41	24	26	12.86	0.75	0.274	3.5
42	25	26	8.0	0.6	0.328	4.5
43	26	27	8.0	0.6	0.408	4.5
44	27	28	33.75	2.25	0.066	4.

APPENDIX B. BASIC MODEL

This is a computer program using Fortran-77 for the basic model.

```

C
C ----< BASIC MODEL >---  MADE BY   LEE, JAE YEONG (1988.2.6) ---
C
      INTEGER    NA, NN, NOA, NOP, RBN, RRESER, BCO, PLTN
      PARAMETER (NA=44, NN=28, NOA=3, NOP=2, PLTN=40)
      PARAMETER (RBN=500, RRESER=150, BCO=170)
      INTEGER    REDAVE(NOA), SMAVE(NOA), PMAVE(NOA)
      INTEGER    ARC(NA), TAIL(NA), HEAD(NA), TAVE(NOA)
      INTEGER    PMARC(5), SMARC(3), IDARC(4,0:1001)
      INTEGER    IFA(4,1000), MFA(4,1000), DFA(4,1000)
      INTEGER    POIF, BLUEP1, BLUEP2, ANS1, ANS2, ANS3, ANS4
      INTEGER    INPUT, OUTPUT, TP1, TP2, DIF, DPMF, DSMF, INCRE, WID
      INTEGER    IFANS, MFANS, DFANS, TEND
      REAL       DIST(NA), WIDTH(NA), TIME(NA)
      REAL       SPEED(NA), OSPEED(NA), ADSP(NA)
      REAL       BREAKP(4), BREAKT(4)
      REAL       RF(4,0:1001), BF(4,0:1001), WHERE(4,0:1001), SP(4,0:1001)
      REAL       IFC(4,0:1001), MFC(4,0:1001), RDFC(4,0:1001),
1      IMDC(4,0:1001), BDFC(4,0:1001)
      REAL       RBP(4), IFSUM(4), MFSUM(4), RDFSUM(4), BDFSUM(4)
      REAL       IFCAS, MFCAS, DFCAS, BLEFT1, BLEFT2, WHOLD
      REAL       CLOCK, RANGE, BRDIST, AR, RB

      DATA      DIF, DPMF, DSMF    /10,20,15/
      DATA      PMAVE              /1,3,1/
      DATA      PMARC              /15,19,23,25,32/
      DATA      RANGE              /1.1/
      DATA      RB                 /0.0/

      DATA      REDAVE             /0,2,1/
      DATA      POIF               /2/
      DATA      SMAVE              /0,2,1/
      DATA      BLUEP1, BLUEP2     /1,2/

      INPUT = 12
      OUTPUT = 13
C---OPEN OUTPUT FILES !
C---FILE 'TSTEP' HAS RED AND BLUE FORCE SIZES ON EACH AVENUE
C---FILE 'REDCAS' HAS RED CASUALTIES ON EACH AVENUE
      OPEN ( UNIT = OUTPUT, FILE = 'TSTEP' )
      OPEN ( UNIT = 21, FILE = 'REDCAS' )

      WRITE(6,9)
      DO 10 I = 1, NA
        READ(INPUT,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),WIDTH(I),
1        SPEED(I)
        WRITE(6,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),WIDTH(I),

```

```

1          SPEED(I)
10         CONTINUE
9          FORMAT(1X,50('-',),/2X,'ARC TAIL-HEAD TIME      DIST  WIDTH ',
1          'SPEED',/1X,50('-',))
11         FORMAT(3X,I2,2(3X,I2),2X,F6.2,6X,F4.2,4X,F5.3,3X,F5.3)

          CALL OPTION (NA,NOA,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SPEED,
1          DIST,TIME,PMARC,SMARC,ANS1,ANS2,ANS3)
          IF(ANS1 .EQ. 0) GO TO 999
          IF(ANS2 .EQ. 0) GO TO 999
          IF(ANS3 .EQ. 0) GO TO 999

          DO 19 I = 1,NA
              CALL ASPEED (I,NA,ANS1,SPEED,ADSP)
              SPEED(I) = ADSP(I)
19          OSPEED(I) = SPEED(I)

          WRITE(13,25)REDAVE(1),REDAVE(2),REDAVE(3),SMAVE(1),SMAVE(2),
1          SMAVE(3),SMARC(1),SMARC(2),SMARC(3),BLUEP1,BLUEP2
          WRITE(6,25) REDAVE(1),REDAVE(2),REDAVE(3),SMAVE(1),SMAVE(2),
1          SMAVE(3),SMARC(1),SMARC(2),SMARC(3),BLUEP1,BLUEP2
25         FORMAT(/1X,'RED OPTION ==>',3I3,/1X,'BLUE OPTION',
1/4X,'* SCATERABLE MINEFIELD ==>',3I3,
1/4X,' (LOCATED ARCS) ==>',3I3,
1/4X,'* FORCE ALLOCATION =====>',2I3,/)

          NNN = 0
          IUSED = 0
          NEQ12 = 0
          NEQ34 = 0
          DO 5 I = 1,4
              IFSUM(I) = 0.0
              MFSUM(I) = 0.0
              RDFSUM(I) = 0.0
              BDFSUM(I) = 0.0
5          CONTINUE

          C---DEFINE INITIAL FORCE LEVEL AND LOCATION !
          RF(1,0) = REDAVE(1)*RBN
          RF(2,0) = (REDAVE(2)*RBN)/2
          RF(3,0) = (REDAVE(2)*RBN)/2
          RF(4,0) = REDAVE(3)*RBN
          DO 28 I = 1,4
              WHERE(I,0) = 0.
              IFC(I,0) = 0.
              MFC(I,0) = 0.
              RDFC(I,0) = 0.
              IMDC(I,0) = 0.
              BDFC(I,0) = 0.
28          RBP(I) = RB*RF(I,0)
          BF(1,0) = BLUEP1*BCO + PLTN/2
          BF(2,0) = BLUEP1*BCO + PLTN/2
          BF(3,0) = BLUEP2*BCO + PLTN/2
          BF(4,0) = BLUEP2*BCO + PLTN/2

          NOC = 0

```

```

INCRE = 1
DO 9999 IT = 1,500,INCRE

```

```

CLOCK = IT
DO 30 IA = 1,4

```

```

BREAKP(IA) = 0.
BREAKT(IA) = 0.
  IFC(IA,IT) = IFC(IA,IT-1)
  MFC(IA,IT) = MFC(IA,IT-1)
  RDFC(IA,IT) = RDFC(IA,IT-1)
  IMDC(IA,IT) = IMDC(IA,IT-1)
  BDFC(IA,IT) = BDFC(IA,IT-1)
  RF(IA,IT) = RF(IA,IT-1)
  BF(IA,IT) = BF(IA,IT-1)
  WHOLD = WHERE(IA,IT-1)
  CALL DETECT (IA,IT,INCRE,WHOLD,WID)
    IF(WID.EQ. 0) GO TO 999
  IDARC(IA,IT) = WID
  BRDIST = 9999.
  SP(IA,IT) = SPEED(WID)
  TS = (SPEED(WID)/60)*INCRE
  WHERE(IA,IT) = WHOLD + TS

```

```

C---IS THERE INDIRECT FIRE ? OR MINEFIELD ? OR DIRECT FIRE ?

```

```

  CALL IDFIND (IA,CLOCK,POIF,IFANS)
  CALL MFFIND (PMARC,SMARC,WID,MFANS)
  CALL DRFIND (IA,WHOLD,RANGE,BRDIST,DFANS)

```

```

  IFA(IA,IT) = IFANS
  MFA(IA,IT) = MFANS
  DFA(IA,IT) = DFANS

```

```

  IF(IFANS.EQ. 0 .AND. MFANS.EQ. 0 .AND. DFANS.EQ. 0) GO TO 30

```

```

C---COMPUTE THE CASUALTY OF INDIRECT-FIRE !

```

```

  IF(IFANS.EQ. 1) THEN
    CALL IDFIRE (IA,IT,RF,REDAVE,POIF,IFCAS)
    RF(IA,IT) = RF(IA,IT) - IFCAS
    IFSUM(IA) = IFCAS + IFSUM(IA)
    IFC(IA,IT) = IFC(IA,IT) + IFCAS
  END IF

```

```

C---COMPUTE THE CASUALTY BY MINE-FIELD !

```

```

  IF(MFANS.EQ. 1 .OR. MFANS.EQ. 2) THEN
    CALL MFIELD (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)
    RF(IA,IT) = RF(IA,IT) - MFCAS
    MFSUM(IA) = MFCAS + MFSUM(IA)
    MFC(IA,IT) = MFC(IA,IT) + MFCAS
  END IF

```

```

C---COMPUTE THE CASUALTY BY DIRECT-FIRE !

```

```

  IF(DFANS.EQ. 1 .OR. DFANS.EQ. 2) THEN
    IF( RF(IA,IT) .LT. BF(IA,IT) .AND.
1      IUSED.EQ. 0 .AND.
1      RF(IA,0) .GT. 0.0 ) THEN

```

```

        RF(IA,IT) = RF(IA,IT) + RRESER
        IUSED = 1
    END IF
    CALL DRFIRE (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
1          PLTN,RANGE,NNN,ACO,AMO)

    RF(IA,IT) = RF(IA,IT) - RDFCAS
    BF(IA,IT) = BF(IA,IT) - BDFCAS
    RDFSUM(IA) = RDFCAS + RDFSUM(IA)
    BDFSUM(IA) = BDFCAS + BDFSUM(IA)
    RDFC(IA,IT) = RDFC(IA,IT) + RDFCAS
    BDFC(IA,IT) = BDFC(IA,IT) + BDFCAS
    END IF

    IF(RF(IA,0) .GT. 0. .AND. RF(IA,IT) .LE. RBP(IA)) THEN
        CALL BREAK (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)
    END IF

C---COMPUTE THE REDUCED SPEED DUE TO THE INDIRECT FIRE OR MINEFIELD OR
C   UNDER THE DIRECT FIRE BASED ON THE RANGE OF TWO FORCES !

    CALL RSPEED (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
1          IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

    SP(IA,IT) = SPEED(WID)
    TS = (SPEED(WID)/60)*INCRE
    WHERE(IA,IT) = WHOLD + TS
    IMDC(IA,IT) = IFC(IA,IT) + MFC(IA,IT) + RDFC(IA,IT)

30  CONTINUE

    IF(NEQ12 .NE. 0) GO TO 36
        BF(1,IT) = MIN( BF(1,IT),BF(2,IT) )
        BF(2,IT) = MIN( BF(1,IT),BF(2,IT) )
36  IF(NEQ34 .NE. 0) GO TO 37
        BF(3,IT) = MIN( BF(3,IT),BF(4,IT) )
        BF(4,IT) = MIN( BF(3,IT),BF(4,IT) )
37  IF(NEQ12 .NE. 0) GO TO 38
    IF(DFA(1,IT) .EQ. 2 .AND. DFA(2,IT) .EQ. 2 .AND.
1  RF(1,IT) .GT. 0. .AND. RF(2,IT) .GT. 0.) THEN
        BF(1,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(1,IT)
        BF(2,IT) = (RF(2,IT) / (RF(1,IT)+RF(2,IT))) * BF(2,IT)
        NEQ12 = IT
    END IF
38  IF(NEQ34 .NE. 0) GO TO 39
    IF(DFA(3,IT) .EQ. 2 .AND. DFA(4,IT) .EQ. 2 .AND.
1  RF(3,IT) .GT. 0. .AND. RF(4,IT) .GT. 0.) THEN
        BF(3,IT) = (RF(3,IT) / (RF(3,IT)+RF(4,IT))) * BF(3,IT)
        BF(4,IT) = (RF(4,IT) / (RF(3,IT)+RF(4,IT))) * BF(4,IT)
        NEQ34 = IT
    END IF
39  WRITE(OUTPUT,40) IT,RF(1,IT),RF(2,IT),RF(3,IT),RF(4,IT)
    WRITE(OUTPUT,40) IT,BF(1,0)-(BDFC(1,IT)+BDFC(2,IT)),
1          BF(2,0)-(BDFC(1,IT)+BDFC(2,IT)),
1          BF(3,0)-(BDFC(3,IT)+BDFC(4,IT)),
1          BF(4,0)-(BDFC(3,IT)+BDFC(4,IT))

```

```

WRITE(OUTPUT,42) IT,WHERE(1,IT),WHERE(2,IT),WHERE(3,IT),WHERE(4,IT)
WRITE(OUTPUT,42) IT,SP(1,IT),SP(2,IT),SP(3,IT),SP(4,IT)

WRITE(21,40) IT,IFC(1,IT),IFC(2,IT),IFC(3,IT),IFC(4,IT)
WRITE(21,40) IT,MFC(1,IT),MFC(2,IT),MFC(3,IT),MFC(4,IT)
WRITE(21,40) IT,RDFC(1,IT),RDFC(2,IT),RDFC(3,IT),RDFC(4,IT)
WRITE(21,40) IT,IMDC(1,IT),IMDC(2,IT),IMDC(3,IT),IMDC(4,IT)
WRITE(21,40) IT,BDFC(1,IT),BDFC(2,IT),BDFC(3,IT),BDFC(4,IT)
40  FORMAT(1X,I6,4(3X,F6.1))
41  FORMAT(1X,I6,4(3X,I6))
42  FORMAT(1X,I6,4(3X,F6.3))

9999  CONTINUE

999    CALL PRINT (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,OUTPUT,
1      IFSUM,MFSUM,RDFSUM,BDFSUM)

C
C-----PRINT FOR CHECKING THE INPUT DATA
C
WRITE(6,9)
DO 998 I = 1, NA
998   WRITE(6,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),WIDTH(I),
1     SPEED(I)
WRITE(6,'(///)')
STOP 'THIS MODEL IS COMPLETE !   THANK YOU !'
END

*****
* 1. SUBROUTINE FOR SELECTING THE RED AND BLUE OPTIONS
*****
SUBROUTINE OPTION (NA,NOA,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SPEED,
1  DIST,TIME,PMARC,SMARC,ANS1,ANS2,ANS3)

INTEGER REDAVE(NOA),POIF,SMAVE(NOA),BLUEP1,BLUEP2
INTEGER PMARC(5),SMARC(3),ANS1,ANS2,ANS3,ANS4
REAL SPEED(NA),DIST(NA),TIME(NA)

1002 WRITE(6,'(///)')
PRINT *, 'HOW DO RED FORCE ALLOCATE THEIR UNIT ON EACH AVENUE ?'
PRINT *, '(CHOOSE THE NUMBER OF OPTION 1,2,3 OR 4)'
PRINT *, '*****'
PRINT *, ' *   OPTION      AVE-#1    AVE-#2    AVE-#3    *'
PRINT *, ' *       1.         1 BN      1 BN      1 BN      *'
PRINT *, ' *       2.         0 BN      2 BN      1 BN      *'
PRINT *, ' *       3.         0 BN      1 BN      2 BN      *'
PRINT *, ' *       4.         0 BN      3 BN      0 BN      *'
PRINT *, ' *       0.         EXIT THE RPROGRAM !    *'
PRINT *, '*****'
READ(5,*) ANS1
GO TO (1011,1012,1013,1014) ANS1
1011 REDAVE(1) = 1
    REDAVE(2) = 1
    REDAVE(3) = 1
    GO TO 1010
1012 REDAVE(1) = 0

```

```

        REDAVE(2) = 2
        REDAVE(3) = 1
1013    GO TO 1010
        REDAVE(1) = 0
        REDAVE(2) = 1
        REDAVE(3) = 2
1014    GO TO 1010
        REDAVE(1) = 0
        REDAVE(2) = 3
        REDAVE(3) = 0
        GO TO 1010
    IF(ANS1 .EQ. 0) THEN
        GO TO 1999
    ELSE
        PRINT*, '<< ERROR >> : ENTER THE NUMBER 1-4 OR 0 ==> TRY AGAIN !'
        GO TO 1002
    END IF
1010    WRITE(6, '(///)')
        PRINT *, 'HOW DO BLUE FORCE ALLOCATE THE SCATTERABLE MINES ?'
        PRINT *, ' (CHOOSE THE NUMBER OF OPTION 1,2,3 OR 4)'
        PRINT *, ' *****'
        PRINT *, ' *   OPTION      AVE-#1    AVE-#2    AVE-#3    *'
        PRINT *, ' *       1.         1 PKG     1 PKG     1 PKG     *'
        PRINT *, ' *       2.         0 PKG     2 PKG     1 PKG     *'
        PRINT *, ' *       3.         0 PKG     1 PKG     2 PKG     *'
        PRINT *, ' *       4.         0 PKG     3 PKG     0 PKG     *'
        PRINT *, ' *       0.         EXIT THE RPROGRAM ! *'
        PRINT *, ' *****'
        READ(5,*) ANS2
        GO TO (1031,1032,1033,1034) ANS2
1031    SMAVE(1) = 1
        SMAVE(2) = 1
        SMAVE(3) = 1
        GO TO 1025
1032    SMAVE(1) = 0
        SMAVE(2) = 2
        SMAVE(3) = 1
        GO TO 1025
1033    SMAVE(1) = 0
        SMAVE(2) = 1
        SMAVE(3) = 2
        GO TO 1025
1034    SMAVE(1) = 0
        SMAVE(2) = 3
        SMAVE(3) = 0
        GO TO 1025
    IF(ANS3 .EQ. 0) THEN
        GO TO 1999
    ELSE
        PRINT*, '<< ERROR >> : ENTER THE NUMBER 1-4 OR 0 ==> TRY AGAIN !'
        GO TO 1010
    END IF

1025    WRITE(6, '(///)')
        PRINT *, 'WHICH ARC WILL HAVE SCATTERABLE MINES ? '
        PRINT *, ' ( ENTER THE THREE INDEX NUMBER OF ARCS FROM 1 TO 44)'

```

```

      READ(5,*) (SMARC(I), I=1,3)
      IF(SMARC(1).GT.44 .OR. SMARC(2).GT.44 .OR. SMARC(3).GT.44) THEN
        PRINT*, '<< ERROR >> : INPUTS MUST BE LESS THAN 44==>TRY AGAIN !'
        GO TO 1025
      ELSE
        WRITE(6,1026) (SMARC(I), I=1,3)
1026  FORMAT(1X,'<< NOTE >> : SCATTERABLE MINES WILL BE ON ',
1I2,',',I2,',',I2,', ARCS')
      END IF

1020  WRITE(6,'(///)')
      PRINT*, 'HOW DO BLUE FORCE ALLOCATE THEIR UNIT ON EACH POSITION ?'
      PRINT *, ' (CHOOSE THE NUMBER OF OPTION 1 OR 2)'
      PRINT *, ' *****'
      PRINT *, ' * OPTION POSITION#1(NODE28) POSITION#2(NODE27) *'
      PRINT *, ' *      1.          2 CO          1 CO      *'
      PRINT *, ' *      2.          1 CO          2 CO      *'
      PRINT *, ' *      0.          EXIT THE RPOGRAM !      *'
      PRINT *, ' *****'
      READ(5,*) ANS3
      IF(ANS3 .EQ. 1) THEN
        BLUEP1 = 2
        BLUEP2 = 1
        GO TO 1999
      ELSE IF(ANS3 .EQ. 2) THEN
        BLUEP1 = 1
        BLUEP2 = 2
        GO TO 1999
      ELSE IF(ANS3 .EQ. 0) THEN
        GO TO 1999
      ELSE
        PRINT*, '<< ERROR >> : ENTER THE NUMBER 1,2 OR 0 ==> TRY AGAIN !'
        GO TO 1020
      END IF
1999  RETURN
      END

*****
* 2. SUBROUTINE FOR DETECTION WHICH ARC THE RED FORCES ARE ?
*****
      SUBROUTINE DETECT (IA,IT,INCRE,WHOLD,WID)

      INTEGER INCRE,WID
      REAL A1(4),A21(8),A22(6),A3(6),WHOLD

      DATA A1 /2.75,6.35,9.35,10.25/
      DATA A21 /1.15,3.3,4.7,5.45,6.4,7.1,8.55,9.45/
      DATA A22 /1.15,3.3,4.7,6.15,6.8,7.45/
      DATA A3 /4.5,6.6,8.85,12.35,12.95,13.55/

      GO TO (3011,3012,3013,3014) IA
3011  IF(WHOLD .LE. A1(1)) THEN
        WID = 5
        GO TO 1390
      ELSE IF(WHOLD.GT.A1(1) .AND. WHOLD.LE.A1(2)) THEN
        WID = 15
        GO TO 1390

```

```

ELSE IF(WHOLD.GT.A1(2) .AND. WHOLD.LE.A1(3)) THEN
    WID = 33
    GO TO 1390
ELSE IF(WHOLD.GT.A1(3) .AND. WHOLD.LE.A1(4)) THEN
    WID = 35
    GO TO 1390
ELSE IF(WHOLD.GT.A1(4)) THEN
    WRITE(13,1380) IT-1
1380 FORMAT(1X,'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END !'
1/5X,'(BATTLE TIME ==> ',14,' MINUTE)')
    PRINT *, 'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END !'
    PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
    GO TO 1399
END IF
3012 IF(WHOLD.LE.A21(1)) THEN
    WID = 4
    GO TO 1390
ELSE IF(WHOLD.GT.A21(1) .AND. WHOLD.LE.A21(2)) THEN
    WID = 7
    GO TO 1390
ELSE IF(WHOLD.GT.A21(2) .AND. WHOLD.LE.A21(3)) THEN
    WID = 19
    GO TO 1390
ELSE IF(WHOLD.GT.A21(3) .AND. WHOLD.LE.A21(4)) THEN
    WID = 24
    GO TO 1390
ELSE IF(WHOLD.GT.A21(4) .AND. WHOLD.LE.A21(5)) THEN
    WID = 29
    GO TO 1390
ELSE IF(WHOLD.GT.A21(5) .AND. WHOLD.LE.A21(6)) THEN
    WID = 32
    GO TO 1390
ELSE IF(WHOLD.GT.A21(6) .AND. WHOLD.LE.A21(7)) THEN
    WID = 34
    GO TO 1390
ELSE IF(WHOLD.GT.A21(7) .AND. WHOLD.LE.A21(8)) THEN
    WID = 35
    GO TO 1390
ELSE IF(WHOLD.GT.A21(8)) THEN
    WRITE(13,1381) IT-1
1381 FORMAT(1X,'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 : BATTLE ',
1'END !',/5X,'(BATTLE TIME ==> ',14,' MINUTE)')
    PRINT *, 'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 : BATTLE END !'
    PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
    GO TO 1399
END IF
3013 IF(WHOLD.LE.A22(1)) THEN
    WID = 4
    GO TO 1390
ELSE IF(WHOLD.GT.A22(1) .AND. WHOLD.LE.A22(2)) THEN
    WID = 7
    GO TO 1390
ELSE IF(WHOLD.GT.A22(2) .AND. WHOLD.LE.A22(3)) THEN
    WID = 19
    GO TO 1390
ELSE IF(WHOLD.GT.A22(3) .AND. WHOLD.LE.A22(4)) THEN

```

```

        WID = 25
        GO TO 1390
    ELSE IF(WHOLD.GT.A22(4) .AND. WHOLD.LE.A22(5)) THEN
        WID = 30
        GO TO 1390
    ELSE IF(WHOLD.GT.A22(5) .AND. WHOLD.LE.A22(6)) THEN
        WID = 39
        GO TO 1390
    ELSE IF(WHOLD.GT.A22(6)) THEN
        WRITE(13,1382) IT-1
1382  FORMAT(1X,'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE ',
1'END !',/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
        PRINT *, 'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE END !'
        PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
        GO TO 1399
    END IF
3014  IF(WHOLD.LE.A3(1)) THEN
        WID = 2
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(1) .AND. WHOLD.LE.A3(2)) THEN
        WID = 11
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(2) .AND. WHOLD.LE.A3(3)) THEN
        WID = 13
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(3) .AND. WHOLD.LE.A3(4)) THEN
        WID = 23
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(4) .AND. WHOLD.LE.A3(5)) THEN
        WID = 42
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(5) .AND. WHOLD.LE.A3(6)) THEN
        WID = 43
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(6)) THEN
        WRITE(13,1383) IT-1
1383  FORMAT(1X,'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE',
1'END !',/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
        PRINT *, 'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE END !'
        PRINT *, 'BATTLE TIME =',IT-1,' MINUTE'
        GO TO 1399
    END IF
1390  RETURN
1399  WID = 0
        RETURN
    END

```

```

*****
* 3. SUBROUTINE FOR IDENTIFYING THE INDIRECT-FIRE !
*****

```

```

SUBROUTINE IDFIND (IA,CLOCK,POIF,IFANS)
INTEGER POIF,IFANS
REAL    CLOCK,STIF,FTIF
DATA    STIF,FTIF /5.0,15.0/

```

```

IF(CLOCK.GE. STIF .AND. CLOCK.LT. FTIF) THEN
    IF(POIF.EQ. 2) THEN

```

```

        IF(IA.EQ. 2 .OR. IA.EQ. 3) THEN
            IFANS = 1
            GO TO 1444
        ELSE
            IFANS = 0
            GO TO 1444
        END IF
    ELSE IF(POIF .EQ. 3) THEN
        IF(IA .EQ. 4) THEN
            IFANS = 1
            GO TO 1444
        ELSE
            IFANS = 0
            GO TO 1444
        END IF
    END IF
ELSE
    IFANS = 0
END IF
1444 RETURN
END
*****
* 4. SUBROUTINE FOR IDENTIFYING THE MINE-FIELD !
*****
SUBROUTINE MFFIND (PMARC,SMARC,WID,MFANS)
INTEGER MFANS,WID,PMARC(5),SMARC(3)

DO 1510 I = 1,5
    IF(WID .EQ. PMARC(I)) THEN
        MFANS = 1
        GO TO 1599
    END IF
1510 CONTINUE
1511 DO 1520 J = 1,3
    IF(WID .EQ. SMARC(J)) THEN
        MFANS = 2
        GO TO 1599
    END IF
1520 CONTINUE
1521 MFANS = 0
1599 RETURN
END
*****
* 5. SUBROUTINE FOR IDENTIFYING THE DIRECT-FIRE !
*****
SUBROUTINE DRFIND (IA,WHOLD,RANGE,BRDIST,DFANS)

INTEGER IC,IA,DFANS
REAL WHOLD,PATH(4),RANGE,BRDIST,AMBUSH

DATA PATH /10.25,9.45,7.45,13.55/
DATA AMBUSH /4.0/

1 IF(WHOLD .GE. AMBUSH-RANGE/2. .AND.
1 WHOLD .LT. AMBUSH .AND.
1 (IA.EQ. 2. .OR. IA.EQ. 3)) THEN

```

```

        DFANS = 1
        BRDIST = AMBUSH - WHOLD
        GO TO 1699
    ELSE IF( WHOLD .GE. PATH(IA)-RANGE .AND.
1        WHOLD .LT. PATH(IA) ) THEN
        DFANS = 2
        BRDIST = PATH(IA) - WHOLD
        GO TO 1699
    END IF
1600 CONTINUE
    DFANS = 0
1699 RETURN
    END
*****
* 6. SUBROUTINE FOR COMPUTING CASUALTIES BY INDIRECT-FIRE
*****
    SUBROUTINE IDFIRE(IA,IT,RF,REDAVE,POIF,IFCAS)
    INTEGER NROUND,IA,IT,REDAVE(3),POIF
    REAL LETHAL,ROWSP,COLSP,MUX,MUY,RHOX,RHOY,RATIO,PKILL
    REAL RF(4,0:1001),IFCAS

    DATA NROUND,LETHAL /18,70.8/
    DATA MUX,MUY /15.,10./
    DATA RHOX,RHOY /15.,10./

    IF(REDAVE(POIF) .EQ. 1) THEN
        ROWSP = 12.
        COLSP = 12.
        GO TO 1669
    ELSE IF(REDAVE(POIF) .EQ. 2) THEN
        ROWSP = 10.
        COLSP = 10.
        GO TO 1669
    ELSE IF(REDAVE(POIF) .EQ. 3) THEN
        ROWSP = 8.
        COLSP = 8.
        GO TO 1669
    END IF

1669 RATIO = (NROUND*LETHAL) / (ROWSP*COLSP*RF(IA,IT))
    PHI = 3.141592654
    A = ((LETHAL*NROUND)/(2*PHI))**.5
    PKILL = RATIO * (A*A/((A*A+RHOX**2)*(A*A+RHOY**2))**.5) *
1    EXP(-.5*((MUX**2)/(A*A+RHOX**2) + (MUY**2)/(A*A+RHOY**2)))
    IFCAS = PKILL * RF(IA,IT) / 2.
    RETURN
    END
*****
* 7. SUBROUTINE FOR COMPUTING CASUALTIES BY MINEFIELDS
*****
    SUBROUTINE MFIELD (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)

    INTEGER MFANS,INCRE,NA,NOPM,NOSM,WID
    REAL TIME(NA),RF(4,0:1001),PCOEF,SCOEF,MFCAS,TPM,TSM

    DATA NOPM ,NOSM /300,200/

```

```

DATA      TPM ,TSM      /20.0,15.0/
DATA      PCOEF,SCOEF   /.00020,.00015/

IF(MFANS .EQ. 1) THEN
  MFCAS = (PCOEF*RF(IA,IT)*NOPM*(TPM/60.)) / (TIME(WID)/INCRE)
ELSE IF(MFANS .EQ. 2) THEN
  MFCAS = (SCOEF*RF(IA,IT)*NOSM*(TSM/60.)) / (TIME(WID)/INCRE)
END IF
RETURN
END

*****
* 8. SUBROUTINE FOR COMPUTING CASUALTIES BY DIRECT FIRE
*****
SUBROUTINE DRFIRE(DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
1              PLTN,RANGE,NNN,ACO,AMO)
  INTEGER  DFANS,DFA(4,1000),PLTN
  REAL     RF(4,0:1001),BF(4,0:1001),PLBP,FBF(0:1001)
  REAL     BRDIST,RANGE,RED,BLU,RDFCAS,BDFCAS,AR,BR,MU,PL

  DATA    PLBP          / 0.0/
  DATA    AOMEGA,BOMEGA /0.50,1.00/
  DATA    AC,BC          /0.0380,0.0160/
  DATA    AM,BM          /0.23,0.00010/
  DATA    MU             /1.0/

  ACO = AC
  AMO = AM
  IF(NNN .GT. 0) GO TO 1810
  PL = PLTN
1810 FBF(IT) = PL
C---FIND ENGAGED FORCES OF BOTH SIDES ON DIRECT FIRE BATTLE !
  RED = RF(IA,IT)
  BLU = BF(IA,IT)

C---CASE-#1 (MIXED LAW) : BLUE FORCE AMBUSHES THE RED FORCE !
  IF(DFANS .EQ. 1) THEN
    AR = AM * (1.0-BRDIST/RANGE)**MU
    BR = BM * (1.0-BRDIST/RANGE)**MU
    BLU = FBF(IT)
    IF(BLU .LT. PLBP) THEN
      RDFCAS = 0.0
      BLU = 0.0
    ELSE
      RDFCAS = AR * BLU
    END IF
    BDFCAS = BR * BLU * RED
    FBF(IT) = BLU - BDFCAS
    PL = FBF(IT)
    NNN = NNN + 1
    GO TO 1900
  ELSE IF(DFANS .EQ. 2) THEN
    IF(RED .LE. 0. .OR. BLU .LE. 0.) THEN
      BDFCAS = 0.
      RDFCAS = 0.
    
```

```

        GO TO 1900
    END IF
    AR = AC * (1.0-BRDIST/RANGE)**MU
    BR = BC * (1.0-BRDIST/RANGE)**MU
    RDFCAS = AR*((RED/BLU)**(1.0-BOMEGA))*BLU
    BDFCAS = BR*((BLU/RED)**(1.0-AOMEGA))*RED
END IF
1900 RETURN
END
*****
* 9. SUBROUTINE FOR COMPUTING THE ADJUSTED SPEED !
*****
SUBROUTINE ASPEED (I,NA,ANS1,SPEED,ADSP)

    INTEGER  ANS1,AOA1(4),AOA2(3),AOA3(6)
    REAL     SPEED(NA),ADSP(NA)

    DATA    AOA1      /5,15,33,35/
    DATA    AOA2      /4,7,19/
    DATA    AOA3      /2,11,13,23,42,43/

    GO TO (201,202,203,204)  ANS1
201      ADSP(I) = SPEED(I)
        GO TO 2010
202      ADSP(I) = SPEED(I)
        DO 2011 J = 1,3
2011      IF(I.EQ. AOA2(J))  ADSP(I) = 0.9*SPEED(I)
        GO TO 2010
203      ADSP(I) = SPEED(I)
        DO 2012 J = 1,6
2012      IF(I.EQ. AOA3(J))  ADSP(I) = 0.9*SPEED(I)
        GO TO 2010
204      ADSP(I) = SPEED(I)
        DO 2013 J = 1,3
2013      IF(I.EQ. AOA2(J))  ADSP(I) = 0.8*SPEED(I)

2010 RETURN
END
*****
* 10. SUBROUTINE FOR COMPUTING THE REDUCED SPEED !
*****
SUBROUTINE RSPEED (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
1              IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

    INTEGER  NA,WID,IFANS,MFANS,DFANS
    REAL     AR,DIST(NA),SPEED(NA),TIME(NA),MINSPD,RF(4,0:1001)
    REAL     OSPEED(NA)

    DATA    MINSPD    /0.500/

    IF(IFANS.EQ. 1) THEN
        SPEED(WID) = DIST(WID)*60./(TIME(WID)+10.)
    END IF
    IF(MFANS.EQ. 1) THEN
        SPEED(WID) = DIST(WID)*60./(TIME(WID)+20.)
    END IF

```

```

IF(MFANS .EQ. 2) THEN
  SPEED(WID) = DIST(WID)*60./(TIME(WID)+15.)
END IF
IF(DFANS .EQ. 1) THEN
  SPEED(WID) = SPEED(WID) * (1.0-AR/AMO) + MINSPD
  IF(SPEED(WID) .GT. OSPEED(WID)) SPEED(WID) = OSPEED(WID)
END IF
IF(DFANS .EQ. 2) THEN
  IF(RF(IA,IT) .EQ. 0.) THEN
    SPEED(WID) = 0.
  ELSE
    SPEED(WID) = SPEED(WID) * (1.0-AR/ACO) + MINSPD
    IF(SPEED(WID) .GT. OSPEED(WID)) SPEED(WID) = OSPEED(WID)
  END IF
END IF
RETURN
END

*****
* 11. TO FIND THE TIME AND LOCATION WHEN RED FORCE REACH BREAK-POINT !
*****
SUBROUTINE BREAK (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)

  INTEGER RRESER
  REAL BREAKP(4),BREAKT(4),WHOLD,RF(4,0:1001),BF(4,0:1001)

  RF(IA,IT) = 0.
  BF(IA,IT) = BF(IA,IT-1)
  IF(NOC .EQ. 0) THEN
C    RF(IA,IT) = RF(IA,IT-1) + RRESER
    BREAKP(IA) = WHOLD
    BREAKT(IA) = IT
  END IF
  NOC = NOC + 1
1111 RETURN
END

*****
* 12. TO PRINT THE CASUALTIES AND SURVIVORS FOR BOTH SIDES !
*****
SUBROUTINE PRINT (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,OUTPUT,
1  IFSUM,MFSUM,RDFSUM,BDFSUM)

  INTEGER RBN,BCO,BLUEP1,BLUEP2,NA,RRESER,PLTN,OUTPUT
  REAL IFSUM(4),MFSUM(4),RDFSUM(4),BDFSUM(4)
  REAL TIFSUM,TMFSUM,TRDF,TBDF
  CHARACTER*9 AVENUE(4)
  DATA AVENUE /'AVENUE#1','AVENUE#21','AVENUE#22','AVENUE#3'/
  DATA TIFSUM,TMFSUM,TRDF,TBDF /4*0.0/

  WRITE(OUTPUT, '(//)')
  WRITE(OUTPUT,100)
100 FORMAT(5X,'<<< RED CASUALTIES BY EACH TYPE OF BLUE FORCES >>>',
1/60(' - '),
1/15X,'INDIRECT-FIRE',4X,'MINE-FIELD',4X,'DIRECT-FIRE',/60(' - '))
  DO 101 IA = 1,4
    TIFSUM = IFSUM(IA) + TIFSUM
    TMFSUM = MFSUM(IA) + TMFSUM

```

```

        TRDF = RDFSUM(IA) + TRDF
        TBDF = BDFSUM(IA) + TBDF
        WRITE(OUTPUT,102) AVENUE(IA),IFSUM(IA),MFSUM(IA),RDFSUM(IA)
101  CONTINUE
        WRITE(OUTPUT,103) TIFSUM,TMFSUM,TRDF
102  FORMAT(3X,A9,5X,F6.1,10X,F6.1,9X,F6.1)
103  FORMAT(60(' '),/17X,F6.1,10X,F6.1,9X,F6.1)
        TRF = RBN*3.0 + RRESER
        TBF = BCO*3.0 + PLTN
        TRCAS = TIFSUM + TMFSUM + TRDF
        TRSUR = TRF - TRCAS
        TBCAS = TBDF
        TBSUR = TBF - TBCAS
        BFCAS1 = BDFSUM(1) + BDFSUM(2)
        BFCAS2 = BDFSUM(3) + BDFSUM(4)
        BFSUR1 = BLUEP1*BCO + PLTN/2 - BFCAS1
        BFSUR2 = BLUEP2*BCO + PLTN/2 - BFCAS2

        WRITE(OUTPUT,'(//)')
        WRITE(OUTPUT,105) BFCAS1,BFSUR1,BFCAS2,BFSUR2
105  FORMAT(5X,'<<< BLUE FORCE CASUALTIES FOR EACH FORT >>>',
1/60(' '),/15X,'CASUALTIES',5X,'SURVIVORS',/60(' '),/3X,'FORT#1',
15X,F6.1,10X,F6.1,/3X,'FORT#2',5X,F6.1,10X,F6.1,/60(' '))
        WRITE(OUTPUT,'(//)')
        WRITE(OUTPUT,106) TRF,TRCAS,TRSUR,TBF,TBCAS,TBSUR
106  FORMAT(5X,'<<< TOTAL CASUALTIES AND SURVIVORS >>>',
1/60(' '),/13X,'INITIAL FORCE',5X,'CASUALTIES',6X,
1'SURVIVORS',/60(' '),/5X,'RED',9X,F6.1,10X,F6.1,10X,F6.1,
1/5X,'BLUE',8X,F6.1,10X,F6.1,10X,F6.1,/60(' '))

        RETURN
        END

```

APPENDIX C. EXEC FOR BASIC MODEL

This is a execution code of Fortran-77 for the basic model in Appendix B.

FILEDEF 12 DISK THESIS DATA
EXEC WF77 BASIC (NOEXT NOWAR

APPENDIX D. ADVANCED MODEL

This is a computer program using Fortran-77 for the advanced model.

```

C
C ---< ADVANCED MODEL >--- MADE BY   LEE, JAE YEONG (1988.2.6) ---
C
      INTEGER MR,MB
      PARAMETER (MR=4, MB=8)
      REAL RED(MR,MB),BLUE(MR,MB),BATIME(MR,MB),ROB(MR,MB)
      INTEGER ANSWER,REDAVE(3),POIF,SMAVE(3),BLUEP1,BLUEP2,SMARC(3)
      INTEGER OUTPUT,TEND,WAVE2
      INTEGER ARC(44),TAIL(44),HEAD(44)
      REAL DIST(44),WIDTH(44),SPEED(44),TIME(44),OSPEED(44),ADSP(44)
      REAL TRCAS,TBSUR,TBCAS,VALUE(4)
      REAL LINE(MB),SQUA(MB),ROOT(MB),LIN,SQU,ROO
777 WRITE(6, '(///)')
      PRINT *, 'HOW DO RED FORCES ON AVENUE-2 ATTACK ?'
      PRINT *, '*****'
      PRINT *, '* <OPTION>                < EXPLANATION >                *'
      PRINT *, '* 1          ALL FORCES ATTACK TO THE NODE 28          *'
      PRINT *, '* 2          ALL FORCES ATTACK TO THE NODE 27          *'
      PRINT *, '* 3          DIVIDE EQUALLY AND ATTACK TO NODE 27 AND *'
      PRINT *, '*                NODE 28, RESPECTIVELY                *'
      PRINT *, '* 0          EXIT THE PROGRAM !                            *'
      PRINT *, '*****'
      READ(5,*) ANSWER
      IF (ANSWER .EQ. 0) GO TO 888
      IF (ANSWER.NE.1 .AND. ANSWER.NE.2 .AND.
1      ANSWER.NE.3 .AND. ANSWER.NE.0      ) GO TO 777

      GO TO (55,56,57) ANSWER
55      WAVE2 = 1
         GO TO 58
56      WAVE2 = 2
         GO TO 58
57      WAVE2 = 12
         GO TO 58

58      INPUT = 12
         OUTPUT = 24

C---OPEN OUTPUT FILES !
C---FILE 'MOES2' HAS ALL MOE VALUES FOR EACH RED AND BLUE OPTIONS.
C---FILE 'UTIL2' HAS UTILITY VALUES FOR EACH UTILITY FUNCTION.
C---FILE 'WHOW2' REPRESENTS HOW THE BATTLE TERMINATES!
      OPEN ( UNIT = OUTPUT, FILE = 'MOES2' )
      OPEN ( UNIT = 25      , FILE = 'UTIL2' )
      OPEN ( UNIT = 26      , FILE = 'WHOW2' )

      DO 1 IB = 1,MB
         CALL BDATA (IB,WAVE2,POIF,SMAVE,BLUEP1,BLUEP2,SMARC)

```

```

DO 2 IR = 1,MR
  CALL RDATA (IR,REDAVE)

DO 10 I = 1, 44
  READ(INPUT,11) ARC(I),TAIL(I),HEAD(I),TIME(I),DIST(I),
1    WIDTH(I),SPEED(I)

  CALL ASPED1 (WAVE2,I,IR,SPEED,ADSP)
  IF(WAVE2 .EQ. 12) CALL ASPED2 (I,IR,SPEED,ADSP)
  SPEED(I) = ADSP(I)
  OSPEED(I) = SPEED(I)
10    CONTINUE
11    FORMAT(3X,I2,2(3X,I2),2X,F6.2,6X,F4.2,4X,F5.3,3X,F3.1)

C--- READ THE ORIGINAL DATA AGAIN ! -----
  REWIND INPUT
C-----

  IF(WAVE2 .EQ. 1 .OR. WAVE2 .EQ. 2) THEN
    CALL BATLE1 (WAVE2,TRCAS,TBSUR,TEND,TBCAS,
1      IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
1      ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
  ELSE IF(WAVE2 .EQ. 12) THEN
    CALL BATLE2 (TRCAS,TBSUR,TEND,TBCAS,
1      IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
1      ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
  END IF

  RED(IR,IB) = TRCAS
  BLUE(IR,IB) = TBSUR
  BATIME(IR,IB) = TEND
  ROB(IR,IB) = TRCAS/TBCAS
  DO 4 I = 1,44
4    SPEED(I) = OSPEED(I)

2    CONTINUE

  WRITE(OUTPUT,900) IB,RED(1,IB),RED(2,IB),RED(3,IB),RED(4,IB),
1    IB,BLUE(1,IB),BLUE(2,IB),BLUE(3,IB),BLUE(4,IB),
1    IB,BATIME(1,IB),BATIME(2,IB),BATIME(3,IB),BATIME(4,IB),
1    IB,ROB(1,IB),ROB(2,IB),ROB(3,IB),ROB(4,IB)
900  FORMAT( 3X,I3,4(3X,F6.1),/3X,I3,4(3X,F6.1),/3X,I3,4(3X,F6.1),
1    /3X,I3,4(3X,F6.2) )

DO 905 J = 1,4
905  VALUE(J) = BLUE(J,IB)

C---COMPUTE DESIRED VALUES FOR DIFFERENT UTILITY FUNCTIONS !
  CALL UTIL (MR,MB,IB,VALUE,LIN,SQU,ROO)

  LINE(IB) = LIN
  SQUA(IB) = SQU
  ROOT(IB) = ROO

```

```

910  WRITE(25,910)  IB,LINE(IB),SQUA(IB),ROOT(IB)
      FORMAT( 3X,I3,3(3X,F6.2) )

1    CONTINUE

888  STOP  'THIS MODEL IS COMPLETE !   THANK YOU !'
      END

```

```

*****
* I. SUBROUTINE FOR DEFINING RED OPTIONS.
*****

```

```

      SUBROUTINE RDATA (IR,REDAVE)
      INTEGER  IR,REDAVE(3)

      GO TO (1151,1152,1153,1154)  IR
1151  REDAVE(1) = 1
      REDAVE(2) = 1
      REDAVE(3) = 1
      GO TO 1155
1152  REDAVE(1) = 0
      REDAVE(2) = 2
      REDAVE(3) = 1
      GO TO 1155
1153  REDAVE(1) = 0
      REDAVE(2) = 1
      REDAVE(3) = 2
      GO TO 1155
1154  REDAVE(1) = 0
      REDAVE(2) = 3
      REDAVE(3) = 0
      GO TO 1155
1155  RETURN
      END

```

```

*****
* II. SUBROUTINE FOR DEFINING BLUE OPTIONS.
*****

```

```

      SUBROUTINE BDATA (IB,WAVE2,POIF,SMAVE,BLUEP1,BLUEP2,SMARC)

      INTEGER  IB,WAVE2,POIF,SMAVE(3),BLUEP1,BLUEP2,SMARC(3)
      IIB = IB
      IF (IB .LE. 4) THEN
          BLUEP1 = 1
          BLUEP2 = 2
          GO TO 1250
      ELSE
          BLUEP1 = 2
          BLUEP2 = 1
          IB = IB - 4
      END IF

1250  GO TO (1251,1252,1253,1254)  IB
1251  POIF = 2
      SMAVE(1) = 1
      SMAVE(2) = 1
      SMAVE(3) = 1
      SMARC(1) = 30

```

```

SMARC(2) = 35
SMARC(3) = 42
  IF(WAVE2 .EQ. 1) THEN
    SMARC(1) = 30
    SMARC(2) = 34
    SMARC(3) = 42
  ELSE IF(WAVE2 .EQ. 2) THEN
    SMARC(1) = 35
    SMARC(2) = 39
    SMARC(3) = 42
  END IF
GO TO 1267
1252 POIF = 2
      SMAVE(1) = 0
      SMAVE(2) = 2
      SMAVE(3) = 1
      SMARC(1) = 30
      SMARC(2) = 34
      SMARC(3) = 42
      IF(WAVE2 .EQ. 1) THEN
        SMARC(1) = 34
        SMARC(2) = 35
        SMARC(3) = 42
      ELSE IF(WAVE2 .EQ. 2) THEN
        SMARC(1) = 30
        SMARC(2) = 39
        SMARC(3) = 42
      END IF
GO TO 1267
1253 POIF = 2
      SMAVE(1) = 0
      SMAVE(2) = 1
      SMAVE(3) = 2
      SMARC(1) = 30
      SMARC(2) = 42
      SMARC(3) = 43
      IF(WAVE2 .EQ. 1) THEN
        SMARC(1) = 35
        SMARC(2) = 42
        SMARC(3) = 43
      ELSE IF(WAVE2 .EQ. 2) THEN
        SMARC(1) = 39
        SMARC(2) = 42
        SMARC(3) = 43
      END IF
GO TO 1267
1254 POIF = 2
      SMAVE(1) = 0
      SMAVE(2) = 3
      SMAVE(3) = 0
      SMARC(1) = 30
      SMARC(2) = 34
      SMARC(3) = 35
      IF(WAVE2 .EQ. 1) THEN
        SMARC(1) = 32
        SMARC(2) = 34

```

```

        SMARC(3) = 35
      ELSE IF(WAVE2 .EQ. 2) THEN
        SMARC(1) = 25
        SMARC(2) = 30
        SMARC(3) = 39
      END IF
      GO TO 1267
1267  IB = IIB
      RETURN
      END

```

```

*****
* III. SUBROUTINE TO EXECUTE THE "BATTLE1" TYPE BATTLE !
*****

```

```

C
C   THIS PROGRAM DEAL WITH THE BATTLE CASE THAT HAS 3 AVENUES OF
C   APPROACH FOR RED FORCES CONTINUEOUSLY. (I.E., RED FORCES ON AVENUE-2
C   ATTACK TO JUST ONE OF TWO BLUE POSITIONS).
C

```

```

      SUBROUTINE BATLE1 (WAVE2,TRCAS,TBSUR,TEND,TBCAS,
1          IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
1          ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
      INTEGER  NA, NN, NOA, NOP, RBN, RRESER, BCO, PLTN
      PARAMETER (NA=44, NN=28, NOA=3, NOP=2, PLTN=40)
      PARAMETER (RBN=500, RRESER=150, BCO=170)
      INTEGER  REDAVE(NO), SMAVE(NO), PMAVE(NO)
      INTEGER  ARC(NA), TAIL(NA), HEAD(NA)
      INTEGER  PMARC(5), SMARC(3), IDARC(3,0:1001)
      INTEGER  IFA(3,1000), MFA(3,1000), DFA(3,1000)
      INTEGER  POIF, BLUEP1, BLUEP2, ANS1, ANS2, ANS3, ANS4
      INTEGER  INPUT, OUTPUT, TP1, TP2, DIF, DPMF, DSMF, INCRE, WID
      INTEGER  IFANS, MFANS, DFANS, TEND, WAVE2
      REAL     DIST(NA), WIDTH(NA), TIME(NA), SPEED(NA), OSPEED(NA)
      REAL     BREAKP(3), BREAKT(3), RBP(3)
      REAL     RF(3,0:1001), BF(3,0:1001), WHERE(3,0:1001), SP(3,0:1001)
      REAL     IFC(3,0:1001), MFC(3,0:1001), RDFC(3,0:1001),
1          IMDC(3,0:1001), BDFC(3,0:1001)
      REAL     IFSUM(3), MFSUM(3), RDFSUM(3), BDFSUM(3)
      REAL     IFCAS, MFCAS, DFCAS, BLEFT1, BLEFT2, WHOLD
      REAL     CLOCK, RANGE, BRDIST, AR, RB

```

```

      DATA  DIF,DPMF,DSMF  /10,20,15/
      DATA  PMAVE          /1,3,1/
      DATA  PMARC          /15,19,23,25,32/
      DATA  RANGE          /1.1/
      DATA  RB             /0.0/

```

```

      ANS1 = IR
      NNN = 0
      IUSED = 0
      NEQ12 = 0
      NEQ23 = 0

```

```

C---DEFINE INITIAL FORCE LEVEL AND LOCATION !
27  DO 28 I = 1,NOA
      RF(I,0) = REDAVE(I)*RBN

```

```

WHERE(I,0) = 0.0
IFC(I,0) = 0.0
MFC(I,0) = 0.0
RDFC(I,0) = 0.0
IMDC(I,0) = 0.0
BDFC(I,0) = 0.0
IFSUM(I) = 0.0
MFSUM(I) = 0.0
RDFSUM(I) = 0.0
BDFSUM(I) = 0.0
28 RBP(I) = RB*RF(I,0)

IF(WAVE2 .EQ. 1) THEN
  BF(1,0) = BLUEP1*BCO + PLTN
  BF(2,0) = BLUEP1*BCO + PLTN
  BF(3,0) = BLUEP2*BCO
ELSE IF(WAVE2 .EQ. 2) THEN
  BF(1,0) = BLUEP1*BCO
  BF(2,0) = BLUEP2*BCO + PLTN
  BF(3,0) = BLUEP2*BCO + PLTN
END IF

NOC = 0
INCRE = 1
DO 9999 IT = 1,500,INCRE

CLOCK = IT
DO 30 IA = 1,NOA

  BREAKP(IA) = 0.0
  BREAKT(IA) = 0.0
  IFC(IA,IT) = IFC(IA,IT-1)
  MFC(IA,IT) = MFC(IA,IT-1)
  RDFC(IA,IT) = RDFC(IA,IT-1)
  IMDC(IA,IT) = IMDC(IA,IT-1)
  BDFC(IA,IT) = BDFC(IA,IT-1)
  RF(IA,IT) = RF(IA,IT-1)
  BF(IA,IT) = BF(IA,IT-1)
  WHOLD = WHERE(IA,IT-1)
  CALL DETET1 (WAVE2,IA,IT,INCRE,WHOLD,WID)
  IF(WID .EQ. 0) GO TO 999
  IDARC(IA,IT) = WID
  BRDIST = 9999.
  SP(IA,IT) = SPEED(WID)
  TS = (SPEED(WID)/60)*INCRE
  WHERE(IA,IT) = WHOLD + TS

C---IS THERE INDIRECT FIRE ? OR MINEFIELD ? OR DIRECT FIRE ?
  CALL IDFND1 (IA,CLOCK,POIF,IFANS)
  CALL MFFND1 (PMARC,SMARC,WID,MFANS)
  CALL DRFND1 (WAVE2,IA,WHOLD,RANGE,BRDIST,DFANS)

  IFA(IA,IT) = IFANS
  MFA(IA,IT) = MFANS
  DFA(IA,IT) = DFANS

```

```

      IF(IFANS.EQ.0 .AND. MFANS.EQ.0 .AND. DFANS.EQ.0) GO TO 30

C---COMPUTE THE CASUALTY OF INDIRECT-FIRE !
      IF(IFANS .EQ. 1) THEN
        CALL IDFIR1 (IA,IT,RF,REDAVE,POIF,IFCAS)
        RF(IA,IT) = RF(IA,IT) - IFCAS
        IFSUM(IA) = IFCAS + IFSUM(IA)
        IFC(IA,IT) = IFC(IA,IT) + IFCAS
      END IF

C---COMPUTE THE CASUALTY BY MINE-FIELD !
      IF(MFANS.EQ.1 .OR. MFANS.EQ.2) THEN
        CALL MFILD1 (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)
        RF(IA,IT) = RF(IA,IT) - MFCAS
        MFSUM(IA) = MFCAS + MFSUM(IA)
        MFC(IA,IT) = MFC(IA,IT) + MFCAS
      END IF

C---COMPUTE THE CASUALTY BY DIRECT-FIRE !
      IF(DFANS .EQ. 1 .OR. DFANS .EQ. 2) THEN
        IF( RF(IA,IT) .LT. BF(IA,IT) .AND.
1         IUSED .EQ. 0 .AND.
1         RF(IA,0) .GT. 0.0 ) THEN
          RF(IA,IT) = RF(IA,IT) + RRESER
          IUSED = 1
        END IF
        CALL DRFIR1 (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
1                  PLTN,RANGE,NNN)

        RF(IA,IT) = RF(IA,IT) - RDFCAS
        BF(IA,IT) = BF(IA,IT) - BDFCAS
        RDFSUM(IA) = RDFCAS + RDFSUM(IA)
        BDFSUM(IA) = BDFCAS + BDFSUM(IA)
        RDFC(IA,IT) = RDFC(IA,IT) + RDFCAS
        BDFC(IA,IT) = BDFC(IA,IT) + BDFCAS
      END IF

      IF(RF(IA,0) .GT. 0 .AND. RF(IA,IT) .LE. RBP(IA)) THEN
        CALL BREAK1 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)
      END IF

C---COMPUTE THE REDUCED SPEED DUE TO THE INDIRECT FIRE OR MINEFIELD OR
C   UNDER THE DIRECT FIRE BASED ON THE RANGE OF TWO FORCES !

      CALL RSPED1 (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
1                IFANS,MFANS,DFANS,OSPEED)

      SP(IA,IT) = SPEED(WID)
      TS = (SPEED(WID)/60)*INCRE
      WHERE(IA,IT) = WHOLD + TS
      IMDC(IA,IT) = IFC(IA,IT) + MFC(IA,IT) + RDFC(IA,IT)

30  CONTINUE

      IF(WAVE2 .EQ. 1) THEN
        IF(NEQ12 .NE. 0) GO TO 9999

```

```

      BF(1,IT) = MIN( BF(1,IT),BF(2,IT) )
      BF(2,IT) = MIN( BF(1,IT),BF(2,IT) )
      BF(3,IT) = BF(3,IT)
      IF(DFA(1,IT) .EQ. 2 .AND. DFA(2,IT) .EQ. 2 .AND.
1      RF(1,IT) .GT. 0. .AND. RF(2,IT) .GT. 0.) THEN
          BF(1,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(1,IT)
          BF(2,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(2,IT)
          BF(3,IT) = BF(3,IT)
          NEQ12 = IT
      END IF
      ELSE IF(WAVE2 .EQ. 2) THEN
          IF(NEQ23 .NE. 0) GO TO 9999
          BF(1,IT) = BF(1,IT)
          BF(2,IT) = MIN( BF(2,IT),BF(3,IT) )
          BF(3,IT) = MIN( BF(2,IT),BF(3,IT) )
          IF(DFA(1,IT) .EQ. 2 .AND. DFA(2,IT) .EQ. 2 .AND.
1      RF(1,IT) .GT. 0. .AND. RF(2,IT) .GT. 0.) THEN
              BF(1,IT) = BF(1,IT)
              BF(2,IT) = (RF(2,IT) / (RF(2,IT)+RF(3,IT))) * BF(2,IT)
              BF(3,IT) = (RF(3,IT) / (RF(2,IT)+RF(3,IT))) * BF(3,IT)
              NEQ23 = IT
          END IF
      END IF

9999  CONTINUE

999    CALL PRINT1 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
1      WAVE2,IFSUM,MFSUM,RDFSUM,BDFSUM,
1      TRCAS,TBCAS,TRSUR,TBSUR)

      TEND = IT - 1
      RETURN
      END
*****
* III-1. SUBROUTINE FOR LOCATING THE ARC THE RED FORCES ARE ATTACKING.
*****
      SUBROUTINE DETET1 (WAVE2,IA,IT,INCRE,WHOLD,WID)

      INTEGER INCRE,WID,WAVE2
      REAL    A1(4),A21(8),A22(8),A3(6),WHOLD

      DATA A1 /2.75,6.35,9.35,10.25/
      DATA A21 /1.15,3.3,4.7,5.45,6.4,7.1,8.55,9.45/
      DATA A22 /1.15,3.3,4.7,6.15,6.8,7.45,7.45,7.45/
      DATA A3 /4.5,6.6,8.85,12.35,12.95,13.55/

      IF(IA .EQ. 1) THEN
          IF(WHOLD .LE. A1(1)) THEN
              WID = 5
              GO TO 1390
          ELSE IF(WHOLD.GT.A1(1) .AND. WHOLD.LE.A1(2)) THEN
              WID = 15
              GO TO 1390
          ELSE IF(WHOLD.GT.A1(2) .AND. WHOLD.LE.A1(3)) THEN
              WID = 33
              GO TO 1390

```

```

ELSE IF(WHOLD.GT.A1(3) .AND. WHOLD.LE.A1(4)) THEN
  WID = 35
  GO TO 1390
ELSE IF(WHOLD.GT. A1(4)) THEN
  WRITE(26,1380) IT-1
1380 FORMAT(1X,'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END ! '
1/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
  GO TO 1399
END IF
ELSE IF(IA.EQ. 2) THEN
  GO TO (1311,1312) WAVE2
1311 IF(WHOLD.LE. A21(1)) THEN
  WID = 4
  GO TO 1390
ELSE IF(WHOLD.GT.A21(1) .AND. WHOLD.LE.A21(2)) THEN
  WID = 7
  GO TO 1390
ELSE IF(WHOLD.GT.A21(2) .AND. WHOLD.LE.A21(3)) THEN
  WID = 19
  GO TO 1390
ELSE IF(WHOLD.GT.A21(3) .AND. WHOLD.LE.A21(4)) THEN
  WID = 24
  GO TO 1390
ELSE IF(WHOLD.GT.A21(4) .AND. WHOLD.LE.A21(5)) THEN
  WID = 29
  GO TO 1390
ELSE IF(WHOLD.GT.A21(5) .AND. WHOLD.LE.A21(6)) THEN
  WID = 32
  GO TO 1390
ELSE IF(WHOLD.GT.A21(6) .AND. WHOLD.LE.A21(7)) THEN
  WID = 34
  GO TO 1390
ELSE IF(WHOLD.GT.A21(7) .AND. WHOLD.LE.A21(8)) THEN
  WID = 35
  GO TO 1390
ELSE IF(WHOLD.GT. A21(8)) THEN
  WRITE(26,1381) IT-1
1381 FORMAT(1X,'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 : BATTLE ',
1'END ! ',/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
  GO TO 1399
END IF
1312 IF(WHOLD.IE. A22(1)) THEN
  WID = 4
  GO TO 1390
ELSE IF(WHOLD.GT.A22(1) .AND. WHOLD.LE.A22(2)) THEN
  WID = 7
  GO TO 1390
ELSE IF(WHOLD.GT.A22(2) .AND. WHOLD.LE.A22(3)) THEN
  WID = 19
  GO TO 1390
ELSE IF(WHOLD.GT.A22(3) .AND. WHOLD.LE.A22(4)) THEN
  WID = 25
  GO TO 1390
ELSE IF(WHOLD.GT.A22(4) .AND. WHOLD.LE.A22(5)) THEN
  WID = 30
  GO TO 1390

```

```

ELSE IF(WHOLD.GT.A22(5) .AND. WHOLD.LE.A22(6)) THEN
  WID = 39
  GO TO 1390
ELSE IF(WHOLD.GT. A22(6)) THEN
  WRITE(26,1382) IT-1
1382 FORMAT(1X,'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE ',
1'END !',/5X,'(BATTLE TIME ==> ',14,' MINUTE)')
  GO TO 1399
END IF
ELSE IF(IA.EQ. 3) THEN
  IF(WHOLD.LE. A3(1)) THEN
    WID = 2
    GO TO 1390
  ELSE IF(WHOLD.GT.A3(1) .AND. WHOLD.LE.A3(2)) THEN
    WID = 11
    GO TO 1390
  ELSE IF(WHOLD.GT.A3(2) .AND. WHOLD.LE.A3(3)) THEN
    WID = 13
    GO TO 1390
  ELSE IF(WHOLD.GT.A3(3) .AND. WHOLD.LE.A3(4)) THEN
    WID = 23
    GO TO 1390
  ELSE IF(WHOLD.GT.A3(4) .AND. WHOLD.LE.A3(5)) THEN
    WID = 42
    GO TO 1390
  ELSE IF(WHOLD.GT.A3(5) .AND. WHOLD.LE.A3(6)) THEN
    WID = 43
    GO TO 1390
  ELSE IF(WHOLD.GT. A3(6)) THEN
    WRITE(26,1383) IT-1
1383 FORMAT(1X,'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE ',
1'END !',/5X,'(BATTLE TIME ==> ',14,' MINUTE)')
    GO TO 1399
  END IF
END IF
1390 RETURN
1399 WID = 0
      RETURN
      END

```

```

*****
* III-2. SUBROUTINE FOR IDENTIFYING THE INDIRECT-FIRE !
*****

```

```

SUBROUTINE IDFND1 (IA,CLOCK,POIF,IFANS)
INTEGER POIF,IFANS
REAL    CLOCK,STIF,FTIF
DATA    STIF,FTIF /5.0,15.0/

IF(CLOCK.GE. STIF .AND. CLOCK.LT. FTIF) THEN
  IF(IA.EQ. 2) THEN
    IFANS = 1
    GO TO 1444
  ELSE
    IFANS = 0
    GO TO 1444
  END IF
ELSE

```

```

        IFANS = 0
    END IF
1444  RETURN
    END
*****
* III-3. SUBROUTINE FOR IDENTIFYING THE MINE-FIELD !
*****
    SUBROUTINE MFFND1 (PMARC,SMARC,WID,MFANS)
    INTEGER MFANS,WID,PMARC(5),SMARC(3)

    DO 1510 I = 1,5
        IF(WID .EQ. PMARC(I)) THEN
            MFANS = 1
            GO TO 1599
        END IF
1510  CONTINUE
1511  DO 1520 J = 1,3
        IF(WID .EQ. SMARC(J)) THEN
            MFANS = 2
            GO TO 1599
        END IF
1520  CONTINUE
1521  MFANS = 0
1599  RETURN
    END
*****
* III-4. SUBROUTINE FOR IDENTIFYING THE DIRECT-FIRE !
*****
    SUBROUTINE DRFND1 (WAVE2,IA,WHOLD,RANGE,BRDIST,DFANS)

    INTEGER IA,DFANS,WAVE2
    REAL    WHOLD,PATH(3),RANGE,BRDIST,AMBUSH

    DATA    AMBUSH /4.0/
             PATH(1) = 10.25
             PATH(2) = 9.45
             IF(WAVE2 .EQ. 2) PATH(2) = 7.45
             PATH(3) = 13.55

    IF(WHOLD .GE. AMBUSH-RANGE/2. .AND.
1     WHOLD .LT. AMBUSH .AND.
1     IA .EQ. 2 ) THEN
        DFANS = 1
        BRDIST = AMBUSH - WHOLD
        GO TO 1699
    ELSE IF( WHOLD .GE. PATH(IA)-RANGE .AND.
1     WHOLD .LT. PATH(IA) ) THEN
        DFANS = 2
        BRDIST = PATH(IA) - WHOLD
        GO TO 1699
    END IF
    DFANS = 0
1699  RETURN
    END
*****

```

* III-5. SUBROUTINE FOR COMPUTING CASUALTIES BY INDIRECT-FIRE

SUBROUTINE IDFIR1(IA,IT,RF,REDAVE,POIF,IFCAS)

INTEGER NROUND,IA,IT,REDAVE(3),POIF

REAL LETHAL,ROWSP,COLSP,MUX,MUY,RHOX,RHOY,RATIO,PKILL

REAL RF(3,0:1001),IFCAS

DATA NROUND,LETHAL /18,70.8/

DATA MUX,MUY /15.,10./

DATA RHOX,RHOY /15.,10./

IF(REDAVE(POIF) .EQ. 1) THEN

ROWSP = 12.

COLSP = 12.

GO TO 1669

ELSE IF(REDAVE(POIF) .EQ. 2) THEN

ROWSP = 10.

COLSP = 10.

GO TO 1669

ELSE IF(REDAVE(POIF) .EQ. 3) THEN

ROWSP = 8.

COLSP = 8.

GO TO 1669

END IF

PRINT *, IT,IA,RF(IA,IT)

1669 RATIO = (NROUND*LETHAL) / (ROWSP*COLSP*RF(IA,IT))

PHI = 3.141592654

A = ((LETHAL*NROUND)/(2*PHI))**.5

PKILL = RATIO * (A*A/((A*A+RHOX**2)*(A*A+RHOY**2))**.5) *

1 EXP(-.5*((MUX**2)/(A*A+RHOX**2) + (MUY**2)/(A*A+RHOY**2)))

IFCAS = PKILL * RF(IA,IT)

RETURN

END

* III-6. SUBROUTINE FOR COMPUTING CASUALTIES BY MINEFIELDS

SUBROUTINE MFILD1(IA,IT,MFANS,INCR,NA,WID,TIME,RF,MFCAS)

INTEGER MFANS,INCR,NA,NOPM,NOSM,WID

REAL TIME(NA),RF(3,0:1001),PCOEF,SCOEF,MFCAS,TPM,TSM

DATA NOPM,NOSM /300,200/

DATA TPM,TSM /20.0,15.0/

DATA PCOEF,SCOEF /.00020,.00015/

IF(MFANS .EQ. 1) THEN

MFCAS = (PCOEF*RF(IA,IT)*NOPM*(TPM/60.)) / (TIME(WID)/INCR)

ELSE IF(MFANS .EQ. 2) THEN

MFCAS = (SCOEF*RF(IA,IT)*NOSM*(TSM/60.)) / (TIME(WID)/INCR)

END IF

RETURN

END

* III-7. SUBROUTINE FOR COMPUTING CASUALTIES BY DIRECT FIRE

SUBROUTINE DRFIR1(DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,

```

1          PLTN,RANGE,NNN)
INTEGER  DFANS,DFA(3,1000),PLTN
REAL     RF(3,0:1001),BF(3,0:1001),PLBP,FBF(0:1001)
REAL     BRDIST,RANGE,RED,BLU,RDFCAS,BDFCAS,AR,BR,MU,PL

DATA     PLBP          /10.0/
DATA     AOMEGA,BOMEGA /0.50,1.00/
DATA     AC,BC         /0.0490,0.0250/
DATA     AM,BM         /0.23,0.00010/
DATA     MU            /1.0/

IF(NNN.GT. 0) GO TO 1810
PL = PLTN
1810 FBF(IT) = PL
C---FIND ENGAGED FORCES OF BOTH SIDES ON DIRECT FIRE BATTLE !
RED = RF(IA,IT)
BLU = BF(IA,IT)

C---CASE-#1 (MIXED LAW) : BLUE FORCE AMBUSHES THE RED FORCE !
IF(DFANS.EQ. 1) THEN
  AR = AM * (1-BRDIST/RANGE)**MU
  BR = BM * (1-BRDIST/RANGE)**MU
  BLU = FBF(IT)
  IF(BLU.LT. PLBP) THEN
    RDFCAS = 0.0
    BLU = 0.0
  ELSE
    RDFCAS = AR * BLU
  END IF
  BDFCAS = BR * BLU * RED
  FBF(IT) = BLU - BDFCAS
  PL = FBF(IT)
  NNN = NNN + 1
  GO TO 1900

C---CASE-#2 (HEMBOLT EQUATION) !
ELSE IF(DFANS.EQ. 2) THEN
  IF(RED.LE. 0. .OR. BLU.LE. 0.) THEN
    BDFCAS = 0.
    RDFCAS = 0.
    GO TO 1900
  END IF
  AR = AC * (1-BRDIST/RANGE)**MU
  BR = BC * (1-BRDIST/RANGE)**MU
  RDFCAS = AR*((RED/BLU)**(1.0-BOMEGA))*BLU
  BDFCAS = BR*((BLU/RED)**(1.0-AOMEGA))*RED
END IF
1900 RETURN
END

*****
* III-8. SUBROUTINE FOR COMPUTING THE ADJUSTED SPEED BASED ON
* THE NUMBER OF RED UNITS (BATTALIONS) ON EACH AVENUE.
*****
SUBROUTINE ASPED1(WAVE2,I,IR,SPEED,ADSP)

INTEGER WAVE2,IR,AOA1(4),AOA2(8),AOA3(6),AOA21(8),AOA22(8)

```

```

REAL      SPEED(44),ADSP(44)

DATA      AOA1      /5,15,33,35/
DATA      AOA21     /4,7,19,24,29,32,34,35/
DATA      AOA22     /4,7,19,25,30,39,39,39/
DATA      AOA3      /2,11,13,23,42,43/

      DO 2009 K = 1,8
      AOA2(K) = AOA21(K)
2009      IF(WAVE2 .EQ. 2) AOA2(K) = AOA22(K)

      GO TO (201,202,203,204) IR
201      ADSP(I) = SPEED(I)
      GO TO 2010
202      ADSP(I) = SPEED(I)
      DO 2011 J = 1,8
2011      IF(I .EQ. AOA2(J)) ADSP(I) = 0.9*SPEED(I)
      GO TO 2010
203      ADSP(I) = SPEED(I)
      DO 2012 J = 1,6
2012      IF(I .EQ. AOA3(J)) ADSP(I) = 0.9*SPEED(I)
      GO TO 2010
204      ADSP(I) = SPEED(I)
      DO 2013 J = 1,3
2013      IF(I .EQ. AOA2(J)) ADSP(I) = 0.8*SPEED(I)

2010 RETURN
      END
*****
* III-9. SUBROUTINE FOR COMPUTING THE REDUCED SPEED BASED ON
* EACH WEAPON TYPE.
*****
      SUBROUTINE RSPED1(IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
1      IFANS,MFANS,DFANS,OSPEED)

      INTEGER NA,WID,IFANS,MFANS,DFANS
      REAL AR,DIST(NA),SPEED(NA),TIME(NA),MINSPD,RF(3,0:1001)
      REAL OSPEED(NA)

      DATA MINSPD /0.5/
      DATA ACO,AMO /0.06,0.20/

      IF(IFANS .EQ. 1) THEN
        SPEED(WID) = DIST(WID)*60. / (TIME(WID)+10.)
      END IF
      IF(MFANS .EQ. 1) THEN
        SPEED(WID) = DIST(WID)*60. / (TIME(WID)+20.)
      END IF
      IF(MFANS .EQ. 2) THEN
        SPEED(WID) = DIST(WID)*60. / (TIME(WID)+15.)
      END IF
      IF(DFANS .EQ. 1) THEN
        SPEED(WID) = SPEED(WID) * (1-AR/AMO) + MINSPD
        IF(SPEED(WID) .GT. OSPEED(WID)) SPEED(WID) = OSPEED(WID)
      END IF
      IF(DFANS .EQ. 2) THEN

```

```

        IF(RF(IA,IT) .EQ. 0.) THEN
            SPEED(WID) = 0.
        ELSE
            SPEED(WID) = SPEED(WID) * (1-AR/ACO) + MINSPD
            IF(SPEED(WID) GT. OSPEED(WID)) SPEED(WID) = OSPEED(WID)
        END IF
    END IF
    RETURN
END

*****
* III-10. SUBROUTINE TO FIND THE TIME AND LOCATION
*       WHEN RED FORCE REACH BREAK-POINT !
*****
SUBROUTINE BREAK1 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)

    INTEGER RRESER
    REAL    BREAKP(3),BREAKT(3),WHOLD,RF(3,0:1001),BF(3,0:1001)

    RF(IA,IT) = 0.
    BF(IA,IT) = BF(IA,IT-1)
    IF(NOC .EQ. 0) THEN
C        RF(IA,IT) = RF(IA,IT-1) + RRESER
        BREAKP(IA) = WHOLD
        BREAKT(IA) = IT
    END IF
    NOC = NOC + 1
1111 RETURN
END

*****
* III-11. SUBROUTINE TO PRINT THE CASUALTIES AND SURVIVORS
*       FOR BOTH SIDES IN BATTLE1 TYPE.
*****
SUBROUTINE PRINT1 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
1             WAVE2,IFSUM,MFSUM,RDFSUM,BDFSUM,
1             TRCAS,TBCAS,TRSUR,TBSUR)

    INTEGER RBN,BCO,BLUEP1,BLUEP2,NA,RRESER,PLTN,WAVE2
    REAL    IFSUM(3),MFSUM(3),RDFSUM(3),BDFSUM(3)
    REAL    TIFSUM,TMFSUM,TRDF,TBDF
    REAL    TRCAS,TRSUR,TBCAS,TBSUR

    TIFSUM = 0.0
    TMFSUM = 0.0
    TRDF = 0.0
    TBDF = 0.0

    TRCAS = 0.0
    TBCAS = 0.0
    TRSUR = 0.0
    TBSUR = 0.0

    DO 101 IA = 1,3
        TIFSUM = IFSUM(IA) + TIFSUM
        TMFSUM = MFSUM(IA) + TMFSUM
        TRDF = RDFSUM(IA) + TRDF

```

```

      TBDF = BDFSUM(IA) + TBDF
101  CONTINUE
      TRF = RBN*3.0 + RRESER
      TBF = BCO*3.0 + PLTN
      TRCAS = TIFSUM + TMFSUM + TRDF
      TRSUR = TRF - TRCAS
      TBCAS = TBDF
      TBSUR = TBF - TBCAS
      IF(WAVE2.EQ. 1) THEN
          BFCAS1 = BDFSUM(1) + BDFSUM(2)
          BFCAS2 = BDFSUM(3)
          BFSUR1 = BLUEP1*BCO + PLTN - BFCAS1
          BFSUR2 = BLUEP2*BCO - BFCAS2
      ELSE IF(WAVE2.EQ. 2) THEN
          BFCAS1 = BDFSUM(1)
          BFCAS2 = BDFSUM(2) + BDFSUM(3)
          BFSUR1 = BLUEP1*BCO - BFCAS1
          BFSUR2 = BLUEP2*BCO + PLTN - BFCAS2
      END IF

```

```

      TRCAS = TIFSUM + TMFSUM + TRDF
      TRSUR = TRF - TRCAS
      TBCAS = TBDF
      TBSUR = TBF - TBCAS

```

```

      RETURN
      END

```

```

*****
* IV. SUBROUTINE TO EXECUTE THE "BATTLE2" TYPE BATTLE.
*****

```

```

C
C   THIS PROGRAM DEAL WITH THE BATTLE CASE THAT HAS 3 AVENUES OF
C   APPROACH FOR RED FORCES INITIALLY, BUT ATTACK TO BLUE WITH 4 AVENUES
C   OF APPROACH FINALLY. (I.E., RED FORCES ON AVENUE-2 DIVIDE EQUALLY
C   AND ATTACK TO BOTH BLUE POSITIONS : NODE 27 AND NODE 28).
C

```

```

      SUBROUTINE BATLE2 (TRCAS,TBSUR,TEND,TBCAS,
1      IB,IR,REDAVE,POIF,SMAVE,BLUEP1,BLUEP2,SMARC,
1      ARC,TAIL,HEAD,TIME,DIST,WIDTH,SPEED,OSPEED)
      INTEGER    NA, NN, NOA, NOP, RBN, RRESER, BCO, PLTN
      PARAMETER (NA=44, NN=28, NOA=3, NOP=2, PLTN=40)
      PARAMETER (RBN=500, RRESER=150, BCO=170)
      INTEGER    REDAVE(NOA), SMAVE(NOA), PMAVE(NOA)
      INTEGER    ARC(NA), TAIL(NA), HEAD(NA)
      INTEGER    PMARC(5), SMARC(3), IDARC(4,0:1001)
      INTEGER    IFA(4,1000), MFA(4,1000), DFA(4,1000)
      INTEGER    POIF, BLUEP1, BLUEP2, ANS1, ANS2, ANS3, ANS4
      INTEGER    INPUT, OUTPUT, TP1, TP2, DIF, DPMF, DSMF, INCRE, WID
      INTEGER    IFANS, MFANS, DFANS, TEND
      REAL       DIST(NA), WIDTH(NA), TIME(NA), SPEED(NA), OSPEED(NA)
      REAL       BREAKP(4), BREAKT(4), RBP(4)
      REAL       RF(4,0:1001), BF(4,0:1001), WHERE(4,0:1001), SP(4,0:1001)
      REAL       IFC(4,0:1001), MFC(4,0:1001), RDFC(4,0:1001),
1      IMDC(4,0:1001), BDFC(4,0:1001)
      REAL       IFSUM(4), MFSUM(4), RDFSUM(4), BDFSUM(4)
      REAL       IFCAS, MFCAS, DFCAS, BLEFT1, BLEFT2, WHOLD

```

```

REAL      CLOCK,RANGE,BRDIST,AR,RB

DATA      DIF,DPMF,DSMF  /10,20,15/
DATA      PMAVE          /1,3,1/
DATA      PMARC          /15,19,23,25,32/
DATA      RANGE          /1.1/
DATA      RB              /0.0/

ANS1 = IR
NNN = 0
IUSED = 0
NEQ12 = 0
NEQ34 = 0
DO 5 I = 1,4
    IFSUM(I) = 0.0
    MFSUM(I) = 0.0
    RDFSUM(I) = 0.0
    BDFSUM(I) = 0.0
5  CONTINUE
C---DEFINE INITIAL FORCE LEVEL AND LOCATION !
RF(1,0) = REDAVE(1)*RBN
RF(2,0) = (REDAVE(2)*RBN)/2
RF(3,0) = (REDAVE(2)*RBN)/2
RF(4,0) = REDAVE(3)*RBN
DO 28 I = 1,4
    WHERE(I,0) = 0.
    IFC(I,0) = 0.
    MFC(I,0) = 0.
    RDFC(I,0) = 0.
    IMDC(I,0) = 0.
    BDFC(I,0) = 0.
28  RBP(I) = RB*RF(I,0)
    BF(1,0) = BLUEP1*BCO + PLTN/2
    BF(2,0) = BLUEP1*BCO + PLTN/2
    BF(3,0) = BLUEP2*BCO + PLTN/2
    BF(4,0) = BLUEP2*BCO + PLTN/2

NOC = 0
INCRE = 1
DO 9999 IT = 1,500,INCRE

CLOCK = IT
DO 30 IA = 1,4

    BREAKP(IA) = 0.0
    BREAKT(IA) = 0.0
    IFC(IA,IT) = IFC(IA,IT-1)
    MFC(IA,IT) = MFC(IA,IT-1)
    RDFC(IA,IT) = RDFC(IA,IT-1)
    IMDC(IA,IT) = IMDC(IA,IT-1)
    BDFC(IA,IT) = BDFC(IA,IT-1)
    RF(IA,IT) = RF(IA,IT-1)
    BF(IA,IT) = BF(IA,IT-1)
    WHOLD = WHERE(IA,IT-1)
    CALL DETET2(IA,IT,INCRE,WHOLD,WID)
    IF(WID.EQ. 0) GO TO 999

```

```

IDARC(IA,IT) = WID
BRDIST = 9999.
SP(IA,IT) = SPEED(WID)
TS = (SPEED(WID)/60)*INCRE
WHERE(IA,IT) = WHOLD + TS

```

C---IS THERE INDIRECT FIRE ? OR MINEFIELD ? OR DIRECT FIRE ?

```

CALL IDFND2 (IA,CLOCK,POIF,IFANS)
CALL MFFND2 (PMARC,SMARC,WID,MFANS)
CALL DRFND2 (IA,WHOLD,RANGE,BRDIST,DFANS)

```

```

IFA(IA,IT) = IFANS
MFA(IA,IT) = MFANS
DFA(IA,IT) = DFANS

```

IF(IFANS.EQ.0 .AND. MFANS.EQ.0 .AND. DFANS.EQ.0) GO TO 30

C---COMPUTE THE CASUALTY OF INDIRECT-FIRE !

```

IF(IFANS.EQ.1) THEN
CALL IDFIR2 (IA,IT,RF,REDAVE,POIF,IFCAS)
RF(IA,IT) = RF(IA,IT) - IFCAS
IFSUM(IA) = IFCAS + IFSUM(IA)
IFC(IA,IT) = IFC(IA,IT) + IFCAS
END IF

```

C---COMPUTE THE CASUALTY BY MINE-FIELD !

```

IF(MFANS.EQ.1 .OR. MFANS.EQ.2) THEN
CALL MFILD2 (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)
RF(IA,IT) = RF(IA,IT) - MFCAS
MFSUM(IA) = MFCAS + MFSUM(IA)
MFC(IA,IT) = MFC(IA,IT) + MFCAS
END IF

```

C---COMPUTE THE CASUALTY BY DIRECT-FIRE !

```

IF(DFANS.EQ.1 .OR. DFANS.EQ.2) THEN
IF( RF(IA,IT) .LT. BF(IA,IT) .AND.
1 IUSED.EQ.0 .AND.
1 RF(IA,0) .GT. 0.0 ) THEN
RF(IA,IT) = RF(IA,IT) + RRESER
IUSED = 1
END IF
CALL DRFIR2 (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
1 PLTN,RANGE,NNN,ACO,AMO)

RF(IA,IT) = RF(IA,IT) - RDFCAS
BF(IA,IT) = BF(IA,IT) - BDFCAS
RDFSUM(IA) = RDFCAS + RDFSUM(IA)
BDFSUM(IA) = BDFCAS + BDFSUM(IA)
RDFC(IA,IT) = RDFC(IA,IT) + RDFCAS
BDFC(IA,IT) = BDFC(IA,IT) + BDFCAS
END IF

```

```

IF(RF(IA,0) .GT. 0. .AND. RF(IA,IT) .LE. RBP(IA)) THEN
CALL BREAK2 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)
END IF

```

C---COMPUTE THE REDUCED SPEED DUE TO THE INDIRECT FIRE OR MINEFIELD OR
C UNDER THE DIRECT FIRE BASED ON THE RANGE OF TWO FORCES !

```

      CALL RSPED2 (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
1          IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

      SP(IA,IT) = SPEED(WID)
      TS = (SPEED(WID)/60)*INCRE
      WHERE(IA,IT) = WHOLD + TS
      IMDC(IA,IT) = IFC(IA,IT) + MFC(IA,IT) + RDFC(IA,IT)

30  CONTINUE

      IF(NEQ12 .NE. 0) GO TO 36
          BF(1,IT) = MIN( BF(1,IT),BF(2,IT) )
          BF(2,IT) = MIN( BF(1,IT),BF(2,IT) )
36  IF(NEQ34 .NE. 0) GO TO 37
          BF(3,IT) = MIN( BF(3,IT),BF(4,IT) )
          BF(4,IT) = MIN( BF(3,IT),BF(4,IT) )
37  IF(NEQ12 .NE. 0) GO TO 38
      IF(DFA(1,IT) .EQ. 2 .AND. DFA(2,IT) .EQ. 2 .AND.
1  RF(1,IT) .GT. 0. .AND. RF(2,IT) .GT. 0.) THEN
          BF(1,IT) = (RF(1,IT) / (RF(1,IT)+RF(2,IT))) * BF(1,IT)
          BF(2,IT) = (RF(2,IT) / (RF(1,IT)+RF(2,IT))) * BF(2,IT)
          NEQ12 = IT
      END IF
38  IF(NEQ34 .NE. 0) GO TO 9999
      IF(DFA(3,IT) .EQ. 2 .AND. DFA(4,IT) .EQ. 2 .AND.
1  RF(3,IT) .GT. 0. .AND. RF(4,IT) .GT. 0.) THEN
          BF(3,IT) = (RF(3,IT) / (RF(3,IT)+RF(4,IT))) * BF(3,IT)
          BF(4,IT) = (RF(4,IT) / (RF(3,IT)+RF(4,IT))) * BF(4,IT)
          NEQ34 = IT
      END IF

9999 CONTINUE

999  CALL PRINT2 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
1          IFSUM,MFSUM,RDFSUM,BDFSUM,
1          TRCAS,TBCAS,TRSUR,TBSUR)

      TEND = IT - 1
      RETURN
      END
*****
* IV-1. SUBROUTINE FOR LOCATING THE ARC THE RED FORCES ARE ATTACKING.
*****
      SUBROUTINE DETET2 (IA,IT,INCRE,WHOLD,WID)

      INTEGER INCRE,WID
      REAL    A1(4),A21(8),A22(6),A3(6),WHOLD

      DATA  A1      /2.75,6.35,9.35,10.25/
      DATA  A21     /1.15,3.3,4.7,5.45,6.4,7.1,8.55,9.45/
      DATA  A22     /1.15,3.3,4.7,6.15,6.8,7.45/
      DATA  A3      /4.5,6.6,8.85,12.35,12.95,13.55/

```

```

GO TO (3011,3012,3013,3014) IA
3011 IF(WHOLD . LE. A1(1)) THEN
      WID = 5
      GO TO 1390
      ELSE IF(WHOLD. GT. A1(1) . AND. WHOLD. LE. A1(2)) THEN
      WID = 15
      GO TO 1390
      ELSE IF(WHOLD. GT. A1(2) . AND. WHOLD. LE. A1(3)) THEN
      WID = 33
      GO TO 1390
      ELSE IF(WHOLD. GT. A1(3) . AND. WHOLD. LE. A1(4)) THEN
      WID = 35
      GO TO 1390
      ELSE IF(WHOLD . GT. A1(4)) THEN
      WRITE(26,1380) IT-1
1380 FORMAT(1X,'RED FORCE IN AVE#1 TOOK BLUE POSITION#1 : BATTLE END !'
1/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
      GO TO 1399
      END IF
3012 IF(WHOLD . LE. A21(1)) THEN
      WID = 4
      GO TO 1390
      ELSE IF(WHOLD. GT. A21(1) . AND. WHOLD. LE. A21(2)) THEN
      WID = 7
      GO TO 1390
      ELSE IF(WHOLD. GT. A21(2) . AND. WHOLD. LE. A21(3)) THEN
      WID = 19
      GO TO 1390
      ELSE IF(WHOLD. GT. A21(3) . AND. WHOLD. LE. A21(4)) THEN
      WID = 24
      GO TO 1390
      ELSE IF(WHOLD. GT. A21(4) . AND. WHOLD. LE. A21(5)) THEN
      WID = 29
      GO TO 1390
      ELSE IF(WHOLD. GT. A21(5) . AND. WHOLD. LE. A21(6)) THEN
      WID = 32
      GO TO 1390
      ELSE IF(WHOLD. GT. A21(6) . AND. WHOLD. LE. A21(7)) THEN
      WID = 34
      GO TO 1390
      ELSE IF(WHOLD. GT. A21(7) . AND. WHOLD. LE. A21(8)) THEN
      WID = 35
      GO TO 1390
      ELSE IF(WHOLD . GT. A21(8)) THEN
      WRITE(26,1381) IT-1
1381 FORMAT(1X,'RED FORCE IN AVE#21 TOOK BLUE POSITION#1 : BATTLE ',
1'END !',/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
      GO TO 1399
      END IF
3013 IF(WHOLD . LE. A22(1)) THEN
      WID = 4
      GO TO 1390
      ELSE IF(WHOLD. GT. A22(1) . AND. WHOLD. LE. A22(2)) THEN
      WID = 7
      GO TO 1390
      ELSE IF(WHOLD. GT. A22(2) . AND. WHOLD. LE. A22(3)) THEN

```

```

        WID = 19
        GO TO 1390
    ELSE IF(WHOLD.GT.A22(3) .AND. WHOLD.LE.A22(4)) THEN
        WID = 25
        GO TO 1390
    ELSE IF(WHOLD.GT.A22(4) .AND. WHOLD.LE.A22(5)) THEN
        WID = 30
        GO TO 1390
    ELSE IF(WHOLD.GT.A22(5) .AND. WHOLD.LE.A22(6)) THEN
        WID = 39
        GO TO 1390
    ELSE IF(WHOLD.GT.A22(6)) THEN
        WRITE(26,1382) IT-1
1382  FORMAT(1X,'RED FORCE IN AVE#22 TOOK BLUE POSITION#2 : BATTLE ',
1'END !',/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
        GO TO 1399
    END IF
3014  IF(WHOLD.LE.A3(1)) THEN
        WID = 2
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(1) .AND. WHOLD.LE.A3(2)) THEN
        WID = 11
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(2) .AND. WHOLD.LE.A3(3)) THEN
        WID = 13
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(3) .AND. WHOLD.LE.A3(4)) THEN
        WID = 23
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(4) .AND. WHOLD.LE.A3(5)) THEN
        WID = 42
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(5) .AND. WHOLD.LE.A3(6)) THEN
        WID = 43
        GO TO 1390
    ELSE IF(WHOLD.GT.A3(6)) THEN
        WRITE(26,1383) IT-1
1383  FORMAT(1X,'RED FORCE IN AVE#3 TOOK BLUE POSITION#2 : BATTLE ',
1'END !',/5X,'(BATTLE TIME ==> ',I4,' MINUTE)')
        GO TO 1399
    END IF
1390  RETURN
1399  WID = 0
        RETURN
    END

```

```

*****
* IV-2. SUBROUTINE FOR IDENTIFYING THE INDIRECT-FIRE !
*****

```

```

SUBROUTINE IDFND2 (IA,CLOCK,POIF,IFANS)
INTEGER POIF,IFANS
REAL    CLOCK,STIF,FTIF
DATA    STIF,FTIF /5.0,15.0/

```

```

IF(CLOCK.GE. STIF .AND. CLOCK.LT. FTIF) THEN
    IF(POIF.EQ. 2) THEN
        IF(IA.EQ.2 .OR. IA.EQ.3) THEN

```

```

        IFANS = 1
        GO TO 1444
    ELSE
        IFANS = 0
        GO TO 1444
    END IF
ELSE IF(POIF .EQ. 3) THEN
    IF(IA .EQ. 4) THEN
        IFANS = 1
        GO TO 1444
    ELSE
        IFANS = 0
        GO TO 1444
    END IF
END IF
ELSE
    IFANS = 0
END IF
1444 RETURN
END
*****
* IV-3. SUBROUTINE FOR IDENTIFYING THE MINE-FIELD !
*****
SUBROUTINE MFFND2 (PMARC,SMARC,WID,MFANS)
INTEGER MFANS,WID,PMARC(5),SMARC(3)

DO 1510 I = 1,5
    IF(WID .EQ. PMARC(I)) THEN
        MFANS = 1
        GO TO 1599
    END IF
1510 CONTINUE
1511 DO 1520 J = 1,3
    IF(WID .EQ. SMARC(J)) THEN
        MFANS = 2
        GO TO 1599
    END IF
1520 CONTINUE
1521 MFANS = 0
1599 RETURN
END
*****
* IV-4. SUBROUTINE FOR IDENTIFYING THE DIRECT-FIRE !
*****
SUBROUTINE DRFND2 (IA,WHOLD,RANGE,BRDIST,DFANS)

INTEGER IC,IA,DFANS
REAL    WHOLD,PATH(4),RANGE,BRDIST,AMBUSH

DATA    PATH    /10.25,9.45,7.45,13.55/
DATA    AMBUSH   /4.0/

    IF(WHOLD .GE. AMBUSH-RANGE/2. .AND.
1      WHOLD .LT. AMBUSH .AND.
1      (IA.EQ.2. .OR. IA.EQ.3)) THEN
        DFANS = 1

```

```

        BRDIST = AMBUSH - WHOLD
        GO TO 1699
    ELSE IF( WHOLD .GE. PATH(IA)-RANGE .AND.
1        WHOLD .LT. PATH(IA) ) THEN
        DFANS = 2
        BRDIST = PATH(IA) - WHOLD
        GO TO 1699
    END IF
1600 CONTINUE
    DFANS = 0
1699 RETURN
END
*****
* IV-5. SUBROUTINE FOR COMPUTING CASUALTIES BY INDIRECT-FIRE
*****
SUBROUTINE IDFIR2 (IA,IT,RF,REDAVE,POIF,IFCAS)
INTEGER NROUND,IA,IT,REDAVE(3),POIF
REAL LETHAL,ROWSP,COLSP,MUX,MUY,RHOX,RHOY,RATIO,PKILL
REAL RF(4,0:1001),IFCAS

DATA NROUND,LETHAL /18,70.8/
DATA MUX,MUY /15.,10./
DATA RHOX,RHOY /15.,10./

IF(REDAVE(POIF) .EQ. 1) THEN
    ROWSP = 12.
    COLSP = 12.
    GO TO 1669
ELSE IF(REDAVE(POIF) .EQ. 2) THEN
    ROWSP = 10.
    COLSP = 10.
    GO TO 1669
ELSE IF(REDAVE(POIF) .EQ. 3) THEN
    ROWSP = 8.
    COLSP = 8.
    GO TO 1669
END IF

1669 RATIO = (NROUND*LETHAL) / (ROWSP*COLSP*RF(IA,IT))
    PHI = 3.141592654
    A = ((LETHAL*NROUND)/(2*PHI))**.5
    PKILL = RATIO * (A*A/((A*A+RHOX**2)*(A*A+RHOY**2))**.5) *
1    EXP(-.5*((MUX**2)/(A*A+RHOX**2) + (MUY**2)/(A*A+RHOY**2)))
    IFCAS = PKILL * RF(IA,IT) / 2.
    RETURN
END
*****
* IV-6. SUBROUTINE FOR COMPUTING CASUALTIES BY MINEFIELDS
*****
SUBROUTINE MFILD2 (IA,IT,MFANS,INCRE,NA,WID,TIME,RF,MFCAS)

INTEGER MFANS,INCRE,NA,NOPM,NOSM,WID
REAL TIME(NA),RF(4,0:1001),PCOEF,SCOEF,MFCAS,TPM,TSM

DATA NOPM ,NOSM /300,200/
DATA TPM ,TSM /20.0,15.0/

```

```

DATA      PCOEF,SCOEF  /.00020,.00015/

IF(MFANS .EQ. 1) THEN
  MFCAS = (PCOEF*RF(IA,IT)*NOPM*(TPM/60.)) / (TIME(WID)/INCRE)
ELSE IF(MFANS .EQ. 2) THEN
  MFCAS = (SCOEF*RF(IA,IT)*NOSM*(TSM/60.)) / (TIME(WID)/INCRE)
END IF
RETURN
END

*****
* IV-7. SUBROUTINE FOR COMPUTING CASUALTIES BY DIRECT FIRE
*****
SUBROUTINE DRFIR2 (DFANS,DFA,BRDIST,IA,IT,RF,BF,AR,RDFCAS,BDFCAS,
1  PLTN,RANGE,NNN,ACO,AMO)
  INTEGER  DFANS,DFA(4,1000),PLTN
  REAL     RF(4,0:1001),BF(4,0:1001),PLBP,FBF(0:1001)
  REAL     BRDIST,RANGE,RED,BLU,RDFCAS,BDFCAS,AR,BR,MU,PL

  DATA    PLBP          / 0.0/
  DATA    AOMEGA,BOMEGA /0.50,1.00/
  DATA    AC,BC         /0.0380,0.0160/
  DATA    AM,BM         /0.23,0.00010/
  DATA    MU            /1.0/

  ACO = AC
  AMO = AM
  IF(NNN .GT. 0) GO TO 1810
  PL = PLTN
1810 FBF(IT) = PL
C---FIND ENGAGED FORCES OF BOTH SIDES ON DIRECT FIRE BATTLE !
  RED = RF(IA,IT)
  BLU = BF(IA,IT)

C---CASE-#1 (MIXED LAW) : BLUE FORCE AMBUSHES THE RED FORCE !
  IF(DFANS .EQ. 1) THEN
    AR = AM * (1.0-BRDIST/RANGE)**MU
    BR = BM * (1.0-BRDIST/RANGE)**MU
    BLU = FBF(IT)
    IF(BLU .LT. PLBP) THEN
      RDFCAS = 0.0
      BLU = 0.0
    ELSE
      RDFCAS = AR * BLU
    END IF
    BDFCAS = BR * BLU * RED
    FBF(IT) = BLU - BDFCAS
    PL = FBF(IT)
    NNN = NNN + 1
    GO TO 1900

C---CASE-#2 (HEMBOLT EQUATION) !
  ELSE IF(DFANS .EQ. 2) THEN
    IF(RED .LE. 0. .OR. BLU .LE. 0.) THEN
      BDFCAS = 0.
      RDFCAS = 0.
      GO TO 1900

```

```

      END IF
      AR = AC * (1.0-BRDIST/RANGE)**MU
      BR = BC * (1.0-BRDIST/RANGE)**MU
      RDFCAS = AR*((RED/BLU)**(1.0-BOMEGA))*BLU
      BDFCAS = BR*((BLU/RED)**(1.0-AOMEGA))*RED
END IF
1900 RETURN
END
*****
* IV-8. SUBROUTINE FOR COMPUTING THE ADJUSTED SPEED BASED ON
* THE NUMBER OF RED UNITS (BATTALIONS) ON ONE AVENUE.
*****
      SUBROUTINE ASPED2 (I,IR,SPEED,ADSP)

      INTEGER IR,AOA1(4),AOA2(3),AOA3(6)
      REAL SPEED(44),ADSP(44)

      DATA AOA1 /5,15,33,35/
      DATA AOA2 /4,7,19/
      DATA AOA3 /2,11,13,23,42,43/

      GO TO (201,202,203,204) IR
201 ADSP(I) = SPEED(I)
      GO TO 2010
202 ADSP(I) = SPEED(I)
      DO 2011 J = 1,3
2011 IF(I.EQ. AOA2(J)) ADSP(I) = 0.9*SPEED(I)
      GO TO 2010
203 ADSP(I) = SPEED(I)
      DO 2012 J = 1,6
2012 IF(I.EQ. AOA3(J)) ADSP(I) = 0.9*SPEED(I)
      GO TO 2010
204 ADSP(I) = SPEED(I)
      DO 2013 J = 1,3
2013 IF(I.EQ. AOA2(J)) ADSP(I) = 0.8*SPEED(I)

2010 RETURN
END
*****
* IV-9. SUBROUTINE FOR COMPUTING THE REDUCED SPEED
* BASED ON EACH WEAPON TYPE.
*****
      SUBROUTINE RSPED2 (IA,IT,NA,SPEED,TIME,DIST,WID,RANGE,AR,RF,
1 IFANS,MFANS,DFANS,OSPEED,ACO,AMO)

      INTEGER NA,WID,IFANS,MFANS,DFANS
      REAL AR,DIST(NA),SPEED(NA),TIME(NA),MINSPD,RF(4,0:1001)
      REAL OSPEED(NA)

      DATA MINSPD /0.500/

      IF(IFANS.EQ. 1) THEN
        SPEED(WID) = DIST(WID)*60./(TIME(WID)+10.)
      END IF
      IF(MFANS.EQ. 1) THEN
        SPEED(WID) = DIST(WID)*60./(TIME(WID)+20.)

```

```

END IF
IF(MFANS .EQ. 2) THEN
    SPEED(WID) = DIST(WID)*60. / (TIME(WID)+15.)
END IF
IF(DFANS .EQ. 1) THEN
    SPEED(WID) = SPEED(WID) * (1.0-AR/AMO) + MINSPD
    IF(SPEED(WID) .GT. OSPEED(WID)) SPEED(WID) = OSPEED(WID)
END IF
IF(DFANS .EQ. 2) THEN
    IF(RF(IA,IT) .EQ. 0.) THEN
        SPEED(WID) = 0.
    ELSE
        SPEED(WID) = SPEED(WID) * (1.0-AR/ACO) + MINSPD
        IF(SPEED(WID) .GT. OSPEED(WID)) SPEED(WID) = OSPEED(WID)
    END IF
END IF
RETURN
END
*****
* IV-10. SUBROUTINE TO FIND THE TIME AND LOCATION
*   WHEN RED FORCE REACH BREAK-POINT !
*****
SUBROUTINE BREAK2 (IA,IT,NOC,WHOLD,RF,BF,RRESER,BREAKP,BREAKT)

INTEGER RRESER
REAL    BREAKP(4),BREAKT(4),WHOLD,RF(4,0:1001),BF(4,0:1001)

RF(IA,IT) = 0.
BF(IA,IT) = BF(IA,IT-1)
IF(NOC .EQ. 0) THEN
C      RF(IA,IT) = RF(IA,IT-1) + RRESER
      BREAKP(IA) = WHOLD
      BREAKT(IA) = IT
    END IF
    NOC = NOC + 1
1111 RETURN
END
*****
* IV-11. SUBROUTINE TO PRINT THE CASUALTIES AND SURVIVORS
*   FOR BOTH SIDES IN BATTLE2 TYPE.
*****
SUBROUTINE PRINT2 (RBN,BCO,BLUEP1,BLUEP2,RRESER,PLTN,NA,
1          IFSUM,MFSUM,RDFSUM,BDFSUM,
1          TRCAS,TBCAS,TRSUR,TBSUR)

INTEGER RBN,BCO,BLUEP1,BLUEP2,NA,RRESER,PLTN
REAL    IFSUM(4),MFSUM(4),RDFSUM(4),BDFSUM(4)
REAL    TIFSUM,TMFSUM,TRDF,TBDF
REAL    TRCAS,TRSUR,TBCAS,TBSUR

TIFSUM = 0.0
TMFSUM = 0.0
TRDF = 0.0
TBDF = 0.0

TRCAS = 0.0

```

```

TBCAS = 0.0
TRSUR = 0.0
TBSUR = 0.0

DO 101 IA = 1,4
  TIFSUM = IFSUM(IA) + TIFSUM
  TMFSUM = MFSUM(IA) + TMFSUM
  TRDF = RDFSUM(IA) + TRDF
  TBDF = BDFSUM(IA) + TBDF
101 CONTINUE
  TRF = RBN*3.0 + RRESER
  TBF = BCO*3.0 + PLTN
  BFCAS1 = BDFSUM(1) + BDFSUM(2)
  BFCAS2 = BDFSUM(3) + BDFSUM(4)
  BFSUR1 = BLUEP1*BCO - BFCAS1
  BFSUR2 = BLUEP2*BCO - BFCAS2

  TRCAS = TIFSUM + TMFSUM + TRDF
  TRSUR = TRF - TRCAS
  TBCAS = TBDF
  TBSUR = TBF - TBCAS

RETURN
END
*****
* V. SUBROUTINE TO COMPUTE THE WEIGHTED UTILITY VALUES OF BLUE
* SURVIVOR FOR EACH UTILITY FUNCTIONS !
*****
SUBROUTINE UTIL (MR,MB,IB,VALUE,LIN,SQU,ROO)

INTEGER MR,MB
REAL VALUE(4),UL(4),US(4),UR(4)
REAL LIN,SQU,ROO,ALIN,WGT(4)

DATA WGT /0.05,0.70,0.05,0.20/
DATA ALIN /340.0/

TEMP1 = 0.
TEMP2 = 0.
TEMP3 = 0.
C---UTILITY VALUES FOR THE BLUE SURVIVORS !
DO 2301 K = 1,4
  UL(K)=(9./55.)*VALUE(K) + 10.
  IF(VALUE(K) .LE. ALIN) UL(K)=(9./55.)*VALUE(K)
  US(K)=(1./3025.)*VALUE(K)**2.0
  UR(K)=(4.264014327)*VALUE(K)**0.5

  TEMP1 = WGT(K)*UL(K) + TEMP1
  TEMP2 = WGT(K)*US(K) + TEMP2
  TEMP3 = WGT(K)*UR(K) + TEMP3
2301 CONTINUE
  LIN = TEMP1
  SQU = TEMP2
  ROO = TEMP3
RETURN
END

```

APPENDIX E. EXEC FOR ADVANCED MODEL

This is a execution code of Fortran-77 for the advanced model in Appendix D.

```
FILEDEF 12 DISK THESIS DATA  
EXEC WF77 ADVAN (NOEXT NOWAR
```

LIST OF REFERENCES

1. Craig, Dean E., *"A Model for the Planning of Maneuver Unit and Engineer Asset Placement"*, M.S. Thesis, Naval Postgraduate School, Monterey, California, September 1985.
2. McLaughlin, Joseph R., *"The Extension of Unit Allocation and Countermobility Planning Algorithm in the Airland Reach Model"*, M.S. Thesis, Naval Postgraduate School, Monterey, California, March 1986.
3. Choi, Seok Chul, *"Determination of Network Attributes from A High Resolution Terrain Data Base"*, M.S. Thesis, Naval Postgraduate School, Monterey, California, September 1987.
4. Engineering Design Handbook, *"Army Weapon Systems Analysis, Part Two"*, US Army Material Development and Readiness Command, October 1979.
5. Taylor, James G., *"Lanchester-Type Models of Warfare, Volume II"*, Naval Postgraduate School, Monterey, California, 1980.
6. Page, Alfred N., *"Utility Theory a Book of Reading"*, John Wiley & Sons, Inc., 1968.
7. Text book for the course (OA-3601 : Airland Combat Model), *Notes on Measures of Effectiveness*, Naval Postgraduate School, Monterey, California, 1987.
8. Text book for the course (OA-3601 : Airland Combat Model), *Notes on Game Theory*, Naval Postgraduate School, Monterey, California, 1987.
9. McKinsey, J. C. C., *"Introduction to the Theory of Games"*, The RAND Corporation, 1952.
10. Schrage, Linus, *"Linear, Integer and Quadratic Programming with LINDO (Third Edition)"*, The Scientific Press, 540 University Avenue, Palo Alto, California, 1986.

11. DeGroot, Morris H., *"Probability and Statistics (Second Edition)"*, Addison-Wesley Publishing Company, Inc., 1968.
12. Minitab Release 5.1, *"Minitab Reference Manual"*, Naval Postgraduate School, Monterey, California, 1985.

BIBLIOGRAPHY

Jensen, Paul A., Barnes, J. Wesley, "*Network Flow Programming*", John Willey & Sons, Inc., 1980.

Engineering Design Handbook, "*Army Weapon Systems Analysis, Part One*", US Army Material Development and Readiness Command, October 1979.

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