A MATHEMATICAL MODEL OF INFANTRY COMBAT

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THESIS

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ABSTRACT

This thesis presents a Lanchester-based mathematical model of a small unit infantry attack on a defended position. It proposes that a major factor in actual combat is the suppression of fire of one side by a heavy volume of accurate fire from its opponents and incorporates this phenomenon into the model.

Following the development of the model, different offensive tactics are investigated to find the preferred method of attack under varying circumstances.

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I. INTRODUCTION

The mission of the infantry in offensive combat is to close with and destroy the enemy. On the other hand, an infantry unit in a defensive posture has the opposite mission of repelling the offensive unit's assault. The best way for each side to accomplish its specific mission, the question of tactics and fire distribution, has been endlessly studied and debated throughout history.

Nevertheless, in spite of the great interest in the field, a need still exists for a mathematical model which will indicate the relative effectiveness of various tactics employed by small infantry units attacking a defended position.

This is not to imply that models of such engagements have not been constructed. Many, both deterministic and stochastic, have been developed. However, most of them fail to take into account fire suppression, a factor of the utmost importance in actual combat. In fact, the noted military expert Brigadier General S. L. A. Marshall has written that the almost invariable cause of defeat in small unit actions is not excessive casualties but shrinkage of fire [19].

Suppression, or shrinkage, of the enemy's fire is accomplished by subjecting him to fire of such volume and accuracy that he will seek cover rather than continue to fire his weapon. Thus, as one side's fire is reduced, the other side can increase its own. If a simple constant rate of fire is assumed for both sides in an engagement, this interaction of fire intensity and accuracy is not taken into account.

The purpose of this thesis was to develop a deterministic mathematical model of combat which would take into account the phenomenon of fire suppression. This model, based on Lanchester's theories of combat, was then used to investigate the offensive tactics and defensive fire distribution of a small scale infantry action.

Specifically, the type of action studied was an attack against a defended position. The missions of the attacking and defending units were respectively to gain or maintain control of the defended position while holding their own casualties to a minimum. The offensive force had two tactics which it could employ - advance its entire force against the enemy or advance only a portion of its force while using the remainder to lay down a covering fire. The defense then had the decision of how to divide its fires to engage the attacking elements.

The following chapters present in greater detail the background of the problem, the difficulties encountered, and the results of the work. Chapter II discusses small unit infantry actions and defines pertinent terms. Chapter III briefly discusses Lanchester's equations. Chapter IV looks at the model itself, including the scenario, the assumptions made, and the actual development of the model. Chapter V covers model implementation. Chapter VI finally presents conclusions and recommendations for further study.

II. INFANTRY TACTICS

The purpose of offensive infantry tactics is simply to allow an infantry unit to accomplish its primary mission - to close with and destroy the enemy. This chapter will discuss infantry tactics, specifically small unit tactics, in the attack phase of offensive combat in order to serve as a background for the mathematical modeling described later in this thesis. The tactics described and the terminology used are based on U. S. Marine Corps doctrine [18, 29, 30].

It must be remembered that actual combat and the tactics employed therein are not as cut-and-dried as the following descriptions would make them seem. The tactics employed by a military commander will be affected by his mission, the disposition of both the enemy and friendly forces, and by the terrain. However, if anything can be described as typical in war, the following will be a description of a typical small unit attack on an enemy defensive position.

For the purposes of this paper a small infantry unit will be defined as a fire team, squad, or platoon. As constructed by the Marine Corps, a fire team consists of four men. The squad is composed of three fire teams headed by a squad leader. A platoon is formed of three squads and a platoon headquarters. For all practical purposes, the headquarters should not be considered a fighting element, but a controlling unit for the squads.

Offensive combat is divided into four phases:

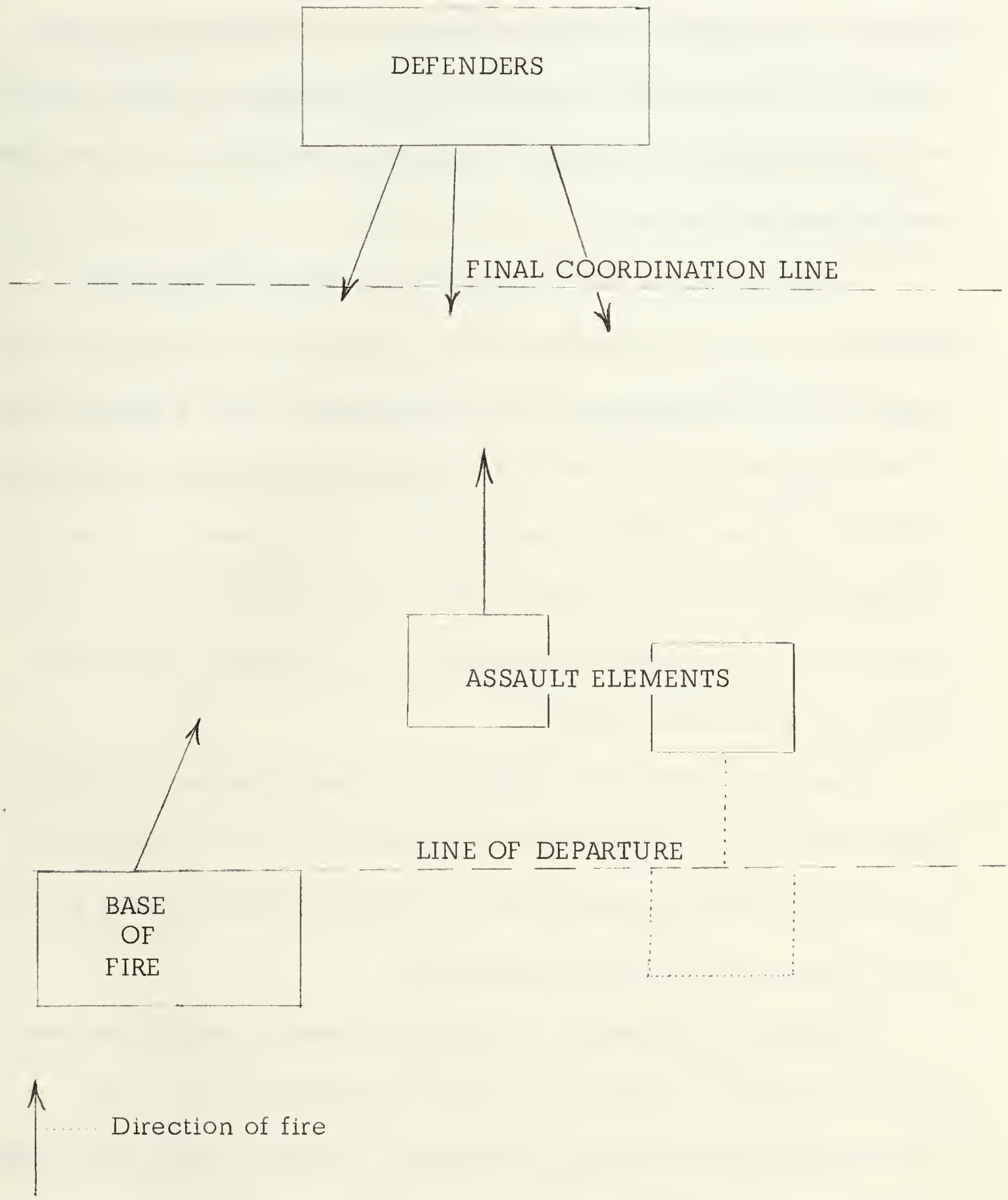
1. Movement to contact
2. Attack
3. Consolidation
4. Exploitation

This paper will concern itself with the attack phase, which can again be divided into four phases:

1. Advance by fire and maneuver
2. Assault position
3. Assault through the assigned objective
4. Pursuit by fire

The attack phase begins when the attacking force crosses the line of departure (LOD), an imaginary coordinating line perpendicular to the direction of advance. The assault units advance, taking advantage of any cover and concealment offered by the terrain. Whenever possible, the assaulting force moves under the protection of a base of fire directed upon the enemy positions by friendly supporting units (see Figure 1).

If subjected to effective small arms fire before reaching the assault position, the assault force advances by fire and maneuver. That is, part of the assault force advances while the remainder fires at the enemy. This type of movement continues until the assault units reach the assault position.



ATTACK ON A DEFENDED POSITION

Figure 1

The assault position is located as close to the enemy as the assaulting elements can move by fire and maneuver without taking excessive casualties and without masking the fire of supporting units. Normally, it is less than 150 meters from the enemy positions. At this point final coordination is made by the assaulting elements as they prepare for the final assault.

Upon order of the assaulting force commander, the assault through the final objective commences. The assault unit moves on line through the enemy positions with individuals delivering a heavy volume of well directed fire from the hip or shoulder. The assault fire, characterized by volume, violence, and accuracy, is designed to either kill the enemy or to keep him pinned down until he can be overrun. As the assault unit moves through the objective, the supporting fires either cease or shift to other targets.

After moving through the objective as rapidly as possible while still maintaining a heavy volume of well-directed fire, the assaulting unit takes up hasty firing positions to pursue the fleeing enemy by fire and to repulse any enemy counterattacks.

Throughout the attack, fire superiority must be maintained over the enemy. That is, the enemy must be subjected to fire of such accuracy and volume that his fire ceases or becomes ineffective. Without this superiority the enemy is capable of directing such a large volume of fire against the assaulting elements that forward movement is difficult, if not impossible, without receiving an unacceptably large amount of casualties.

For small infantry units there are basically two forms of maneuver. One is the frontal attack, which is an attack against the enemy's front with pressure exerted all along the enemy line. The other is the single envelopment, in which part of the attackers maneuver to an assault position on the enemy's flank while the rest of the unit provides a covering base of fire. Often elements of both types of maneuvers are present in an attack.

Since both types of maneuver have the same phases of the attack as discussed above, this paper will not differentiate between the two in deriving a model of the attack.

III. LANCHESTER EQUATIONS

Lanchester equations [31] are mathematical formulations of combat which calculate the rates of attrition for two opposing forces composed of identical units (e.g., infantrymen, tanks, or airplanes). The Lanchester combat model assumes that all units on both sides are within range of all the opponents' weapons.

Lanchester's equations can be divided into two categories - the linear law and the square law.

Lanchester's linear law can be thought of as the attrition rate of one side when the other side uses area fire. This type of fire is best described as when one side, not knowing the exact locations of the opponents, fires into the general area of their positions.

Assume that the two opposing forces can be considered attackers and defenders. Then the linear law for the defenders is

$$\frac{dD}{dt} = -\alpha_A A(t) D(t)$$

where $\frac{dD}{dt}$ is the attrition rate of the defenders at time t, α_A is the rate at which one attacker kills defenders, and A(t) and D(t) are the sizes of the attacking and defending forces respectively at time t.

Lanchester's square law is equivalent to the opponents using aimed fire, where all targets are visible and the fire is distributed uniformly over all live targets.

Again let the two sides be attackers and defenders, but this time let the attackers employ aimed fire. The attrition rate for the defenders can be written

$$\frac{dD(t)}{dt} = -\beta_A A(t)$$

where β_A is the rate at which one attacker kills defenders and A(t) is the number of attackers at time t.

Naturally, similar equations would be used to calculate the attacking force's attrition rate. Thus, by knowing the modes of fire (aimed or area), the opposing strengths, and the attrition rate coefficients for each side, the number remaining on each side after a given length of time can be calculated by solving two simultaneous differential equations.

The most difficult task in formulating these types of equations is the determination of the attrition rate coefficients. Bonder [6] points out that prediction of battle results has been hampered by the inability of analysts to correctly predict these numbers, which are generally developed in the following ways.

The attrition rate coefficient for force A using area fire against force D at time t, $\alpha_A(t)$, is the product of the rate of fire of the individual elements of A at time t multiplied by the quotient of the exposed area of one element of D divided by the total area into which A is firing

$$\alpha_A(t) = r_A(t) \frac{A_{e_D}}{A_D}$$

This, of course, assumes that all elements of D are within A_D.

For aimed fire the attrition rate coefficient for force A firing at force D at time t is

$$\beta_A(t) = P_k(t) \ r_A(t)$$

where $P_k(t)$ is the single shot kill probability at time t and $r_A(t)$ is defined as in the preceding equation.

Often the attrition rate coefficients are formulated as constants and not as functions of time. Especially for dynamic small unit infantry actions, this is a fallacy which weakens the accuracy of the model in predicting final results. As will be seen, this thesis presents a solution which considers these coefficients as time (and range) dependent.

IV. DISCUSSION OF THE MODEL

The model developed in this thesis, based on Lanchester's theories of combat, determines the outcome of a small unit infantry action. Since so many different parameters affect the outcome of such engagements, this can in no way be considered an all inclusive model.

The relative combat power of opposing infantry units is based on many factors - "surprise, maneuver, dispositions, cover, concealment, fields of fire, observations, obstacles, effective firepower, and adequate supplies" in addition to "initiative, human performance, leadership, command, control, and communications" [28]. While maneuver, cover, and concealment are incorporated, the model developed herein looks primarily at opposing numerical strengths and the firepower (both accuracy and volume) of the opponents.

However, these are the most important factors in small unit actions. As Brigadier General Marshall has written, the most important single thing needed in combat is more and better fire, since "almost the invariable cause of defeat in local actions is shrinkage of fire" [19]. This shrinkage is caused both by casualties and by suppression. These are investigated by this model.

A. SCENARIO

The small unit infantry action modelled in this thesis is a daylight attack against a stationary defensive position. The mission of the attackers is to capture the enemy position at all costs. To accomplish this, the attacking force commander has the option of closing the defenders with his entire force by means of fire and maneuver or of advancing a portion of his unit (the assault force) by this method and employing the remainder as a base of fire to cover the advance.

The assault advances by fire and maneuver until it reaches the final coordination line. It then forms on line and advances through the enemy's position. After the final coordination line is past, the base of fire ceases fire entirely to avoid hitting friendly troops.

The defenders' mission is to defend their position to the last man. They are dug in in static positions, but their field fortifications consist of nothing more elaborate than uncovered foxholes and shallow trenches.

The terrain provides the defenders and the base of fire with a limited degree of cover and concealment. It offers no impassable obstacles to the assaulting force and does not slow its advance. On the other hand, the terrain offers no cover or concealment to the attacker unless he is in the prone position.

B. ASSUMPTIONS

Because the model is based on Lanchester's theories of combat, the assumptions associated with those theories must be made in the development of this model. Thus, each individual on either side is within range of all the weapons of the other side. In a small unit infantry action, this seems to be a reasonable assumption.

It must be assumed that each man fires independently of all other individuals. Actually, in a well-trained infantry unit the leader will control the fire of his men so that there is no lull in the firing. However, assuming a constant rate of fire for all shooters produces the same result since the rate of fire for the unit in either case would be a constant.

It must be further assumed that the rounds fired by each shooter are not serially correlated. If it is assumed that every individual on each side is armed with a semi-automatic rifle which fires only one round with each trigger pull, this non-correlation between rounds is not too far from what actually might happen. This is especially so because in the heat of combat it is very difficult to observe the impact of single rounds in order to make aiming corrections.

Lanchester's theories of combat assume that fire is uniformly distributed over an area or group of targets. Generally, when targets are visible, the infantry leader will insure that his unit fires at all targets (assuming they are all of equal importance). But, in area fire, fire will usually be directed at the most likely enemy locations rather than over the whole target area. Nevertheless, the model developed in this thesis has the supposition that area fire is uniform over the entire area.

The model was designed to look at both the case when the two sides employ aimed fire exclusively (i.e., all targets are visible), and the case when area fire is employed against all combatants except the moving element in the assault force. Against these troops, aimed fire is always employed. In actual combat, some mix of area and aimed fire would probably be used in most cases, depending, of course, upon the situation. However, in this thesis only the two extremes were investigated.

It is quite possible for an individual to continue fighting even after being wounded. In this work, however, it is assumed that any person hit becomes a totally non-effective combatant.

It is further assumed that only the base of fire and the non-maneuvering elements of the assault force fire at the defenders. This is in line with accepted doctrine which says that the maneuvering element does not fire but simply moves a predetermined distance on each rush as rapidly as possible. This unit then commences to fire at the defenders and another element of the assault force makes its rush.

In the model, when the assault force reaches the final coordination line (FCL), it immediately launches the final assault, moving on line toward the enemy while firing at a high rate of fire. At the same time the fire from the base of fire ceases. Actually, some coordination time at the FCL would probably be necessary,but ignoring this should have no adverse effects of the results of the model.

It is also assumed that the supply of ammunition is not a factor in the problem. Since both the defenders and the base of fire are stationary, this is not an unreasonable assumption for them. The assault force, on the other hand, would be limited to the number of rounds they could carry. However, for the scenario described above, the assault force should be able to carry a sufficient amount to complete its mission.

The model assumes that a fixed percentage of the defenders fire at the assault elements while the remainder fire at the base of fire. This ratio of fire is maintained until the assault elements reach the FCL, at which time all the surviving defenders shift fire to the assault group.

Another important assumption made is that shooters can be suppressed (i.e., made to cease fire and take cover for a period of time) by incoming rounds which pass within a certain distance of them. While the closeness of the rounds and the number of rounds needed for suppression may be open for debate, the fact that suppression is a valid phenomenon in combat is unquestionable.

The assumptions presented in this section are the more important ones in the development of this thesis. In the sections to follow other assumptions are made in order to construct the different portions of the model. When this occurs, the assumption is clearly identified as such.

C. DEVELOPMENT OF THE MODEL

The model developed in this work forecasts the winning side in a small unit infantry action between an attacking and a defending force. Since the defenders' task is to hold a piece of terrain and deny its use to the attackers, the victors in this model are the ones who have the most men on the objective when the attacking forces reaches the defenders' positions. It was assumed that the two sides at this point in time would kill each other at the same rate so that the more numerous side should have more men remaining when the opponents are completely destroyed.

1. Objectives

Given the scenario described above, the objective of the offensive, or attacking, force is to seize the terrain occupied by the defenders with a minimum number of casualties. In order to successfully carry out this mission, the offensive side must place more men than the defenders on the objective at the end of the fire fight. Also, the offensive force could be working under a time constraint, although this would not always be the case.

This could be represented mathematically by

$$\text{minimize } (A_{tO} - A_{tf})$$

$$\text{subject to } (AA_{tf} - D_{tf}) > O$$

$$tf \leq T_c$$

$$A_{tf}, AA_{tf}, D_{tf} \geq O$$

where tO is the time at which the action starts, tf the time the action terminates, A_{tO} and A_{tf} the total number of attackers at times tO and tf respectively, AA_{tf} the number of attackers on the objective at tf, D_{tf} the number of defenders at tf, and T_c the time in which the action must be completed. AA_{tf} is not necessarily the same as A_{tf} since the offensive force need not assault with its entire force. It may be divided so that a portion of the unit supports the assault by firing from stationary positions.

On the other hand, the objective of the defenders is to repulse the attack while sustaining the least number of casualties possible. Mathematically represented this is

$$\text{minimize } (D_{tO} - D_{tf})$$

$$\text{subject to } (AA_{tf} - D_{tf}) \leq O$$

$$AA_{tf}, A_{tf}, D_{tf} \geq O .$$

In other words both sides want to keep their casualties to a minimum while still having more men on the final objective at the conclusion of the battle. If either problem is infeasible, then the attack or the defense, whichever is applicable, cannot be successfully completed.

2. General Model

In order to achieve their objectives both sides must minimize their casualties. Since the model developed in this thesis is based on Lanchester's theories of combat, the most basic determination of casualties for the attackers would be

$$dA = - \alpha_D A(t_O)\ D(t_O)\ dt$$

where α_D is the rate at which one defender using area type fire kills attackers, $A(t_O)$ is the number of attackers at the start of the action, $D(t_O)$ is the number of defenders at the start of the action, and dt is the duration of the battle.

If the defenders used aimed fire, the number of casualties for the attackers would be

$$dA = -\beta_D D(t_O)\, dt$$

where β_D is the rate at which one defender using aimed fire kills attackers. The rest of the symbols are as defined above.

Similarly, the casualty predicting equations for the defenders would be

$$dD = -\alpha_A A(t_O) D(t_O)\, dt$$

$$dD = -\beta_A A(t_O)\, dt$$

for the attackers employing area and aimed fire respectively.

In the above equations, the attrition rate coefficients were presumed to be constants. Recall from the discussion of Lanchester equations that for area fire

$$\alpha_i(t) = r_i(t)\, P_{Ki}(t) \quad i = A, D$$

with $r_i(t)$ the rate of fire of each man on side i at time t and $P_{Ki}(t)$ the single shot kill probability for side i at time t. $P_{Ki}(t)$ was taken to be equal to the exposed area of an individual on side j, j = A or D, divided by the total area into which i is firing, $\frac{A_{ej}}{A_j}$. It is assumed to be a constant.

For aimed fire the attrition rate coefficient is

$$\beta_i(t) = r_i(t)\, P_{Ki}(t) \quad i = A, D$$

where the symbols are as described above.

If $r_i(t)$ and $P_{Ki}(t)$ were constants throughout the engagement, determining the casualties for each side would simply involve putting these values in the proper equations and performing the necessary mathematics. However, these assumptions are not true, and modifications must be made to the model to take this into account.

3. Single Shot Hit Probability

As was mentioned before, this model assumes that a hit produces an incapacitating casualty, and thus may be regarded as a kill as far as determining the outcome of the conflict.

When area fire is employed, the single shot hit probability for a round fired by side i against side j is

$$(1)\ P_{Hi} = \frac{A_{ej}}{A_j}$$

where A_{ej} is the exposed target area of an individual on side j and A_j is the total area fired into by side i. Recall that this assumes that all members of side j are within A_j (see Figure 2).

For the purposes of this model, P_{Hi} for the area fire case is assumed to be constant. There is the possibility that as the fire fight progresses, side i could better judge A_j and shift fires accordingly. This, however, will not be investigated, except for one instance which will be described in the following chapter.

The single shot hit probability for aimed fire, again labelled $P_{Hi}(t)$, cannot be considered a constant.

It was assumed that the individuals on each side present circular targets to their opponents. Further, it was assumed that fire distribution was described by a circular normal distribution in the plane of the target with the vertical and horizontal standard deviation of the rounds (σ_x and σ_y respectively) being equal. Also, the center of the target was assumed to be the center of impact of the fire distribution. Recall that each round fired was considered independent of all other rounds.

Thus, $P_{Hi}(t)$ can be written

$$P_{Hi}(t) = \int_0^{2\pi} \int_0^{r} \frac{1}{\pi \sigma(t)^2} \exp\left[-\frac{x^2}{\sigma(t)^2}\right] x\,dx\,d\theta$$

where r is the radius of the target and $\sigma(t)$ is the standard deviation of the circular normal distribution ($\sigma(t) = \sqrt{\sigma_x(t)^2 + \sigma_y(t)^2}$). After performing the integration the equation becomes

$$P_{Hi}(t) = 1 - \exp\left[-\frac{r^2}{\sigma(t)^2}\right]$$

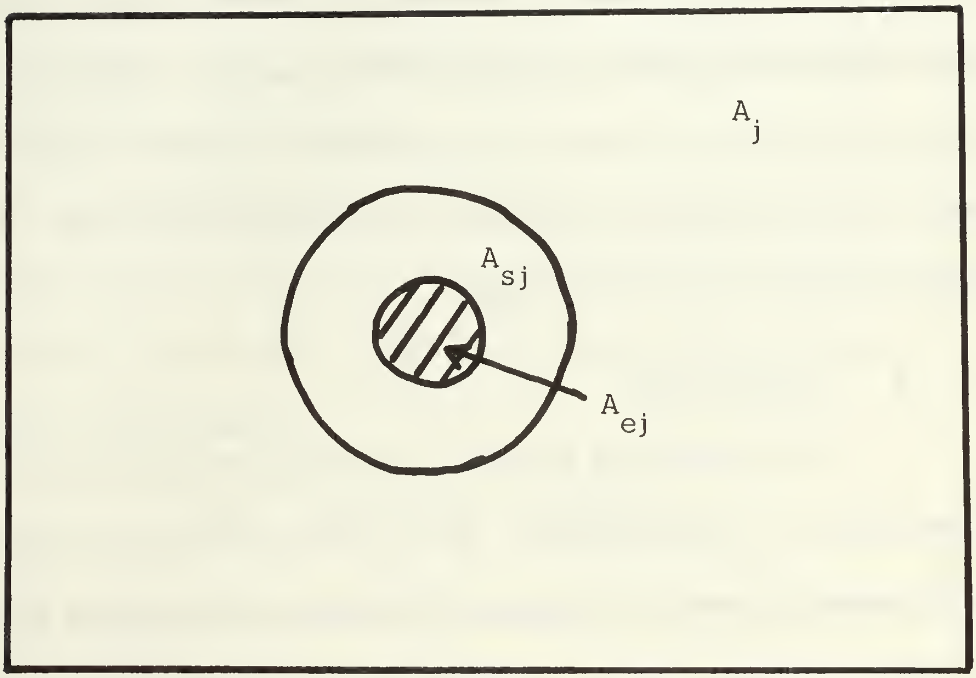
Since the area of the target, A_{ej}, equals πr^2, $P_{Hi}(t)$ can be written

$$P_{Hi}(t) = 1 - \exp\left[-\frac{A_{ej}}{\pi \sigma(t)^2}\right]$$

Finally, it is assumed that the distribution of the angular aim error is independent of range [26]. Thus, when the standard deviation, $\sigma(t)$, is expressed in mils, $P_{Hi}(t)$ becomes

$$(2)\quad P_{Hi}(t) = 1 - \exp\left[-\frac{A_{ej} 10^6}{\pi R(t)^2 a^2}\right]$$

where R(t) is the range to the target at time t and a is the aiming error



A_j = Total Area

A_{ej} = Exposed Area of an Individual

A_{sj} = Area of Suppression of an Individual

Areas for Hits and Suppression

Figure 2

in mils. Range was considered time dependent because in the scenario described the range between the attackers and the defenders decreases with time.

This final result was arrived at by applying the standard conversion formula for mils, $m = \frac{W \times 10^3}{R}$, where W is the width to be converted to mils expressed in some unit of length, and R is the range to the target expressed in the same unit of measure. Thus, it can be seen from equation (2) that unless the battle is fought at one constant range, the single shot hit probability will change with range. As the range decreases, $P_{Hi}(t)$ increases.

4. Suppression

Both equations formulated to calculate single shot hit probabilities, (1) and (2) above, were designed with the understanding that a target is present. However, it will often be the case that an individual in combat, while not hit by an incoming round, will have had a round pass so close to him that it will cause him to seek cover rather than continue to fire his weapon. That is, the individual will be suppressed.

In formulating the model, it was assumed that any participant in a fire fight has an area of suppression, A_s (see Figure 2). If a round enters this area, the individual will seek cover, thus not firing his weapon for a certain length of time, but also not presenting himself as a target during that time period.

As in the study of the hit probability, two cases were looked at - area and aimed fire.

In the case where side i uses area fire against side j, the single shot probability of suppression, P_{si}, is written

$$P_{si} = \frac{A_{sj}}{A_j}$$

with A_{sj} being the area of suppression for an individual on side j and A_j being the total area for side j.

In the case when side i employs aimed fire, the same assumptions were made to derive the single shot probability of suppression, $P_{si}(t)$ as were used to derive $P_{Hi}(t)$ the single shot hit probability. Therefore $P_{si}(t)$ is written

$$P_{si}(t) = 1 - \exp\left[- \frac{10^6 A_{sj}}{\pi R(t)^2 a^2}\right]$$

where R(t) is the range to the target and a is the aiming error in mils.

5. Expected Time Suppressed

Having determined the single shot probability of a round entering an individual's area of suppression, the next task was to determine the expected time that a combatant would be suppressed.

Let λ be the rate at which rounds enter an area of suppression. For area fire by side i against side j

$$\lambda(t) = r_i(t)\, I(t)\, \frac{A_{sj}}{A_j}$$

where $r_i(t)$ is the rate of fire of an individual on side i at time t, I(t) is the number of men on side i at time t, and A_{sj} and A_j are as defined previously.

For aimed fire

$$\lambda = r_i P_{si}(t) \frac{I(t)}{J(t)}$$

where J(t) is the number of men on side j at time t and all other terms are as defined above. By examining this equation it can be seen that by dividing by J(t) it was assumed that incoming fire is evenly divided among the individuals on side j.

Let t_{sO} be the time that an individual is suppressed by one round entering his area of suppression. Let t_{s1} be the additional time that the individual stays suppressed, given that he is already suppressed, when another round enters A_s.

Since the rounds are independent, it can be assumed that they arrive as a Poisson distribution with rate λ. This assumption makes the probability of another round entering A_s while a man is still suppressed

$$P(i.t. \leq t_{sO}) = 1 - \exp\left[-\lambda t_{sO}\right]$$

Then the expected time that an individual would be suppressed in a time period Δt could be written

$$E(t.s.) = \lambda \Delta t(1 - P(i.t. \leq t_{sO}))t_{sO} + \lambda \Delta t P(i.t. \leq t_{sO})t_{s1}.$$

Combining terms this becomes

$$E(t.s.) = \lambda \Delta t \left[t_{sD}P(i.t. > t_{sO}) + t_{s1}P(i.t. \leq t_{sO}) \right.\quad .$$

6. Kill Probability

Having determined the expected time suppressed, E(t.s.), in an interval of time Δt, it was then possible to calculate the kill probability. Recall that the single shot hit probability, $P_{Hi}(t)$, was predicated on the assumption that the target was always present. Actually, the probability that a target is present in some time interval Δt can be described by

$$P(t.p.) = \frac{1 - E(t.s.)}{\Delta t}$$

That is, it is the expected time the target is not suppressed in Δt divided by Δt.

Therefore, the single shot kill probability $P_{Ki}(t)$ can be written

$$P_{Ki}(t) = P_{Hi}(t)\ P(t.p.)$$

7. Rates of Fire

Suppression also affects the rates of fire for both sides, since if an individual is suppressed, he cannot be firing his weapon.

Let r_{oi} be the rate of fire which an individual on side i is capable of maintaining if he is not suppressed. Then to determine the rate of fire, r_i, of that individual given that he is being shot at in some time interval Δt the equation

$$r_i(t) = r_{oi}\ \frac{[\Delta t - E(t.s.)]}{\Delta t}$$

is used, Rewriting, this becomes

$$r_i(t) = r_{oi} [1 - P(t.s.)]$$

where P(t.s.) is the probability of suppression in Δt.

8. Allotting Fires

The next alteration to be made to the simplified model is to incorporate the fact that the offensive force assaults with only a portion of its total strength while employing the remainder as a base of fire to cover the assaulting elements. Therefore, the defending force must divide its fire in some proportion to cover the two portions of the offensive force.

Let ϕ be the fraction of the attackers employed in the base of fire. Let ρ be the percentage of the defending force assigned to fire at the base of fire. Then the casualty rate for the base of fire at time t is

$$\frac{dA_B(t)}{dt} = - \beta_D \rho D(t)$$

if aimed fire is used by the defenders and

$$\frac{dA_B(t)}{dt} = - \alpha_D \rho D(t) A_B(t)$$

if area fire is employed. $A_B(t)$ is the number in the base of fire at time t. Initially, $A_B(t_O) = \phi A(t_O)$, where $A(t_O)$ is the original number in the attacking force.

Since the assault portion of the attacking force can use the technique of fire and maneuver (i.e., a part moves while the rest fire at the defenders), the defense must again make a decision about dividing fires. Let η be the fraction of the defenders firing at the assault force which specifically fires at the non-maneuvering elements of that force. Let M.E. be the number of maneuver elements in the assault force. (Recall that only one maneuver element moves at any one time.) Then the casualty rate for the elements of the assault force stationary at time t is

$$\frac{dA_{AF}(t)}{dt} = -\beta_D(1 - \rho)\eta\, D(t)$$

and for the moving element is

$$\frac{dA_{AM}(t)}{dt} = -\beta_D(1 - \rho)(1 - \eta)\, D(t),$$

assuming aimed fire from the defenders.

For area fire the equation for the non-maneuvering elements becomes

$$\frac{dA_{AF}(t)}{dt} = -\alpha_D(1 - \rho)\eta\, D(t)\,(1 - \frac{1}{M.E.})\, A_A(t)$$

where $A_A(t)$ is the number in the assault group at time t, and $A_A(t_O) = (1 - \phi)\, A(t_O)$. Since the moving element is always visible, it was assumed that the defenders always employ aimed fire against those individuals.

The attrition rate for the defenders at time t would also be different. It is

$$\frac{dD(t)}{dt} = -\left[\beta_{AB}A_B(t) + \beta_{AF}(1 - \frac{1}{M.E.})\, A_A(t)\right]$$

for the attackers using aimed fire, and

$$\frac{dD(t)}{dt} = -\left[\alpha_{AB}A_B(t) + \alpha_{AF}(1 - \frac{1}{M.E.})\, A_A(t)\right] D(t)$$

for area fire.

9. <u>Fire and Maneuver</u>

Another modification to the model is made when the concept of fire and maneuver is employed by the assault force. Since it was assumed that the moving elements were never suppressed, there was no need to modify the hit probability to take into account the fact that a target may be suppressed. However, this does not mean that the hit probability and the kill probability for the moving element are synonymous. This is because when the attackers start their rush, it takes the defenders a time to acquire these new targets.

Let the assault group be divided into M. E. equal elements. The rush time per element, R. T., is the sum of the starting time, S. T., (i.e., the time needed to rise from the prone position and start running) plus the quotient of the distance rushed, y, divided by the rush velocity, v. That is

$$R.T. = S.T. + y/v$$

Let X be the distance to be covered by fire and maneuver before the final assault begins. Then the number of rushes for each maneuver element to cover X is $\left\lceil \frac{X}{y} \right\rceil$.

The total time for the entire assault group to move a distance X is then

$$T.T. = \left\lceil \frac{X}{y} \right\rceil M.E. (R.T. + C.T.)$$

Where C.T. is the time needed by the assault group leader to coordinate the various elements between rushes. Therefore, the total time that the maneuvering fraction of the assault group would be moving and exposing a larger target area would be

$$E.T. = \left[\frac{X}{y}\right] M.E. \ (R.T.)$$

Since the defenders must acquire these targets every time a rush is started, the time, F.T., that the defenders would be firing at the maneuvering element over the entire distance covered by fire and maneuver can be calculated by the equation

$$F.T. = \left[\frac{X}{y}\right] M.E. \ (R.T. - A.T.)$$

where A.T. is the acquisition time at the beginning of each new rush.

The average probability that the defenders will be firing at a maneuvering element, P(ME), is simply the firing time of the defenders against the maneuvering elements divided by the total time needed by the assault force to cover the distance from the line of departure to the final coordination line,

$$P(ME) = \frac{F.T.}{T.T.} \ .$$

This probability would have to be multiplied by the probability of hitting these moving targets in order to calculate the probability of a kill against the maneuvering portion of the assault force.

D. FINAL MODEL

To summarize, the casualty rates for the defending force with the entire offensive force using area fire is

$$(3) \ \frac{dD(t)}{dt} = - \left[A_B(t) \alpha_B(t) + (1 - \frac{1}{M.E.})A_A(t) \alpha_A(t)\right] D(t)$$

and with the entire offensive force employing aimed fire is

$$(4) \ \frac{dD(t)}{dt} = - \left[A_B(t) \beta_B(t) + (1 - \frac{1}{M.E.})A_A(t) \beta_A(t)\right] ,$$

where $A_B(t)$, $A_A(t)$, and $D(t)$ are the sizes of the base of fire, the assault group, and the defending force, respectively, at time t, $\alpha(t)$ is the attrition rate coefficient for area fire and $\beta(t)$ the coefficient for aimed fire at time t, and M.E. is the number of maneuver elements in the assault group.

The casualty rate for the base of fire at time t is

$$(5)\quad \frac{dA_B(t)}{dt} = - \beta_D(t)\, \rho\, D(t)$$

if the defenders use aimed fire and

$$(6)\quad \frac{dA_B(t)}{dt} = - \alpha_D\, \rho\, D(t) A_B(t)$$

if area fire is used. In the above equations ρ is the fraction of the defenders firing at the base of fire, with all other terms being the same as in equations (3) and (4).

For the assault group the casualty rate for the non-maneuvering elements when area fire is used against them is

$$(7)\quad \frac{dA_{AF}(f)}{dt} = - \alpha_D (1 - \rho)\, \eta\, D(t)\ (1 - \frac{1}{M.E.}) A_A(t)$$

and when aimed fire is employed by the defense is

$$(8)\quad \frac{dA_{AF}(t)}{dt} = - \beta_D(t)\ (1 - \rho)\, \eta\ D(t)$$

where η is the fraction of the defending force firing at the assault group which concentrates its fire on the non-maneuvering elements.

Since it was assumed that only aimed fire is used against the maneuvering element, the casualty rate for that unit is

$$(9)\quad \frac{dA_{AM}(t)}{dt} = -\beta_{DM}(t)\,(1-\rho)\,(1-\eta)D(t)$$

with $\beta_{DM}(t)$ being the attrition rate coefficient for the defenders employing aimed fire against the maneuver element.

Equations (3) through (9) hold until the final coordination line is reached. At this time the base of fire ceases fire and the assault group attacks in an on-line formation. The casualty rates then become

$$(10)\quad \frac{dD(t)}{dt} = -\beta_{AA}(t)A_A(t),$$

$\beta_{AA}(t)$ being the attrition rate coefficient for the assault group in the final assault, and

$$(11)\quad \frac{dA_B(t)}{dt} = -\beta_D(t)D(t)$$

assuming both sides use aimed fire. If the attackers use area fire equation (10) becomes

$$(12)\quad \frac{dD(t)}{dt} = -\alpha_A D(t)A_A(t)$$

The attrition rate coefficients, which vary over time, are simply the single shot kill probability multiplied by the rate of fire.

$$\alpha_i = P_{Ki}r_i(t)$$

$$\beta_i = P_{Ki}(t)r_i(t)$$

where α_i and β_i are the attrition rate coefficients for side i using area and aimed fire, respectively, against side j.

$P_{Ki}(t)$, the single shot kill probability, equals the single shot probability of a hit, given that a target is present, multiplied by the probability that a target is present.

The rate of fire at time t, $r_i(t)$, is written

$$r_i(t) = r_{oi} [1 - P(t.s.)]$$

with r_{oi} being the rate of fire for an individual on side and P(t.s.) being the probability that a shooter on side i is suppressed.

V. IMPLEMENTATION OF THE MODEL

As was mentioned previously, the purpose of this thesis was to investigate within a limited scenario whether it is more advantageous for an attacking unit to employ part of its strength as a base of fire or to advance its entire force by fire and maneuver. To do this, a computer program was designed to calculate the outputs of the model, thus determining the results of engagements fought under different conditions. This chapter discusses the program itself and investigates the results of battles fought with different tactics employed by the offensive force.

A. THE COMPUTER PROGRAM

The program designed to calculate the outputs of the model uses FORTRAN IV language and was run on an IBM 360 computer. At the end of every time increment, dt, it calculates the casualties and rates of fire for both sides along with the range and time length of engagement. It then uses these as new inputs for the next time iteration. The program runs until either the assaulting force or the defending force is completely annihilated or until the assault force is within 10 meters of the defenders' positions. If the latter case occurs, the side with the most men remaining, not counting the base of fire, is declared the winner. The casualties are assumed to be on a 1 to 1 ratio from this point on, so the larger force (assault or defense) is decreased by the number of men remaining in the smaller force, and the smaller force is reduced to zero.

B. INPUT PARAMETERS

The parameters used in the model were of two types - variant and invariant. The invariant parameters, to be described below, were held constant over the entire course of the problem, no matter what values the variable parameters were assigned. The variable parameters were those which were manipulated to investigate the results of different offensive tactics and different distributions of fire by the defense.

1. Parameters Held Constant

The values for the invariant parameters used in this model were derived from military manuals and research documents and from the professional judgment of knowledgeable infantry officers.

a. Target Areas, Total Areas, and Areas of Suppression

The actual target areas presented by the individuals in the action were taken from the Army's Infantry Rifle Unit Study [26]. This report stated that the area of a man firing from the prone position was 0.1 square meters, from the kneeling position was 0.2 m^2, and from the standing position was 0.3 m^2.

The target areas for the defenders and the individuals in the base of fire were assumed to be those presented by prone shooters, 0.1 m^2. The members of the assault force presented an area of 0.3 m^2 during rushes and during the final assault.

It was assumed that since the non-maneuvering members of the assault force have less time to select and prepare their positions, if they were exposing themselves in order to fire at the defenders, they presented a larger target than the prone firers - 0.15 m^2. On the other hand, if they did not fire, they could take cover more effectively than a prone shooter and thus presented less of a target - 0.05 m^2.

The total area occupied by the defense, i.e., the area into which the attacking force is firing, was assumed to be 50 m^2 when the initial defensive strength is 4 men. This area would, of course, vary with the terrain, but the size decided upon seemed reasonable. When the defenders start with 12 men, the size of the area was tripled to 150 m^2.

Since, in this study, the same number of men were initially in the base of fire, if one was used, as were in the defense, the total area for the base of fire was the same as that for the defenders.

The total area for the non-maneuvering elements of the assault group was assumed to be 100 m^2 when the total number of attackers was initially 12 and 300 m^2 when the initial number was 36. Again these areas are arbitrary. However, it was felt that to make them any larger would spread the assault force so much that it would be unmanageable.

These areas held until the final assault. At this point, it was assumed that the assault group, being within 50 meters of the defenders, would be better able to judge the defenders' total area. Therefore, this area was reduced to 30 and 90 m^2 respectively for initial defensive strengths of 4 and 12.

The area of suppression was assumed to be 3.14 m^2. This was arrived at by the supposition that any round passing within 1 meter of an individual will cause him to be suppressed. Since the area of suppression, as well as the target area is assumed to present a circular target, such an area with a radius of 1 meter has an area of approximately 3.14 m^2.

b. Time of Suppression

The Army's <u>Small Arms Weapons Systems</u> report [27] estimated the time an individual is suppressed to be approximately 2 seconds. Since their assumptions concerning suppression were somewhat different than those made in this model, the time has been modified herein to 1.5 seconds for initial suppression. The additional suppression time caused by another round passing while an individual is still suppressed was given the value of 0.75 seconds. It was felt that going any more deeply into the additional suppression time would add little to the model.

c. Acquisition, Starting, Coordination, and Target Exposure Times

Christy experimentally obtained times to complete rushes of 5, 10, 20, 30 and 40 meters [8]. By examining these values it was found that after the initial 5 meters, the speed of movement for all other distances was approximately 7 meters per second. The first 5 meters could be covered in approximately 1.5 seconds.

It was assumed that prior to running the individual requires a certain time to rise from the prone to the erect position. This starting time, STIME, was given the value of 1 second.

To calculate the target exposure time of an individual rushing 5 meters or more, the starting time and the time to complete the rush were summed,

$$ETIME = STIME + 1.5 + \frac{DRUSH - 5}{7} .$$

The rushers were not fired upon during their entire exposure time, since it would take a defender a certain amount of time to aim his weapon at these newly presented targets. This acquisition time, ATIME, was given the value of 2 seconds.

Between rushes, the assault force leader would need time to coordinate his elements. This coordination time, CTIME, was assumed to be 5 seconds. It is quite possible that this time is overly optimistic in that it assumed very tight control by the leader.

d. Rush Distance

The rush distance selected for use in this model was a constant 20 meters from the time the assault force crossed the line of departure until it reached the final coordination fine. This distance was selected because Christy's work indicated that longer rush distances were more effective if these distances remained constant throughout the battle [8].

In actual practice, longer rush distances would probably be employed at longer ranges and would decrease as the distance to the enemy decreased, and hence his kill probability increased. This, however, is beyond the scope of this study.

e. Rates of Fire

In combat, an individual rifleman armed with a semi-automatic weapon is expected to deliver 10 well-aimed rounds per minute [30]. Since it was assumed that all troops in the scenario were so armed, the rate of fire for every participant was assumed to be 10 rounds per minute if he were not suppressed.

The only exception to this is during the final assault. Here the rate of fire should increase as a high volume of fire is critical at this point. To take this into account, all rates of fire were doubled to 20 rounds per minute for this portion of the action.

f. Aiming Error

The aiming error was the most difficult of the nonvariant inputs to judge. The BRL report on the accuracy of rifle fire gives a miss distance of 3 mils for a semi-automatic M-14 rifle fired from a prone position at a target 300 meters distant [5]. Sterne and Yudowitch have stated that aiming error is a function of target exposure time [22]. Using the latters' data, Christy estimated that an average aiming error would be 10 mils for defenders firing at moving attackers and 12 mils for attackers using fire and maneuver shooting at defenders [8].

This author has estimated the aiming error for stationary individuals firing at stationary targets (i.e., defenders firing at the base of fire, and vice versa) to be 5 mils. This increases the aiming error determined by the BRL report to reflect the more difficult conditions of the scenario.

Christy's estimates of the aiming errors for the stationary defenders firing at the assault force, 10 mils, and the assault force firing at the defenders, 12 mils, have been accepted as reasonably accurate.

The aiming error for the assault force during the final assault has been estimated to be 20 mils. This is so because the individuals are then firing while in an upright position and moving, a difficult way to fire a rifle accurately.

g. Time Increment

The increment of time, dt, used to recalculate rates of fire, casualties, and remaining force levels was chosen to be 5 seconds. Any time less than this used too much computer time and, for trial runs, did not affect the outcome of the problem or significantly change the number of total casualties.

h. Final Coordination Line

The final coordination line (FCL) was chosen to be at a distance of 50 meters from the defensive positions. While this would vary with the combat situation, 50 meters seemed to be a reasonable distance to use.

2. Parameters Systematically Varied

The parameters which were varied in the model to test their significance were opposing strengths, types of attack, types of fire, the initial range of engagement, and the distribution of fire.

a. Opposing Strengths

The attacking force was always given a 3 to 1 advantage in initial force size since this ratio of attackers to defenders is generally accepted as the differential needed for an attacking force to secure a defended objective.

The model was run with 12 attackers against 4 defenders and 36 attackers against 12 defenders. In relating this to actual practice, these strengths would be equivalent to a squad attacking a fire team and a platoon attacking a squad.

b. Type of Attack

Four types of attacks were used in the model - a frontal assault on line with no fire and maneuver and no base of fire, the same type of attack with a base of fire, a frontal assault using fire and maneuver with a base of fire, and a frontal assault employing fire and maneuver without a base of fire. Except for flanking attacks, these are basically the only types of attacks possible by a small infantry unit.

In dividing the attacking force into maneuver elements and a base of fire, a triangular organization was assumed. That is, when a base of fire was used, it would be one-third of the total force. With or without a base of fire, each maneuvering element in the assault force would also be one-third of the total attacking force.

To investigate the effectiveness of the fire of the assault force, the problem was run with and without the non-maneuvering elements of the assault force shooting at the defenders during the fire and maneuver phase of the attack. During the final assault, the assault force always fired.

c. Distribution of Fire

The fraction of defenders firing at the base of fire, RHO, was given the values of 0.0, 0.25, 0.50, 0.75, 1.0 whenever the base of fire was employed. This looked at enough of the defenders' options as far as firing at the base of fire was concerned to indicate how their fire should be best distributed.

When the attackers used fire and maneuver, the fraction of defenders not firing at the base of fire, (1 - RHO), who specifically fired at the non-maneuvering elements of the assault force, ETA, was varied. The values assigned were again 0.0, 0.25, 0.50, 0.75, and 1.0, for the same reasons as given above for RHO.

d. Types of Fire

Two types of fire were investigated - aimed and area. Whichever type was used for each data run was used by both sides. The one exception to this is that the maneuvering element, since visible, always received aimed fire.

It is possible that one side could be firing aimed and the other side area fire. While the model will handle this problem, it was not addressed in this work.

e. Initial Range of Engagement

Two initial ranges of engagement - 200 and 300 meters - were selected for use in this thesis because they are distances at which small unit actions are likely to start. It was assumed for both ranges that the distance of the base of fire (BOF) from the defenders was the same as the line of departure (LOD) for the assault force. This assumption does not have to be made since the model can incorporate different ranges for the BOF and the LOD. However, since it is reasonable to assume in actual practice that the ranges would be identical, this is the supposition made herein.

VI. DISCUSSION OF RESULTS

Tables 1 through 4 give the results of attacks conducted by fire and maneuver with and without a base of fire. The tables also record whether aimed or area fire was used and give the fire distribution of the defensive force. Recall that RHO is the percentage of the defenders firing at the base of fire and ETA is the fraction of the (1 - RHO) defenders not firing at the base of fire who are specifically firing at the non-maneuvering elements of the assault force.

The tables give the results of only those engagements where elements of the assault group fire at the enemy during the fire and maneuver (F&M) phase of the assault. However, in this section is a discussion of what occurred when the assault group did not fire during F&M.

It was mentioned previously that the program was run for both 12 attackers versus 4 defenders and 36 attackers versus 12 defenders. It was found that since all the total areas were tripled when force sizes were tripled, the results obtained were exactly three times the results of the 12 vs 4 test runs for both area and aimed type fire. Therefore, it was decided to record only the 12 versus 4 results herein.

When the attacking force employed a frontal attack with no fire and maneuver and no base of fire, from either 200 or 300 meters, it invariably lost. Some attackers reached the final coordination line, but none were able to advance closer than 35 meters from the defenders before being completely wiped out.

When the offense employed a base of fire (BOF) but advanced without F&M, it again always met with defeat. In both the aimed and area fire case from 200 and 300 meters the defenders always minimized their casualties by concentrating all their fire on the assault force and ignoring the base of fire.

The BOF was most effective when aimed fire was employed from 200 meters. However, even in this case the defenders were better off to concentrate on the assault group since it had a shorter distance to cover, 150 rather than 250 meters, before it began the final assault.

Both of the above cases were conducted with tactics which would rarely be employed in modern warfare since the accuracy and firing rate of small arms today would make attacks with the assault force constantly exposed very costly. The real question to be answered was whether a unit using fire and maneuver should attack a defended position with or without a base of fire. Recall that when a BOF is employed, only two maneuver elements are available, versus three when the BOF is not used.

In examining Tables 1 and 3, which contain the data for aimed fire, it can be seen that the attacking force will always win when it enjoys a 3 to 1 initial size advantage.

The defenders were always able to inflict more casualties by concentrating the fire of the riflemen shooting at the assault group on the non-maneuvering elements. There are two reasons for this. The first is that as the assault group closes the range, its fire becomes more effective, since the single shot kill probability is a function of range. The second reason is that while the defenders firing at the maneuvering element fire only a portion of the total time, the other defenders are firing continuously. Thus, more rounds can be fired at the non-maneuvering elements, which increases the likelihood of a kill.

It can also be noted that the defenders' fire is deadlier against an offensive force with a BOF if at 300 meters the base of fire is ignored and at 200 meters it is engaged heavily. This is simply because as the range decreases, the fire of the BOF becomes more accurate, thus making it more of a factor in the battle.

Assuming that the defenders fire in the most effective manner, the offense was better off if it employed a base of fire from both 200 and 300 meters. This result held also in the case where the assault group did not fire until it reached the final coordination line. In fact, in that case the attack could not succeed without a base of fire.

In contrast to this, Tables 2 and 4 show that when area fire was employed by both sides, the offensive force was better off by assaulting with its entire force. The principal reason for this is that since the fire is less accurate than in the aimed case, the attacking force would find it more beneficial to have a greater volume of fire during the final assault rather than a relatively low volume of unaimed fire delivered by the BOF before the final assault.

It can be seen in the area fire case that the defensive force is most effective in minimizing its casualties when it concentrates fire on the maneuver element. This is because it was assumed that aimed fire is always employed against that visible element. Thus, the single shot probability of a hit against it is much higher than against an area type target.

From the above results it can be concluded that when aimed fire is used by both sides, an attacking force with a three to one manpower and firepower advantage should use a base of fire when within 200 and 300 meters of the defensive positions in order to reduce casualties. On the other hand, when area fire is employed, the entire offensive force should close with the enemy to insure victory.

Table 1

Aimed Fire - 300 Meters

TACTIC	RHO	ETA	VICTOR	OFF. CAS.	DEF. CAS.
F&M w/o BOF	0.0	0.0	A	2.127	4.000
	0.0	0.25	A	2.383	4.000
	0.0	0.50	A	2.642	4.000
	0.0	0.75	A	2.905	4.000
	0.0	1.00	A	3.172	4.000
F&M w/BOF	0.0	0.0	A	1.848	4.000
	0.0	0.25	A	2.054	4.000
	0.0	0.50	A	2.260	4.000
	0.0	0.75	A	2.464	4.000
	0.0	1.0	A	2.667	4.000
	0.25	0.0	A	1.982	4.000
	0.25	0.25	A	2.142	4.000
	0.25	0.50	A	2.302	4.000
	0.25	0.75	A	2.462	4.000
	0.25	1.0	A	2.621	4.000
	0.50	0.0	A	2.102	4.000
	0.50	0.25	A	2.212	4.000
	0.50	0.50	A	2.323	4.000
	0.50	0.75	A	2.433	4.000
	0.50	1.0	A	2.543	4.000
	0.75	0.0	A	2.206	4.000
	0.75	0.25	A	2.263	4.000
	0.75	0.50	A	2.320	4.000
	0.75	0.75	A	2.377	4.000
	0.75	1.0	A	2.434	4.000
	1.0	0.0	A	2.291	4.000

Table 2

Area Fire - 300 Meters

TACTIC	RHO	ETA	VICTOR	OFF. CAS.	DEF. CAS.
F&M w/o BOF	0.0	0.0	A	3.803	4.000
	0.0	0.25	A	3.932	4.000
	0.0	0.50	A	4.023	4.000
	0.0	0.75	A	4.080	4.000
	0.0	1.0	A	4.104	4.000
F&M w/BOF	0.0	0.0	D	8.040	3.568
	0.0	0.25	D	8.040	3.839
	0.0	0.50	A	7.280	4.000
	0.0	0.75	A	6.807	4.000
	0.0	1.0	A	6.152	4.000
	0.25	0.0	A	7.397	4.000
	0.25	0.25	A	7.157	4.000
	0.25	0.50	A	6.698	4.000
	0.25	0.75	A	6.231	4.000
	0.25	1.0	A	5.756	4.000
	0.50	0.0	A	6.495	4.000
	0.50	0.25	A	6.202	4.000
	0.50	0.50	A	5.905	4.000
	0.50	0.75	A	5.605	4.000
	0.50	1.0	A	5.301	4.000
	0.75	0.0	A	5.363	4.000
	0.75	0.25	A	5.220	4.000
	0.75	0.50	A	5.840	4.000
	0.75	0.75	A	5.745	4.000
	0.75	1.0	A	5.650	4.000
	1.0	0.0	A	5.333	4.000

Table 3

Aimed Fire - 200 Meters

TACTIC	RHO	ETA	VICTOR	OFF. CAS.	DEF. CAS.
F&M w/o BOF	0.0	0.0	A	2.182	4.000
	0.0	0.25	A	2.437	4.000
	0.0	0.50	A	2.696	4.000
	0.0	0.75	A	2.960	4.000
	0.0	1.0	A	3.228	4.000
F&M w/BOF	0.0	0.0	A	1.934	4.000
	0.0	0.25	A	2.094	4.000
	0.0	0.50	A	2.250	4.000
	0.0	0.75	A	2.403	4.000
	0.0	1.0	A	2.550	4.000
	0.25	0.0	A	2.144	4.000
	0.25	0.25	A	2.273	4.000
	0.25	0.50	A	2.400	4.000
	0.25	0.75	A	2.524	4.000
	0.25	1.0	A	2.646	4.000
	0.50	0.0	A	2.346	4.000
	0.50	0.25	A	2.438	4.000
	0.50	0.50	A	2.530	4.000
	0.50	0.75	A	2.620	4.000
	0.50	1.0	A	2.710	4.000
	0.75	0.0	A	2.536	4.000
	0.75	0.25	A	2.585	4.000
	0.75	0.50	A	2.634	4.000
	0.75	0.75	A	2.683	4.000
	0.75	1.0	A	2.732	4.000
	1.0	0.0	A	2.707	4.000

Table 4

Area Fire - 200 Meters

TACTIC	RHO	ETA	VICTOR	OFF. CAS.	DEF. CAS.
F&M w/o BOF	0.0	0.0	A	6.396	4.000
	0.0	0.25	A	5.991	4.000
	0.0	0.50	A	5.575	4.000
	0.0	0.75	A	5.146	4.000
	0.0	1.0	A	4.707	4.000
F&M w/BOF	0.0	0.0	D	8.040	2.291
	0.0	0.25	D	8.040	2.407
	0.0	0.50	D	8.040	2.522
	0.0	0.75	D	8.040	2.874
	0.25	0.0	D	8.181	2.461
	0.25	0.25	D	8.181	2.546
	0.25	0.50	D	8.181	2.669
	0.25	0.75	D	8.181	2.817
	0.25	1.0	D	8.181	2.963
	0.50	0.0	D	8.314	2.670
	0.50	0.25	D	8.314	2.768
	0.50	0.50	D	8.314	2.865
	0.50	0.75	D	8.314	2.962
	0.50	1.0	D	8.314	3.058
	0.75	0.0	D	8.440	2.967
	0.75	0.25	D	8.440	3.015
	0.75	0.50	D	8.440	3.063
	0.75	0.75	D	8.440	3.110
	0.75	1.0	D	8.440	3.157
	1.0	0.0	D	8.559	3.302

VII. SUMMARY AND RECOMMENDATIONS FOR FURTHER STUDY

A model has been developed in this thesis to predict the casualties for both sides in an infantry attack on a defended position. The results of this model show that for the attacks launched at distances of 200 and 300 meters from a defended position, a base of fire should be used by the offensive unit if aimed fire is employed by both sides, i.e., all targets are visible. However, if area fire is employed by both sides, i.e., no targets are visible except the maneuver element, the assault should be carried out by the entire attacking force.

While these results seem quite reasonable, there are many areas of the model which could be further studied. One is the concept of aimed and area fire. Aimed fire presumes perfect intelligence about the enemy. That is, the enemy's location is always known, and when he is killed, fire is immediately shifted to a new target. On the other hand, area fire presumes no intelligence about the enemy except for his general location.

In most cases, neither one of these extremes holds exclusively. A worthwhile effort would be to examine the model with different combinations of these two types of fire.

Another shortcoming of the model is that it is designed for only single shot weapons. Since automatic weapons are very much a part of modern warfare, altering the model to handle correlated rounds from other than single shot weapons would be most beneficial.

In the model, it was assumed that if defenders were assigned to fire at the maneuvering element, they would do so exclusively. Thus, this group of riflemen would not be firing at all when no element of the assault group was making a rush. It would be interesting to see how the results would change if these defenders were to fire at the prone members of the assault group when a maneuvering element was not visible.

Another refinement which could be made in the model would be to shorten the rush distance as the range to the defenders decreased. This could be done either by programming shorter rush distances at shorter ranges or by making the rush distance a function of the defenders' fire.

```
C    A MATHEMATICAL MODEL OF INFANTRY COMBAT BASED ON
     LANCHESTER'S THEORIES OF COMBAT



C    AEA = EXPOSED AREA OF ASLT MEMBER (MOVING)
C    AEB = EXPOSED AREA OF A BOF MEMBER
C    AED = EXPOSED AREA OF A DEFENDER
C    AEF = EXPOSED AREA OF ASLT MEMBER (NOT MOVING)
C    ASB = AREA OF SUPPRESSION OF A BOF MEMBER
C    ASD = AREA OF SUPPRESSION OF A DEFENDER
C    ASLT = ASSUALT ELEMENT
C    ATA = TOTAL AREA OF ASSUALT GROUP
C    ATB = TOTAL AREA OCCUPIED BY BOF
C    ATD = TOTAL AREA OCCUPIED BY DEFENDERS
C    ATIME = ACQUISITION TIME
C    AVEL = VELOCITY OF FINAL ASSUALT
C    BOF = BASE OF FIRE
C    CTIME = COORDINATION TIME
C    DRUSH = RUSH DISTANCE
C    DT = TIME INCREMENT (IN SECONDS)
C    ETA = % OF (1-RHO) DEFENDERS FIRING AT NONMANEUVERING
           ELEMENTS OF ASLT
C    FI = % OF ATTACKERS IN BOF
C    FCL = DISTANCE OF FINAL COORDINATION LINE
C    NTSD = TYPE OF FIRE OF DEF (1 = AREA FIRE)
C    NTSM = TYPE OF FIRE OF NONMAN. ASLT (1 = AREA FIRE)
C    NTST = TYPE OF FIRE OF BOF (1 = AREA FIRE)
C    R = RANGE OF ASLT GROUP
C    RFA = RATE OF FIRE OF ASLT MEMBER
C    RFMO = RATE OF FIRE OF ASLT MEMBER (DURING FIRE AND MAN)
C    RHO = % OF DEFENDERS FIRING AT BOF
C    ROD = RATE OF FIRE OF DEFENDER (WITHOUT SUPPRESSION)
C    ROA = RATE OF FIRE OF BOF MEMBER (WITHOUT SUPPRESSION)
C    RR = DISTANCE OF BOF FROM DEFENDERS
C    RSTRT = DISTANCE AT WHICH ASLT GROUP STARTS
C     ALL AIMING ERRORS IN MILS
C    SIG2 = AIMING ERROR OF DEFENDERS AGAINST ASLT
C    SIGA2 = AIMING ERROR OF ASLT DURING FINAL ASSUALT
C    SIGM2 = AIMING ERROR OF ASLT DURING FIRE AND MANEUVER
C    SIGS2 = AIMING ERROR OF BOF AND DEF AGAINST STATIONARY
             TARGETS
C    STIME = STARTING TIME OF RUSHERS
C    TS0 = INITIAL SUPPRESSION TIME
C    TS1 = ADDITIONAL SUPPRESSION TIME
C    XME = NUMBER OF MANEUVER ELEMENTS
C    XNA = # OF ATTACKERS
C    XND = # OF DEFENDERS



   10 READ(5,101)ROA,ROD,RFMO,RFA,RSTRT,RR,FCL
      READ(5,101)XME,FI,RHO,ETA,DRUSH,XNA,XND
      READ(5,102)NTST,NTSD,NTSM,NTSA,KEND
  101 FORMAT(7F5.0)
  102 FORMAT(5I2)
      XNA0=XNA
      XND0=XND
C
C    INVARIANT PARAMETERS
C
      IF(DRUSH.LE.0.0)DRUSH=RSTRT-FCL
      ASB=3.14
```

```
      AEB=0.1
      ASD=3.14
      AED=0.1
      AEA=0.3
      ASA=3.14
      ATB=150.0
      ATD=150.0
      ATA=300.0
      AVEL=1.0
      SIG2=10.0
      SIGA2=20.0
      SIGM2=12.0
      SIGS2=5.0
      DT=5.0
      TS0=1.5
      TS1=0.75
      ATIME=2.0
      STIME=1.0
      CTIME=5.0
      IF(REMO.GT.0.0)GO TO 105
      AFF=0.05
      GO TO 106
  105 AFF=.15
C
C     WRITE STARTING SITUATION
C
  106 IF(NTST.EQ.1)GO TO 109
      WRITE(6,115)
      GO TO 110
  109 WRITE(6,116)
  110 IF(NTSD.EQ.1)GO TO 111
      WRITE(6,117)
      GO TO 112
  111 WRITE(6,118)
  112 IF(NTSM.EQ.1)GO TO 113
      WRITE(6,121)
      GO TO 114
  113 WRITE(6,122)
  114 WRITE(6,119)
      WRITE(6,120)XNA,XND,FI,RHO,ETA
      WRITE(6,123)
      WRITE(6,124)RR,RSTRT,DRUSH,XME,FCL
  115 FORMAT(1H0, 5X,'BOF USES AIMED FIRE')
  116 FORMAT(1H0, 5X,'BOF USES AREA FIRE')
  117 FORMAT(1H0, 5X,'DEFENDERS USE AIMED FIRE')
  118 FORMAT(1H0, 5X,'DEFENDERS USE AREA FIRE')
  119 FORMAT(1H0,5X,'ATTACKERS',5X,'DEFENDERS',5X,'% IN BOF'
     15X,'% FIRING AT BOF',5X,'% FIRING AT NONMAN')
  120 FORMAT(1H0,5X,F7.3,7X,F7.3,6X,F7.3,5X,F7.3,15X,F7.3)
  121 FORMAT(1H0, 5X,'MANEUVER ELEMENTS USE AIMED FIRE')
  122 FORMAT(1H0, 5X,'MANEUVER ELEMENTS USE AREA FIRE')
  123 FORMAT(1H0,5X,'RANGE OF BOF',5X,'STARTING DIST.',5X,
     1'RUSH DIST.',5X,'# OF MAN. ELEMENTS',5X,'FCL')
  124 FORMAT(1H0,7X,F7.3,12X,F7.3,7X,F7.3,9X,F7.3,15X,F7.3)
C
C     FIRE AND MANEUVER
C
      Z=RSTRT-FCL
      IF(DRUSH.GE.Z)GO TO 128
      RTIME=STIME+1.5+(DRUSH-5.0)/7.0
      GO TO 129
  128 RTIME=Z/2.0
  129 RUSHN=(RSTRT-FCL)/DRUSH
      ETIME=RUSHN*XME*RTIME
      TTIME=RUSHN*XME*(RTIME+CTIME)
      FTIME=RUSHN*(RTIME-ATIME)*XME
      PDME=FTIME/TTIME
C
C     INITIALIZE
C
      BOF=FI*XNA
      ASLT=XNA-BOF
```

```
      L=0
      T=0.
      R=RR
      RA=ROA
      RD=ROD
      REM=REMO
  100 T=T+DT
C
C   RANGE
C
      IF(L.EQ.1)GO TO 125
      DR=(DT/TTIME)*(RSTRT-ECL)
      GO TO 130
  125 DR=AVEL*DT
  130 R=R-DR
C
C   PROBABILITY DEFENDER SUPPRESSED
C
      IF(L.EQ.1)GO TO 200
      IF(NTSM.EQ.1)GO TO 140
      POWM=ASD*(10.0**6)/(3.14*(R*SIGM2)**2)
      PDSM=1.0-(1.0/EXP(POWM))
      DLDAM=REM*PDSM*ASLT*(1.0-1.0/XME)/XND
      GO TO 145
  140 PDSM=ASD/ATD
      DLDAM=REM*PDSM*ASLT*(1.0-1.0/XME)
  145 IF(NTST.EQ.1)GO TO 150
      POWD=ASD*(10.0**6)/(3.14*(RR*SIGS2)**2)
      PDS=1.0-(1.0/EXP(POWD))
      DLMDA=(RA*PDS*BOF/XND)+DLDAM
      GO TO 160
  150 PDS=ASD/ATD
      DLMDA=RA*PDS*BOF+DLDAM
      GO TO 160
C
C   EXPECTED TIME DEFENDER SUPPRESSED
C
  200 IF(NTSA.EQ.1)GO TO 201
      POWD=ASD*(10.0**6)/(3.14*(R*SIGA2)**2)
      PDS=1.0-(1.0/EXP(POWD))
      DLMDA=REA*PDS*ASLT/XND
      GO TO 160
  201 PDS=ASD/ATD
      DLMDA=REA*PDS*ASLT
  160 PINAD=1-1/EXP(TSO*DLMDA/60.0)
      XTSD=DLMDA*DT*(TSO*(1-PINAD)+TS1*PINAD)/60.0
  203 IF(XTSD.GE.DT)XTSD=DT
C
C   PROB BASE OF FIRE SUPPRESSED
C
      IF(L.EQ.1)GO TO 230
      IF(BOF.LE.0.0)GO TO 217
  206 IF(NTSD.EQ.1)GO TO 210
      POWB=ASB*(10.0**6)/(3.14*(RR*SIGS2)**2)
      PBS=1.0-(1.0/EXP(POWB))
      BLMDA=RD*PBS*XND*RHO/BOF
      GO TO 215
  210 PBS=ASB/ATB
      BLMDA=RD*XND*PBS*RHO
C
C   EXPECTED TIME BOF SUPPRESSED
C
  215 PINAB=1-1/EXP(TSO*BLMDA/60.0)
      XTSB=BLMDA*DT*(TSO*(1-PINAB)+TS1*PINAB)/60.0
      IF(XTSB.GE.DT)XTSB=DT
      GO TO 218
  217 XTSB=DT
C
C   PROB FIRE OF ASLT ELEMENTS SUPPRESSED
C
  218 IF(NTSD.EQ.1)GO TO 220
      IF(XME.LE.1.0)GO TO 219
```

```
      POWA=ASA*(10.0**6)/(3.14*(R*SIG2)**2)
      PMS=1.0-(1.0/EXP(POWA))
      ALMDA=RD*PMS*ETA*(1.0-RHO)*XND/(ASLT*(1.0-(1.0/XME)))
      GO TO 225
  219 ALMDA=0.0
      GO TO 225
  220 PMS=ASA/ATA
      ALMDA=RD*(1.0-RHO)*ETA*XND*PMS
C
C     EXPECTED TIME FIRE OF ASLT SUPPRESSED
C
  225 PINAA=1-(1/EXP(TSO*ALMDA/60.0))
      XTSA=ALMDA*DT*(TSO*(1.0-PINAA)+TS1*PINAA)/60.0
      IF(XTSA.GE.DT)XTSA=DT
C
C     RATES OF FIRE
C
  230 RD=ROD*(1-XTSD/DT)
      RA=ROA*(1-XTSB/DT)
      REM=REMO*(1.0-XTSA/DT)
C
C     PROB TARGET PRESENT
C
      PTB=(DT-XTSB)/DT
      PTD=(DT-XTSD)/DT
      PTA=(DT-XTSA)/DT
C
C     PROB OF HIT GIVEN TARGET PRESENT
C
      IF(L.NE.1)GO TO 305
      PODA=AED*(10.0**6)/(3.14*(R*SIGA2)**2)
      PHDA=1.0-(1.0/EXP(PODA))
      PHB=0.0
      GO TO 322
  305 IF(NTSM.EQ.1)GO TO 300
      PODA=AED*(10.0**6)/(3.14*(R*SIGM2)**2)
      PHDA=1.0-(1.0/EXP(PODA))
      GO TO 306
  300 PHDA=(AED/ATD)*XND
  306 IF(NTST.EQ.1)GO TO 310
      POD=AED*(10.0**6)/(3.14*(RR*SIGS2)**2)
      PHD=1.0-(1.0/EXP(POD))
      GO TO 320
  310 PHD=(AED/ATD)*XND
  320 IF(NTSD.EQ.1)GO TO 321
      POH=AEB*(10.0**6)/(3.14*(RR*SIGS2)**2)
      PHB=1.0-(1.0/EXP(POH))
      GO TO 322
  321 PHB=(AEB/ATB)*POF
  322 POTPA=AEA*(10.0**6)/(3.14*(R*SIG2)**2)
      PHTPA=1.0-(1.0/EXP(POTPA))
      IF(XME.LE.1.0)GO TO 325
      IF(NTSD.EQ.1)GO TO 330
      POTPM=AEE*(10.0**6)/(3.14*(R*SIG2)**2)
      PHTPM=1.0-(1.0/EXP(POTPM))
      GO TO 340
  325 PHTPM=0.0
      GO TO 340
  330 PHTPM=(AEE/ATA)*(ASLT*(1.0-(1.0/XME))+ASLT*(1.0-ETIME/
     1TTIME)/XME)
C
C     PROB OF A KILL
C
  340 PKDB=PHD*PTD
      PKDA=PHDA*PTD
      PKA=PHTPA*PDME
      PKB=PHB*PTB
      PKM=PHTPM*PTA
C
C     ATTRITION
C
      IF(L.EQ.1)GO TO 405
```

```
      DD=(RA*PKDB*BOF+RFM*PKDA*ASLT*(1.0-(1.0/XME)))*(DT/60.
      GO TO 406
  405 DD=RFA*PKDA*ASLT*DT/60.0
  406 DB=RD*PKB*RHO*XND*DT/60.0
      DA=XND*(DT/60.0)*(1.0-RHO)*RD*(PKA*(1.0-ETA)+PKM*ETA)
      XND=XND-DD
      ASLT=ASLT-DA
      BOF=BOF-DB
      IF(XND.GT.0.)GO TO 803
      GO TO 999
  803 IF(ASLT.GT.0.)GO TO 804
      GO TO 999
  804 IF(BOF.GT.0.)GO TO 805
      BOF=0.0
      RHO=0.0
  805 IF(R.GT.FCL)GO TO 100
      RHO=0.0
      I=1
      ETA=0.0
      XME=1.0
      PDME=1.0
      ROA=0.0
      ROD=20.0
      ASD=.75
      ATD=90.0
      IF(R.LT.10.0)GO TO 999
      GO TO 100
C
C     TOTAL CASUALTIES
C
  999 IF(ASLT.GT.XND)GO TO 990
      WRITE(6,995)
      IF(ASLT.LT.0.0)ASLT=0.0
      XNDS=XNDO-XND+ASLT
      XNDS=XNDO-XNDS
      XNAS=XNAO-BOF
      GO TO 991
  990 WRITE(6,996)
      XNAF=BOF+ASLT-XND
      XNDS=XNDO
      XNAS=XNAO-XNAF
  991 WRITE(6,997)
      WRITE(6,998)XNAS,XNDS,R,T
      WRITE(6,994)
  994 FORMAT(1H0,'********************************')
  995 FORMAT(1H0,'DEFENSE WINS')
  996 FORMAT(1H0,'OFFENSE WINS')
  997 FORMAT(1H0,5X,'OFFENSE CAS.',5X,'DEFENSE CAS.',5X,
     1'RANGE',5X,'TOTAL TIME')
  998 FORMAT(1H0,5X,F7.3,9X,F7.3,9X,F7.3,5X,F7.3)
      IF(KEND.NE.1)GO TO 10
      STOP
      END
```

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13. ABSTRACT

This thesis presents a Lanchester-based mathematical model of a small unit infantry attack on a defender position. It proposes that a major factor in actual combat is the suppression of fire of one side by a heavy volume of accurate fire from its opponents and incorporates this phenomenon into the model.

Following the development of the model, different offensive tactics are investigated to find the preferred method of attack under varying circumstances.

14 KEY WORDS	LINK A		LINK B		LINK C	
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