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MEASURING THE EFFECTIVENESS OF SCATTERABLE MINES IN THE ARMOR COMBAT ENVIRONMENT

by

Terry Winslow Curl

September 1976

Thesis Advisor: S. H. Parry

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Measuring the Effectiveness
of
Scatterable Mines in the Armor Combat Environment

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I. INTRODUCTION

United States Army landmines are among the best artificial obstacles -- they are portable, installed relatively easily, and consititue a hazard to the enemy. However, large scale employment of conventional mines (pressure activated) requires considerable time, manpower, and logistical efforts. Mines delay and force direction of enemy movement, lower the enemy's will to fight, and cause fear of sudden and unexpected casualties. [3]

The introduction of scatterable mines in the early 1970's offered a new dimension in landmine employment. A scatterable mine is a target activated munition which is capable of rapid emplacement by scattering from aircraft, artillery shells, rocket warheads and ground dispensers. Scatterable mines can be delivered faster and require fewer number of personnel to emplace compared to conventional mines. Also, a recognized pattern of scatterable mines is much harder to detect than one of conventional mines.

In 1971, the United States Army Engineer School undertook a study entitled "Family Of Scatterable Mines (FASCAM)". The purposes of FASCAM were: 1. to define the place of the scatterable target activated munition of the modern battlefield; 2. to analyze the family of scatterable self destruction mines to insure that those in development are the most suitable, effective and mission oriented; and 3. to refine and redefine the specific characteristics of each member of the family of scatterable mines in terms of the modern battlefield as influenced by the requirement of cost effectiveness.

The FASCAM study was concluded and the findings presented to Commanding General, Training and Doctrine Command in April 1974. Following that presentation and based upon the study recommendations Combat Developments Experimentation Command (CDEC) initiated action to develop an experimentation program to validate some of the findings from FASCAM. The experiment will be conducted in October 1976 and the results of the experiment presented to the U. S. Army Engineer School in early 1977.

This thesis addresses the design of the experiment to measure the effectiveness of scatterable mines to be conducted at CDEC, and also provides an analysis plan to be used on the field experiments data.

The primary objective of this thesis is to determine if there is a weapons enhancement by the employment of scatterable mines with direct fire weapons systems. Other questions to be addressed are: 1. What range band should scatterable mines be located?; 2. What density should the minefield be?; 3. What should be the configuration of scatterable mines?; and 4. What defensive force in combination with scatterable mines would provide the best effectiveness against an anticipated armor threat force?

Four measures of effectiveness (MOE) are utilized in this study: red casualties, blue casualties, exchange ratio, and distance to the objective (DTO). These MOE's are determined by forming various ratios at time, red casualty, blue casualty, and DTO specified analysis points. An analysis point is a specified value for time, red casualty, blue casualty, and DTO.

The general field experimentation considerations to include methodology, scenario, and a typical trial are discussed in Chapter III. The analytical model utilized a full factorial design. Without consideration of CDEC's equipment, instrumentation, and personnel constraints, the "normal" model results in a total of 432 trials for that design. When CDEC's constraints were introduced, the "reduced" model consists of 176 trials.

The analysis plan to be used after the data is reduced from the field experiment is described in Chapter V. There are 23 experimental designs which should receive primary consideration. Appropriate Analysis of Variance programs would be used on the 23 experimental designs. The hypothesis testing procedure for determining if there is a synergistic effect with the use of scatterable mines is then described.

The application of the analysis plan for DTO at the ten minute analysis point is discussed in Chapter VI From the example it is shown that it is not sufficient only to look at which factors or interactions of factors are significant from the ANOVA. The multiple classification analysis (MCA) determines which levels of the factors (e.g., type of minefield, density) are significant. If interactions of the factors are significant, mean value differential analysis is needed to determine which combination of levels of factors contribute the most to the dependent variable's grand mean and to the defensive forces advantage.

The thesis experimental design differs significantly from CDEC's design for Tactical Effectiveness Mines in the Anti-Armor Weapons Systems (TEMAWS). The thesis design considered the experiment as an exploratory design in which as many as possible levels of the factors would be considered. Also, no input from the FASCAM study was used in the design. CDEC's TEMAWS design, had fewer factors and utilized some of the results of the FASCAM study to include in the TEMAS design. The explanation of TEMAWS experimental design, and its comparison with the thesis design is in Chapter VII. Finally, the summary and recommendations are presented in Chapter VIII.

II. OBJECTIVES AND MEASURES OF EFFECTIVENESS

A. OBJECTIVES

The purpose of this study is to evaluate the effectiveness of scatterable landmines in an armor combat environment. The objectives of the study are as follows:

1. Evaluate the synergistic effects of scatterable mines.

2. Evaluate various densities of scatterable minefields against an armor heavy threat force.

3. Evaluate various range locations of the scatterable minefield in front of the defensive forces position.

4. Evaluate various defensive force combinations of weapons systems against an anticipated armor force.

5. Compare the effectiveness of a continuous versus belted scatterable minefield.

This study encompasses the design of a field experiment and develops an analysis plan to be used on the data collected from the experiment to evaluate the effectiveness of scatterable mines. It is extremely important to have a comprehensive and detailed experimental design and analysis plan prior to actual field experimentation. The first part of this study develops appropriate measures of effectiveness. Secondly, the various factors and their levels are defined and discussed, with no consideration given to field experimentation constraints on equipment, instrumentation, or personnel. Next, an analysis plan is developed based on the final experimental design considering the constraints of the field experimentation testing organization. The analysis plan is then applied to hypothetical data. Next, the proposed experimental design is compared with CDEC's design. Finally, summary and recommendations are presented to summarize the study and give implications for further experimentation to measure the effectiveness of scatterable mines.

B. MEASURES OF EFFECTIVENESS

The four measures of effectiveness selected to evaluate scatterable mines are exchange ratio, blue casualties, red casualties, and distance to the objective. These measures were selected to relate the effectiveness of scatterable mines to casualties, time, and force separation. Throughout the study, blue refers to the defensive friendly force and red refers to the attacking threat force.

From blues point of view, it would be desirable to have a large number of red loses and a small number of blue loses. It would also be advantageous for blue to attain a high exchange ratio (e.g., red casualties/blue casualties) as early in the engagement and at the maximum force separation possible from blue's defensive position. Hopefully, scatterable mines in combination with the appropriate defensive force mix significantly contribute to blues effectiveness in defending his position.

The distance to the objective variable (DTO) is the straight line distance in meters from Red's position at any time to

Blue's defensive position. The DTO value is computed based on the location of the three red platoon leaders at various times in the battle. At a specified time, the DTO for each red platoon is calculated, and the maximum value is used. If there is more than one replication under the same level of independent variables (e.g., factors), the maximum value of each replication is determined, and averaged over the replications to determine DTO. Thus, this value of DTO represents the average distance of the red element to their objective.

A "casualty" for the red or blue forces occurrs at the first time that an element is effectively hit by direct fire weapon or by detonation of a mine. This hit causes the element to lose either its mobility and/or firepower, or is totally destroyed.

The measures of effectiveness are calculated at various analysis points. An analysis point is a selected measure that is held constant while other measures are compared. Four factors are used as analysis points to calculate the MOE's. These factors are time, distance to the objective (DTO), the number of red casualties, and the number of blue casualties. Each of these factors is fixed at specified values for the analysis points. The specified analysis points for each factor will be discussed in Chapter IV.

III. GENERAL FIELD EXPERIMENTATION CONSIDERATIONS

In this chapter, the force structures, tactical scenario, typical trial, data requirements and collection, methodology, and experimentation site are addressed. The organization designated by Training and Doctrine Command to conduct the experiment is Combat Developments Experimentation Command (CDEC).

A. DEFENSIVE AND THREAT FORCE

The defensive force will be a mechanized infantry platoon consisting of five weapons systems and will vary during the conduct of the experiment. In the actual execution of the experiment, only the five weapons and the platoon leader will be physically played.

The threat force will be a reinforced tank company from a mechanized rifle battalion. The mechanized rifle battalion will be equipped with fourteen simulated T-62 tanks, one simulated BRDM-2 (ATGM), two simulated BMP-A (ICV), and one simulated ZSU23-4.

B. TACTICAL SCENARIO

1. Threat (Red)

The reinforced tank company as an element of a first echelon battalion, is given the immediate mission of penetration three to five kilometers into the enemy defense and engaging the first echelon of the defending enemy force. A frontal attack will be employed, with the objective of penetrating forward enemy positions, creating a breakthrough area for subsequent exploitation. The antitank and antiaircraft sections will assume an overwatch position.

Enemy elements, consisting of antitank and antipersonnel weapons have been reported by the reconnaissance platoon on or near the objective area. The opposing force is expected to employ mines forward of their position.

2. Friendly Defensive Force (Blue)

A reinforced mechanized infantry platoon, as part of a mechanized infantry battalion, will occupy defensive positions on or near the FEBA. Mines will be employed at various range bands 1000 meters forward of the FEBA. The platoon will have five weapons on all trials except for those trials in which there will be no defensive force covering the minefield. The threat force is expected to conduct a frontal attack.

C. TYPICAL TRIAL

Each trial will consist of one attack by a threat reinforced tank company on a defending reinforced mechanized infantry platoon.

Prior to each trial, the defending mechanized infantry platoon leader will be given an order to occupy specified positions on the FEBA. The defensive positions allow for coverage of the minefield by all weapons (e.g., since the maximum effective range of the Dragon is 1000 meters, the minefield's outer edge will not exceed 1000 meters).[3] As the attacking force approaches the platoon's defensive position, individuals and leaders will observe threat force elements and either engage them or communicate their presence to other platoon members so that they may engage the threat vehicles. The platoon leader will control the fire effectiveness of his platoon through direct instructions to his assigned weapons crews. The implementation of his defense plan will provide for interlocking fires, cover, concealment, dispersion and coverage of the minefield by all weapons. The defending platoon will engage and attempt to destroy all threat elements.

Prior to each trial, the threat force company commander will be given an attack order. The objective, axis of advance, and tactic will be specified. On commencement of the trial, the reinforced tank company will deploy with platoons on line. The position of elements within each platoon will vary depending on the tactical situation. The company commander will control all his elements through the platoon leaders by means of FM radio, hand and arm signals, and his attack plan. Whenever mines are encountered, either visually detected or by detonation, threat elements will employ the bulling tactic or utilize a countermeasure device, and each platoon will clear a path through the minefield. As individuals and leaders observe targets enroute to the objective, they will engage those targets or cause them to be engaged by other members of the attacking force. The threat force will attempt to destroy all defending forces and weapons.

A trial will terminate whenever 50% of the threat force or friendly force is destroyed, or 50% of the threat force reaches the trial termination line which is approximately 100 meters in front of the defensive force. This trial termination criterion was established by the proponent agency for the experiment, the U. S. Army Engineer School

D. DATA REQUIREMENTS AND COLLECTION

Data will be collected by means of instrumented and manual data acquisition systems. The instrumental systems will include the Direct Fire Simulation (DFS), Range Measuring System (RMS), Central Processing System (CPS), and Range Timing System (RTS).[4] These systems will be used as a primary means of recording event range and time data, acquisition and engagement events. The manual system will be used as a backup in case of instrument failure.

Data to be collected and evaluated during this experiment include time, range, and frequency data for primary events that will occur during the conduct of each trial.

A time line profile describing events associated with each minefield condition and weapon system will be developed for each trial. These profiles will serve the dual purpose of aiding in the verification of data and providing a basis for preliminary analysis. Each profile will summarize a trial by showing relevant events by time, range, target, weapon system, and results of casualty assessment.

E. METHODOLOGY

The experiment will employ real time assessment of casualties during a simulated tank-antitank battle, both with and without minefields.

A real time casualty assessment program will be used. Player's weapons on each side will be equipped with Direct Fire Simulators (DFS) linked to the Central Processing System (CPS) via the Range Measuring System (RMS).[4]

The program will incorporate, select, and treat appropriate weapons systems, related kill equations, and corresponding random numbers for assessing the outcome of each engagement. For direct fire weapons, the outcome of each engagement will be no kill, mobility kill, firepower kill, or total kill. Mine encounters will be no kill, mobility kill, or total kill. If a kill is assessed, appropriate cues will be displayed, the players notified, the vehicle/weapon laser emitting device deactivated, and the vehicle/weapon classified as out of play.

A Scatterable Mine Simulator has been developed by Picatinny Arsenal for this experiment, and it will be used to portray the physical characteristics of the XM70 scatterable mine. The simulator will provide a means of automatically recording the occurrence of a target's encounter with the mines. If a target vehicle approaches to within six feet of the mine simulator, the receiver will sense the coded signal from a transmitter mounted on the threat vehicle and will relay this information to the central computer, where it will be recorded, processed, and a casualty assessed.

The sequence of trials will be randomized to reduce the bias in successive replications of factor levels. With a repetitious operation the order of events are important, either because a learning process is involved which tends to make later operations better than the earlier ones, or because fatigue tends in the opposite direction. Systematic biases are avoided by randomizing the order in which the operation is performed on the different factors in a replication.[1] The equipment and physical environemnt may also introduce bias which can be reduced by randomization.

F. EXPERIMENTATION SITE

The physical dimensions of the experimentation site will be 1000 meters by 1000 meters. [5]

Each defensive position will contain numerous pre-selected primary and alternate positions for individual weapons systems. Players and weapons systems will be assigned to specific individual positions for each trial.

The minefield will be located in the armored killing zone in front of the defensive positions. [2] Defensive positions will allow coverage of the minefield by all weapons systems. The trial termination line will be 100 meters in front of the defensive position. A trial will terminate when the threat force or defensive force attains 50% or more casualties. A casualty is defined as a mobility, firepower, or total kill. A threat vehicle may continue firing if it reaches the trial termination line but cannot advance further due to safety requirements. The personnel and equipment will be provided by the 7th Infantry Division at Fort Ord, California.

IV. EXPERIMENTAL DESIGN MODEL

In this chapter, the analytical model and experimental design are presented. A "normal" model is discussed, which does not consider CDEC's experimentation constraints to include instrumentation and equipment. The "normal" model is then modified to include actual field experimentation constraints, resulting in the "modified" model. Finally, based on the "modified" model, specific analysis points for DTO, time, red casualies, and blue casualties are defined.

A. GENERAL ANALYTICAL MODEL

The general linear model is $Y_{ijklmn} = u + A_i + B_j + C_k + D_l + E_m + I_{ijklm} + \varepsilon_{ijklmn}$

where,

Y_{ijklm} = the dependent variable,

u = grand mean,

A_i = ith level of "type of minefield" factor,

B_j = jth level of "density of minefield" factor,

C_k = kth level of "location of minefield" factor,

D_l = lth level of "threat tactic"

E_m = mth level of "defensive force mix" factor,

I_{ijklm} = interactions of main effects,

ε_{ijklmn}= residual error.

The assumption of the model are that all factors are fixed effects and that residual error is normally distributed (i.e., $\varepsilon \mathcal{L} N(0, \sigma^2)$).

The Family of Scatterable Mines study (FASCAM) identified the five factors described above to be varied in a field experiment to verify some of the study results. The five factors are discussed in the following section.

B. "NORMAL" MODEL

1. <u>Type of Minefield</u>

There are two levels of type of minefield: continuous and belted. A continuous minefield has mines distributed in a continuous random pattern. The standard depth of a continuous scatterable minefield is 300 meters. [3] A belted scatterable minefield has gaps in which no mines are located. Normally, a belted minefield pattern would consist of 100 meters in depth of a specified density of mines, a gap of 50 to 75 meters of no mines, 100 meters of scatterable mines, etc., to a total depth of 300 meters of mines at a specified density. It is felt that the belted minefield would create the illusion to the enemy that the minefield has been cleared when in fact they have cleared only one of several belts in the field.

2. <u>Density of Minefield</u>

There are two levels of the density of minefield factor: .001 mines per square meter and .005 mines per square meter. The FASCAM study conducted sensitivity analysis on different densities of scatterable minefields and found the most significant densities to be .001 and .005 mines per square meter.

One important aspect of the determination of the number of levels of "density" factor was the availability of scatterable mine simulators. There will be 4,000 simulators constructed for this experiment. It is anticipated that approximately 20% of the simulators will be damaged during the conduct of trials. Due to the limited number of simulators only two levels of the "density" factor will be used in the experimental design.

3. Location of Minefield

There are three levels of location of minefield factor: 100 to 400 meters, 400 to 700 meters, 700 to 1000 meters. Minefield doctrine specifies that the minefield must be covered by either direct fire and/or indirect fire weapons. [3] It is essential to have the minefield covered by fire to impede the neutralization of the field. The minefield should be located so that all defensive weapons can cover the minefield within their maximum effective range. Of those weapons considered in the defensive force, the Dragon is the weapon with the least maximum effective range, which is 1000 meters. Therefore, the minefield's outer edge should not exceed 1000 meters. The instrumentation of CDEC and the performance characteristics of the weapons limit the width and depth of the experimentation site to 1000 meters by 1000 meters. Since minefield doctrine specifies a minimum minefield depth of 300 meters, the minefield can have a maximum of three range bands: 100 to 400 meters, 400 to 700 meters, 700 to 1000 meters. The minefield cannot be located closer than 100 meters due to safety considerations.

4. Threat Tactic

There are four levels of the threat tactic factor: bulling (rapid rate of advance), and the use of the line charge, roller attached to an T-62 tank, and a plow attached to an T-62 tank. Based on the latest intelligence information, there are the four threat tactics used when encountering minefields. The bulling tactic has the armored vehicles in a line formation. The vehicles move at a rapid rate of advance, exploding mines enroute to the objective. The three other tactics are employed with the T-62 tank. The roller or plow is activated when encountering a minefield and clears a path through the field. One path is cleared for each platoon. The line charge is similar to the United States Army's bangelor torepedo. When the line charge is fired, it clears a certain width and depth of the minefield.

5. Defensive Force

There are nine levels of the defensive force factor as shown in Table I.

Table I

DEFENSIVE FORCE FACTOR

Level	Tow	Dragon	M60A1
1	2	2	1
2	2	1	2
3	1	2	2
4	1	1	3
5	4	0	1
6	0	4	1
7	3	1	1
8	1	3	1
9	0	0	0

The defensive force will consist of a total of five weapons. There will be at least one type of weapon (e.g., TOW, Dragon, M60A1) for each force level. The TOW, Dragon, and M60A1 were chosen as the defensive weapons because of their capability to defend against a tank heavy threat force.

Table II summarizes the factors and their levels that will be used in the experimental design for the "normal" model.

Table II

SUMMARY OF FACTORS AND LEVELS

Factor	Number of Levels
Type of Minefield	2
Density of Minefield	2
Location of Minefield	3
Threat Tactic	4
Defensive Force	9

B. "REDUCED" MODEL

A factorial design was chosen because it permits the experimenter to evaluate the combined effect of two or more experimental variables when used simultaneously. Information obtained from factorial experiments is more complete than that obtained from a series of single factor experiments, in the sense that factorial experiments permit the evaluation of interaction effects.[1] An interaction effect is an effect attributable to the combination of variables above and beyond that which can be predicted from the variables considered singly.[9] The inclusion of all orders or interactions will allow a determination of which factors and interactions are significant at a specified level.

The linear model with all interactions included is

$$Y_{ijklmn} = u + A_i + B_j + C_k + D_l + E_m + A_iB_j + \cdot\cdot\cdot D_lE_j +$$
$$A_iB_{\underline{i}}C_k + A_iB_iD_l + \cdot\cdot\cdot C_kD_lE_m + A_iB_jC_lD_l + \cdot\cdot\cdot B_jC_kD_lE_m +$$

$A_iB_jC_kD_lE_m + \varepsilon_{ijklm}$, where, $i, j, k = 1,2$, $m = 1,\cdot \cdot$ [illegible], $l = 1,\cdot \cdot \cdot 4$.

The total number of trials for one replication for all levels of each factor would be 432 (e.g., 2x2x3x4x9). This 432 trials constitute the number of trials for the "normal" model.

The 432 trials must now be compared with CDEC's instrumentation, equipment, site layout, and personnel constraints to determine whether that number of trials is possible to achieve.

The TETAM (Tactical Effectiveness Testing Antitank Missiles) experiment conducted by CDEC is similiar in equipment, instrumentation, and personnel requirements to the proposed experiment. The average time per trial to conduct a two sided real time casualty assessment combat battle was 45 minutes. With the changing of the minefield and other instrumentation, the expected average number of trials per day is three. The total time for the execution of the experiment was established at 60 days by TRADOC (Training and Doctrine Command). In summary, the total number of trials that CDEC can be expected to complete in 60 days is 180.

Since there is considerable discrepancy between CDEC's trial capability and the number of trials specified using the "normal" model (e.g., 432 trials), there are two possible ways to reduce the number of trials: reduce the factors, or reduce the levels of the factors.

The objective of the experiment will not be met if any of the factors are eliminated.

The trials can be reduced by eliminating some of the levels of the factors. The minimum number of levels of each factors is two, since further reduction of a factor below two levels eliminates that factor as an independent variable.

The type of minefield and the density of minefield factors cannot be reduced and still allow for comparison within the factors. The density of minefield factor has two levels used in the full factorial, .001 mines per square meter and .005 mines per square meter. A "no mines" case will be used in a separate part of the experiment to establish a base case for comparison.

The threat tactic has four levels. The line charge cannot be realistically played due to field experimentation personnel consideration. Currently no data is available to evaluate the effectiveness of the line charge in the clearing of scatterable minefields. The roller and plow are so similiar in capabilities (e.g., clearing width of minefield, probability of destroying mines) that only one of these countermeasure devices will be employed in the experiment. Therefore, threat tactic will have two levels: bulling and the plow.

The location of minefield factor can be reduced to two levels and still allow for discrimination of the factor. These two levels are 0-500 meters and 500-1000 meters.

The defensive force factor has nine levels in the "normal" model. This factor can be reduced to five levels as shown in Table 3 and still allow for discrimination of the factor. By reducing this factor, however, it is not possible to do detailed marginal analysis on the defensive force configuration.

Table III

DEFENSIVE FORCE FACTOR

Level	Tow	Dragon	M60A1
1	2	2	1
2	4	0	1
3	0	4	1
4	1	1	3
5	0	0	0

With the levels of factors reduced as described above, the number of trials total 80 (e.g., 2X2X2X2X5) for one replication. Since there are 80 trials based on the reduced levels of each factor and CDEC has a capability of 180 trials, it would be possible to perform two replications of each of the 80 trials. A full factorial design incorporating the 160 trials is shown in Table IV.

A "no mines" baseline case is necessary to provide a basis of comparison with the "mines" cases. The design for the "no mines" case is shown in Table V. There will be four trials per cell, resulting in 16 total trials for the base case design.

The total number of trials for the full factorial design and the base case design is 176 trials. The "modified" model which incorporates the capabilities and limitations of CDEC has 176 trials; whereas, the "normal" model would have 432 trials.

Table VI depicts the design matrix for the 176 trials for the "reduced" model.

TABLE IV

FULL FACTORIAL EXPERIMENTAL DESIGN

MINEFIELD	THREAT	CONTINUOUS MINEFIELD										BELTED MINEFIELD									
		.001 MINES/SQ.MT.					.005 MINES/SQ.MT					.001 MINES/SQ.MT.					.005 MINES/SQ.MT.				
LOCATION	TACTIC	DEFENSIVE FORCE MIX																			
		D_1^1	D_2^2	D_3^3	D_4^4	D_5^5	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
0 – 500 METERS	T_1*																				
	T_2**																				
500 – 1000 METERS	T_1																				
	T_2																				

NOTE 4: * T_1 = Bulling Tactic
** T_2 = Plow Tactic

NOTE 2: $D_i = \underline{X}, \underline{Y}, \underline{Z}$
$\overline{X}$ = # of Tows
Y = # of Dragons
Z = # of M60A1 Tanks

1 D_1 = 2,2,1
2 D_2 = 4,0,1
3 D_3 = 0,4,1
4 D_4 = 1,1,3
5 D_5 = 0,0,0

NOTE 3: 2 Trials Per Cell

TABLE V

BASE CASE DESIGN FOR NO MINES

THREAT TACTIC	NO MINEFIELD (.000 MINES/SQ.MT)			
	DEFENSIVE FORCE MIX			
	D_1	D_2	D_3	D_4
T_1				

TABLE VI

DESIGN MATRIX FOR 176 TRIALS

			BULLING					PLOW				
			D_1^1	D_2^2	D_3^3	D_4^4	D_5^5	D_1	D_2	D_3	D_4	D_5
100 – 500 METERS	CONT.	.001	2	2	2	2	2	2	2	2	2	2
		.005	2	2	2	2	2	2	2	2	2	2
	BELT	.001	2	2	2	2	2	2	2	2	2	2
		.005	2	2	2	2	2	2	2	2	2	2
500 – 1000	CONT.	.001	2	2	2	2	2	2	2	2	2	2
		.005	2	2	2	2	2	2	2	2	2	2
	BELT	.001	2	2	2	2	2	2	2	2	2	2
		.005	2	2	2	2	2	2	2	2	2	2
NO "MINES" CASE .000			4	4	4	4						

Di = X, Y, Z
X = # of Tows
Y = # of Dragons
Z = # of M60A1

1. D_1 = 2,2,1
2. D_2 = 4,0,1
3. D_3 = 0,4,1
4. D_4 = 1,1,3
5. D_5 = 0,0,0

C. SCOPE

The objectives of this experiment will be addressed in a series of two-sided simulated attacks by a tank threat force on a reinforced mechanized infantry platoon occupying prepared defensive positions. Assessment of the direct fire engagements and mine encounters will be automated and casualties will be extracted from trial data in near real time. Comparative data will be obtained using two minefield locations, five defensive force mixes, two threat tactics, two minefield densities, and two types of minefields. The experimental design allows approximately two weeks of player training, four weeks of exploratory trials, and fourteen weeks of record experimentation.

D. SPECIFIC ANALYSIS POINTS

The four factors defined in Chapter II to be used as analysis points are time, distance to the objective (DTO), the number of red casualties, and the number of blue casualties. Each factor can now be assigned specific values since the factors and their levels have been specified by the "modified" model.

Time is fixed relative to the start of a trial. The time analysis points are 10 minutes, 20 minutes, 30 minutes, and trial termination.

The DTO factor is fixed at 900 meters, 600 meters, and 300 meters.

Red casualties are fixed at 12%, 24%, 35%, and 47% points of the red force. These percentages translate into two, four, six, and eight red casualties out of a total red force of 17 elements for each replication.

Blue casualties are fixed at 20% and 40% points of the blue force. With five elements in each trial, these points translate into one and two blue casualties, respectively.

V. ANALYSIS PLAN

In this chapter, the analysis plan to be used for the field experiment data is discussed. The analysis of variance procedures are presented, and hypothesis tests to be applied to the data to determine if scatterable minefields have a synergistic effect are discussed.

A. ANALYSIS OF VARIANCE (ANOVA)

The purpose of ANOVA is to test statistical hypotheses concerning the mean values of the various factors as they affect observed values of a specified dependent variable. The linear model for a full factorial design was discussed in Chapter IV.

One of the assumptions of the linear model is that the experimental error is independent of all main effects and interactions of factors. Furthermore, within each cell in the population, the experimental error, ε, is assumed to be normally distributed with mean equal to zero and variance equal to σ^2 for all cells in the population.[1]

Prior to conducting the ANOVA on the experimental data, appropriate statistical tests are performed to determine whether there is homogenity of variances in the error terms (e.g., Bartlett, Goldfelt-Quandt, Hartley).[8]

The general form of the ANOVA is shown in Table VII. The F ratio is determined by taking the mean square (MS) for each factor or combinations of factors and dividing by the mean square for the error term. MS is computed by dividing sum of squares (SS) by degrees of freedom (DF).

The Statistical Package for Social Sciences (SPSS) is a collection of statistical routines to assist in data analysis using a digital computer. The output format for SPSS ANOVA is shown in Table VII. An example using hypothetical data with the SPSS ANOVA is discussed and the interpretation of the results given in Chapter VIII.

The SPSS ANOVA printed output gives the F tabled level at which that factor or combination of levels of factors is significant. Most ANOVA techniques test all factors under one level of significance.[7]

Also available in the SPSS routines is the Multiple Classification Analysis (MCA). The ANOVA table provided only the statistics necessary for significance testing. The fact that a particular factor is significant merely indicates that the mean of at least one level of the factor is significantly different from the grand mean. It is important to examine the patterns of the factors relative to the dependent variable. The MCA table can be viewed as a method of displaying the results of analysis of variance especially when there are no significant interaction effects.[7]

TABLE VII

ANALYSIS OF VARIANCE SPSS OUTPUT FORMAT

Source of Variation	SS	DF	MS	F	Significance of F
Main Effects					
A_i		1			
B_j		1			
C_k		1			
D_l		1			
E_m		4			
2-Way Interactions					
A_iB_j		1			
.		.			
.		.			
.		.			
D_lE_m		4			
3-Way Interactions					
$A_iB_jC_k$		1			
.		.			
.		.			
.		.			
$C_kD_lE_m$		4			
4-Way Interactions					
$A_iB_jC_kD_l$		1			
.		.			
.		.			
.		.			
$B_jC_kD_lE_m$		4			
5-Way Interactions					
$A_iB_jC_kD_lE_m$		4			
EXPLAINED		79			
RESIDUAL		80			
TOTAL		159			

The SPSS MCA output table is shown in Table VIII. Column one is the mean of each category, expressed as deviation from the grand mean. In calculating this value, adjustment is not made for the other factors. The numbers in the second column indicate the adjusted mean values for each category (expressed as deviations from the grand mean) when the other factors are adjusted for. The computation for column two considers the use of controlling for other factors. As an example, the deviation from the grand mean for range of minefield 100-500 meters in column two is the deviation from the grand mean for that range controlling for threat tactic, density, type of minefield, and defensive force. The effect of the control variables is assumed to be linear throughout its range. If a new variable is introduced for each factor by assigning the MCA scores to each category the resultant standardized partial regression coefficient is partial beta, printed in column two. The column one partial beta is the simple correlation between that factor and the independent variable. The column two partial beta is the partial correlation coefficient between the independent variable and the other factors. By looking at the values of the partial betas from column one to column two, it is possible to determine the effect on beta as more factors are introduced as controlled variables.

The Multiple R at the bottom of Table VIII indicates the overall relationship between the dependent variable and the factors. R^2 in the second column represents the proportion of the variance in the dependent variable explained by the factors.

If there is strong interaction between factors, the MCA table must be used in conjunction with a mean differential analysis of the significant interaction of factors. The mean differential analysis computes the means for each combination of levels of factors for the significant interaction factors. As an example, suppose range and tactic are significant main effects. In the second order interaction between the two factors, the interaction was significant. The MCA table output provides the deviation of each main effect from the grand mean but does not give interaction results. The mean differential analysis would compare the various combinations of levels of tactic and range to determine the deviations from the grand mean.

TABLE VIII

SPSS MCA OUTPUT FORMAT

```
                 MULTIPLE CLASSIFICATION ANALYSIS

                  DTO BY RGE-TAC-TMFD-DENS-DEF

   GRAND MEAN __________. (1)                        (2)
                       UNADJUSTED              ADJUSTED FOR
                    N DEV'N ETA                INDEPS.
                                               DEV'N BETA
   Variable + Category

   RGE
       1.   100-500 meters
       2.   500-1000 meters

   TAC
       1.   Bulling
       2.   Plow

   TMFD
       1.   Continuous
       2.   Belted

   DENS
       1.   .001
       2.   .005

   DEF
       1.   2 2 1
       2.   4 0 1
       3.   0 4 1
       4.   1 1 3
       5.   0 0 0

 MULTIPLE R SQUARED                                    __________

 MULTIPLE R                                            __________
```

Table IX depicts the various MOE's and the various analysis breakpoints. There are 43 possible combinations of MOE's and analysis points which constitute 43 experimental designs.

The use of ANOVA allows for multiple hypothesis testing in a compact way. By using the SPSS ANOVA routine at the various analysis points, significant main effects and interaction of factors can be noted. The use of ANOVA statistical technique greatly reduces the data analysis task.

From the 43 possible cases, the following 23 cases should receive primary consideration: 1. Red casualties at the DTO and blue casualty points; 2. Blue casualties at the DTO and red casualty points; 3. Exchange ratio at the time and DTO analysis points; 4. DTO at the time analysis points. Those ANOVA's to be performed are indicated by "X" in Table IX.

Once the ANOVA's have been computed a table similar to Table IX would be prepared to depict the significant results of the MOE's at the various analysis points. The significant factors and interactions would be analyzed further by looking at tabular and graphical results to see how these factors and interactions change at other analysis points. A detailed example is presented in the next chapter for a specified MOE at a particular analysis point.

There will be a trade off in any type of analysis. A particular main effect or interaction of factors might be significant at an analysis point (e.g., DTO at 900 meters) but, at a different analysis point (e.g., DTO at 300 meters) the main effects or interaction of factors may not be significant. The factors and interactions which contribute to blue's advantage should receive primary consideration for further analysis.

TABLE IX

MOE'S AT SPECIFIED ANALYSIS POINTS

	TIME				DTO			RED CASUALTIES				BLUE CASUALTIES	
	10	20	30	TTT	900 MTS	600 MTS	300 MTS	12%	24%	35%	47%	20%	40%
RED CASUALTIES					☒	☒	☒	-	-	-	-	☒	☒
BLUE CASUALTIES					☒	☒	☒	☒	☒	☒	☒	-	-
EXCHANGE RATIO	☒	☒	☒	☒	☒	☒	☒						
DTO	☒	☒	☒	☒	-	-	-						

B. HYPOTHESIS TESTING

In the determination of whether there is a synergistic effect provided by a scatterable minefield, hypothesis testing can be used to determine if it is significant. This concept is illustrated in the following example. (Other MOE's could also be used in the analysis.) Consider the hypothesis

$$H_0: \ u_T = u_1 + u_2$$

$$H_1: \ u_T > u_1 + u_2$$

where,

u_T = number of red casualties using the direct fire weapons and scatterable minefield,

u_1 = number of red casualties by direct fire weapons only,

u_2 = number of red casualties by scatterable mines only.

It is assumed that the number of red casualties for all three populations is normally distributed (e.g., red casualties $\overset{d}{\sim} (u_i, \sigma^2)$ where $i = T, 1, 2$). The homogenity of variance assumption must be tested using statistical techniques (e.g., Bartlett, Goldfelt-Quandt, Hartley). [8] If the statistical test used to test for homogenity of variances results in significant differences in the variances then the hypothesis testing procedure presented cannot be used.

For the field experiment, n_T equals 128 trials, n_1 equals 16 trials, and n_2 equals 32 trials; where, n_T equals the number of trials for direct fire and scatterable minefield, n_1 equals number of trials for direct fire weapons only, n_2 equals number of trials for scatterable minefield only.

Suppose that the three samples from their populations have a mean and standard deviation given by $\bar{X}_T, \bar{X}_1, \bar{X}_2$ and S_T, S_1, and S_2, respectively. Under the null hypothesis, H_0, the "t" statistic, which is a function of the data, is equal to:

$$\frac{\bar{X}_T - (\bar{X}_1 + \bar{X}_2)}{\hat{\sigma}\sqrt{\frac{1}{n_T} + \frac{1}{n_1} + \frac{1}{n_2}}}$$

where, is the pooled standard deviation and is given by:

$$\hat{\sigma} = \sqrt{\frac{n_T S_T^2 + n_1 S_1^2 + n_2 S_2^2}{n_T + n_1 + n_2}}$$

. [6]

The t statistic above is distributed with a t distribution with $n_T+n_1+n_2-3$ degrees of freedom. For hypothesis testing purposes in this experiment, the degrees of freedom for the t distribution is 173. The t value with 173 degrees of freedom and a level of significance of 5% is 1.645.[8] If the t statistic is less than 1.645 accept the H_0 that there is no synergistic effect; otherwise, reject H_0. The rejection of H_0 implies that H_1, the alternate hypothesis, is accepted.

Other hypothesis tests would be conducted in a similiar manner. Red Casualties could be replaced by blue casualties to see if their is a significant reduction of blue casualties by the addition of scatterable minefields to the direct fire weapons.

A simple graph can aid in presentation of the results to amplify the statistical conclusions. The graph is independent of the sum of squares; whereas, the statistical tests considers the sum of squares. The statistical testing procedure might conclude that there is no significant synergistic contribution by a scatterable minefield but the graph might depict a synergistic effect even though it would not be statistically significant at a specified level.

VI. APPLICATION OF ANALYSIS PLAN TO DYPOTHETICAL DATA

In Chapter V, the analysis plan was described. In this chapter the analysis plan is applied to hypothetical data. The hypothetical data has been generated to demonstrate application of the developed methodologies. Interpretation of the analysis of the data will also be discussed.

A. ANALYSIS OF VARIANCE

The distance to the objective (DTO) at the ten minute analysis point is the MOE and analysis point chosen for the example. Table X depicts the hypothetical data for DTO at the ten minute analysis point with each cell containing two observations (replications).

Tables XI and XII present the analysis of variance and multiple classification analysis, respectively, for DTO at the ten minute analysis point.

Analysis of Table XI shows that all main effects are significant at the .01 level. All two way interactions are significant at the 0.05 level except for the interactions of range and tactics, range and type of minefield, tactic and type of minefield, and tactic and density. The only three way interaction that is significant at a .05 level is the type of minefield - density-defensive force interaction. No four way or five way interactions are significant at the .05 level.

The MCA SPSS output for DTO at the ten minute analysis point is shown in Table XII. In reviewing the use of the MCA output, it can be viewed as a method of displaying the results of the analysis of variance especially when there are no significant interactions. If there is significant interaction, a mean value differential analysis on the interaction would be utilized.

Blue can control the location of minefield, defensive force, density of minefield, and type of minefield, whereas, red can control the tactic he will employ. Therefore, blue may have to hedge against the red threat tactic in determining which levels of the factors blue will employ.

In the output of Table XII, blue wants DTO to be at maximum positive deviation from the grand mean (e.g., greater than 389.76 meters). The level of each factor which contributes to blues advantage from Table XII are: defensive force mix two (e.g., largest positive deviation from grand mean, +199.06; level two is four twos, zero dragons, one M60A1); location of minefield level two (e.g., 500-1000 meters); density level two (e.g., .005 mines/square meter); type of minefield level two (e.g., belted). The red elements would use threat tactic two, plow, because that level reduces the DTO from the grand mean by 45.22.

TABLE X

DATA FOR DISTANCE TO OBJECTIVE (DTO) AT 10 MINUTE ANALYSIS POINT

MINEFIELD LOCATION	THREAT TACTIC	CONTINUOUS MINEFIELD										BELTED MINEFIELD									
		.001 MINES/SQ.MT					.005 MINES/SQ.MT					.001 MINES/SQ.MT					.005 MINES/SQ.MT				
		DEFENSIVE FORCE MIX																			
		D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
100 - 500 METERS	T_1	310 305	450 425	210 220	375 360	150 125	406 500	560 530	400 110	375 360	130 125	450 420	510 460	310 320	410 405	160 140	502 500	705 703	200 210	701 680	190 210
	T_2	180 160	360 370	190 110	340 330	100 110	199 230	290 460	180 100	390 450	140 110	375 400	400 220	190 193	370 630	130 125	420 375	690 670	100 100	670 660	230 110
500 - 1000 METERS	T_1	725 460	735 720	460 420	510 560	190 220	680 745	701 703	190 200	110 850	120 110	790 650	790 760	480 503	590 465	170 190	760 630	870 890	125 130	780 705	105 260
	T_2	350 360	610 620	360 470	420 200	100 100	425 180	710 690	300 110	310 690	100 100	575 480	400 280	400 210	501 600	110 125	525 380	790 799	510 210	625 670	210 100

NOTE 1:
T_1 = Bullying Tactic
T_2 = Plow Tactic

NOTE 2:
D_i = X, Y, Z
X = # of Tows
Y = # of Dragons
Z = # of M60A1 Tanks

D_1 = 2,2,1
D_2 = 4,0,1
D_3 = 0,4,1
D_4 = 1,1,3
D_5 = 0,0,0

NOTE 3: 2 Trials per cell

TABLE XI

SPSS ANALYSIS OF VARIANCE OUTPUT
FOR DTO AT 10 MINUTE ANALYSIS POINT

DEPENDENT VARIABLE - DISTANCE TO OBJECTIVE
INDEPENDENT VARIABLE - RANGE, TACTIC, TYPE OF MINEFIELD, DENSITY, DEFENSIVE FORCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	5564805.00	8	695600.625	76.399	0.001
RGE	554955.750	1	554955.750	60.952	0.001
TAC	327157.625	1	327157.625	35.932	0.001
TMFD	279140.500	1	279140.500	30.659	0.001
DENS	73831.000	1	73831.000	8.109	0.006
DEF	4329720.00	4	1082430.00	118.885	0.001
2-WAY INTERACTIONS	1109089.00	22	50413.133	5.537	0.001
RGE TAC	18597.652	1	18597.652	2.043	0.153
RGE TMFD	11475.152	1	11475.152	1.260	0.264
RGE DENS	33321.754	1	33321.754	3.660	0.056
RGE DEF	234973.000	4	58743.250	6.452	0.001
TAC TMFD	1139.556	1	1139.556	0.125	0.999
TAC DENS	13487.254	1	13487.254	1.481	0.225
TAC DEF	201736.625	4	50434.156	5.539	0.001
TMFD DENS	50374.504	1	50374.504	5.533	0.020
TMFD DEF	156806.937	4	39201.734	4.306	0.004
DENS DEF	387176.500	4	96794.125	10.631	0.001
3-WAY INTERACTIONS	369488.000	28	13196.000	1.449	0.102
RGE TAC TMFD	2037.756	1	2037.756	0.224	0.999
RGE TAC DENS	26291.254	1	26291.254	2.888	0.089
RGE TAC DEF	76555.375	4	19138.844	2.102	0.087
RGE TMFD DENS	1911.306	1	1911.306	0.210	0.999
RGE TMFD DEF	12798.121	4	3199.530	0.351	0.999
RGE DENS DEF	22479.977	4	5619.992	0.617	0.999
TAC TMFD DENS	3715.256	1	3715.256	0.408	0.999
TAC TMFD DEF	36717.965	4	9179.488	1.008	0.409
TAC DENS DEF	70497.437	4	17624.359	1.936	0.112
TMFD DENS DEF	116482.937	4	29120.734	3.198	0.017
4-WAY INTERACTIONS	172522.000	17	10148.352	1.115	0.355
RGE TAC TMFD DENS	507.656	1	507.656	0.056	0.999
RGE TAC TMFD DEF	26626.656	4	6656.641	0.731	0.999
RGE TAC DENS DEF	30703.234	4	7675.809	0.843	0.999
RGE TMFD DENS DEF	20432.723	4	5108.180	0.561	0.999
TAC TMFD DENS DEF	94251.625	4	23562.906	2.588	0.042

```
5-WAY INTERACTIONS            15364.000      4      3841.000    0.422  0.999
   RGE      TAC      TMFD     15364.516      4      3841.129    0.422  0.999
            DENS     DEF

EXPLAINED                    7231268.00     79     91535.000   10.053  0.001

RESIDUAL                      728386.000    80      9104.824

TOTAL                        7959654.00    159     50060.715
```

TABLE XII

SPSS MULTIPLE CLASSIFICATION ANALYSIS OUTPUT FOR DTO AT 10 MINUTE ANALYSIS POINT

```
DEPENDENT VARIABLE     - DISTANCE TO OBJECTIVE
INDEPENDENT VARIABLES  - RANGE, TACTIC, TYPE OF MINEFIELD,
                         DENSITY, DEFENSIVE FORCE

GRAND MEAN =    389.76                                   ADJUSTED FOR
                                          UNADJUSTED      INDEPENDENTS
VARIABLE + CATEGORY               N       DEV'N  ETA      DEV'N   BETA

RGE
   1 000-500M                    80      -58.89          -58.90
   2 500-1000M                   80       58.89           58.89
                                                0.26                0.26

TAC
   1 BULLING                     80       45.22           45.22
   2 PLOW                        80      -45.22          -45.22
                                                0.20                0.20

TMFD
    1 CONTINOUS                  80      -41.77          -41.77
    2 BELTED                     80       41.77           41.77
                                                0.19                0.19

DENS
    1 .001                       80      -21.48          -21.48
    2 .005                       80       21.48           21.48
                                                0.10                0.10

DEF
    1 2 2 1                      32       65.78           65.77
    2 4 0 1                      32      199.96          199.96
    3 0 4 1                      32     -132.72         -132.73
    4 1 1 3                      32      113.12          113.12
    5 0 0 0                             -246.13         -246.13
                                                0.74                0.74

MULTIPLE R SQUARED                                                 0.699
MULTIPLE R                                                         0.836
```

Since there is significant interactions, the MCA results must be further divided. The mean value differential analysis is used to determine which levels of the interactions contribute significantly to variations in DTO. An example of a mean value differential analysis between type of minefield and density factors is shown in Table XIII.

TABLE XIII

MEAN VALUE DIFFERENTIAL ANALYSIS
FOR TYPE OF MINEFIELD AND DENSITY INTERACTION

GRAND MEAN 389.76

MOE-DTO AT 10 MINUTE ANALYSIS POINT

Main Effect Factor

A. Type of Minefield

Level		Differential From GRAND Mean
1	Continuous	-41.77
2	Belted	41.77

B. Density

Level		
1	.001 mines per square meter	-21.48
2	.005 mines per square meter	21.48

2nd Order Interaction

Level (Type of Minefield)	Level (Density)	Differential from GRAND Mean
1	1	-63.25
1	2	-20.29
2	1	+20.29
2	2	+63.25

The numbers depicted in Table XII are for illustrative purposes only.

The grand mean was calculated to be 389.76. The differential, -41.77, represents the grand mean minus the factor level mean (e.g., 389.76 — 431.53). The differential for type of minefield level one with both levels of density are negative values, indicating that the continuous minefield reduces the DTO for either density. The employment of belted minefield, level two, gives values of +20.29 and +63.25 differential when using level one or level two of the density factor respectively. The largest positive DTO occurs when a belted minefield (level two) is employed with a density of .005 mines per square meter (level two). The threat vehicles would appear to be delayed at the belted minefield in either density due to the illusion that the minefield has been cleared when in effect only one belt has been cleared. The higher density of .005 provides a somewhat larger value of DTO, but may or may not be cost effective.

The MCA table indicates that the defensive force factor explained the largest proportion of variation in DTO (e.g., $.74^2$ X 100 = 54% of variation in DTO). The density factor explained the smallest amount of variation in DTO (e.g., $.1^2$ X 100 = 1% of variation in DTO). The multiple R squared value of .699 indicates that 69% of variation in DTO is accounted for by the five factors.

Based on the analysis of the MOE's at the various analysis points the level of each factor should be chosen which results in the greatest contribution to blue's advantage.

B. HYPOTHESIS TESTING

The application of the hypothesis testing procedure is illustrated in the following example:

Consider the hypothesis

$H_0 : u_T = u_1 + u_2$

$H_1 : u_1 > u_1 + u_2$

where,

u_T = number of red casualties using direct fire weapons and scatterable minefield,

u_1 = number of red casualties using direct fire weapons only.

u_2 = number of red casualties by scatterable mines only.

The assumption is that the number of red casualties (X) are normally distributed with the same variance (e.g., $N(U_i, \sigma^2)$ i = T,1,2.).

As an example, hypothetical data was collected for red casualties at a twenty minute analysis point. The data collected is shown in Table XIV. In the table, n_i is the number of trials, $\overline{X}_i$ is the average number of red casualties, and S_i is the sample standard deviations; where, i = T, for direct fire weapons and scatterable minefield, i = 1 for direct fire weapons only, and i = 2 for scatterable minefield only.

TABLE XIV

HYPOTHETICAL DATA FOR DETERMINING SYNERGISTIC EFFECT

Number of Trials	Average Number of Red Casualties	Sample Standard Deviation
$n_T = 128$	$\overline{X}_T = 11$	$S_T = 2$
$n_1 = 16$	$\overline{X}_1 = 6$	$S_1 = 1$
$n_2 = 32$	$\overline{X}_2 = 2$	$S_2 = 2$

The pooled sample standard deviation is computer as follows:

$$\hat{\sigma} = \sqrt{\frac{n_T S_T{}^2 + n_1 S_1{}^2 + n_2 S_2{}^2}{n_T + n_1 + n_2 - 3}}$$

$$\hat{\sigma} = \sqrt{\frac{128.4 + 16.1 + 32.4}{128 + 16 + 32}}$$

$$\hat{\sigma} = 1.93$$

The t statistic, t (data), is computed as follows:

$$t\ (\text{data}) = \frac{\overline{X}_T - (\overline{X}_1 + \overline{X}_2)}{\hat{\sigma}\sqrt{\frac{1}{n_T + n_1 + n_2}}}$$

$$= \frac{11 - (6+2)}{1.93\sqrt{\frac{1}{128+16+32}}}$$

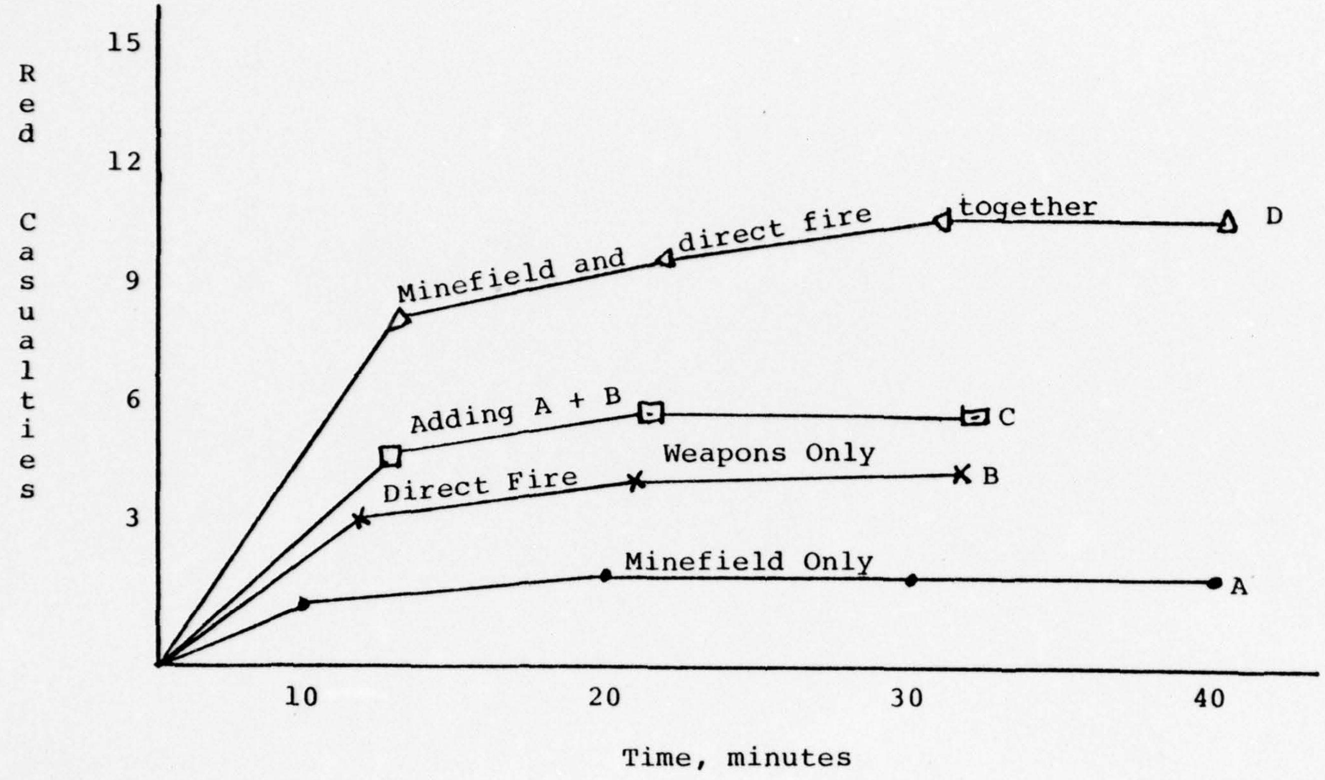
$$t \text{ (data)} = 19.89$$

The tabled t value for level of significance .05 and five degrees of freedom is 1.645. Since the t statistic 19.89 is greater than the tabled t value, 1.645, the null hypothesis, H_0, is rejected and H_1 is accepted. This implies that there is a synergistic effect in employing scatterable mines with direct fire weapon systems.

A graphical representation of red casualties versus time is illustrated in Figure I. At the ten minute analysis point, the number of red casualties is one and three for minefield only (curve A), and direct fire weapon systems only (curve B), respectively. At the ten minute point, there are eight casualties when using direct fire weapon and scatterable mine. Therefore, the use of a scatterable minefield in combination with direct fire weapons increase the number of red casualties by four as compared to adding the red casualties attributable to direct fire weapons and minefield independently. The synergistic effect is clearly depicted in Figure I at all the time analysis points (e.g., 10, 20, 30 minutes).

FIGURE I

RED CASUALTIES VS. TIME



VII. CDEC'S EXPERIMENTAL DESIGN(TEMAWS) VERSUS THESIS EXPERIMENTAL DESIGN

In this chapter, the Combat Development Experimentation Commands (CDEC) experimental design for Tactical Effectiveness of Mines in the Antiarmor Weapons System (TEMAWS) is presented. A comparison is made between TEMAWS and the thesis design.

A. CDEC EXPERIMENTAL DESIGN FOR TEMAWS

Table XIV shows the CDEC design matrix for TEMAWS. The experimental design is a sequential design consisting of three independent variables. The first factor is "type of minefield" which has two levels, continuous and belted. The second factor is minefield density with three levels, .001, .005, and .000 mines per square meter. The third factor is threat tactic, which has four levels (e.g., bulling, mine roller attached to simulated T-62 tank, plow attached to simulated T-62 tank, and the line charge).

Part one will consist of sixteen days of exploratory trials.

Part two will consist of 60 trials to be conducted using one threat tactic, bulling, against the three levels of minefield density. The analysis of the results of these trials will be used to establish the minimum credible density, defined as that scatterable minefield density which results in 40% to 50% attrition of the total threat force when employing the bulling tactic. [5]

Part three will consist of 60 trials to be conducted using four threat tactics against a minimum credible density of scatterable mines, which was determined in part two of the experiment.

Part four will consist of 20 trials to be conducted using the minimum credible density determined from part two, and one of the threat tactics evaluated in part three against a scatterable minefield configuration of three belts.[5] The design matrix shown in Table XIV will consist of 140 trials. Twenty trials will be conducted in each of the marked cells.

The defensive force will consist of two TOW's, two Dragon's, and one M60A1. The "location of minefield" factor is not included in this experiment by CDEC. The defensive force mix to be used in the experiment was determined by analysis of results of a combat simulation computer model developed at CDEC. The scenario, experimentation site, equipment, instrumentation for TEMAWS is the same as discussed in Chapter III and Chapter IV.

TABLE XIV

CDEC'S TEMAWS DESIGN MATRIX

SCATTERABLE MINEFIELD	TACTIC / DENSITY	CONTINUOUS			BELTED		
		T_1	T_2	T_3	T_1	T_2	T_3
	D_1	PART TWO					
	D_2						
	D_3						
	D_4	PART THREE				PART FOUR	

B. COMPARISON OF TEMAWS EXPERIMENTAL DESIGN WITH THESIS DESIGN

Throughout the remainder of this section CDEC's experimental design and the thesis experimental design will be referred to as TEMAWS design and thesis design, respectively.

In part two of TEMAWS design the bulling threat tactic is used against a continuous minefield at the three density levels. This selection assumes that the minimum credible density will result from the continuous minefield, whereas the belted minefield might actually establish the minimum credible density. The TEMAWS design does not consider the belted minefield over various levels of the density factor.

There is a ten per cent variation in the definition of minimum credible density. This ten per cent variability translates into ± 2 red casualties. The minimum credible density should be specified at some particular percentage value, such as 40%.

The thesis design does not divide the experiment into parts. The continuous and belted minefields are used with the three levels of density against the bulling and plow tactic. The minimum credible density can then be established after analysis of the results of the above trials.

The TEMAWS design does not have the location of minefield or defensive force factors. The defensive force mix (e.g., two TWO's, two Dragon's, and one M60A1) was determined by analysis of results of a CDEC computer simulation model.

The thesis design has two levels of minefield location and five levels of the defensive force. The minefield location will be within the maximum effective range of all defensive weapons systems. There might be an advantage from blue's point of view to have the minefield located at a close range. The thesis design considers five defensive force mixes, allowing for determination of the preferred defensive force from blue's point of view.

The TEMAWS design uses four levels of the threat tactic factor. The thesis design uses two levels, bulling and the plow attached to a simulated T-62 tank. It has been determined that the plow and roller have similiar performance capabilities (e.g., clearing area, reliability, probability of detonating mines). Therefore, the plow was included in the thesis design and the roller excluded. The line charge was not included in the thesis design because of the difficulty in communicating the line charge assesment from the computer to player personnel. Furthermore, the line charge effect on scatterable minefields is unknown at this time.

The TEMAWS design uses the results from one part of the experiment as input for the next part. If problems develop in a certain part which delays analysis, the succeeding part will also be delayed. The thesis design is not divided into parts and the analysis of results from previous trials is not needed to conduct other trials.

VIII. SUMMARY AND RECOMMENDATIONS

A field experiment was designed to be conducted at CDEC to measure the effectiveness of scatterable mines in the armor combat environment. An analysis plan to be used for the proposed field experiment data was presented.

The four measures of effectiveness selected to evaluate scatterable mines were exchange ratio, blue casualties, red casualties, and distance to the objective. The four measures of effectives would be calculated at various analysis points of four factors (e.g., time, red casualty, blue casualty, distance to the objective).

The experimental design considered two models. A "normal" model was designed without taking into consideration CDEC's constraints on instrumentation, equipment, and personnel. A "modified" model was then designed by reducing the factor levels of the "normal" model. The experimental design, analysis methodology, and a hypothetical example were presented to indicate implementation of the thesis model. Finally, a comparison of the thesis model was made with CDEC's TEMAWS model design. The thesis design is a full factorial with two replications per cell, whereas the TEMAWS design is sequential with twenty replications per cell. The thesis design is indicative of an exploratory experiment, whereas the TEMAWS design requires additional assumptions and sequential decisions to be made.

Upon completion of TEMAWS field experiment by CDEC and analysis of the field experiment data by the U. S. Army Engineer School, there will be two major studies on scatterable mines, Family of Scatterable Mines and TEMAWS. The following recommendations are made for future consideration in minefield studies:

1. The minefield depth should be varied.
2. The belted minefield should have belts with different densities.
3. The belted minefield should have variable gap depth where no mines are present.
4. The use of decoy mines in combination with active mines.
5. The determination of the effectiveness of the line charge against scatterable mines.
6. Consideration should be given to the adequacy of U. S. anti-mine training of ground forces.
7. Conventional mines in combination with scatterable mines might be more effective than using either one independently.
8. The scatterable mine may require more research and development on providing more protection from visual detection.
9. The effective of other weapons systems (e.g., artillery, mortars) against scatterable mines should be considered.
10. Consideration should be given to moving the minefield further than 1000 meters from the defensive position. Even

though the minefield would be out of range of some weapons the overall benefit might be better from the defenses point of view.

11. Comparison of the belted versus continuous minefield should be made fixing both with the same number of mines. The depth of the belted minefield would be larger than the continuous minefield to maintain the same density.

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