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Develop and Demonstrate a Methodology Using Janus(A) to Analyze Advanced Technologies

by

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Develop and Demonstrate A Methodology Using
Janus(A) To Analyze Advanced Technologies

by

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requirements for the degree of

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ABSTRACT

This thesis presents a study of a methodology for analyzing advanced technologies using the Janus (A) High Resolution Combat Model. The goal of this research was to verify that the methodology using Janus(A) gave expected or realistic results. The methodology used a case where the results were known: the addition of a long range direct fire weapon into a force on force battle. Both weapon characteristics and force mixes were used as input parameters/variables. A Central Composite Design experiment was conducted in Janus(A) to examine the relationship between the Long Range Tank (LRT) and the other tank killing systems in the force. The results of the research indicate that weapon system range is critically important in the Janus(A) model as is competent tactical positioning of the forces. The LRT significantly increased the destructive capability of the force as long as it was positioned in a tactically sound area. But, when overwhelmed by enemy forces, the LRT still contributed to the number of enemy kills, but the contribution to the survivability of friendly forces was not as evident. Response Surface Methodology was used to build a mathematical model of the relationship between the response and input variables of the experiment.

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The reader is further cautioned that certain vehicle system input parameters used and portions of the computer program developed in this research are not valid for all scenarios of interest. While every effort has been made, within the time available, to ensure that the computer programs were free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user(s).

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I. INTRODUCTION

The Army of the 21st century will be a highly technical, flexible, and lighter force than has been seen in the past. While the size of the Army may shrink, this reduction will not necessarily result in a loss in the destructive capability of each unit, only the size of that unit and the number of units on the battlefield will diminish. To meet these changes, the Army must develop weapons that are more powerful, and require fewer soldiers (reduced crew size) with the goal of producing a force of adequate capability.

Reduced force size comes with demands for a reduced military budget. The control of costs, always important, can be expected to dominate all aspects of Army operations. Significantly, cost control for the development of new weapons will be critical as the Army moves to modernize its forces. One way to control costs is to provide an efficient method to test new weapon concepts before they are actually built. Those concepts which prove useful are likely candidates for further development.

A framework for analyzing new weapon concepts which incorporates advanced technologies was recently developed at the Operations Research Center (ORCEN) of the Department of Systems Engineering, United States Military Academy at West Point (see APPENDIX A). The ORCEN is used by the Army and cadets for the analysis of system design, operations research, and combat modelling. This framework is a logical ordering of inputs, processes, and outputs to consider when conducting an operational analysis of a technologically advanced weapon system using a computer simulation model.

The goal of the research presented in this thesis is to demonstrate an analytical method for using a computer simulation that fits within the proposed framework to perform conceptual analysis of an hypothesized advanced future weapon system. The computer simulation selected for this study was Janus(A). This simulation is currently being used by the Army and Marine Corps as a tool for training and the analysis of weapons and tactics. It is used at the ORCEN to teach cadets modelling and analysis.

There are several reasons for using Janus(A) as an analytical tool to explore the operational implications of advanced technological weapon systems. First, it is relatively easy for warfighters to use, not just programmers. Second, it is supported by Army analytical agencies (Training and Analysis Command, Institute for Defense Analysis, etc.). Third, it uses straightforward attrition based measures of effectiveness (MOE) and measures of performance (MOP). Also, Janus(A) uses well understood battle calculus (stochastic processes) in the model. Using Janus(A) will allow analysts to evaluate technologies early on in the research and development phase to assess the viability of future technologies. Furthermore, Janus(A) is the primary high resolution analytical model used at Training and Analysis Command-Monterey (TRAC-Mtry) and at the ORCEN.

This thesis attempts to model an advanced technological system placed in an actual battle and analyze its impact on the force's destructive capability as a whole. The major objectives to accomplish this goal include:

1. Research, identify, and select those model input parameters for an advanced weapon system that could justifiably model the implications of technology in Janus(A).

2. Define a straight forward methodology (design an experiment) to be used to measure the effects of the technology on the force as a whole.

3. Build a mathematical model that approximates the relationship between a desired response (i.e., number of enemy kills) and the system characteristic variables (i.e., weapon range).

II. ANALYSIS METHODOLOGY

The methodology chosen to demonstrate this study was to take a case with expected results, replicate that case in Janus(A), and compare the results. The steps to accomplish this are to: 1) posit a case with known results, 2) select an appropriate scenario to analyze the advanced technology, 3) select appropriate input parameters, 4) select appropriate measures of effectiveness, 5) select an effective and efficient experimental design, and, 5) conduct thorough data analysis to compare the results against the expected results.

To check the feasibility of using Janus(A), a case is posited where the answers are already known. This will enable the analyst to determine if, in fact, Janus(A) provides expected reasonable results. The case for this study is the addition of a long range direct fire weapon system in a desert scenario. This is an important case because the future of advance technologies is leaning toward smaller units capable of destroying the enemy quicker, at greater ranges, and with less ammunition.

A. EXPECTED RESULTS.

The expected results for a long range direct fire weapon system in a long range scenario seem trivial. It is expected that there will be more long range kills. This will allow the force with the long range weapon to engage and kill the enemy first, keeping the enemy further away for a longer period of time and thus bring other weapons to bear on the enemy. While the long range weapon may not increase the Blue (friendly) Force's survivability against overwhelming odds, it is expected that it will create more Red (enemy) casualties. It is expected that the long range weapon will be superior to the current main battle tank (MBT) and tube-launched optically tracked wire guided (TOW) anti-tank weapon system.

B. SCENARIO.

The actual scenario chosen for the analysis is a National Training Center (NTC) battle that took place in 1988. The reason for using this battle is that it took place on ground where long range visibility is possible. Also, this was an actual training battle. The scenario pits a battalion level tank heavy task force in the defense (Blue Force) against an attacking Motorized Rifle Regiment (Red Force). The scenario was replicated into Janus(A) by CPT David Dryer [Ref. 13]. A brief explanation of the scenario can be found in APPENDIX B.

The main reason for using this scenario is the fact that there are no biases from the author in the development of the scenario for the study. Developing a scenario from scratch could lend itself to tactical and doctrinal errors. This scenario actually occurred. Commanders and soldiers influenced the battlefield with actual decisions. The scenario begins where the units are separated, converge, and engage in two separate battles. For this study, a simulation of this scenario was allowed to run until the middle of the first battle. This allowed the collection of data for the long range portion of the battle to determine the contribution of the long range weapon to the force.

C. WEAPON SYSTEM CHOSEN.

The advanced technological weapon posited in this scenario is a direct fire, high velocity, kinetic energy tank gun system with a maximum effective range of 6000 meters. This weapon system would be mounted on an armored chassis and have the capability on firing an Armor Piercing (AP) round at a velocity and range greater than that of an existing main battle tank.

The operational requirement for this weapon system comes from the hypothesis that it is feasible to develop a weapon system capable of engaging enemy armored systems at a greater range than current tanks, and achieve a greater probability of kill given a hit from the increased velocity of the round.

The Defense Science Board proposed such an advanced technology in 1984. The envisioned system fired a high velocity, kinetic energy projectile from an armored platform to engage enemy targets at ranges up to 6000 meters with roughly the same probability of hit/kill and armored piercing capabilities of a main battle tank (MBT) at 3000 meters [Ref.11]. Sensors and engagement systems are assumed to be more advanced than the current main battle tank systems to allow the engagements at such extended ranges. The guidance system for this weapon may either be heat seeking, magnetic, or laser guided.

For this study, the system will be referred to as a Long Range Tank (LRT).

D. INPUTS.

There are two types of parameters that were chosen for this study: weapon system parameters and force mix parameters. Weapon system parameters are those weapon system characteristics that are varied throughout the experiment to determine what effect they might have on the response. Force mix parameters are force ratios of one weapon system to another. The force ratios used for this study consisted of the number of new systems replacing the old system divided by the total number of old systems initially in the force (before replacement). The force ratios are varied, thus replacing different quantities of a weapon with the system under study. This allows the analyst to measure the effect of the weapon system in relation to the force mix with another weapon system.

The input parameters (factors) chosen for this study are: 1) ratio of #LRT/(max # of TOWs), 2) ratio of #LRT/(max # of MTBs), 3) Main battle tank opening range, 4) TOW opening range, and 5) LRT maximum effective range. These were chosen because they represented the force mix issue (#1 and #2), the opening range issue (#3 and #4, to be discussed later), and the advanced technological weapon system characteristic, maximum effective range (#5).

A question arose as to how to put the LRT into the force structure. Replacing all of the TOWs and MTBs with the LRT eliminates the interactive contribution of the systems together in the force. Therefore, ratios of the LRTs to TOWs and MBTs were decided upon as inputs in the experiment. Also, random replacement of each TOW and MBT by the LRT removed any bias due to positioning in the scenario. Each TOW and MBT system had an equal probability of being replaced, thus positioning and movements for the LRT were predetermined based on the position and movement of the system it replace. These factors relate the number of TOWs and MBTs that were randomly replaced by the LRTs. For each run, a specified number of TOWs and MBTs were replaced randomly. This means that keeping everything else constant (movement routes, firing posture, tactical position, etc.), a certain number of TOWs and MBTs were switched and made LRTs. No run had the same replacement as any other run. This was done with a FORTRAN random number generation program that used the program RANNUM (uniform distribution) to get a random number, converted that random number into an integer, checked to insure that the integer had not been previously selected, and repeated the process until the required number of integer numbers was selected. The program can be seen in APPENDIX E.

Each weapon system was given a line number in the Janus(A) data base. The forces were numbered sequentially from one to the number of elements in the force size. For this random replacement, each of the TOW systems were numbered from 1 to 23 (the initial number of TOWs in the scenario). Each of the MBTs were numbered from 1 to 39 (the initial number of MBTs in the scenario). The random number generator then selected a desired number of integers from a specified range (1-23, 1-39). This random replacement eliminated bias due to positioning. Using this ratio as a parameter provided a measure of effectiveness of the LRT versus the TOW and MBT. It is expected that range matters for this scenario. The longer range for a weapon is more desirable and it will be advantageous to replace the shorter range weapons with the LRT. It is also expected that the longer range weapons will dominate the weaker weapons and therefore, replacement of the weaker weapons (less survivable) will occur first.

The maximum opening range of a weapon system is a parameter that was thought to be sensitive in Janus(A) from previous studies [Ref. 2]. Restricting the opening range of a weapon prevents firing at maximum range (minimum effectiveness). This restriction would improve the P_h and P_k values for a single shot but would allow the enemy to engage with fire within his maximum range without exposure to return fire. If a weapon opens fire at its maximum range, two things occur: his position is potentially detectable by the blast of the weapon, and the small P_h and P_k values produce a minimal effect on the enemy. Introducing the opening ranges of the TOW and MBT as inputs will hopefully

The LRT maximum range incorporates both the opening range as described above *and* the maximum effectiveness of the weapon system, which includes the effect of the hyper-velocity kinetic energy round. The values in the P_h and P_k tables were not changed from those for the MBT. The range bands associated with the values were altered to represent the maximum effective ranges. Improving the range of the weapon system, while keeping the P_k and P_k values the same, gives better results at the shorter ranges. Figure 1 graphically portrays the single shot probability of kill (SSPk) for the MBT (solid line) as a function of range. The dashed and dotted lines represent the SSPk curves for the LRT at maximum effective ranges of 4500 meters and 6000 meters (the center point and axial point for the experiment discussed later). Within Janus(A), the maximum opening range was changed to coincide with the P_h and P_k maximum range band.

E. MEASURES OF EFFECTIVENESS.

A measure of effectiveness (MOE) is a measure of the contribution of a factor to the overall effectiveness of the force. It is the response variable (dependent variable) that is a measure to quantify the results of the model output. The MOEs selected for this experiment are:

1. Number of red kills
2. Number of blue kills

MOE #1 gives a measure of destructive capability (lethality) and MOE #2 gives

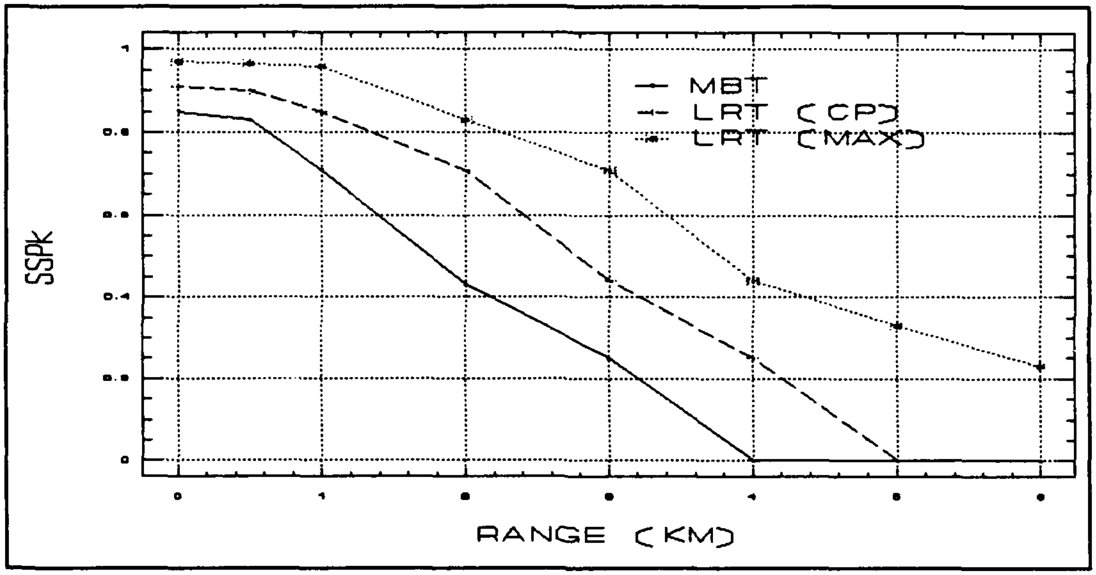

Figure 1. SSPk Curve for MBT and LRT.

a measure of survivability. Both can easily be recorded and analyzed. These allow an analysis to determine which of the previously discussed factors had a significant effect on both enemy casualties and friendly survivability.

The number of RED Kills include not only those kills by the TOW, MBT, and LRT, but also artillery kills, machine gun kills, etc. While there are contributors to the number of red kills other than the TOW, MBT, or LRT, this study is interested in displaying the effect of the parameters on the lethality of the force as a whole. MOE #1 obeys the two fundamentals of MOE selection: keep it simple and bigger is better. MOE #2 is simple and has a direct relationship to the one theme of this study: the survivability effects of the force by replacing the TOW or MBT.

III. EXPERIMENTAL DESIGN

Experiments may either confirm knowledge about a system or explore the effect of new conditions of the system [Ref. 1: p.1]. This experiment is expected to confirm the operational benefit of a proposed advanced technological weapon system. Additionally, this experiment will demonstrate how to apply force ratios to the model as parameters. Models such as Janus(A) ultimately are a transformation of a set of inputs (the scenarios and circumstances of combat) to a set of outputs. Using such a model equates to selecting the inputs and then "running" the model to examine "what happens". Because this analysis concerns the performance of a weapon which exists only in concept, the exact value of all inputs is not known. Uncertainty in model inputs suggest parametric analysis which is often considered a problem of experimental design. In the context of this research, the issue is to select an efficient design which will identify the sensitivity of scenario inputs which express how a future technology weapon performs and how it is used. These are questions of performance capabilities and force structure. Performance capabilities relate to physical characteristics such as rate of fire, range or weapons, and ability of sensors to detect targets. Force structure issues concern the number and type of weapons which comprise a force along with information about how these weapons are used.

As previously described, Janus(A) incorporates inputs which describe both weapon performance and force structure composition. The issue for analysts is, therefore, to select an experimental design which will demonstrate how well a force performs given various combinations of these inputs. In this case, the objective is to determine how changes in various performance characteristics of a future weapon will influence the overall combat capability of the friendly force.

A. EXPERIMENTAL DESIGNS CONSIDERED.

A level is a specific value set for the input or parameter being analyzed. The results attained from several runs of a model at various levels of particular factors represent the output of the model to changes of the factor. Geometrically, this output characterizes a response surface as a function of input parameters. There is no reason to believe that responses are linear, therefore, at least three levels are chosen for this study. Several experimental designs are available which provide a methodology to perform this type of analysis. A few will be considered for this study: factorial, fractional factorial, and central composite designs. Factorial designs are important for the following reasons [Ref. 3: p.306]:

1. They require relatively few runs per factor; and although they are unable to explore fully a wide region in the factor space, they can indicate major trends and so determine a promising direction for further

experimentation.

2. They can be suitably augmented to form composite designs.
3. They form the basis for *fractional* factorial designs.
4. These designs and the corresponding fractional designs may be used as building blocks so that the degree of complexity of the finally constructed design can match the sophistication of the problem.
5. The interpretation of the observations produced by the designs can proceed largely by using common sense and elementary arithmetic.

For this experiment, due to time and resources, the interest is on the main effects of the inputs on the response with a manageable number of runs.

1. Full Factorial Design.

A full factorial design is one where all possible combinations of factors and levels are considered. For **n** levels and **k** factors, there are $\mathbf{n^k}$ possible combinations of experimental runs to consider. For this study, there are five factors or inputs. This would require $\mathbf{3^5 = 243}$ experimental runs to cover all combinations. However, time and resource constraints force the consideration of some type of reduced factorial design.

2. Fractional Factorial Design.

A fractional factorial design is one that considers certain high-order interactions to be negligible. Therefore, those runs which provide information about the negligible higher order interactions are eliminated. Thus a fraction of the full factorial design may be sufficient to capture the relevant information. Fractional designs are widely used in screening experiments, those interested in identifying those factors that have large effects [Ref. 1: p.325]. As the goal of this research is to identify such cases, this design warrants further consideration.

For this experiment, one half of the full factorial design is unmanageable in terms of effort and time (120 experimental runs). One fourth fractional designs may be more manageable but the loss of some low-order effects may be significant. Also, for fractional designs, the interactions that will be eliminated may be significant to this study. Therefore, another fractional factorial design alternative will be considered and chosen.

3. Central Composite Design (CCD).

An alternative to the 3^k factorial system is a class of composite designs called the central composite design (CCD). "This design is greatly used by workers applying second order response surface techniques [Ref. 4: p.126]." The CCD is the 3^k factorial or fractional factorial design augmented with a specific number of axial points. The center points "are experimental runs with all factor levels set half-way between their minimum and maximum settings [Ref. 5: pp.9-10]." Axial points are runs with a factor set at its minimum or maximum level and all other factors set at their center point level. Therefore, the CCD is a five level experimental design. The preceding discussion of the CCD is a very brief and general overview of a complex class of experimental designs. For additional information, the reader is encouraged to examine *Response Surface Methodology* [Ref. 4] and *Understanding Industrial Designed Experiments* [Ref. 5].

The Central Composite Design reduces the number of experimental runs that would be needed if a full or fractional factorial design were used. The number of experimental runs for this five factor experiment is 52: 32 factorial points, 10 axial points, and 10 replications at the center point [Ref. 4: p.153]. This is significantly less than the 243 runs required in a full factorial design. The CCD can also be used to fit a second order response surface. Since it is unclear what type of response surface to expect from this experiment, an estimated response surface must be approximated. The CCD approximates a second order response surface. It provides information about main and low-order effects. This design is rotatable, meaning:

> A design is said to be rotatable when the variance of the estimated response - that is, the variance of y, which of course depends on a point of interest x_1, x_2, ..., x_k - is a function only of the *distance* from the center of the design and *not* on the direction [Ref. 4: p.139].

This means that "points in the factor space which are the same distance from the center point (origin) are treated as being *equally important* [Ref. 4: p.165] "

The experimental design chosen for this study was the CCD. The CCD is perhaps the most popular class of designs used for estimating the coefficients in a second degree model [Ref. 6: p.32]. It is difficult to physically interpret what is meant by third, fourth, and, for this experiment, fifth order interactions. Assuming those higher order interactions to be negligible supported use of the CCD. This is reasonable because higher order interactions (third, fourth, and fifth order) are difficult to physically interpret and are confounded in the main and second order interaction effects. This is reasonable because models such as Janus(A) are intended to have orthogonal inputs. Also, the statistical techniques involved in response surface methodology are very similar to those associated with simple linear regression analysis. Recall, two of the objectives for this research were to design an experiment to measure the effects of a technology on a response and then to build a mathematical model to approximate the relationship between the response and the variable inputs. Use of the CCD and the response surface methodology satisfies these objectives. Response surface methodology will be discussed in more detail in Chapter V.

IV. CENTRAL COMPOSITE DESIGN EXPERIMENT

This section describes how the CCD design was implemented for this study. The CCD is a five level experimental design that assumes that higher order interactions are confounded by the main effects and second order interactions. The CCD is composed of three parts: the full factorial design at the radial points (equi-distant from the center of the design), the single runs at each axial point (the minimum and maximum points of each factor), and the center point (average value component of each factor) replications. Given the weapon, the scenario, the factors (parameters), and the MOEs, the levels for each factor must be determined. The first step is to build the design, or run matrix which defines the levels of input parameters used for each run of the simulation.

A. DESIGN CENTER POINT AND FACTOR RANGES.

The experimental center point (CP) for each factor is determined from the maximum and minimum values for that factor. The ranges of each factor are determined by the experimenter. For this design, the CP is defined as:

$$CP_{factor} = \frac{MIN_{factor} + MAX_{factor}}{2} \quad (1)$$

which is the midpoint of the range of values considered reasonable for each factor. The minimum and maximum values for the force ratios (X_1 and X_2) were obviously set at 0.0 and 1.0. These relate to the number of elements replaced for a given ratio. At 0.0, no TOWs or MBTs were replaced by LRTs, while at 1.0, all of the TOWs and MBTs were replaced by LRTs. The minimum values for the TOW and MBT opening ranges were set at 500 meters. This put the center point at a reasonable level. The maximum ranges were the AMSAA values in the data base (3000 meters for the MBT, 3750 meters for the TOW). The CP for the LRT range was determined using the current MBT maximum range (3000 meters) as its minimum opening range (hypothesizing that the LRT was no worse that the current tank) and the hypothesized maximum range of 6000 meters.

The CP for the force ratios (#LRT/#TOW, #LRT/#MBT) is 0.5. The CP for the TOW and MBT opening range was determined using equation (1). The CP values for each factor are as follows:

$$CP_{LRT/TOW} = 0.5$$

$$CP_{LRT/MBT} = 0.5$$

$$CP_{MBT\ RANGE} = 1750$$

$$CP_{TOW\ RANGE} = 2125$$

$$CP_{LRT\ MAX\ RANGE} = 4500$$

The center is defined as $(X_1, X_2, X_3, X_4, X_5) = (0.5, 0.5, 1750, 2125, 4500)$.

B. FACTORIAL COMPONENT OF CCD.

Delta (δ) is the amount a factor is varied around the CP which is the two factor portion of the design. This is necessary to calculate the factor's experimental levels. The following equation is used to calculate the appropriate δ value for each factor:

$$\delta_{factor} = \frac{MAX_{factor} - CP_{factor}}{\alpha} = \frac{MAX_{factor} - CP_{factor}}{2.378} \qquad (2)$$

Alpha (α) is defined as the distance from the design center point to an axial point [Ref. 5: p.62] and is calculated by the equation $(2^k)^{1/4}$, where k is the number of factors. For this experiment, $\alpha = (2^5)^{1/4} = 2.378$. The δ values for the factors in this study are as follows:

$$\delta_{LRT/TOW} = 0.21$$

$$\delta_{LRT/MBT} = 0.21$$

$$\delta_{MBT\ RANGE} = 526 \text{ meters}$$

$$\delta_{TOW\ RANGE} = 683 \text{ meters}$$

$$\delta_{LRT\ MAX\ RANGE} = 631 \text{ meters}$$

The preceding discussion provides the necessary information for determining the five levels for each factor listed in Table 1.

Determining the five levels for the LRT MAX RANGE was different from the other levels in that each P_h and P_k table is a function of range. Each table is divided into five range bands. The CCD levels only consider the maximum range. Each table was changed to reflect the appropriate range band given the maximum range (the minimum range is zero). JANUS(A) uses a piecewise continuous function composed of 4 line segments to describe the probabilities of hit and kill for a given weapon as a function of range. The CCD levels for the range bands are shown in APPENDIX D.

TABLE 1. CCD FACTOR LEVELS.

	MIN	CP-δ	CP	CP+δ	MAX
LRT/TOW	0.0	0.29	0.5	0.71	1.00
LRT/MBT	0.0	0.29	0.5	0.71	1.00
MBT RG	500	1224	1750	2276	3000
TOW RG	500	1442	2125	2808	3750
LRT MAX RG	3000	3869	4500	5131	6000

C. BUILDING THE EXPERIMENTAL RUNS.

The number of experimental runs required for this experimental design with five factors (k=5) is 52 [Ref. 4: p.153]. That is, there are $2^5=32$ full factorial runs, 10 axial point runs, and 10 replications at the center point. An axial point is an experimental run with a factor set at either its minimum or maximum level and all other factors set at their center point levels. The 10 center point runs will allow an estimate of the experimental error to be made. Thus, a check for model adequacy is possible [Ref. 5: pp.7-62]. The complete design matrix for this research is located in APPENDIX D.

The experimental runs were conducted by manipulating specific portions of the JANUS(A) data base. The different force ratios required that individual weapon systems be replaced by the LRT. This replacement was done randomly for each run (as mentioned previously). This random replacement removed the bias due to positioning of the system in the force.

A consequence of this random replacement was that certain key systems (MBTs, TOWs) were killed immediately due to poor tactical placement of the element. Some of the elements in the actual NTC scenario were positioned in noncombat or tactically unsound areas due to mechanical breakdowns or poor positioning by the force commander. In any event, certain systems were killed immediately and others shortly after the battle began at long exposed ranges. If those elements were picked by the random number generator to be replaced by the LRTs, then the contribution to the survivability of the Blue force would have to include the sound tactical employment of those weapons.

The actual manipulation of the data in Janus(A) can be accomplished by following the instructions in the *JANUS Documentation and Users Manual* [Ref. 7: p. 3-1 to 3-25].

V. DATA ANALYSIS METHODOLOGY AND RESULTS

The methodology used in this thesis consists of the design of the experiment and the data analysis. This chapter contains a description of the response surface methodology and the data analysis associated with the results of the experiment.

A. RESPONSE SURFACE METHODOLOGY.

Response surface methodology (RSM) consists of a set of techniques used in the empirical study of relationships between one or more responses and a group of input variables [Ref.6:p.1]. For this study, response surface methodology was applied to the results obtained from the CCD experiment. RSM was used because: 1) it assumes the residual errors to follow a normal distribution (thus permitting simple significance tests to be done), 2) it uses least squares regression techniques allowing a mathematical model to be built to approximate the relationship between the response and the variables, and 3) it approximates a convex surface in which the optimum operating conditions are met [Ref.4:p.63]. The result, or response is the measure of effectiveness (MOE) associated with each experimental run. Recall, the two MOEs selected for this experiment were the number of RED kills and the number of BLUE kills.

Response Surface Methodology (RSM) is a set of techniques designed to find the "best" value of the response [Ref.6:p.1]. There are several reasons for choosing RSM as a statistical technique [Ref.2:p.33]. First, RSM allows one to develop a mathematical model to approximate the relationship between a measurable response and the input variables over a selected region. Second, with RSM, it is possible to identify the factors which have the most effect and least effect on the response. Third, RSM is very similar to multiple regression analysis, specifically the method of least squares. RSM applies regression analysis "in an attempt to gain a better understanding of the characteristics of the response system under study [Ref.6:p.1]." Lastly, the CCD type of experiment and the related response surface methodology results in greater precision in estimating the regression coefficients with a minimal of experimental effort [Ref.4:p.126].

1. The Response.

The response is the measurable quantity whose value is assumed to be affected by changing the levels of the factors [Ref.6:p.2]. The factors for this study are the force ratios of LRTs to TOWs and MBTs, maximum opening ranges of MBTs and TOWs, and LRT maximum range. The true value of the response corresponding to any of the 52 experimental runs is denoted by η. The term "true response, η" means the hypothetical value of η that would be obtained in the absence of experimental error [Ref.6:p.2]. However, error is always present in experiments and the actual value observed for any given combination of factor levels is $Y=\eta+\epsilon$, where ϵ is the experimental error. Recall the MOEs chosen for this experiment are the number of red kills and the number of blue kills.

2. The Response Function.

The value of the response η depends on the levels $X_1,X_2,\ldots,X_k$ of k quantitative factors, $\xi_1,\xi_2,\ldots\xi_k$. Therefore, there exists a mathematical function, ϕ, of $X_1,X_2,\ldots,X_k$, the values of which, for any given combination of factor levels, provide the corresponding value of η. The response function is given by equation (3).

$$\eta = \phi(X_1,X_2,\ldots,X_k) \tag{3}$$

The response function, ϕ, is called the true response function and is assumed to be a continuous function of the X_i's [Ref.6:p.2].

3. The Response Model and Fitted Response Surface.

The second order response model of k factors takes the following general form:

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k}\sum_{m=1}^{k} \beta_{jm} X_j X_m + \sum_{j=1}^{k} \beta_{jj} X_j^2 \tag{4}$$

where the β_j's are the regression coefficients for the first-degree terms, the β_{jj}'s are coefficients for the pure quadratic terms, the β_{jm}'s are the coefficients for the cross product terms and the Xs represent the experimental levels of the k factors. The estimates and parameters are then obtained using the method of least squares. The predicted response function is given by the following equation:

$$\hat{Y} = b_0 + \sum_{j=1}^{k} b_j X_j + \sum_{j=1}^{k} \sum_{m=1}^{k} b_{jm} X_j X_m + \sum_{j=1}^{k} b_{jj} X_j^2 \tag{5}$$

where the b's are estimates of the β parameters. Equation (5) can be used to estimate values of η for given values of $X_1, X_2, \ldots, X_k$ [Ref.6:p.2].

The discussion above is only a general overview of a complex statistical technique. For further information concerning the response surface methodology, one should refer to *Response Surface Methodology* [Ref.4] and *How to Apply Response Surface Methodology* [Ref.6].

B. RESPONSE SURFACE ANALYSIS AND RESULTS.

1. Model Response.

The 52 experimental runs were executed and the total number of RED kills and BLUE kills were tabulated for each of the runs. The statistical package SAS (Statistical Analysis Software) was used to calculate the fit of the model and the significance of the variables. The experimental responses are tabulated in Tables 2 and 4.

2. The Fitted Response Surface Model.

The statistical package SAS was used to perform the multiple regression necessary to build the second order response surface model for both RED Kills response and BLUE Kills response. The SAS outputs are displayed in APPENDIX F. The assumption of quadratic response surface allows for the estimation of 21 model parameters, including the intercept [Ref.5:p.7-65].

TABLE 2. EXPERIMENTAL RESPONSE - RED KILLS

RUN	RED KILLs	RUN	RED KILLs	RUN	RED KILLS	RUN	RED KILLS
1	63	14	44	27	42	40	44
2	47	15	62	28	43	41	51
3	59	16	39	29	42	42	48
4	45	17	59	30	43	43	44
5	63	18	39	31	61	44	41
6	51	19	45	32	35	45	51
7	60	20	39	33	50	46	43
8	47	21	66	34	43	47	59
9	48	22	37	35	44	48	43
10	41	23	51	36	60	49	45
11	50	24	39	37	47	50	47
12	48	25	51	38	42	51	52
13	55	26	39	39	52	52	38

3. RED Kills Response Surface Model.

The regression analysis for the response RED Kills produced the following model:

$$\eta_R = 47.754 + 2.425X_1 + 2.075X_2 - 0.125X_3 + 0.475X_4 + 5.725X_5 + 0.906X_1X_2 - 0.094X_1X_3 - 0.594X_1X_4 - 0.156X_1X_5 + 0.031X_2X_3 + 1.782X_2X_4 + 1.344X_2X_5 + 0.281X_3X_4 - 1.531X_3X_5 + 0.344X_4X_5 - 0.881X_1^2 + 0.244X_2^2 + 1.244X_3^2 - 0.006X_4^2 - 0.256X_5^2 \quad \textbf{(6)}$$

where X_1=#LRTs/#TOWs, X_2=#LRTs/#MBTs, X_3=MBT Range, X_4=TOW Range, and X_5=LRT max Range. Table 3 summarizes the estimated coefficients, standard error of estimate, t-ratio, and p-value. The t-ratio and associated p-value are used to test the null hypothesis that the coefficients (the βs) are equal to zero against the alternate hypothesis that the coefficients are not equal to zero. That is:

$$H_o:\ \beta_i = 0\ ,\ i=1,2,...$$

$$H_a:\ \beta_i \neq 0\ ,\ i=1,2,...$$

If a coefficient is equal to zero at some significance level, this implies that the variable associated with that coefficient has no effect on the fitted model. This hypothesis test is a *two-tailed* t-test and the significance level (α) at which one would reject H_o is established at a level of $\alpha=0.05$. Since the test is *two-tailed*, the significance level becomes ($\alpha/2 = 0.025$). The p-value listed in Table 3 represents the smallest level of significance, α, for which one would reject H_o. The rejection region for this hypothesis test corresponds to any value of $|t| > t_{\alpha/2}$. The table value of $t_{0.025}$ with 31 degrees of freedom is approximately 2.04. Those factors marked "*" in Table 3 are significant at $\alpha = 0.05$.

TABLE 3. RED KILLS REGRESSION MODEL SUMMARY.

VARIABLE	COEFF. EST.	STD. DEV.	t-RATIO	p-VALUE
X_1	2.4250	0.9241	2.62	0.0134*
X_2	2.0750	0.9241	2.25	0.0320*
X_3	-0.1250	0.9241	-0.14	0.8933
X_4	0.4750	0.9241	0.51	0.6109
X_5	5.7250	0.9241	6.19	0.0001*
X_1^2	-0.8810	1.0164	-0.87	0.3927
X_2^2	0.2439	1.0164	0.24	0.8119
X_3^2	1.2449	1.0164	1.22	0.2302
X_4^2	-0.0060	1.0164	-0.01	0.9953
X_5^2	-0.2560	1.0164	-0.25	0.8028
X_1X_2	0.9062	1.0332	0.88	0.3872
X_1X_3	-0.0937	1.0332	-0.09	0.9283
X_1X_4	-0.5937	1.0332	-0.57	0.5697
X_1X_5	-0.1562	1.0332	-0.15	0.8808
X_2X_3	0.0312	1.0332	0.03	0.9761
X_2X_4	1.7812	1.0332	1.72	0.0947
X_2X_5	1.3437	1.0332	1.30	0.2030
X_3X_4	0.2812	1.0332	0.27	0.7873
X_3X_5	-1.5312	1.0332	-1.48	0.1484
X_4X_5	0.3437	1.0332	0.33	0.7416
CONSTANT	47.7540	1.8182	26.26	0.0001*

TABLE 4. EXPERIMENTAL RESPONSE - BLUE KILLS

RUN	BLUE KILLs	RUN	BLUE KILLs	RUN	BLUE KILLS	RUN	BLUE KILLS
1	55	14	60	27	60	40	64
2	65	15	57	28	67	41	56
3	54	16	60	29	58	42	61
4	60	17	56	30	58	43	62
5	56	18	62	31	62	44	63
6	60	19	63	32	73	45	60
7	54	20	60	33	60	46	58
8	60	21	69	34	63	47	57
9	61	22	67	35	64	48	64
10	65	23	59	36	54	49	62
11	54	24	62	37	57	50	59
12	58	25	56	38	60	51	59
13	58	26	63	39	59	52	64

4. BLUE Kills Response Surface Model.

The regression analysis for the response BLUE Kills produced the following model:

$$\eta_B = 59.887 - 1.500X_1 - 0.100X_2 - 0.700X_3 + 0.300X_4 - 1.950X_5 - 0.312X_1X_2 + 0.875X_1X_3 + 1.250X_1X_4 - 0.312X_1X_5 - 0.312X_2X_3 + 0.937X_2X_4 + 0.250X_2X_5 + 0.250X_3X_4 - 0.437X_3X_5 + 0.187X_4X_5 + 0.544X_1^2 - 0.331X_2^2 + 0.044X_3^2 + 0.044X_4^2 + 0.294X_5^2 \quad (7)$$

where X_1=#LRTs/#TOWs, X_2=#LRTs/#MBTs, X_3=MBT Range, X_4=TOW

Range, and X_5=LRT max Range. Table 5 summarizes the estimated coefficients, standard error of estimate, t-ratio, and p-value. The table value of $t_{0.025}$ with 31 degrees of freedom is the same as the RED Kills model and is approximately 2.04. Again, those factors marked "*" in Table 3 are significant at $\alpha = 0.05$.

TABLE 5. BLUE KILLS REGRESSION MODEL SUMMARY.

VARIABLE	COEFF. EST.	STD. DEV.	t-RATIO	p-VALUE
X_1	-1.5000	0.5626	-2.67	0.0121*
X_2	-0.1000	0.5626	-0.18	0.8601
X_3	-0.7000	0.5626	-1.24	0.2228
X_4	0.3000	0.5626	0.53	0.5977
X_5	-1.9500	0.5626	-3.47	0.0016*
X_1^2	0.5443	0.6188	0.88	0.3858
X_2^2	-0.3306	0.6188	-0.53	0.5969
X_3^2	0.0443	0.6188	0.07	0.9433
X_4^2	0.0443	0.6188	0.07	0.9433
X_5^2	0.2940	0.6188	0.48	0.6376
X_1X_2	-0.3125	0.6290	-0.50	0.6228
X_1X_3	0.8750	0.6290	1.39	0.1741
X_1X_4	1.2500	0.6290	1.99	0.0558
X_1X_5	-0.3125	0.6290	-0.50	0.6228
X_2X_3	-0.3125	0.6290	-0.50	0.6228
X_2X_4	0.9375	0.6290	1.49	0.1462
X_2X_5	0.2500	0.6290	0.40	0.6938
X_3X_4	0.2500	0.6290	0.40	0.6938
X_3X_5	-0.4375	0.6290	-0.70	0.4919
X_4X_5	0.1875	0.6290	0.30	0.7676
CONSTANT	59.8871	1.2069	54.10	0.0001*

5. Analysis of Variance - Red Kills.

For multiple regression, the analysis of variance is a technique that is used to partition the variance and to compare models that include different sets of variables [Ref.8:p.48]. The output provided from the SAS includes an analysis of variance table (ANOVA). The ANOVA table corresponding to this experiment is presented in Table 6 below.

TABLE 6. ANALYSIS OF VARIANCE TABLE - RED KILLS

SOURCE	DF	SS	MS	F-VALUE	p-VALUE
REGRESSION	20	2189.69	109.48	3.55	0.0008
ERROR	31	955.29	30.81		
TOTAL	51	3144.98			

The total variation in the data is called the "total sum of squares", SST, and is computed by adding the sum of squares due to the regression (SSR) and the sum of squares of the residuals (SSE) [Ref.6:p.10]. The degrees of freedom associated with the SST is N-1, where N is the total number of experimental observations (N=52). The degrees of freedom associated with the SSR is n-1, where n is the number of terms in the fitted model (n=21). The degrees of freedom for the SSE is N-n=31.

The F statistic is used to test the null hypothesis (H_0) that the fitted response surface model does not have a significant effect on the measured response. The alternate hypothesis (H_a) is that the fitted surface model does have a significant effect on the measure response. The F_{model} statistic is calculated using values associated with the mean square of the regression and the mean square of the residuals (as follows) [Ref.6:p. 11].

$$F_{Model} = \frac{Mean\ Square\ Regression}{Mean\ Square\ Residuals} = \frac{SSR/(n-1)}{SSE/(N-n)} \tag{8}$$

The value of F_{Model} is compared to the table value $F_{n-1,N-n,\alpha}$. If $F_{Model} > F_{n-1,N-n,\alpha}$, then the null hypothesis is rejected at a reasonable level of significance ($\alpha = 0.05$). If $F_{Model} < F_{n-1,N-n,\alpha}$, then the one fails to reject the null hypothesis at the α level of significance. The table value for $F_{20,31,0.05}$ is 1.92 for the RED Kills.

6. Analysis of Variance - BLUE Kills.

The analysis of variance table for the BLUE Kills is shown in Table 7. The degrees of freedom for the BLUE Kills is the same as the RED Kills. The value of F_{Model} is again compared to the table value $F_{n-1,N-n,\alpha}$. If $F_{Model} > F_{n-1,N-n,\alpha}$, then the null hypothesis is rejected at the α level of significance ($\alpha = 0.05$). If $F_{Model} < F_{n-1,N-n,\alpha}$, then the one fails to reject the null hypothesis at the α level of significance. The table value for $F_{20,31,0.05}$ is 1.92 for the BLUE Kills.

TABLE 7. ANALYSIS OF VARIANCE TABLE - BLUE KILLS

SOURCE	DF	SS	MS	F-VALUE	p-VALUE
REGRESSION	20	405.27	20.26	1.60	0.1167
ERROR	31	392.50	12.66		
TOTAL	51	797.77			

7. Analysis of Results.

a. RED Kills Model.

The regression model and the ANOVA table indicate that the null hypothesis (H_o) that the fitted model *does not* have a significant effect can be *rejected* (3.55>1.92). Therefore, the alternate hypothesis is accepted that the fitted model does have an effect on the response at α level of significance. Further investigation of the regression results indicate that most of the estimated coefficients may be zero. If the values of $|t| > t_{\alpha/2}$ for each estimated coefficient, then the null hypothesis that the coefficient is zero can be rejected at α level of significance. Also, the p-values for the remaining variables are so large that H_o will never be rejected. The variables not associated with the zero coefficients (see asterisks in Table 3) and for which H_o is rejected are: X_1 (#LRT/#TOW), X_2 (#LRT/#MBT), X_5 (LRT max range), and the constant. This does not mean that the other variables do not influence the results, rather, there is not sufficient evidence to provide accurate estimates of their effects [Ref.6:p.12]. These three variables are all associated with the LRT (force ratio and range).

b. BLUE Kills Model.

For the BLUE kills model, it was expected that the blue force would be killed due to the RED force outnumbering the BLUE force and RED attacking BLUE. Using the regression model and the ANOVA table for the BLUE Kills model indicate that the null hypothesis (H_o) that the fitted model *does not* have a significant effect **cannot** be rejected ($F_{20,31,\alpha}=1.92 > F_{Model}=1.60$). Therefore, there is no evidence to reject the hypothesis that the fitted model has no effect on the response at 11.67% level of significance. Further investigation of this regression model also indicates that most of the estimated coefficients may be zero. If the value of $|t| > t_{\alpha/2}$ for each estimated coefficient, then the null hypothesis that the estimated coefficient is zero can be rejected at the (α) level of significance. The table value of $t_{48,0.025}$ is 2.01. Also, the p-values for the remaining variables are so large that H_o will never be rejected. The variables not associated with the zero coefficients (see asterisks in Table 5) and for which H_o is rejected ($|t| > 2.01$) are: X_1 (#LRT/#TOW), X_5 (LRT max range), and the constant. This does not mean that the other variables do not influence the results, rather, there is not sufficient evidence to provide accurate estimates of their effects [Ref.6:p.12].

Recall, this model is based on the number of BLUE Kills response. It is desirable to keep the response as small as possible (survivability). Therefore, it is hoped that the impact of the coefficients contribute to decreasing the response variable. The sign of the significant coefficients is negative, supporting the previous statement. As a LRT is added to the force replacing a TOW, the response is decreased through the negativity of the coefficient for those factors. This indicates that it is better to replace the TOW first (the more vulnerable weapon system) but adding more LRTs to the system will decrease the number of BLUE kills. Also, the magnitude of the coefficient for the LRT/TOW ratio is smaller (larger negative) than the LRT/MBT ratio. This indicates that it is better to replace the TOW first and then the MBT with the LRT. Increasing the number of LRTs that replace the TOW increases negatively the number of BLUE Kills more than replacing the MBTs with LRTs.

C. CONCLUSIONS.

The results from the RED Kills model indicate that the regression model is a fairly good predictor of the response variable. The key parameters that influence the variation in the response are the LRT force ratios and the LRT Max Range. This agrees with what one would instinctively believe when given a longer range weapon. Since the regression equation is second order, it is convex. Therefore there exist an extreme point. The nonlinear program solver General Algebraic Modelling System (GAMS) was used to maximize the regression equation. The result indicated that the model is maximized at the upper endpoints (all variables set at their maximum level). This indicates that JANUS(A) is sensitive to opening range and that a longer range weapon system (in this terrain) will significantly contribute to the destructive capability of the force. Also, the significant coefficients were all positive. This indicates that raising the factor level for the force ratios or the LRT range will increase the response (number of RED kills). The magnitude of the coefficient for X_2 was larger than X_1. This indicates that it is more beneficial to first replace the TOW (the weaker weapon) then the MBT. All of these results agree with the answers posited prior to conducting this experiment and support the hypothesis that the longer the range of a weapon system and the number of those systems in the force, the larger the contribution to the destructive capability of the force.

The results from the BLUE Kills model were also as posited. While the model is not as good a fit to the variation in the response and therefore not sufficient as a basis from which to draw conclusions, the significant coefficients are those expected. The model indicates that the non-zero coefficients X_1 and X_5 contribute negatively to the response variation. Recalling that the desired response for this model is as small as possible (# of Blue Kills), this indicates that as X_1 and X_5 increase, the response decreases (the number of BLUE kills decreases). This coincides with what was posited at the beginning of this paper: that the addition of a long range weapon system will increase the survivability of the owning force. One possible reason for the bad regression model may be due to the random replacement of the LRTs for TOWs and MBTs (as mentioned in Chapter III). Another possible explanation for this is that as more LRTs are entered into the force, the detectability of the Blue force by the Red force increases, thus exposing them to enemy fire sooner than that if the LRTs were not in the force.

D. FURTHER TESTING AND ANALYSIS.

In order to determine possible reasons for the lack of the BLUE Kills regression to model the response, a follow-on experiment was conducted. For this experiment, a more traditional method was chosen, and ten additional Janus(A) runs were made. The values for each of the variables were fixed at what was felt might be the most reasonable settings if this system was inserted into the scenario (no variation in the factors). The force ratios were set at their center point, while the TOW and LRT were set at their maximum ranges. The MBT opening range was set at its upper radial point. This configuration was chosen because the P_h and P_k values for the MBT decrease rapidly at the maximum range and it was felt that realistically, MBT gunners do not open fire at their maximum range, but wait to get more efficient shots at the enemy. Also, these are the values where the P_h and P_k values begin to drop off rapidly and gunners get effective shots at long ranges. These are the posited influential values indicated in Chapter I. Therefore, the values of the parameters were ($X_1=0, X_2=0, X_3=1, X_4=2, X_5=2$). The results of the runs are shown in Table 8.

TABLE 8. RESULTS OF ADDITIONAL RUNS.

RUN	RED KILLS	BLUE KILLS	RUN	RED KILLS	BLUE KILLS
53	51	55	58	51	59
54	64	55	59	56	57
55	64	56	60	61	58
56	54	43	61	76	54
57	66	53	62	63	50

For these runs, as in the first 52 runs, the replacements were done randomly for each run.

To study the effects of range on both the RED Kills and BLUE Kills, the number of kills by weapon system was plotted in 500 meter range bands. Six box plot graphs were developed: one for each BLUE system (LRT, TOW, MBT) plotting the number of RED Kills versus 500 meter range bands and one for each BLUE system plotting the number of BLUE Kills of that system versus the range bands in which they were killed (Figures 2 through 7).

Figures 2 and 3 depict the LRT, both the number of RED kills scored by the LRT and the number of LRTs killed by RED systems. It is apparent that the LRT scored most of its kills at the longer ranges (5-6 kms). It is also apparent that the RED force killed the LRTs at the RED force's maximum ranges. This means that having a LRT in one's force will kill more enemy at

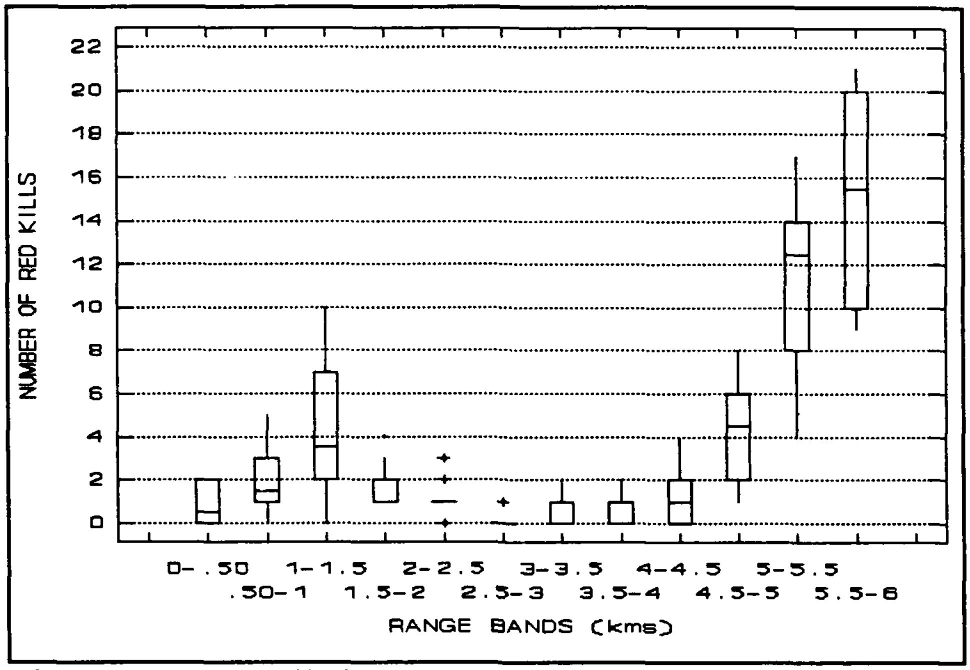

Figure 2. LRT Kills in 500 meter Range Bands.

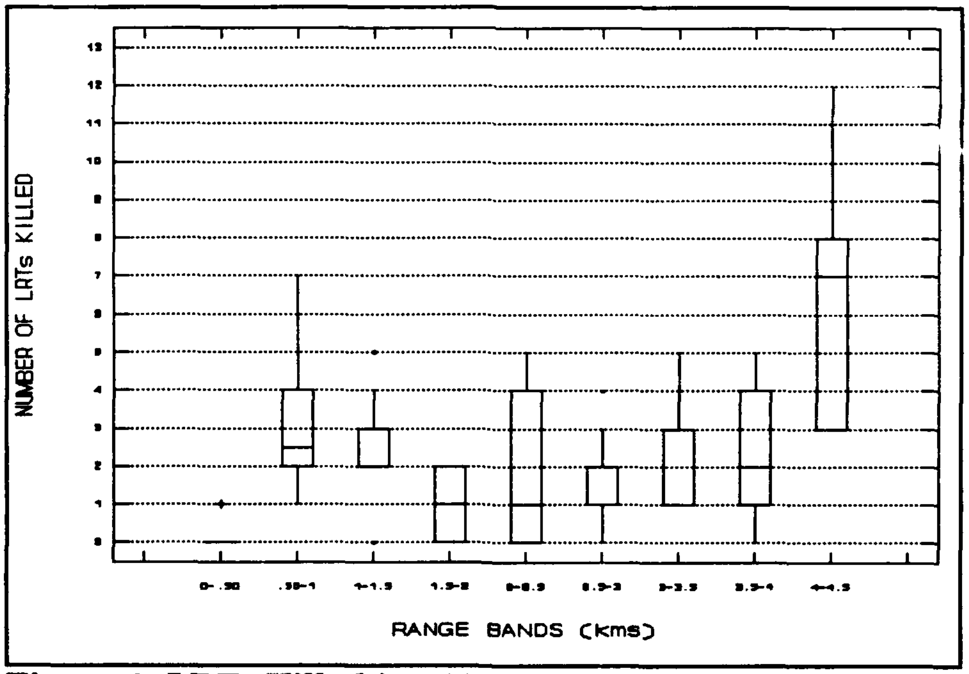

Figure 3. LRTs Killed in 500 meter Range Bands.

greater ranges but it will also attract more enemy fire at the enemy's maximum ranges. The LRT's long range fire exposes their positions to the RED force, who then return fire.

Figures 4 and 5 are box plots of the kills scored by the MBT and the number of MBTs killed by range bands. These figures indicate that the MBT did most of its killing at the longer ranges with the main tank round. But, at the shorter ranges, where the alternate weapon (machine gun) might be more practical, the alternate weapon was, in fact, used. For the number of MBTs killed by the RED force, again the enemy engages the MBTs at the earliest possible time - the maximum range of their weapons.

Figures 6 and 7 depict the same information as discussed above for the TOW. The significant point here is that the TOW scored such a small amount of kills that the impact of this weapon can hardly be evaluated. The TOW uses its antitank weapon to engage targets at the longer ranges and its machine gun to engage targets at the shorter ranges. With such few TOWs initially in the force and the discrete values of the number of TOWs, the significance of the number of TOWs killed by the RED force cannot be evaluated.

Positioning of the weapon systems greatly affected the probability of the systems being killed early on in the battle, at close or far ranges. These graphs make it difficult to tell what is going on with the addition of the LRTs except that the weapons on both sides attempt to kill targets at the greater ranges.

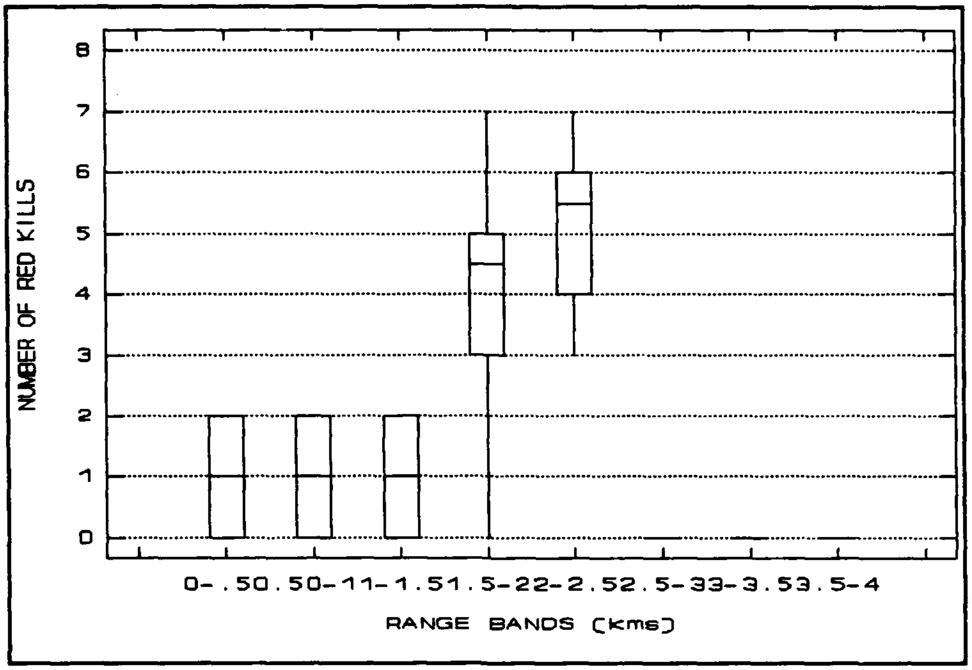

Figure 4. MBT Kills in 500 meter Range Bands.

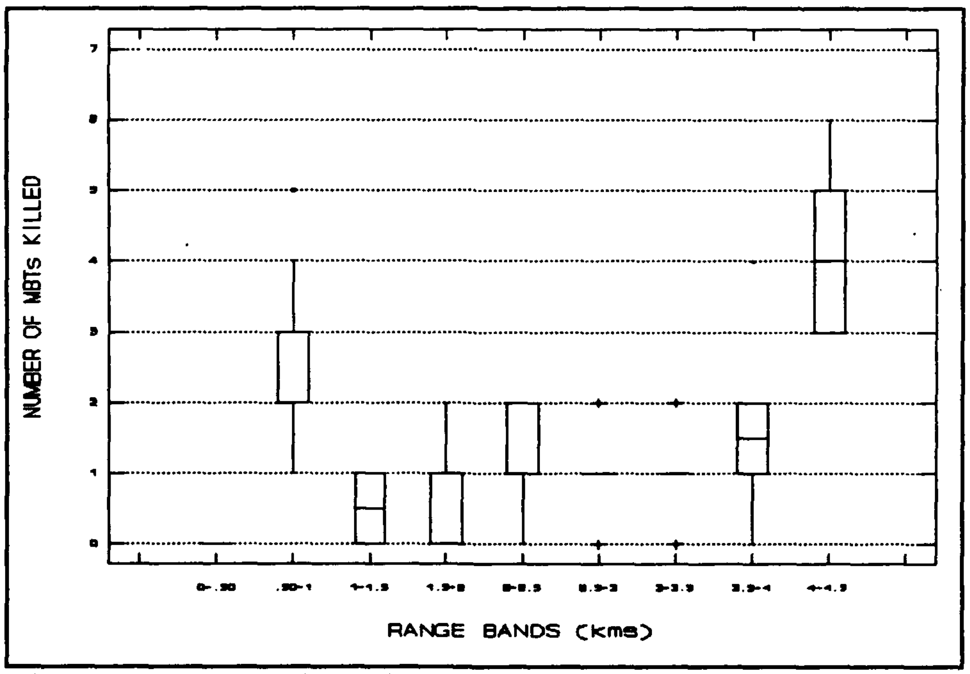

Figure 5. MBTs Killed in 500 meter Range Bands.

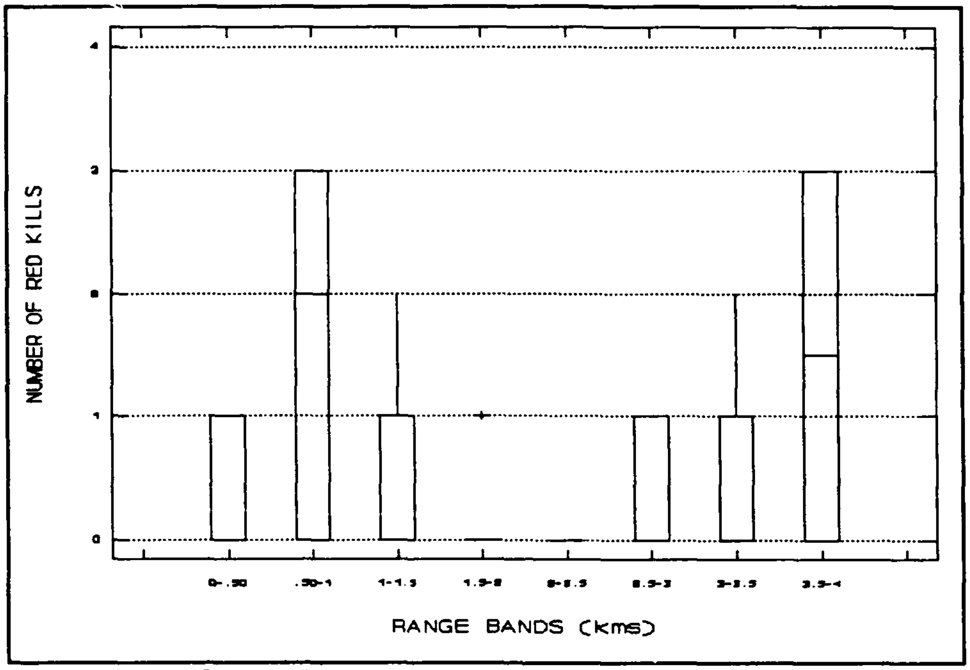

Figure 6. TOW Kills in 500 meter Range Bands.

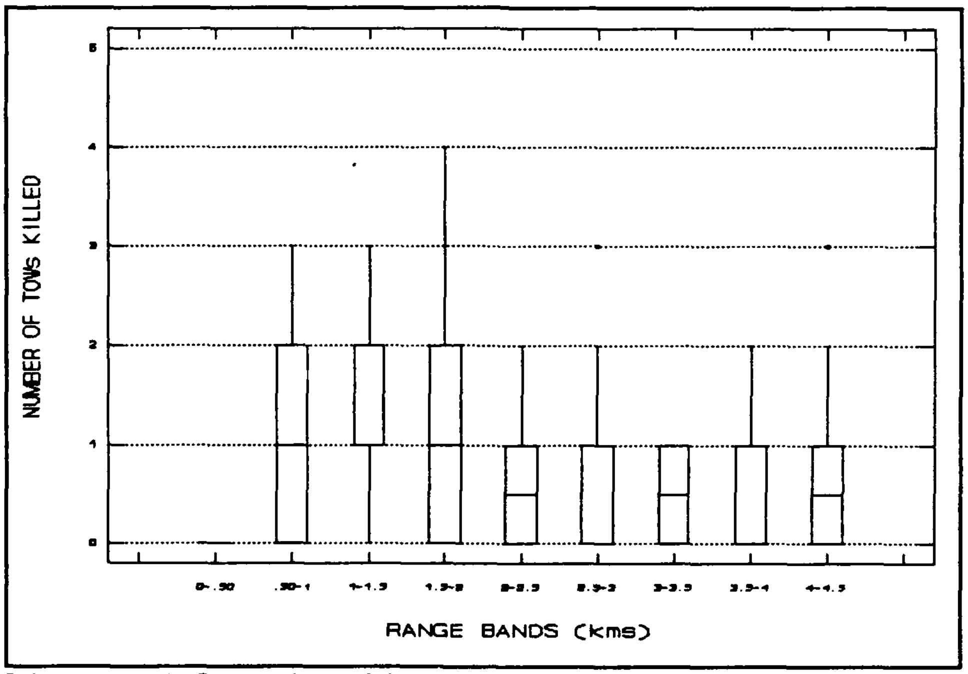

Figure 7. TOWs Killed in 500 meter Range Bands.

The results depicted what was intuitively suspected and what the CCD experiment depicted: that range matters in this scenario.

The other intuitive result from this additional research is that the more long range weapons in a force, the larger the contribution to the destructive capability of that force. The LRT comprised 50% of the Blue force, while the TOW and MBT comprised 18% and 32%, respectively. The contribution by each of the Blue systems to the total number of Red Kills was 71%, 9%, and 21%, respectively, for the LRT, TOW, MBT. This indicates only that the most dominate system, in term of total number of systems, does most of the killing. There are more LRTs in the force than any other system - so they do most of the killing. This does not mean that the LRTs are "best" overall.

Two conclusions drawn from this additional experiment are that: 1) the results agree with the CCD experiment that range matters both to the survivability and the destructive capability of the force, and 2) a system exposed to the enemy will be fired upon and killed. This means that no matter how good a system is, if it is positioned in a tactically unsound area, the likelihood of it contributing to the overall force is small.

V. CONCLUSIONS AND RECOMMENDATIONS.

A. CONCLUSIONS.

The results of this study demonstrated that the CCD is an efficient and effective experimental design in the analysis of advanced technologies using Janus(A). Reducing the number of experimental runs while still gaining the statistical significance of the main and second order effects allows the analyst to obtain the important data without a large number of experimental runs.

For this study and the advanced technology chosen to demonstrate using Janus(A) and the CCD, the results were encouraging. In almost every respect, the Janus(A) results were those expected for this scenario. The regression analysis and ANOVA indicated that the addition of a long range direct fire weapon system greatly improves the destructive capability of the force. The effect of the LRT on the survivability of the BLUE force was not as evident. This study showed that, in fact, the TOW, and maybe the main battle tank, may be obsolete for this scenario if this advanced technological system was available. The LRT and its long range capability clearly dominated the effects of the MBT and TOW. The results indicated that the impact on the blue survivability was unclear due to the overwhelming red force and the fact that the scenario was not run through the end of the battle. However, the addition of a long range direct fire weapon system may decrease the number of blue systems killed in this scenario.

Another result from this study was that using force ratio as a factor in the experiment allowed the analysis of an optimal force mix for the scenario. From the analytical results of the CCD and response surface, an optimal force mix for this scenario was found at the upper end points of the design. For this scenario, replacing all of the TOWs and MBTs with LRTs gave the best results in terms of number of RED kills. Use of these force ratios enabled the model to pick out the weaker system, both in terms of destructive capability and survivability. The scenario was ideal for a long range armored vehicle, therefore the TOW, the short ranged, lightly armored system, was replaced entirely in both the RED Kills model and the BLUE Kills model.

Given the results observed by this analysis, Janus(A) may be an appropriate simulation model to study the influence of advanced technological weapons on battle outcomes. It was easy to use, both as an experimental tool and as a data collector. Using the CCD enabled a manageable number of experimental runs to be made during a short period of time. The response surface methodology was very effective in identifying the factors which had the most and least effect on the responses. The results supported the initially expected outcome of this study.

B. RECOMMENDATIONS.

Several recommendations are presented stemming from problems and discoveries learned by the author. As Janus(A) comes to wider uses in the Army, more people will learn more about it. Its entire use has not yet been explored.

It is recommended that further studies of advanced technologies using Janus(A) be conducted. Studies involving the weapon characteristics themselves as the isolated factors should be done. In particular, follow-up studies of the propulsion system and target sensors on a long range direct fire system are warranted. Aiming a weapon at greater ranges poses possible problems with aiming errors. The type and characteristics of the propulsion of a round to great ranges at high velocities may also pose physical problems. These problems may be analyzed in Janus(A) early on to get an indication of the magnitude of the effect in a force on force scenario.

This study considered only one scenario. A follow-up study should consider this weapon, the LRT, in a wooded type terrain, where long ranges are not abundant. Consideration for the type of mission given the force would also warrant further study. This study considered the defensive mission given the BLUE force. Both of these variations are of importance when considering a weapon system for further development. If all the world were flat and open, the LRT might be the answer, but, with various terrains, various missions, various mixes of other weapon systems, the results would be different. It is recommended that further studies of this weapon in different scenarios be conducted.

Finally, it is evident that the CCD is an extremely efficient and effective experimental design. It is recommended that the CCD and response surface methodology be used more often when time and resources prevent replicated full factorial designs. The benefit of the CCD is the amount of information gained through a fairly small number of experimental runs.

APPENDIX A: ANALYSIS FRAMEWORK

This appendix describes in general terms the Analysis Framework shown in Figure 8. While this framework can be applied to almost any simulation model, JANUS(A), was the simulation model used for this thesis.

A. BACKGROUND.

JANUS is an interactive, two-sided, closed, stochastic, ground combat, wargaming simulation featuring precise color graphics. It comes in several versions. One, developed initially as a nuclear effects modelling simulation by the Lawrence Livermore National Laboratory, is called JANUS(L). TRADOC Analysis Command (TRAC) at White Sands Missile Range developed a version for Army combat development needs called JANUS(T). JANUS(A) is a version of JANUS(L) developed for the Army for use in both combat development and training communities.

Interactive refers to the interplay between the military analysts who decide what to do in crucial situations during simulated combat and the system that models that combat. Two-sided refers to the two opposing forces directed simultaneously by two sets of players. Closed means that the actions of the opposing side are relatively unknown to each other. Stochastic refers to the way the system determines the results of actions like direct fire engagements,

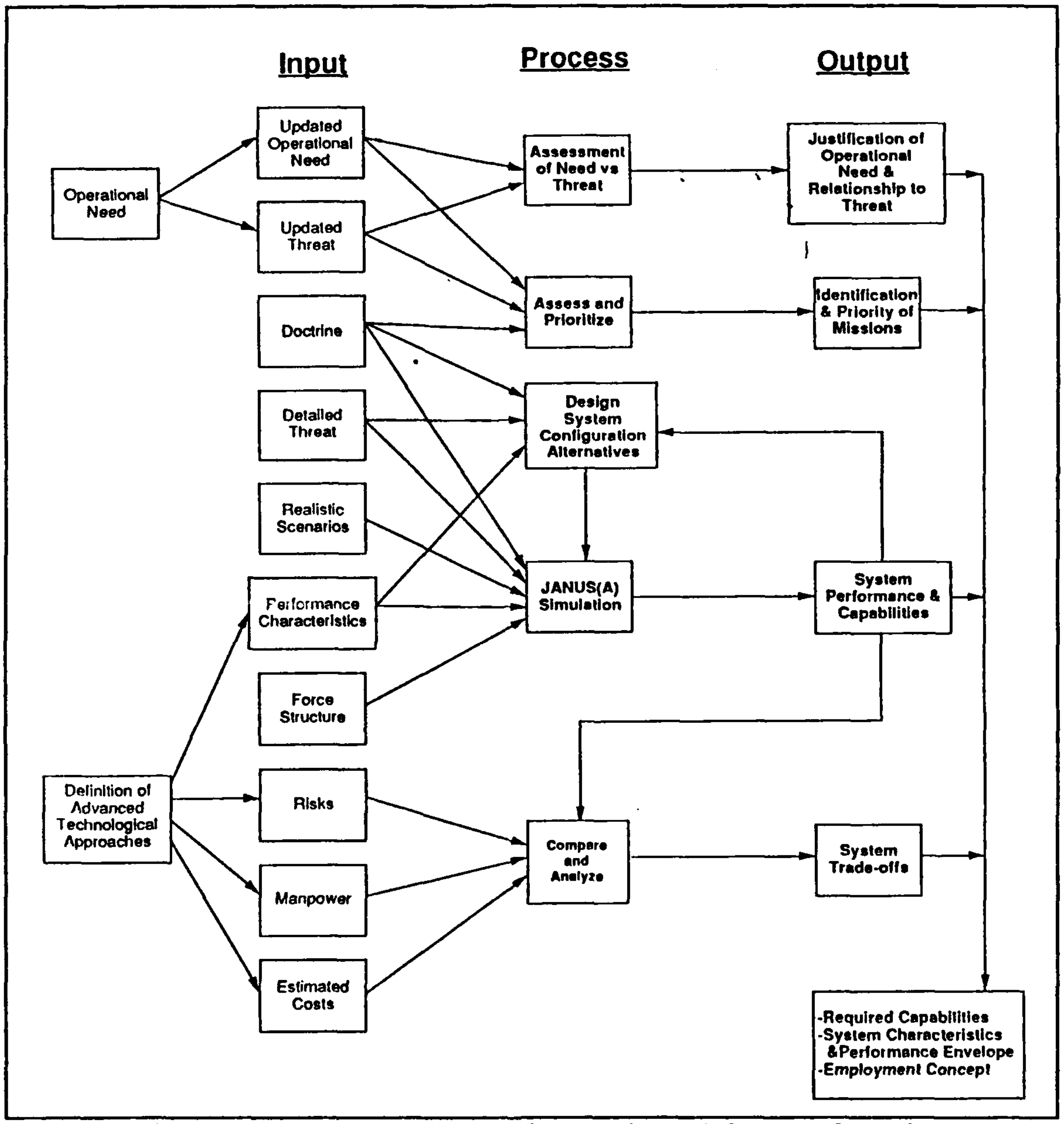

Figure 8. Analysis Framework for the study of Advanced Technologies.

i.e., according to the laws of probability and chance. The principal focus of the battle is on the ground maneuver and artillery units, but JANUS(A) is able to model weather conditions, day and night visibility, engineer support, minefield employment and breaching, rotary and fixed wing aircraft, resupply, and a chemical environment. The simulation uses digitized terrain developed by the Defense Mapping Agency and displays it with contour lines, roads, rivers, vegetation, and urban areas. Additionally, the terrain realistically affects visibility and movement.

A decision was made to use JANUS(A) as a research tool for the Operations Research Center (ORCEN) and as a teaching tool for cadets at USMA. JANUS(A) is currently used to evaluate new potential technologies in a classroom environment. The intention is to use JANUS(A) as an actual analytical tool for realistic advanced technologies. With a methodology established, it is felt that the results of an analysis could be used as input into the decision making process for further research or procurement.

B. APPROACH.

The Analysis Framework shown in Figure 8 forms the basis for incorporating inputs, processes, and outputs into a detailed, step-by-step process. The final output would be a report of the required capabilities, system characteristics and performance envelope, and the employment concept for the advanced technology being studied.

The initial step in this analysis is to determine the **operational need**, the motivation for development of an advanced technology. There may be doctrinal, operational, organizational, or mission changes or a newly recognized threat that requires a material response. An exploitation of a technological or operational advantage held by the Army or some vulnerability existing within the threat is also valid justification of a need. TRADOC and AMC (defined earlier) are the agencies which may have this information. With this in mind, the analysis will be guided toward satisfying the operational need rather than the success of the technology.

Along with the operational need, the analyst will need to have the definitions of **advanced technological approaches**. These provide information on the material options available to address a capability shortfall or enhancement opportunity that supports the operational need. These advanced technological approaches provide the analyst with the desired technologies in terms of relationships between system performance (range, reliability, endurance, lethality, survivability, etc.), system physical characteristics (weight, size, ease of maintenance, etc.), cost, schedule for availability, supportability factors, and technical risk [Ref.10]. It is important to note that the performance data must be available for the analyst before proceeding with this methodology. These advanced technologies must be engineered and tested rather than experimental. Preferred documentation will include technical and test reports from the supporting technology base effort (Army, other service, or industry). With this in mind, the analyst can proceed with this methodology.

1. INPUTS.

The inputs for this methodology are items (explained below) that may be provided for the analyst. Possible sources of information are provided with each explanation.

a. Updated Operational Need.

A current, detailed operational need translates a battlefield deficiency or desired capability improvement into an operational concept for a material solution. This is the underlying basis for the analysis. This can normally be gotten from the appropriate TRADOC school/center.

b. Updated Threat.

As world events change, so changes the THREAT. An updated threat is critical for the analyst in determining what forces the technology will be used against. In the last year, the threat has changed from the Soviet Union to the Middle East. The future threat is unknown and we must be prepared for a number of different levels of threat forces. This has tremendous impact on the way the Army thinks and operates in terms of operational need. Updated threat information may be obtained from the Intelligence Threat Analysis Center (ITAC) or from any TRADOC school/center.

c. **Doctrine.**

As the world events and the threat changes, our doctrine with existing systems must change. As new weapon systems are developed, doctrine to employ that system must be developed. New technologies may affect current doctrines for existing systems. A structured enemy, like the Soviets, will use a different doctrine than an unstructured enemy as we found in Panama and the Middle East. The doctrine to fight these unstable forces must be developed and incorporated into current doctrines. This information may not be available and therefore must be estimated. The appropriate TRADOC school/center for the weapon system being analyzed will be able to provide assistance in this area.

d. **Detailed Threat.**

This differs from b. above in that now a complete detailed breakdown of enemy forces, weapon systems, etc., must be available to provide the correct opposition for the system being analyzed. This detailed threat should also include the scenario and terrain in which we expect the enemy to operate. A European threat is much different than a Middle East threat. Again, this information would be best provided by the appropriate TRADOC school/center.

e. **Realistic Scenarios.**

A scenario must be built to correctly test the new technology (system). The scenario must be appropriately conducted to obtain the most realistic results possible. A system designed for the close-in battle would not be analyzed using a deep battle scenario, theater-level scenario, etc. The scenario must coincide with system being analyzed and its mission. The scenario must also coincide with the threat expected for this weapon system. A base scenario should be built, without the new system, and run to give the analyst a basis for comparing the test results for the new system. This information should be obtained through the appropriate TRADOC school/center, experienced officers and analysts, and common sense.

f. Performance Characteristics.

From the definition of advanced technological approaches, the analyst should obtain the performance characteristics. These characteristics provide data on the material capability test results from the engineering of the advanced technologies. This information can be obtained from the technical and test reports from the supporting technology base effort (Army, other service, or industry).

g. Force Structure.

A force structure must be designed to support the technology being analyzed. This structure should be consistent with the level of operation of the advanced technology. A theater defense system would not normally be analyzed at the company level. An important issue here is that for JANUS(A), a decision must be made to use systemic runs of the model or man-in-the-loop runs. Systemic runs will give more consistent data than the man-in-the-loop runs. If humans are involved, as they are in battle, the results may become skewed due to the operators personality, lack of experience, etc. Both the level and type of force structure should be designed to isolate and incorporate the system being analyzed. Again, this information comes from using common sense and the appropriate TRADOC school/center.

h. Risks.

All weapon systems have an inherent risk associated with their use. The risks associated with an advanced technology should be defined in the advanced technological approaches. These risks may not be quantifiable but should be included in the analysis of the performance and capability results.

i. Manpower.

In today's Army, personnel strengths play an important part of cost analysis. The manpower required to operate and maintain a new technology must be included in any analysis. For this Janus(A) analysis, only the manpower required to operate the system or technology needs to be known. This information will come from the definition of advanced technological approaches.

j. Estimated Costs.

While this study is not a Cost and Operational Effectiveness Analysis (COEA), the cost must be included in the final analysis. This approach concentrates on the performance and capabilities of a new technology, but costs greatly impact the analysis of any new technology. Costs versus capability trade-offs should be included in the final analysis. The estimated costs can be gotten from the definition of advanced technological approaches.

2. PROCESSES.

The processes used to take the given input information and employ various analyses and simulations will be developed by the analyst. Each piece of input information is placed into a process, analyzed, and incorporated into the output.

a. Assessment of Need versus Threat.

Using the updated operational need and updated threat, an assessment of the need against the expected threat should be conducted. Does the need adequately coincide with the threat? Is the need lacking? Does the need sufficiently meet the threat? These are the types of questions that need to be answered in detail during this process.

b. Assess and Prioritize.

During this process, the updated operational need, threat, and doctrine needed to support the advanced technologies are analyzed. Each is assessed and prioritized based on importance and impact on the battlefield. This should narrow the focus of the analysis to the mission area required for the technology.

c. Design System Configuration Alternatives.

This process allow the analyst/cadet to use the doctrine, detailed threat, and performance characteristics and design alternatives to meet the operational need. The alternatives may come from modifying existing systems, off-the-shelf systems, or new systems. Another alternative that must be addressed is the force structure. A new or advanced technology may produce different results using different force structures. Whatever the alternative, the design must be consistent with performance data available, engineered rather than experimental, and possibly have an expected cost associated with each. These alternatives will be used for the Janus(A) simulation runs.

d. Janus(A) Simulation.

With all the pertinent information, the analyst is ready to input the data into Janus(A) and begin the runs. The details for this process will be described later. *Janus(T) Documentation and User's Guide* [Ref.7] provides specific procedures for inputting the data into Janus(A) and checking final data prior to beginning any runs. Upon completion of the Janus(A) runs, the analyst should be able to describe the system's performance and capabilities.

e. Compare and Analyze.

This process involves incorporating the inputs of risks, manpower, and estimated costs along with the system performance and capabilities from the Janus(A) runs to compare and analyze this information. Measures of Effectiveness (MOEs) are verified. Data and sensitivity analysis are conducted. All previous data is used to determine the overall system trade-offs.

3. OUTPUT.

The outputs for this methodology are the reports generated from the processes described above. Each output contributes to the bottom line: does the new system or advanced technology meet the operational need and required capabilities? The final report should address the following items: required capabilities, system characteristics, performance envelope, and employment concept.

a. Justification of Operational Need and Relationship to Threat.

Using the assessment of the need versus the threat, the analyst should be able to justify the need and its relationship to the threat.

b. Identification and Priority of Missions.

After assessing and prioritizing the operational need, threat, and doctrine, the analyst should be able to identify the battlefield functional mission area and capability packages. The analyst should use the Janus(A) results to help prioritize its missions. Each capability package has numerous tasks that accomplish the missions. These tasks should be considered when analyzing the system and its purpose.

c. System Performance and Capabilities.

Upon completion of a set of Janus(A) runs, the analyst should be able to describe the system's performance and capabilities. Whether or not the capabilities met the operational need is determined at this step. If other alternatives need to be evaluated, the procedure returns to the design system configuration alternatives process and another set of Janus(A) runs conducted. If the system's performance and capabilities are adequate, then the information is used in the compare and analyze process. The system's performance and capabilities are a major portion of the final report.

d. System Trade-Offs.

Upon completion of the analysis, a matrix of system trade-offs should be produced. This graphically displays how parameter/performance increases impacts other performance characteristics. This provides the decision maker the ability to see what effect a specific capability has on the other capabilities. The analyst should graphically examine the relationships between each key design parameter or bands of performance and its associated measures of effectiveness. The use of bands of performance rather than point estimates is encouraged. The limits and parameters for each band should be carefully defined for each appropriate characteristic or performance factor. Weighted factors may also be included in this analysis. The operational need, capabilities, risks, and costs of the system should always be considered in the trade-off analysis. A faster tank might mean less accuracy with the main gun, for example. This output depicts to the reader what the impact of possible personal or professional desires might have on a given system.

4. FINAL REPORT.

The final output of this methodology would be the culmination of all of the above analysis. Inputs for the final report include the justification of the operational need and relationship to the threat, identification and priority of missions, system performance and capabilities (as simulated by Janus(A)), and the system trade-offs in terms of the need, required capabilities, risks, and costs. Also included should be the advantages and disadvantages of the system configuration alternatives, key design parameters in the system, identification of any shortfalls or discrepancies in the advanced technology, and recommendations for improvement to the technology. The three main areas to be addressed should be: 1) required capabilities, 2) system characteristics and performance envelope, and 3) employment concept.

a. Required Capabilities.

This portion of the final report should address the required capabilities of the system to meet the operational need. Shortfalls and discrepancies as related to the operational need should be detailed.

b. System Characteristics and Performance Envelope.

This section of the report will contain the recommended characteristics of the system and the performance data achieved to meet the operational need. Specific information such as height, weight, overall dimensions, and weapon characteristics of the system may be included if available. This section will include the recommended environment(s) in which the system will operate, the number of crew members needed to operate the system, the mission of the system, the vulnerabilities of the system, and the expected costs of the system. The system trade-offs will be analyzed and included in this section. This section will also include the performance data from the Janus(A) runs, recommendations for improvement to any part of the system, and observed Janus(A) problems or deficiencies for the system.

c. Employment Concept.

An analysis of the expected deployment and employment will have been done prior to the Janus(A) runs. This information will allow the analyst to decide the best employment possibilities for the system. Upon completion of the Janus(A) runs, considering the operational need and mission of the system, the analyst will be able to recommend employment considerations for this system.

C. JANUS(A) SIMULATION.

This section of the methodology will detail the steps needed to use Janus(A) to conduct analysis of an advanced technology. This section details the brief discussion in paragraph B.5.d above. Following the *Janus(T) Documentation and User's Guide* [Ref.7] will enable the analyst to quickly and thoroughly enter all of the required data prior to any Janus(A) run. As with the above methodology, there are inputs, processes, and outputs for the Janus(A) runs (see Figure 1b), described in detail below.

1. INPUTS.

As in the methodology above, prior to any process, there must be inputs provided. These inputs, like those given above, will be provided primarily for the analyst. There may be a situation where the analyst will have to use his/her best judgement for the data or information. Most of the inputs are found in the previous references but will be mentioned again in the proper context.

a. Suitable Terrain.

Prior to inputting data into Janus(A), a decision as to the type of terrain should be decided. Janus(A) can be used on any terrain available from the Defense Mapping Agency. Future world situations and expected future political climates will dictate which terrain might be suitable. Other considerations for analysis should be time of day (or night or both), time of year, weather conditions, temperature, etc. All of these should be considered as the terrain scenarios are built.

b. Level of Operations.

The level of operations or level of force structure should be kept at a minimum. This allows a better analysis of the impact of the system against enemy targets (system oriented one-on-one or one-on-few simulations). Janus(A) can model force levels from individual up to brigade level. For individual weapons, individual soldiers can be depicted. For weapon systems, squad, company, or battalion size forces can be depicted. The level of operations must coincide with the purpose (or mission) of the system being analyzed.

c. Doctrine.

As mentioned above, the doctrine of the Army must be known or estimated for the particular system or technology being analyzed. How will the system be deployed and employed? Information from the appropriate school/center may be helpful. Common sense should be utilized. During the Janus(A) runs, the doctrine decided upon should be used strictly and consistently. This will prevent the results from being skewed due to human variances. Realizing that in battle there will be human variations, the analyst should attempt to produce a clean simulation (free of biases) that can be replicated to isolate the impact of the system being analyzed to the battle.

d. Detailed Threat.

This step in the methodology requires specific information on the possible threat technologies that may be available during the time being analyzed. The future threat technologies that may counter our systems is to be input into Janus(A) along with our advanced technologies. This information may be more difficult to obtain and may require a modification/upgrade to the threat system(s). Information may be obtained from the Intelligence Threat Analysis Center (ITAC). Threat system characteristics must be input into Janus(A) using the same procedure as for the blue (friendly) side.

e. Performance Characteristics.

The detailed weapon performance characteristics for both friendly and threat forces must be input into Janus(A). Janus(A) uses probability of hit and probability of kill tables, detection data, engagement ranges, and other data to determine outcomes of engagements. Without specific data on the new technology, values of existing data must be used and perhaps upgraded to reflect the estimated values of the new system. A scenario must then be built to best evaluate this system with its estimated values. The data must be verified with the test reports. The data must also reflect the entire range of values for a particular characteristic (range, weight, lethality, speed, muzzle velocity). This is the most important of the steps. If incorrect data is used, the analysis will be skewed and unreliable.

f. Prioritize Key Parameters.

Advanced technologies have a multitude of characteristics or parameters. Deciding which parameters to vary and analyze is a difficult task. Using only those parameters or bands of performance which are key and vital to the mission and prioritizing those will allow the analyst to get a better grasp on the analysis portion of the methodology.

2. PROCESSES.

The processes for the Janus(A) simulation consists of those events necessary to narrow the scope of the analysis to a reasonable level. These processes require some thought and reason. The number of parameters in an analysis of this size may be too numerous to vary each parameter and conduct runs for each change. Therefore, this methodology should limit the number of runs to those critical to the design of the system.

a. Select System Trade-Offs.

Using an interaction matrix with the key parameters on each axis, the analyst can decide which parameters or bands of performance have a significant interaction with each other. This allows the analyst to select only those key parameters that may have a significant interaction for the simulation runs. A run design such as full factorial, fractional factorial, or Central Composite Design may be used to assist in selecting the number of parameters to analyze. Common sense and detailed analysis will contribute to this step.

b. Develop a Run Matrix.

With the above interaction trade-off matrix, the analyst now needs to develop a run matrix. This is a matrix that determines which simulation runs will be used in Janus(A) and which key parameters will be varied for each run. One axis may have several key parameters (weapon lethality, range, detectability, etc) while the other axis may have several trade-off parameters (height1 versus rate of fire1, height2 versus detectability1, etc.) from the above matrix. Those key parameters and the key system trade-offs help determine which Janus(A) runs to conduct. Some study in Response Surface Methodology may be useful for this area.

c. Janus(A) Runs.

With the above matrices and all of the system characteristics, data, doctrine, threat, terrain, etc. the simulation can be loaded and run. If possible, several runs (using different seeds) should be made. Depending on the type of system being analyzed, the Janus(A) runs can be done in one of several ways. The forces could be input, deployed, employed, planned, and the battle started without any human interaction during the battle. This provides a simulation that can be easily replicated. Changing the seed only changes the random occurrence of events. Using human interaction during the battle may provide a more realistic scenario but will be harder to replicate and may make the data more difficult to analyze due to human factors. An offensive-minded controller may use more of his forces forward to defeat the enemy quicker, even on the defense, and therefore incur more casualties but accomplish the mission quicker that a defensive, more conservative controller. An artillery-minded controller may use more artillery to augment a tank system than an armor-minded controller. These examples demonstrate how data may be skewed during the simulation runs. Output files from the Janus(A) post processor should be recorded and analyzed. If key parameters need to be changed to reflect the full range of values, then the input considerations need to be re-evaluated, the processes conducted again, and another Janus(A) run conducted. When all desired key parameters have been evaluated through the simulation runs, the output files need to be analyzed and the system's performance and capabilities documented.

D. CONCLUSIONS.

This methodology is a common sense approach using Janus(A) to evaluate and analyze advanced technological approaches. This methodology uses thought processes similar to those used in other concept analysis agencies. This methodology is designed so the user can follow a step-by-step procedure and use Janus(A) as the simulation model. This methodology can be used with Janus(A) immediately as a training tool for students and researchers.

APPENDIX B: JANUS (A) TACTICAL SCENARIO

1. Reference.

The following information is extracted from a report by CPT (P) David Dryer, titled, *Comparison of the Janus (A) Combat Model to National Training Center (NTC) Battle Data: Phase II.* It is provided to briefly describe the mission scenario used in this research. Anyone desiring to know more about this study should contact the TRAC-MTRY facility at the Naval Postgraduate School, located in Monterey, California.

2. Initial Mission Assessment.

One should get an overall picture of the battle, before getting immersed in the details. This can be done by looking at the video mission summary; the written Take Home Packet; and a replay of the battle on LLNL's AWS, or a PC with General-purpose NTC Analysis of Training Tool (GNATT-II), or the Sun Advanced Home Station Workstation (if available).

a. BLUEFOR Mission, Task Organization, and Concept of Operation

The BLUEFOR mission and commander's intent is found in both the Take Home Packet and the video mission summary. The task organization and concept of operation are described in the video mission summary. In FY 91, ARI-POM also started maintaining written mission sheets which contain the above BLUEFOR information. In order to understand these concepts, a display of intelligence and operational graphics, with associated names, needs to be available. Task force operational overlays are available at the ARI-POM warehouse for most of the missions from FY 89 to the present. Both the VAX and GNATT-II systems at ARI-POM have capability to show battlefield graphics, but not the names associated with these graphics. The video mission summary also displays the important battlefield graphics when talking about the BLUEFOR concept of operation.

The NTC battle being used for illustration is a modernized armored task force (TF) defense in sector (DIS) mission which occurred in the Siberia training area of NTC during FY 1988. The task force's decision support template is shown in Figure 2. Six battalion size mobility corridors are identified. Two forward teams from the task force are to observe decision point 9 (DP9) and report which mobility corridors the enemy regiment is moving along. The task force operational graphics are shown in Figure 3. The task force mission was to defend in sector from PL VICTORIA to PL GERALD NLT 242400 --- 88 to destroy enemy forces and allow no penetration of PL LAWTON. The task force commander's intent was to deceive the enemy as to the location of primary positions and fight an aggressive counter-reconnaissance battle by positioning elements forward. After the counter-reconnaissance battle has ended, the commander intended to shift these forces into positions in depth in order to destroy the enemy in EA's SHARK and PIRANHA.

The BLUEFOR task organization is listed in the video mission summary and is shown in Table 1. The BLUEFOR concept of the operation is divided into two phases. Phase one is the counter-reconnaissance battle and phase two is the defense in sector. During phase one, Tm Scout will have an infantry platoon from Tm A and an infantry platoon from Tm F OPCON which will occupy battle positions (BPs) 12 and 21, respectively. B Co will continue to

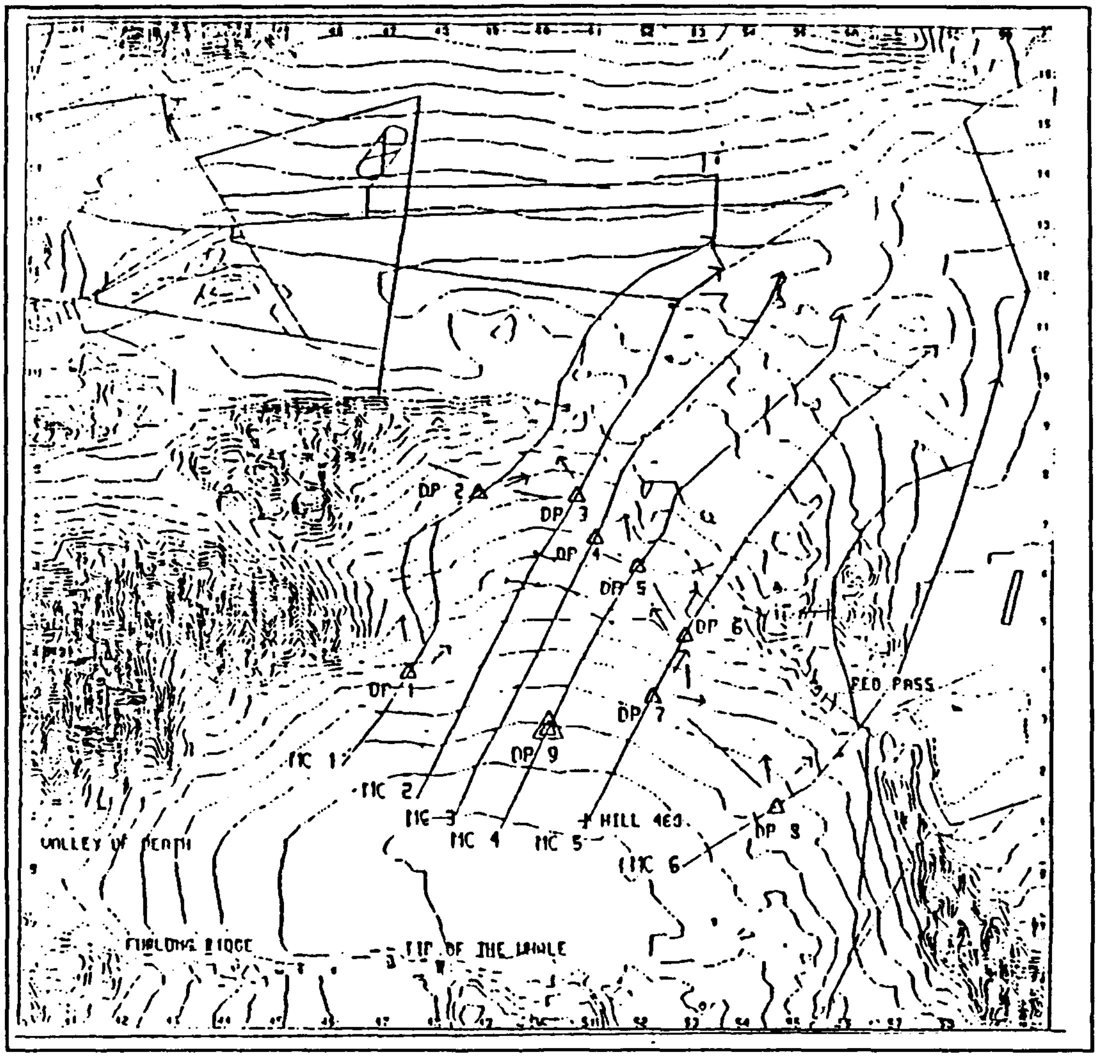

Figure 2. BLUEFOR Decision Support Template

occupy BP 14. Tm Scout will screen along Phase Line (PL) Wendy. At the end of phase one, B Co will move to BP 24 and the two forward infantry platoons will rejoin their parent units.

During phase two, Tm A will defend from BP 22, orienting from target reference points (TRPs) 29 to 27. D Co(-), B Co, and Tm F will defend from BP 25, BP 24, and BP 21, respectively. If the enemy attacks along mobility corridors (MCs) 1, 2, or 3, Tm F will reposition to BP 31, orienting from TRPs 33 to 35. If the enemy attacks along MC 6, B Co will reposition along Route Blue to BP 34, orienting on TRP 37, and D Co(-) will move southwest to a firing line vicinity the center of engagement area (EA) Cuda in order to engage

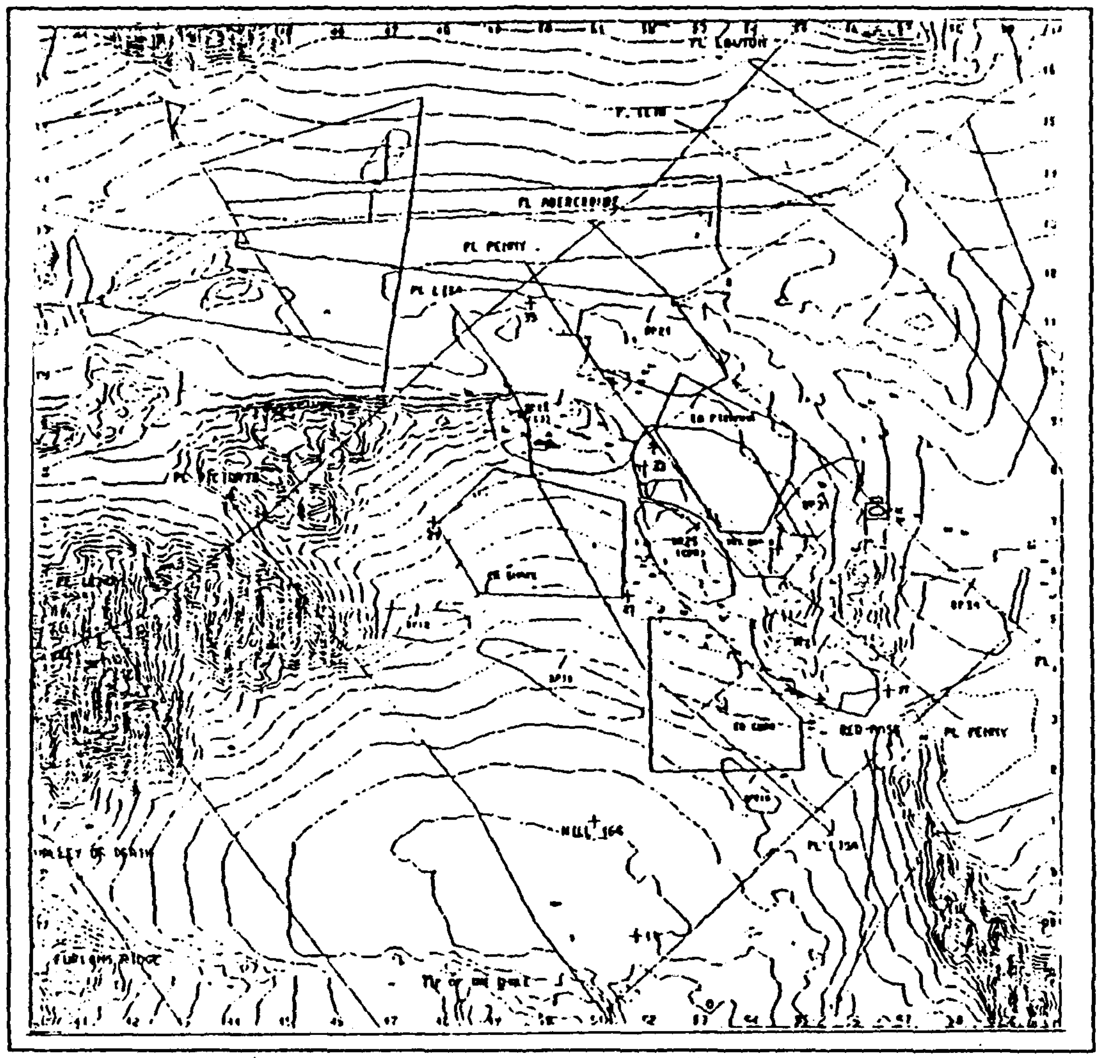

Figure 3. BLUEFOR Task Force Operational Graphics

the second echelon motorized rifle battalion (MRB). The Vulcan Platoon will position in BP 25. The priority for countermobilty was shifted from Tm F and EA Shark, on order EA Piranha to EA Shark and BP 25, on order Tm F. The TF combat trains will locate northeast of EA Piranha. The TF commander will be with D Co(-), the TF operations officer (S-3) will be with Tm A, and the TF executive officer (XO) will be with the tactical operations center (TOC). A task force FRAGO was given in matrix form and is shown in Table 2.

Table 1. BLUEFOR Task Organization

Tm Scout	Tm A	Tm F
Sct Plt	1/A Armor	1/A Mech
2xStingers	2/A Armor	3/A Mech
	2/A Mech	3/A Armor
	2/B Mech	Stinger
B Co	D Co(-)	TF Control
1/B Armor	2/D Armor	Hqs Tk Sec
2/B Armor	3/D Armor	A/--- EN(-)
3/B Armor	1/E AT	1/A/-- EN
Stinger	Vul Plt (DS)	Hvy Mtr Plt

Table 2. BLUEFOR Task Force FRAGO Matrix

PHASE	TM SCT	TM A	TM F	D CO(-)	B CO
RECON/ CTR-RECON	Screen Fwd to PL Wendy Establish OP's	Occupy BP12 Orient from TRP 16-15	Occupy BP21A Orient from TRP 09-23		Occupy BP14 Orient from TRP 15-11
CTR-RECON	ID Enemy Forces/ Main Atk Handover Ctr-Recon Battle to Co B/Fwd Mech Plts	Occupy BP22 Orient from TRP 29-27	Occupy BP21 Orient from TRP 23-26	Occupy BP25 Orient from TRP 28-27 O/O from TRP 26-09	
DEFENSE IN SECTOR	ID Enemy Follow-On Forces/Direction	Fwd Mech Plt Returns Occupy BP22	Fwd Mech Plt Returns Occupy BP21	Be Prep to Flex A Plt Fwd vic TRP 27 or vic 526046	Occupy BP24 Orient from TRP 33-34 O/O from TRP 35-36

b. OPFOR Mission and Concept of Operation

The OPFOR mission and concept of the operation is found only in the video task force after action review (AAR) tape. The OPFOR commander briefly explained his concept and execution in the AAR, but no associated OPFOR graphics or written orders are maintained in the CTC ARI-POM archive.

The mission of the enemy motorized rifle regiment (MRR) was to conduct a regimental attack from positions in contact at 25 0230 hrs. The purpose was to penetrate forward positions, destroy the majority of BLUEFOR combat power, and have enough OPFOR combat power remaining at the objective to conduct a follow-on attack.

The OPFOR concept of the operation was to initially conduct a strong reconnaissance effort by positioning six Division Reconnaissance Teams (DRTs) in the TF sector starting on the night of the 23d and then infiltrating the Regimental Reconnaissance Company (RRC) and two dismounted infantry companies during the night of the 24th. The OPFOR Forward Detachment (Fwd Det), consisting of a reinforced MRB, was to move through the Whale Gap and up to the Red Pass area. The Fwd Det was not to penetrate Red Pass, but establish a firing line short of Red Pass to fix the BLUEFOR team in this vicinity. The main body of the MRR was to attack on two axes: the Valley of Death and the Langford Lake approaches and move to a decision point vicinity Hill 466. The MRR main body would then turn behind the Fwd Det into the least likely avenue of approach, corresponding to the BLUEFOR's MC 5 along the Siberian Ridge and pass the MRR's second echelon through to the final objective to the east.

c. Critical Mission Events

A narrative of mission execution is contained in the video mission summary. Critical timing and attrition information is available in this narrative, which aids in the synchronization of the scenario. Key events are listed below:

23	Night-	First part of counter-reconnaissance battle. The OPFOR has
24	Day	2 of 6 DRTs compromised and 3 T-72s destroyed attempting to secure the Whale Gap. The BLUEFOR has 3 of 5 Scout Bradleys destroyed
24	Night	4 BRDMs and 4 BMPs from the RRC and two dismounted infantry companies attempt to infiltrate TF sector
24	2055	BLUEFOR Scout SC3 killed due to artillery fratricide
24	2400	BLUEFOR defend in sector mission start time
25	0015	2 BMPs and 2 BRDMs destroyed
25	0056	Fwd Det crossed PL Whitley.
25	0136	Lead tank of Fwd Det entered a FASCAM minefield and was destroyed
25	0200	Fwd Det was vicinity the tip of the Whale
25	0225	Fwd Det was vicinity TRP 11 moving northeast and the lead elements of the MRR was vicinity the 37 north-south grid line
25	0245	MRR was vicinity PL Whitley and Tm F in BP 21A began to engage the Fwd Det
25	0247	A32/Tm F killed B23/Fwd Det at a range of 1530 meters
25	0300	MRR was vicinity the tip of the Whale
		B Co was halted southwest of checkpoint (CP) 19

		Tm F and D Co(-) engaging Fwd Det vicinity EA Cuda
25	0330	D Co(-) had lost 5 of 10 tanks and one Improved TOW Vehicle (ITV)
		The Fwd Det was combat ineffective and the MRR was vicinity TRP 9 and 11 beginning to swing northeast on MC 5
25	0400	Lead of MRR was vicinity EA Piranha
		D Co(-), Tm F, and B Co were combat ineffective
25	0430	MRR crossed PL Abercrombie with approximately 60% strength
25	0440	BLUEFOR TF receives change of mission

APPENDIX C: FIVE FACTOR CCD EXPERIMENTAL DESIGN MATRIX

A. DESIGN VALUE NOTATION.

Design Values	-2	-1	0	+1	+1
Real Values	MIN_{factor}	$CP - \delta$	CP	$CP + \delta$	MAX_{factor}

B. LRT MAX RANGE LEVELS.

CCD VALUE	**RANGE HEADINGS**				
-2	0000	500	1000	2000	3000
-1	0000	645	1290	2579	3869
0	0000	750	1500	3000	4500
+1	0000	855	1710	3421	5131
+2	0000	1000	2000	4000	6000

C. DESIGN MATRIX.

The following 2 pages display the design matrix used for the experimental runs. It includes the factorial portion of the matrix (runs 1-32), the center point replications (runs 33-42), and the axial point runs (runs 43-52).

RUN #	LRT/ TOW	LRT/ MBT	MBT RG	TOW RG	LRT RG
1	1	1	1	1	1
2	1	1	1	1	-1
3	1	1	1	-1	1
4	1	1	1	-1	-1
5	1	1	-1	1	1
6	1	1	-1	1	-1
7	1	1	-1	-1	1
8	1	1	-1	-1	-1
9	1	-1	1	1	1
10	1	-1	1	1	-1
11	1	-1	1	-1	1
12	1	-1	1	-1	-1
13	1	-1	-1	1	1
14	1	-1	-1	1	-1
15	1	-1	-1	-1	1
16	1	-1	-1	-1	-1
17	-1	1	1	1	1
18	-1	1	1	1	-1
19	-1	1	1	-1	1
20	-1	1	1	-1	-1
21	-1	1	-1	1	1
22	-1	1	-1	1	-1
23	-1	1	-1	-1	1
24	-1	1	-1	-1	-1
25	-1	-1	1	1	1
26	-1	-1	1	1	-1

RUN #	LRT/ TOW	LRT/ MBT	MBT RG	TOW RG	LRT RG
27	-1	-1	1	-1	1
28	-1	-1	1	-1	-1
29	-1	-1	-1	1	1
30	-1	-1	-1	1	-1
31	-1	-1	-1	-1	1
32	-1	-1	-1	-1	-1
33	0	0	0	0	0
34	0	0	0	0	0
35	0	0	0	0	0
36	0	0	0	0	0
37	0	0	0	0	0
38	0	0	0	0	0
39	0	0	0	0	0
40	0	0	0	0	0
41	0	0	0	0	0
42	0	0	0	0	0
43	2	0	0	0	0
44	-2	0	0	0	0
45	0	2	0	0	0
46	0	-2	0	0	0
47	0	0	2	0	0
48	0	0	-2	0	0
49	0	0	0	2	0
50	0	0	0	-2	0
51	0	0	0	0	2
52	0	0	0	0	-2

APPENDIX D: RANDOM NUMBER GENERATION PROGRAM

A. FORTRAN RANDOM INTEGER PROGRAM.

This program generates a specified number in integer numbers (without replacement) from a uniform distribution within a set of boundaries. The inputs are the seed, the number if desired integers, and the maximum value of the interval (minimum set at 1).

```
      PROGRAM UNIRAND

      INTEGER SEED, B(50),I, J, Y(50,50), L, Z, M
      REAL X,K
      OPEN (UNIT=11,FILE='UNIOUT2')
      DO 19 I=1,50
        DO 18 J=1,50
          Y(I,J)=0
18      CONTINUE
19    CONTINUE
      PRINT *,'ENTER THE SEED'
      READ *, SEED
      M=1
      REWIND (11)
10    PRINT *,'ENTER THE NUMBER OF RANDOM VALUES YOU DESIRE:'
      READ *,L
      PRINT *,'ENTER THE MAX VALUE OF THE INTERVAL:'
      READ *,B(M)
      IF (L. GE. B(M)) THEN
        PRINT *, 'YOU HAVE ENTERED MORE VALUES THAN MAX.'
        GO TO 50
      ENDIF
      K=REAL(B(M))
C     PRINT *, 'YOUR VALUES ARE',L,K
      I=1
20    CALL RANNUM(1, SEED, 1.0,K,0, X)
      Y(M,I)=INT(X)
      IF (I .EQ. 1) GO TO 40
      DO 30 J=1,I-1
        IF (Y(M,J) .EQ. Y(M,I)) GO TO 20
30    CONTINUE
40    I=I+1
      IF (I .LE. L) GO TO 20
      PRINT *,'IF YOU DESIRE ANOTHER RUN, TYPE 1.'
```

```
      READ *,Z
      IF (Z .EQ. 1) THEN
        M=M+1
        GO TO 10
      ELSE
        DO 100 J=1,M
          WRITE (11,*) 'FOR',L,'RANDOM VALUES FROM 1 TO',B(J)
          WRITE (11,45)(Y(J,I), I=1,L)
100     CONTINUE
      ENDIF
45    FORMAT (1X,20(I2,1X))
50    STOP
      END
```

B. SUBROUTINE RANNUM.

This subroutine was written by Professor PAW Lewis, Department of Operations Research, Naval Postgraduate School, to generate random values for given distributions.

```
C_______________________________________________________
      SUBROUTINE RANNUM(DISTN, SEED, RPARM1, RPARM2, IPARM, X)
C_______________________________________________________
C     THIS SUBROUTINE PROVIDES AN INTERFACE WITH THE LLRANDOMII
C     ROUTINES PROVIDED IN THE NONIMSL LIBRARY.  THE PARAMETER
C     REQUIREMENTS AND CALLING PROCEDURES ARE AS FOLLOWS:
C
C     DISTN = DISTRIBUTION TYPE YOU WANT TO SELECT
C           AN INTEGER BETWEEN 1 AND 7
C     SEED = THE RANDOM NUMBER SEED YOU WISH TO USE
C     RPARM1, RPARM2, AND IPARM ARE REAL AND INTEGER PARAMETERS
C       PASSED TO THE ROUTINE WITH MEANINGS WHICH VARY WITH THE
C       TYPE OF DISTRIBUTION YOU DESIRE
C       NOTE: IPARM IS CURRENTLY NOT BEING USED.
C       X = THE RETURNED RANDOM NUMBER, IT IS ALWAYS REAL
C
C     DISTRIBUTION NUMBERS AND THE ASSOCIATED PARM DEFINITIONS:
C
C     1--UNIFORM ON THE INTERVAL RPARM1 TO RPARM2
C     2--NORMAL WITH MEAN RPARM1 AND VARIANCE RPARM2
C     3--EXPONENTIAL WITH RATE RPARM1
C     4--COUCHY WITH A = RPARM1 AND B = RPARM2
C     5--GAMMA WITH SHAPE RPARM2 AND RATE RPARM1
C     6--POISSON WITH RATE RPARM1
C     7--GEOMETRIC WITH P = RPARM1
C
      REAL RPARM1, RPARM2, X
      INTEGER DISTN, SEED, IPARM, N
C
      REAL TEMP, VARIAT(1)
      IF (DISTN.LE.0.OR.DISTN.GT.8) THEN
        WRITE(10, *) 'ILLEGAL CALL TO RANNUM, BAD DISTN'
        STOP
      ENDIF
```

```
C
      GOTO (10, 20, 30, 40, 50, 60, 70), DISTN
C
C     GENERATE A UNIFORM BETWEEN RPARM1 AND RPARM2
10    CONTINUE

      IF (RPARM1 - RPARM2.EQ.0) THEN
        WRITE(10, *) 'ILLEGAL EQUAL RPARMS IN RANNUM'
        STOP
      ENDIF
      IF (RPARM1.GT.RPARM2) THEN
        TEMP = RPARM1
        RPARM1 = RPARM2
        RPARM2 = TEMP
      ENDIF
      CALL LRND(SEED, VARIAT, 1, 1, 0)
      VARIAT(1) = RPARM1 + (RPARM2 - RPARM1) * VARIAT(1)
      GOTO 99
C
C     GENERATE A NORMAL WITH MEAN RPARM1 AND STDDEV RPARM2
20    CALL LNORM(SEED, VARIAT, 1, 1, 0)
      VARIAT(1) = (VARIAT(1) * RPARM2) + RPARM1
      GOTO 99
C
C     GENERATE AN EXPONENTIAL WITH RATE (1/MEAN) RPARM1
30    CONTINUE
      IF (RPARM1.EQ.0) THEN
        WRITE(10, *) 'ILLEGAL ZERO RATE IN RANNUM'
        STOP
      ENDIF
      CALL LEXPN(SEED, VARIAT, 1, 1, 0)
      VARIAT(1) = VARIAT(1) / RPARM1
      GOTO 99
C
C     GENERATE A COUCHY WITH A = RPARM1 AND B = RPARM2
40    CONTINUE
      IF (RPARM2.LE.0) THEN
        WRITE(10, *) 'ILLEGAL COUCHY SPREAD IN RANNUM, B = ',RPARM2
        STOP
      ENDIF
      CALL LCCHY(SEED, VARIAT, 1, 1, 0)
      VARIAT(1) = (VARIAT(1) * RPARM2) + RPARM1
      GOTO 99
C
50    CONTINUE
      IF (RPARM1.LE.0) THEN
        WRITE(10, *) 'ILLEGAL NONPOSITIVE GAMMA RATE IN RANNUM'
        STOP
      ENDIF
      IF (RPARM2.LE.0) THEN
        WRITE(10, *) 'ILLEGAL SHAPE PARAMETER IN RANNUM'
        STOP
      ENDIF
      CALL LGAMA(SEED, VARIAT, 1, 1, 0, RPARM2)
      VARIAT(1) = VARIAT(1) * (1.0 / RPARM1)
      GOTO 99
C
60    CONTINUE
```

```
      IF (RPARM1.LE.0) THEN
        WRITE(10, *) 'ILLEGAL POISSON RATE IN RANNUM'
        STOP
      ENDIF
      CALL LPOIS(SEED, VARIAT, 1, 1, 0, RPARM1)
      GOTO 99
C
70    CONTINUE
      IF (RPARM1.LE.0) THEN
        WRITE(10, *) 'ILLEGAL GEOM PROB IN RANNUM'
        STOP
      ENDIF
      CALL LGEOM(SEED, VARIAT, 1, 1, 0, RPARM1)
      GOTO 99
C
99    CONTINUE
      X = VARIAT(1)
      END
```

C. ASSOCIATED SYSTEM LINE NUMBERS.

RANDOM #	TOW LINE #	MBT LINE #	RANDOM #	TOW LINE #	MBT LINE #
1	36	1	**21**	102	71
2	37	2	**22**	103	72
3	38	52	**23**	104	73
4	39	53	**24**		74
5	40	54	**25**		75
6	41	55	**26**		76
7	42	56	**27**		77
8	43	57	**28**		78
9	44	58	**29**		79
10	82	59	**30**		80
11	83	60	**31**		81
12	84	61	**32**		87
13	85	62	**33**		88
14	86	63	**34**		89
15	95	64	**35**		90
16	97	65	**36**		91
17	98	66	**37**		92
18	99	68	**38**		93
19	100	69	**39**		94
20	101	70			

APPENDIX E: SAS OUTPUT

This APPENDIX contains the SAS output used for the multiple regression analysis, the subsequent regression of the significant variables, and the ANOVA tables for both the RED Kills and BLUE Kills MOEs.

A. SAS OUTPUT - RED Kills.

The following is the SAS output for the RED Kills multiple regression:

```
1                THESIS DATA                    1
                       14:40 MONDAY, MAY 6, 1991
          GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: Y

SOURCE              DF   SUM OF SQUARES      MEAN SQUARE

MODEL               20   2085.94447891       104.29722395
ERROR               31   1059.03629032        34.16246098
CORRECTED TOTAL       51   3144.98076923

MODEL F =           3.05                PR > F = 0.0026

R-SQUARE            C.V.        ROOT MSE          Y MEAN
0.663261         12.1719      5.84486621      48.01923077


SOURCE              DF         TYPE I SS  F VALUE  PR > F

X1                  1      235.22500000    6.89   0.0134
X2                  1      172.22500000    5.04   0.0320
X3                  1        0.62500000    0.02   0.8933
X4                  1        9.02500000    0.26   0.6109
X5                  1     1311.02500000   38.38   0.0001
X1*X1               1       23.20530627    0.68   0.4161
X2*X2               1        2.58349868    0.08   0.7851
X3*X3               1       50.54325739    1.48   0.2330
X4*X4               1        0.00704023    0.00   0.9886
X5*X5               1        2.16787634    0.06   0.8028
X1*X2               1       26.28125000    0.77   0.3872
X1*X3               1        0.28125000    0.01   0.9283
```

SOURCE	DF	TYPE I SS	F VALUE	PR > F
X1*X4	1	11.28125000	0.33	0.5697
X1*X5	1	0.78125000	0.02	0.8808
X2*X3	1	0.03125000	0.00	0.9761
X2*X4	1	101.53125000	2.97	0.0947
X2*X5	1	57.78125000	1.69	0.2030
X3*X4	1	2.53125000	0.07	0.7873
X3*X5	1	75.03125000	2.20	0.1484
X4*X5	1	3.78125000	0.11	0.7416

SOURCE	DF	TYPE III SS	F VALUE	PR > F
X1	1	235.22500000	6.89	0.0134
X2	1	172.22500000	5.04	0.0320
X3	1	0.62500000	0.02	0.8933
X4	1	9.02500000	0.26	0.6109
X5	1	1311.02500000	38.38	0.0001
X1*X1	1	25.66787634	0.75	0.3927
X2*X2	1	1.96787634	0.06	0.8119
X3*X3	1	51.16787634	1.50	0.2302
X4*X4	1	0.00120968	0.00	0.9953
X5*X5	1	2.16787634	0.06	0.8028
X1*X2	1	26.28125000	0.77	0.3872
X1*X3	1	0.28125000	0.01	0.9283
X1*X4	1	11.28125000	0.33	0.5697
X1*X5	1	0.78125000	0.02	0.8808
X2*X3	1	0.03125000	0.00	0.9761
X2*X4	1	101.53125000	2.97	0.0947
X2*X5	1	57.78125000	1.69	0.2030
X3*X4	1	2.53125000	0.07	0.7873
X3*X5	1	75.03125000	2.20	0.1484
X4*X5	1	3.78125000	0.11	0.7416

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	47.75403226	26.26	0.0001	1.81825318
X1	2.42500000	2.62	0.0134	0.92415449
X2	2.07500000	2.25	0.0320	0.92415449
X3	-0.12500000	-0.14	0.8933	0.92415449
X4	0.47500000	0.51	0.6109	0.92415449
X5	5.72500000	6.19	0.0001	0.92415449
X1*X1	-0.88104839	-0.87	0.3927	1.01643443
X2*X2	0.24395161	0.24	0.8119	1.01643443
X3*X3	1.24395161	1.22	0.2302	1.01643443
X4*X4	-0.00604839	-0.01	0.9953	1.01643443
X5*X5	-0.25604839	-0.25	0.8028	1.01643443
X1*X2	0.90625000	0.88	0.3872	1.03323613
X1*X3	-0.09375000	-0.09	0.9283	1.03323613
X1*X4	-0.59375000	-0.57	0.5697	1.03323613
X1*X5	-0.15625000	-0.15	0.8808	1.03323613
X2*X3	0.03125000	0.03	0.9761	1.03323613
X2*X4	1.78125000	1.72	0.0947	1.03323613
X2*X5	1.34375000	1.30	0.2030	1.03323613
X3*X4	0.28125000	0.27	0.7873	1.03323613

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
X3*X5	-1.53125000	-1.48	0.1484	1.03323613
X4*X5	0.34375000	0.33	0.7416	1.03323613

B. SAS OUTPUT - BLUE Kills.

The following is the SAS output for the BLUE Kills multiple regression:

1 THESIS DATA 1

14:36 MONDAY, MAY 6, 1991

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: Y

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	20	405.26761787	20.26338089
ERROR	31	392.50161290	12.66134235
CORRECTED TOTAL	51	797.76923077	

MODEL F = 1.60 PR > F = 0.1167

R-SQUARE	C.V.	ROOT MSE	Y MEAN
0.508001	5.8964	3.55827800	60.34615385

SOURCE	DF	TYPE I SS	F VALUE	PR > F
X1	1	90.00000000	7.11	0.0121
X2	1	0.40000000	0.03	0.8601
X3	1	19.60000000	1.55	0.2228
X4	1	3.60000000	0.28	0.5977
X5	1	152.10000000	12.01	0.0016
X1*X1	1	9.91737892	0.78	0.3830
X2*X2	1	3.33399471	0.26	0.6115
X3*X3	1	0.10406404	0.01	0.9283
X4*X4	1	0.09712644	0.01	0.9308
X5*X5	1	2.86505376	0.23	0.6376
X1*X2	1	3.12500000	0.25	0.6228
X1*X3	1	24.50000000	1.94	0.1741
X1*X4	1	50.00000000	3.95	0.0558
X1*X5	1	3.12500000	0.25	0.6228
X2*X3	1	3.12500000	0.25	0.6228
X2*X4	1	28.12500000	2.22	0.1462
X2*X5	1	2.00000000	0.16	0.6938
X3*X4	1	2.00000000	0.16	0.6938
X3*X5	1	6.12500000	0.48	0.4919
X4*X5	1	1.12500000	0.09	0.7676

SOURCE	DF	TYPE III SS	F VALUE	PR > F
X1	1	90.00000000	7.11	0.0121
X2	1	0.40000000	0.03	0.8601
X3	1	19.60000000	1.55	0.2228
X4	1	3.60000000	0.28	0.5977
X5	1	152.10000000	12.01	0.0016
X1*X1	1	9.79838710	0.77	0.3858
X2*X2	1	3.61505376	0.29	0.5969
X3*X3	1	0.06505376	0.01	0.9433
X4*X4	1	0.06505376	0.01	0.9433
X5*X5	1	2.86505376	0.23	0.6376
X1*X2	1	3.12500000	0.25	0.6228
X1*X3	1	24.50000000	1.94	0.1741
X1*X4	1	50.00000000	3.95	0.0558
X1*X5	1	3.12500000	0.25	0.6228
X2*X3	1	3.12500000	0.25	0.6228
X2*X4	1	28.12500000	2.22	0.1462
X2*X5	1	2.00000000	0.16	0.6938
X3*X4	1	2.00000000	0.16	0.6938
X3*X5	1	6.12500000	0.48	0.4919
X4*X5	1	1.12500000	0.09	0.7676

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	59.88709677	54.10	0.0001	1.10692872
X1	-1.50000000	-2.67	0.0121	0.56261315
X2	-0.10000000	-0.18	0.8601	0.56261315
X3	-0.70000000	-1.24	0.2228	0.56261315
X4	0.30000000	0.53	0.5977	0.56261315
X5	-1.95000000	-3.47	0.0016	0.56261315
X1*X1	0.54435484	0.88	0.3858	0.61879197
X2*X2	-0.33064516	-0.53	0.5969	0.61879197
X3*X3	0.04435484	0.07	0.9433	0.61879197
X4*X4	0.04435484	0.07	0.9433	0.61879197
X5*X5	0.29435484	0.48	0.6376	0.61879197
X1*X2	-0.31250000	-0.50	0.6228	0.62902063
X1*X3	0.87500000	1.39	0.1741	0.62902063
X1*X4	1.25000000	1.99	0.0558	0.62902063
X1*X5	-0.31250000	-0.50	0.6228	0.62902063
X2*X3	-0.31250000	-0.50	0.6228	0.62902063
X2*X4	0.93750000	1.49	0.1462	0.62902063
X2*X5	0.25000000	0.40	0.6938	0.62902063
X3*X4	0.25000000	0.40	0.6938	0.62902063
X3*X5	-0.43750000	-0.70	0.4919	0.62902063
X4*X5	0.18750000	0.30	0.7676	0.62902063

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