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Evaluation of the MOSCOW Low Resolution
Land Combat Model

by

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Evaluation of the MOSCOW Low Resolution Land Combat Model

by

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From p. 1)

ABSTRACT

This thesis assesses the methodology and input sensitivity of the Method of Screening Operational Concepts of Warfare (MOSCOW) model. This assessment illuminates the fundamental assumptions underlying the model's methodology and evaluates the model's sensitivity to small percentage changes of inputs. Results provide an estimate of MOSCOW's limitations, suggesting which parts of the model may need to be improved.

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The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are 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.

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I. INTRODUCTION

Recent research conducted by the RAND Corporation for the U.S. Army has resulted in the development of a new low resolution land combat model. This model, Method of Screening Operational Concepts of Warfare (MOSCOW), is designed to allow users to evaluate the differences between various war fighting concepts. Briefly stated, this model uses a Lanchesterian square law formulation to compute the quantity of Blue force resources required to secure a specified attrition of Red forces in a given combat scenario. The central features of the model are described in RAND report R-3643-A, A New Approach for the Design and Evaluation of Land Defense Concepts. This report provides a brief explanation of the model's general methodology and how such a model can be used to aid in war fighting concept analysis.

The traditional aim of land combat modeling is to answer the question, "Who will win the Battle?" The approach used to answer this question usually combines knowledge of a battle's initial conditions (force levels, doctrine, weapons' characteristics), the attrition relationships between weapons, and, for each side, the set of conditions or condition that constitutes losing. The Vector-In-Commander model, currently the Army's primary modeling tool to address force analysis issues, uses this approach. MOSCOW, by contrast, attempts to answer the question, "How much friendly force is needed to win?" To accomplish this, MOSCOW combines information about a specific scenario with a description of the combat capabilities of an individual friendly combat unit. Scenario information includes the size, organization, and weapons characteristics of the opposing force, effects of the environment and terrain, and the attrition relationships between enemy and friendly weapons. Friendly forces are described only in terms of an "average" combat unit. Such units are typically one or two echelons smaller than the total size of the opposing force. MOSCOW uses this information to determine the number of such friendly units required to destroy a sufficient quantity of the opposing force to produce victory. Victory is defined as the amount of attrition which friendly forces must impose on the enemy.

In its current version, MOSCOW has several desirable features. First, it is implemented as a LOTUS 1-2-3 spreadsheet. Entering or modifying any of the approximately 350 input parameters, running the program, or capturing the results of model runs requires a personal computer and a minimum of experience with LOTUS. Model run time is on the order of seconds. Most favorable, however, is the intuitive appeal of the model's output which simply lists the amount of resources needed for the friendly, or Blue, force to accomplish its tactical objective. The advantage of this approach is that it allows for simple comparisons between different sets of model inputs. Where one set of inputs may, for example, require nine friendly units to achieve victory, another set may require ten. Thus, MOSCOW's outputs can be easily ranked, allowing the most favorable (e.g., those requiring the fewest resources) to be immediately identified. An example of the output screen produced by the current version of MOSCOW is shown in Table 1. This example was

TABLE 1

Output Display Screen from MOSCOW

BLUE REQUIREMENTS FOR SUCCESS

CATEGORY	RESOURCE	AMT REQD	MAX AVAIL.	AFFORD-ABLE?	REQD/AVAIL
TOTAL MVR	STANDING	35.1 mvrs	21.8	*NO*	161%
NEEDED	ST. + REPL	39.1 mvr+eqvs	30.4	*NO*	129%
	TOTAL	48636 pers	250000	YES	19%
CASUALTIES	AVG/DAY: %	19384 pers/day	5000	*NO*	388%
	PEAK/DAY/MVR	35.7% of mvr (DEF)	15.0%	*NO*	238%
REPL MMVR-EQVS	MAX REPL	4.0 mvr-eqvs	8.6	YES	47%
NEEDED	REPL/DAY	1.60 mvr-eq/d	0.29	*NO*	561%
		(MIN=	2.4)	YES	
REPLACEMENT	PERSONNEL	23923 pers	200000	YES	12%
STOCKS NEEDED	VEHICLES	5630 veh	12000	YES	47%
1.4E+05	AMMO	9.5E+04 tons	7.0E+05	YES	14%
(Red Ammo)	POL	4.3E+04 tons	5.0E+06	YES	1%
	OTHER	1.1E+04 tons	1.0E+05	YES	11%
	LIFT	3.8E+05 tons	1.5E+06	YES	25%
	RESOURCE	AMT REQD	AMT AV	AFFRDBL?	REQ/AV
AVERAGE DAILY	PERSONNEL	9534.5 pers/d	4000.0	*NO*	238%
REPLACEMENTS	VEHICLES	2243.9 veh/d	400.0	*NO*	561%
5.5E+04	AMMO	3.8E+04 tons/d	2.0E+04	*NO*	189%
(Red ammo)	POL	1.7E+04 tons/d	4.0E+05	YES	4%
NEEDED	OTHER	4.5E+03 tons/d	4.0E+03	*NO*	111%
	LIFT	1.5E+05 tons/d	1.1E+04	*NO*	1379%
SUPPLY & HQs	#S VEHS	2.1E+05 # vehs	1.0E+05	*NO*	208%
NEEDED	# HQs	6.3 # HQs	8.0	YES	78%
		ACHIEVED	DESIRED		
	DELAY	1.96 days	3.00	*NO*	153%

produced by inputs representing the defense of Europe.[1] In this situation, friendly units are measured in terms of divisions (approx. 1400 combat vehicles) and the success objective is defined as the destruction of 80% attacking enemy divisions (each enemy division contains approximately 1100 combat vehicles). Note that this output is divided into three parts. The first part reports the total friendly force requirements needed to achieve success. The second part summarizes total logistic and personnel cost. The last section is a report of the average daily logistic and personnel cost. The "delay" output measures the additional time enemy forces will need to achieve a specified penetration into friendly territory due to combat with friendly units. This penetration limit may be seen as the enemy force objective. In this example, the penetration limit is 30 kilometers. An explanation of the many abbreviations used in Table 1 is in Appendix A.

Although this type of output substantially eliminates the need for data reduction or post-processing common to other higher resolution models[2] which rely on killer-victim score boards, sensitivity analysis requires multiple model runs.

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[1] Table 1 shows an output screen for inputs proposed by Romero [Ref. 1] which depict a scenario for the defense of Europe using MOSCOW version MO031188. This paper investigates the performance of this version of MOSCOW.

[2] The Vector-In-Commander (VIC) model stands in stark contrast to MOSCOW in this regard.

This is required since MOSCOW's output is the result of completely deterministic calculations. The current version contains one method of recording the results of such experiments for later comparisons.

A. OBJECTIVE

The central aim of this paper is to provide an assessment of MOSCOW for use as a low resolution land combat model. This assessment is based both on an analysis of the general methodology used in MOSCOW and the results of experiments. These experiments explore model sensitivity by examining the difference in MOE's produced by various inputs. Results focus on MOSCOW's limitations and possible improvements.

B. SCOPE OF ANALYSIS

This analysis has two distinct parts. The first part is an investigation of MOSCOW's modeling methodology. This investigation indicates the circumstances in which underlying methodology may be incompatible with a potential combat scenario. The second part explores the sensitivity of the model to changes in a subset of fundamental input parameters. This exploration illuminates where the natural variability of inputs may produce instability or unexpected results. Such relationships are a point of concern in any model verification effort. These sensitivity experiments provide an initial look at model verification by illuminating obvious modeling errors.

II. OVERVIEW OF MOSCOW'S METHODOLOGY

MOSCOW is a computationally complex model which ultimately represents a real battlefield by a series of simple battles between appropriate numbers of two different combat systems or forces. Consider a real world conflict between two sides, Red and Blue, where each combatant uses a large number of different types of direct and indirect fire systems. The first step in using MOSCOW is to quantitatively arrive at a set of input values which express not only the average lethality, mobility, vulnerability, and logistical attributes for both Red and Blue forces, but also incorporates the effects of morale, doctrine, terrain, and the synergism which may exist between weapons systems. This step is not trivial. Training and Doctrine Analysis Command, Ft. Leavenworth draft technical report, A Methodology for Estimating MOSCOW Inputs, proposes one method using harmonic averaging of weapon system and force characteristics to compute input value estimates[3]. Appendix B gives a brief description of the various types of inputs and lists two sets of unclassified inputs generated using this procedure. While this reference gives a complete description of specific inputs, the central feature of MOSCOW

[3] This report also discusses assumptions implicit to the input estimation process and provides two unclassified sets of inputs which depict a US Corps employing airland battle doctrine in both attack and defend scenarios on NORTHAG terrain.

is the simplicity of the methodology used to construct an attrition model. This model incorporates the contributions of direct fire weapons, indirect fire support means, and attacking aircraft (including helicopters and fixed wing).

A. FUNDAMENTAL ASSUMPTIONS IN MOSCOW

One important result of the input estimation process is the formulation of "average" combat vehicle attributes for Red and Blue. These values represent an abstraction from reality, expressing the operational attributes expected from a myriad of real weapon systems in a single vehicle. Another important result of input estimation is the aggregation of direct and indirect fire attributes of maximum range, rate of fire, and lethality. This is important since these quantities define the rate of attrition a force is able to inflict on its opponent during battle. Although the combination of both direct and indirect fire components in an attrition model can be modeled using a heterogeneous system of differential equations [Ref. 2], MOSCOW uses the following assumptions that:

1. The rate at which targets are susceptible to attack by indirect fire systems is constant throughout the battle.

2. For each side, the proportion of direct and indirect fire systems as a fraction of the total force remains constant throughout the battle.

These assumptions reduce a complex heterogeneous formulation to the simpler square law case[4]. The viability of these assumptions is not addressed in the existing description of MOSCOW's methodology[5].

The simplification to a square law formulation has the advantage of an explicit solution [Ref. 2]. An alternative method would be to use a Helmbold formulation [Ref. 3] of the form:

$$dx/dt = -a\,(x/y)^{1-w}\,y \qquad (1)$$

$$dy/dt = -b\,(y/x)^{1-w}\,x \qquad (2)$$

This method would require a numeric solution and necessitate a significant programming effort to implement in the current version of MOSCOW[6]. Its advantage, however, is that the relationship between the direct and indirect portions

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[4] Mathematical details of how this simplification works are in Appendix C.

[5] In fact, these assumptions are not directly discussed. Limitations suggested by Romero (section 4.2.1) indicate that MOSCOW is suited only to those situations where a sufficiently large number of units (at least 3 - 5) are in combat long enough to establish a relatively constant tempo of combat activities.

[6] Recoding would be required to replace closed form solutions of the square law formulation with a subprogram which calculates a numerical approximation. Since such methods typically require iterative calculation, incorporating this change in the current version of MOSCOW will be difficult because MOSCOW already requires a separate iterative procedure and only one such procedure can be explicitly coded into LOTUS.

of the battle can be examined directly by varying the parameter, w, which is an exponential scaling parameter. One way to obtain values for the attrition rate coefficients, a and b, is to aggregate the results of higher resolution models. In any event, setting w = 1 reduces the formulation to the square law case while w = 1/2 approximates the linear law case. However, Taylor, [Ref. 4] shows that estimating this exponential parameter is difficult for any given scenario. MOSCOW currently claims to provide a similar capability based on an exponential change in the form of the time dependent solution to the square law formulation [Ref. 1]. As shown in Appendix D, this change produces an attrition relationship which is not equivalent to the square law case. Not explained further by Romero, it is apparently a heuristic technique which can be used to change the pace of attrition.

B. ACTIVITY CYCLE CONSTRUCTION

MOSCOW uses an activity cycle concept to describe the various related activities of Red and Blue forces. As expected, these activities are not symmetric between attacker and defender. Table 2 lists the fifteen activities used in the current version of MOSCOW.

TABLE 2. List of MOSCOW Activity Cycle Events

Defend Activities	Attack Activities	Common Activities
Prepare defenses	Move to wpn range	Survey and Reconnoiter
Defend	Attack (Initial)	Delay for orders
	Attack (Reinforced)	Disengage
	Reclose	Reconstitute
		Move to exchange point
		Load supplies
		Repair
		Rest
		Move to standby position

A potential criticism of this methodology is that it is ill suited to describe the combat processes of large organizations (corps/division) which are doctrinally committed to continuous combat operations. MOSCOW eliminates this problem by defining activity cycles in terms of the time an individual combat system can expect to spend in each activity event. This avoids the problem of trying to define the length of a division's attack event, or, with even greater absurdity, trying to decide on the distance an entire division must artificially travel to resupply even though such supplies are doctrinally brought forward to units in contact with the enemy.

C. AIR SUPPORT

MOSCOW uses a simple method to describe air support in a land combat scenario. This method avoids the use of a Lanchester type formulation by assuming that the attrition rate per sortie is constant. The total number of sorties flown is computed directly from user supplied inputs of the total number of aircraft available, attrition rate per sortie, and the sortie rate[7]. Vehicle attrition which results from close air support (CAS) and air interdiction (AI) is assumed to be proportional to the total number of sorties flown.

To eliminate difficulties in linking the air and ground portions of the model, the initial numbers of Red and Blue ground combat systems are lowered by the attrition effects of air attacks during the entire battle[8]. Using these revised force levels, the attrition produced by ground combat is calculated using the square law relationships previously discussed. While this partition of attrition calculations obviously limits MOSCOW's capacity to model many possible methods of employing air support, the model provides a certain flexibility in that support can be partitioned between CAS and AI with further allocations to vehicle attrition, imposing delay, or disruption of enemy command, control, and communication capabilities.

D. HEADQUARTERS ARTILLERY

Although MOSCOW aggregates the effects of indirect fire systems into the direct fire battle by using the simplifying assumption detailed in Appendix C, the model attempts to account for counterbattery fire, artillery attacks on enemy

[7] See Appendix E

[8] This methodology avoids the timing problems which can result from the linkage of air and ground battle models [Ref. 5].

command and control installations, and long range attacks on troop concentrations. This is accomplished by assuming a specified amount of destruction or disruption is inflicted for every ton of ammunition fired by "headquarters artillery". These units represent those which provide indirect fire support to the battle but are not subject to the battle attrition. Attrition effects, as in the case of those caused by air attacks, are subtracted from initial force levels used in the subsequent Lanchester ground attrition calculations. Disruption of command and control is accomplished by increasing factors which result in lengthening a unit's "delay for orders" activity event and thus slowing the pace of the battle.

As a consequence of this methodology, the real combat systems represented by "Headquarters artillery[9]" do not enter into any attrition calculations. This is a result of the square law simplification which leaves no possibility of explicitly partitioning indirect fires between attacks on enemy headquarters, fire support means, or maneuver forces. Because of this methodology, the sets of inputs listed in Appendix B which refer to "Headquarters artillery" are set to zero, thus removing this class of inputs from the model.

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[9] Romero suggests multiple rocket launcher systems can be described in this way. [Ref. 1, sec A-1.7]

E. SIMULTANEITY

MOSCOW is essentially a system of simultaneous equations which, when solved iteratively, converge to a solution. The need for iterative calculations stems inherently from the model's structure in three ways[10]. First, combat is initiated when enough combat power on each side is massed to achieve an engagement threshold determined by the force ratio requirements of both Red and Blue. The time needed to mass this combat power is assumed to be inversely proportional to the density of the respective forces. Since the density of the Blue force is a function of the model's output, the model is self referential. Additionally, since an increase in the number of Blue units results in a proportional increase in force density, which in turn decreases the time required to mass sufficient Blue forces, the result is a subsequent decrease in the number of Blue units required. Thus, the system converges. The same type of relationship holds for combat activities which delay attacking units.

Combat events, such as air attacks directed against an attacking force, typically delay an attacker's advance. The amount of delay imposed on an attacker in a given time period tends to decrease as the defending force is attrited. But any event which serves to increase the duration of the battle will, necessarily, allow more time for the defender to be

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[10] See Romero sections 4.3.1 and 4.3.4

attrited, resulting in a decrease of the battle's duration. Thus, this system must converge to a point which balances the overall battle duration and force levels.

Lastly, MOSCOW's definition of tactical mobility establishes the "average" engagement distance which scales the lethality coefficients used to compute attrition. As the duration of an engagement increases, the closure of forces results in a decrease in the average engagement distance with the result that lethality is increased. Hence, the length of the battle decreases. This system must also converge as in the previous cases.

The important consequence of simultaneity is that model output is made more accurate by increasing the number of recalculations performed on a given set of inputs. The number of recalculations for any given level of accuracy must be established by experiment[11].

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[11] Romero suggest 12 - 15 iterations are sufficient.

III. ASSESSMENT OF METHODOLOGICAL LIMITATIONS

MOSCOW's methodology limits its suitability to accurately represent certain combat scenarios.

A. ANNIHILATION OF FORCES CANNOT BE APPROACHED

Stochastic models which attempt to account for randomness in combat are known to produce results which differ from otherwise equivalent deterministic modeling formulations[12]. These differences appear in square law attrition processes when two side have approximate parity (equality terms of numbers and lethality) or when one side approaches a point of annihilation. In the first case, parity of forces will result in MOSCOW's underestimating the length of a battle [Ref. 2]. Although this parity is unlikely in attack scenarios (logically, rational doctrine precludes attack with little hope of victory), it is possible, perhaps common, in the defense[13]. In MOSCOW, however, any discrepancy between deterministic and stochastic results should be minimized because actual battle attrition occurs in only a small

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[12] See Hartman, sec F.6

[13] Historical examples from World War I suffice to make this point.

fraction of the total campaign length.[14] Thus, this case is of little concern.

In the second case, where one side is annihilated, Hartman [Ref 2, sec F-6] demonstrates that a deterministic square law model will overestimate the winning force size while underestimating the size of the losing force. Furthermore, an annihilation condition would violate an assumption of constant "area fire" target availability[15]. Because this limitation is fundamental to it's underlying formulation, MOSCOW should not be used in such circumstances. The point where annihilation effects become serious, however, is unknown. This is an area for further research.

B. MINIMAL LINKAGE OF AIR-GROUND BATTLE

Because attrition of ground forces produced by air attacks is only a function of the total number of sorties, MOSCOW cannot directly account for any synergism between air and ground forces. Within a given number of sorties, only questions concerning allocation between close air support and air interdiction missions can be addressed. If the question to be answered involves trying to determine the "best"

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[14] See Romero, Appendix B, Sec 2. Romero observes that, historically, units spend proportionally little time engaged in actual combat.

[15] See Appendix B.

allocation, MOSCOW is ill suited to provide answers since it has no mechanism for optimization[16].

C. CONSTANT PROPORTION OF DIRECT AND INDIRECT FIRE SYSTEMS

As shown in Appendix C, the reduction of a complex attrition processes between direct and indirect fire systems requires the simplifying assumption that such attrition leaves the proportion of direct and indirect fire systems constant throughout the battle. The limitation this assumption places on the use of MOSCOW is unknown. The possibility exists, however, that a battle process which results in wide variation of this proportion will not be accurately modeled in some instances. This is another topic for further investigation.

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[16] See Romero Sec IV.

IV. ANALYSIS FOR ASSESSING MODEL PERFORMANCE

In order to assess the performance of the current version of MOSCOW, the sensitivities exhibited by the model to changes in various inputs were calculated from the results of factorial experiments. These results were examined using two criteria: the magnitude of change the variation of an input produces in specific measures of effectiveness, and whether or not the direction of the resulting change agrees with intuition. Although the interpretation of these results does not represent a formal verification of MOSCOW, it does illuminate which portions of the model seem to perform according to expectation and which areas may contain obvious errors.

A. FUNDAMENTAL ASSUMPTIONS

This analysis relies on an assumption that a suitable low resolution land combat model will exhibit one basic characteristic. This characteristic is that, all other things being equal[17], a small change in one force attribute or scenario circumstance will produce a correspondingly small change in the amount of force attrition which results from combat. This assumption is reasonable in that it agrees with

[17] This is essentially the situation in MOSCOW, where the process of input estimation effectively fixes the tactics and organizations of the combatants.

intuition. Suppose, for example, that the lethality of direct fire weapons increases by a small increment because of a technological improvement. With no change in tactics, a tremendous increase in combat capability would be unexpected. It would be far more likely to observe some incremental improvement in combat effectiveness, making the opposing force a "little" easier to kill. A similar argument can be made for an incremental decrease of a force attribute. As applied to MOSCOW, this reasoning suggests that small changes in input variables should produce correspondingly small changes in the number of Blue forces needed to attain a specified attrition of Red.

This reasoning implies a general measure of MOSCOW's overall suitability is to assess its sensitivity to small changes in inputs. This approach requires quantitative definitions be assigned to the terms "sensitivity" and "small changes". To this end, a small input change is defined[18] as one which does not alter the level of the input by more than 10%. Similarly, a model output measure of effectiveness is considered "sensitive" with respect to a specific input variable if changing the level of the input by a given proportion produces a change in output of equal or greater

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[18] This definition is not purely ad hoc. It is consistent with current U.S. Army readiness classifications which consider a unit "fully mission capable" if it possesses 90% or more of its authorized strength in personnel and equipment.

proportion. For example, if a 10% change in an input results in a 10% or greater change of an output, the output measure is "sensitive" to the input variable at the 10% level.

A further possibility is that the effects of varying two or more inputs may interact in combination to change the levels of output measures of effectiveness. If inputs are varied in the same proportion, a reasonable definition of sensitivity is to call an output "sensitive" to the interaction of inputs if the magnitude of the resulting change is equal to or greater than the proportional changes in the inputs which produced the interaction[19]. Thus, if two inputs are varied by 10% and the resulting interactions produce a change in output which is equal to or greater than 10%, the output is considered "sensitive" to the interaction of these inputs at the 10% level.

B. FACTORIAL EXPERIMENT DESIGN

One well known technique which examines the effects of varying two or more inputs is to use experiments with a factorial design. These methods are well understood and easily applied to experiments with MOSCOW because, as a completely deterministic model, questions concerning the experimental significance of effects are irrelevant due to the fact that multiple model runs using identical inputs will

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[19] This definition agrees with the way levels of interaction are computed in factorial experiments. See Davies, section 7.33.

produce identical results. Thus, the natural variation of experimental results, common to "real world" or stochastic processes, never occurs and analysis of variance cannot be performed. The use of a factorial design with this simplification reduces to a procedure for calculating the main effects of input variables and their associated interactions.

Of all possible designs for factorial experiments, the simplest way to compute both main effects and interactions of inputs is using a 2^n factorial design [Ref. 6:pp. 257]. This method examines the effects of varying n inputs. Each input takes one of two values: a lower, or base level, and a higher level. By examining the effects of all possible combinations of input levels, the main effect of each input can be calculated by finding the difference between the average model output when an input is held at a high level and the average observed at lower input levels. For two different inputs, A and B, the interactions between A and B can be measured by computing the difference in the effect of A when B is at a higher level, and the effect of A when B is at a lower level[20]. Details of this method are in Appendix F.

C. ADVANTAGES AND LIMITATIONS OF 2^n FACTORIAL DESIGN

As shown by Davies [Ref. 6, sec 7.27], the principle advantage of a factorial design is maximum efficiency when compared to other methods. Complete factorial experiments

[20] See Davies, Section 7-44, p. 259-260

such as a 2^n design are free from the confounding of interactions found in partial designs. The fundamental limitation imposed by a 2^n design is that it involves performing a number of experiments which rises exponentially with the number of variables. Additionally, the algorithm used to compute main effects and interactions has complexity $O(2^n)$. In a practical sense, this complexity means that computation time and computer memory requirements increase by a factor of 2^n as the number of inputs increase. This fact limits the number of variables which can be considered in such an experiment using the model's current LOTUS format and a Z-248 computer to about ten input variables[21].

D. GROUPING OF INPUTS FOR EXPERIMENTATION

The two sets of inputs found in Appendix B represent two completely different scenarios which use different scales of resolution. The Attack scenario is fought with Brigade/Regiment sized units (approx 300 vehicles per unit) while the Defense scenario is an engagement between Divisions (approximately 1000 vehicle per unit). To see if the sensitivity of MOSCOW's inputs appears to be relatively consistent across these two scenarios and two scales, 12 factorial experiments were performed on each scenario using corresponding inputs. To meet the limitation of no more than

[21] Using MOSCOW's LOTUS programming format, a 2^{10} experiment requires approximately 18 hours of computing time with a Zenith 248 series personal computer.

ten input variables per experiment, input groups were chosen in an ad hoc attempt to find large interactions. For each scenario, experiments were generally partitioned between Red and Blue with separate experiments on groups of logically related input variables such as weapon attributes, logistic/maintenance constraints, battle scaling inputs, unit description, and inputs related to activity cycle construction. Additionally, one experiment dealt with what appear to be critical scenario variables such a the length of time each day usable for combat and the number of Red units allowed to survive. This last input defines the Blue force success criteria. A complete listing of input variables used in each experiment is in Appendix G.

E. SELECTION OF MODEL OUTPUTS USED IN VARIABLE COMPARISON

The question of which model outputs are the "best" to use as a means of evaluating the effects of changes in model inputs is difficult because existing documentation is silent on this issue. For the lack of a better method, it seems reasonable to use outputs which most directly result from MOSCOW's underlying attrition and activity cycle algorithms because the inherent sensitivity of these algorithms is the issue which bears on the model's overall suitability. Outputs which are a direct measure of Blue's force requirements clearly meet this criteria. In MOSCOW, this total force requirement number is expressed as the sum of two values: the number of Blue units required at the start of combat, and the number of Blue units required as reinforcements[22]. Since these two outputs are obviously basic to the model's purpose, their selection is a logical choice. Two other outputs from MOSCOW's supplementary calculations also meet this criteria since they are a direct measure of activity cycle calculations. These outputs measure the number of Attack and Defend cycles Blue forces are able to successfully execute during a battle. Lastly, one of MOSCOW's supplementary outputs gives the ratio of Red to Blue forces required to meet Blue victory conditions. Since such ratios are a commonly used measure of force effectiveness, this output was selected because of its familiarity[23].

Each of these five outputs are direct results of attrition and activity cycle calculations. Other outputs, notably those dealing with personnel, fuel, and ammunition requirements, are

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[22] Romero refers to initial Blue force requirements as "standing" Blue units while follow on forces are called "replacements"

[23] This familiarity is expressed in two ways. First, force ratio attrition models use the ratio of fire power indices as a measure of the relative combat power in a battle (see Hartman, Chapter 4). Although MOSCOW does not use this technique, such a ratio measure is part of folklore from earlier ATLAS and IDAGAM models. The concern with force ratio in terms of numbers of weapons is also a common measure used by Soldiers to assess the relative strength of forces in a battle. This is the interpretation used in MOSCOW.

not computed by attrition calculations[24]. As such, none of these outputs were used in sensitivity experiments. However, as more information about MOSCOW's algorithms becomes available, some of these outputs may prove to be better measures of input sensitivity than those chosen for this investigation.

F. MODEL ITERATION REQUIREMENTS

A consequence of the simultaneity inherent to MOSCOW is that successive spreadsheet recalculations (model iterations) produce a convergence of model outputs to unique values which are a function of the inputs. The practical problem the user faces is to determine how many recalculations are sufficient to produce "adequate" convergence. By adequate is meant the convergence necessary to produce results with a level of accuracy specified by the model user.

For the investigation of input sensitivity, the minimum number of recalculations sufficient for convergence were found experimentally for both Attack and Defend scenarios. Adequate convergence was defined as the number of recalculations beyond which any additional recalculation will change the number of "Standing" Blue units required by less than half of one Blue combat vehicle. This definition of adequate convergence is sufficient to insure model resolution to the level of an

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[24] The model developer, Phil Romero, confirmed this interpretation of the secondary nature of logistic requirements calculations during discussions on 15 April 1988.

individual Blue combat vehicle. While this resolution may be excessive, especially for battles involving hundreds of combat vehicles, it is the highest level of resolution which makes any practical sense[25]. Appendix H contains a description of the experimental procedure used to find the iteration requirements for both scenarios. The results of these experiments suggest that 21 recalculations will produce adequate convergence in the Attack scenario while the Defense scenario needs only 15 recalculations.

G. IMPLEMENTATION OF A 2^n FACTORIAL EXPERIMENT WITHIN MOSCOW

Programming factorial experiments within MOSCOW's LOTUS spreadsheet format was done using LOTUS macro commands. The code implementing a 2^n experiment was imbedded in a sufficiently large range of empty cells. This program addition contains three main sections. The first section computes the difference between an experimental variable's upper and lower levels. The second section consists of a series of nested loops which insure the levels of desired inputs are varied to produce all input level combinations specified by the factorial design. This section also writes a table of results which records the level of each experimental variable and the corresponding value of the five outputs for each experimental trial. The last section writes

[25] Since the size of a Blue unit is naturally expressed as a whole numbers of combat vehicles, resolution in model outputs beyond one vehicle makes no sense.

the results table to an output file for later analysis. Details of this macro coding are in Appendix I.

The computation of main effects and interactions was done by first converting the tabular results produced by factorial experiment macros from LOTUS spreadsheet format to one which could be read directly by an APL*PLUS interpreter. This was accomplished using the file conversion facilities within the STATGRAPHICS statistical software package. Main effects and interactions were computed using an interactive APL function which implements the algorithm in Appendix F. A listing of this function is in Appendix J.

V. RESULTS OF SENSITIVITY EXPERIMENTS

A. MAGNITUDE OF MODEL INPUT SENSITIVITY

The interpretation of the magnitude of both main effects and interactions relies on the observation that if interaction terms are "large", then the corresponding main effects of the inputs which produce the interaction do not have much meaning [Ref. 6, sec 7.34]. This is a practical result of the observation that if a combination of inputs is responsible for a large effect, then the degree to which a change of one input produces a change of model output must depend heavily on the levels of other inputs. Conversely, if interactions are small, then the effects produced by different inputs must be essentially independent. This relationship yields a procedure for analyzing the results of a factorial experiment which is to compare the magnitude of interactions with the corresponding main effects, determining whether or not the effects of the inputs are independent. Having found the independent main effects and dominating interactions, the inputs which produce these results can then be examined on the basis of intuition about expected model performance.

Table 3 contains the significant interactions found for all factorial experiments; that is, the interactions where a 10% change in inputs produces a 10% or greater change in model output. The resulting changes of model output are in terms

TABLE 3

Significant Input Interactions

SCENARIO: DEFENSE

EXPERIMENT: Red Maneuver Unit Description and Operational Policy

Interacting Inputs	STAND	REPL	R:B	ATK	DEF
#RED VEHICLES/RED UNIT C^3 ERROR BY ENEMY ELECTRONIC WARFARE		.095	-.444	.029	
DESIRED ATTACKING FORCE RATIO %FIRERS-DIRECT FIRE			.331		
DESIRED ATTACKING FORCE RATIO C^3 ERROR BY ENEMY ELECTRONIC WARFARE			-.565		
%FIRERS-DIRECT FIRE C^3 ERROR BY ENEMY ELECTRONIC WARFARE			-.434	.021	
DESIRED ATTACKING FORCE RATIO %FIRERS-DIRECT FIRE C^3 ERROR BY ENEMY ELECTRONIC WARFARE			.331		
10% Significance Level (Absolute Value)	.332	.065	.331	.019	.192

(Columns STAND through DEF: Model Output Levels)

SCENARIO: ATTACK

EXPERIMENT: Single Inputs of Interest

Interacting Inputs	STAND	REPL	R:B	ATK	DEF
#RED ENGINEER UNITS #BLUE ENGINEER UNITS	-1.286			-.659	-.258
10% Significance Level (Absolute Value)	.332	.065	.331	.019	.192

(Columns STAND through DEF: Model Output Levels) of the standing Blue units (STAND) and replacement Blue units required (REPL). These values express the numbers of Blue brigades in the Attack scenario and Blue divisions in the Defense scenario required to meet victory conditions. The output which reports the change in the ratio of the overall number of forces (R:B) has no units, while the change in the number of Blue attack (ATK) and defense (DEF) activity cycles corresponds to operations at the brigade level in the Attack scenario and division level in the Defense scenario. Of the approximately 10,000 interactions examined in 24 factorial experiments, only six inputs combine to produce large interactions.

Comparing these interactions with the corresponding table of large main effects in Table 4, it is immediately apparent that interactions involving the input representing the amount of command and control errors induced on Red forces by Blue electronic warfare (EW) efforts has no effect on any significantly large interactions. Large pairwise interactions with this input equal the main effect of the paired input. For example, the interaction of the inputs Desired Red Attacking Force Ratio and Red C^3 Error by Blue Electronic Warfare produces a R:B (force ratio) interaction of -.565 in the defense scenario. This is exactly equal to the main effect of the Desired Red Attacking Force Ratio on the R:B output MOE. Thus, with the exception of the interaction of

TABLE 4

Significant Input Main Effects

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
HRS/DAY USABLE	1.144				.313	.358				.234
# RED ENGINEER UNITS	1.286			.659	.258					
RED PENETRATION LIMIT					-.227	-.463				-.276
# BLUE ENGINEER UNITS	-1.861			-.950	-.376	-1.616	-.056	.248	-.065	-.965
# RED VEH/RED UNIT	1.332	.252	-.264	.651	.300		.095	-.444	.029	
RED ATK FORCE RATIO		.135	-.425		.261			-.565		
RED %FIRERS-DIRECT FIRE		.189	-.446					-.434	.022	
RED C^3 ERROR BY BLUE EW						6.233	1.181	7.244	.342	3.616
# BLUE VEH/ BLUE UNIT	-1.561	-.309		-.885	-.246	-.582	-.130		-.034	-.345
BLUE ATK FORCE RATIO									.025	
MISC LETHALITY (Red atk)			-.209							
MISC VULN (Blue def)		.131	-.220							
COEF BLUE ENG ABILITY	-1.825			-.887	-.414	-1.414			-.056	-.846
COEF RED ENG ABILITY					.226					
BLUE DIRECT FIRE RATE							.070			
BLUE SIDE ARMOR COEF		-.138	.174							
MAX CUM RED UNIT ATTRITION									.023	
RED TIME STATIONARY IN ATK				-.757					.029	
%ATK ENGMENT END BY BLUE				.752						
%BLUE KILLED BY EACH RED DEF					.210					
10% Level - (Absolute Value)	1.137	.113	.161	.607	.201	.332	.065	.331	.019	.192

Desired Red Attacking Force Ration and Red %Firers Direct Fire, all significant interactions in the Defense scenario reduce to main effects. The one remaining interacting is only barely significant in the output MOE R:B.

The interaction of the inputs which represent the number of Blue and Red engineer units in the attack scenario follows the same pattern. Comparing this interaction with the corresponding main effects reveals that the combined effect of these inputs appears to depend only on the level of Red engineer units with the unexpected result that the change produced by the interaction of Red and Blue engineers is exactly equal to the negative of the main effect for the number of Red engineers[26]. This result is completely unexpected since the obvious relationship is that Red engineer units tend to negate the efforts of Blue engineers and visa versa. Thus the expected result is surly that the interaction of these two inputs should be small in relation tho the corresponding main effects. This result indicates a possible problem with the part of MOSCOW's algorithm which accounts for the influence of engineer assets on the attrition process. This indication is reinforced by the observation, from Table 4, that the four inputs which specify both the number of engineer units and their capabilities relative to each other produce significant main effects.

[26] In fact, with the exception of negation, the results are identical for all model outputs to four decimal places.

Another area of difficulty is MOSCOW's sensitivity to changes in the number of Red command and control errors produced by Blue electronic warfare. Not only does the Defense scenario exhibit extreme sensitivity to this input, but the observed relationship between an increase in Red command and control errors appears to result in increased Blue force requirements. This clearly violates the intuition that those factors which are a detriment to Red's combat capability should be of benefit to Blue. Additionally, if the observed results are correct, then the reported increase in Blue standing and replacement unit requirements should translate into an increase in the total numbers of Blue forces and, therefore, a reduction in the force ratio (R:B). But this is contrary to the observation which shows a large increase in force ratio. Since no obvious errors can be found in either the programming of the factorial experiment or in data analysis, the possibility of an inconsistency involving this input within MOSCOW clearly exist.

Lastly, although MOSCOW may appear sensitive to the number of vehicles found in both Red and Blue units, this is not the case. A simple example which makes this point clear is to consider the Attack scenario. Blue units in this scenario consist of 369 vehicles and MOSCOW computes a standing force requirement of 11.37 Blue units. This translates to an initial need for 4196 Blue combat vehicles. If the size of a Blue unit is increased by 10%, to 406 vehicles, the main effect of this change, as reported in Table 3, will be a decrease in the number of standing Blue units required by 1.56 units. The total number of Blue vehicles required with larger Blue units is:

(406 veh/unit) x (11.37 units - 1.56 units) = 3983 veh

This represents a decreased requirement for Blue combat vehicles of only 5%. Thus a 10% increase in the size of blue units results in only a 5% reduction in the total number of Blue combat systems, demonstrating that this change of model input meets the criteria of producing a small change in output. Similar results hold for changes in the number of vehicles assigned to Red units. The remaining inputs which produce significant main effects for at least one output do appear to have obvious explanations. The appropriateness of model sensitivity to changes in these inputs is a subject for further study.

B. GENERAL ANALYSIS OF MAIN EFFECTS

Experience holds much information about how the relative capabilities of combat forces will change under the pressure of improving technology. Historically, this pressure has developed continuous improvements in weapon systems. Most often, these improvements are seen as increases in weapons performance: more accurate guns of greater lethality, capable of firing at longer ranges, better armor to meet the threat of better weapons, greater mobility under conditions of adverse terrain and weather, more responsive logistical support, and a general improvement in command, control, and communications capabilities. In every case "better" weapon systems are seen to translate into "more capable" forces.

The clear assumption underlying this reasoning is that an incremental technological improvement of a weapon results in an incremental increase of a combat unit's overall capability. Because this idea has great historical appeal and many of MOSCOW's inputs are the direct expression of weapon system characteristics, a reasonable expectation of model performance is that the main effect of a small improvement in Red weapons capabilities will require an increase in the number of Blue units if the definition of victory remains constant. The converse should be true if Blue has the benefit of improved technology. In terms of the expected changes in model outputs examined as the result of factorial experiments, the increase of a Red force attribute should logically produce an increase in the number of standing and replacement Blue units, a decrease in the numerical ratio of total forces (R:B), and an increase in the numbers of the Attack and Defend cycles which Blue must accomplish to achieve victory. The opposite changes should occur if Blue receives the benefit of improved technology. Similar reasoning can also be applied to explain the changes in output that should logically be expected from changes in victory conditions such as the depth of Red penetration when Blue is defending or the amount of attrition to be inflicted on Red by Blue attacks.

The expectations about the influence a small change in input will have on model output can be compared to the input's observed main effects as computed from the results of a factorial experiment. If the directions of the observed changes agree with intuition, there is no reason to reject the notion that the model appears to be performing according to expectation. If, on the other hand, changes in input produce unexpected changes in output, then two possibilities exist. First, the input's main effect may be dominated by interactions with other inputs. This is the situation discussed earlier where the existence of large interactions indicates strong dependency between interacting inputs with the result that little importance can be associated with the computed main effect. The second case is that, if the main effect dominates, the model produces results which are contrary to expectation.

The only requirement for making use of this method is that some rule must be used to decide how large a given interaction must be before the associated main effects become unimportant. For the purpose of this analysis, main effects are considered inconsequential if a interaction term exists which has a magnitude which is equal to or greater than one half the magnitude of the main effect. The relative importance of any main effect can be decided by comparing the magnitude of the main effect to the magnitude of the magnitude of the input's largest interaction term. With this criterion, the main effects computed from the results of factorial experiments can be examined to discover those areas where model performance may not agree with intuition. Table 5 contains the main effects computed for the same Blue force inputs in both the Attack and Defend scenarios. A reasonable expectation of the effects of a small increase of the first input (# Blue Vehicles / Blue Unit) is that such units will be slightly more capable, hence the number of units needed as standing and replacement forces should decrease along with the number of attack and defend cycles, while the numerical ratio of forces (R:B) should increase. This expected result is identical with observation. Furthermore, all main effects can be shown to dominate their corresponding interactions.

The last four inputs of Table 5 represent cases where the expected influence of small increases is a reduction in Blue unit capability. Thus, the requirements for standing and replacement units along with the numbers of attack and defend cycles should increase, whereas the numerical ratio of forces should decrease. Comparing this expected result with the observation reveals numerous discrepancies. In Table 5, for example, the main effects observed for the last input appear to completely contradict expectation. However, in each case where an unexpected result occurs, the observed main effect

TABLE 5

Blue Maneuver Unit Description and Operational Policy

Input	Attack Scenario STAND	REPL	R:B	ATK	DEF	Defense Scenario STAND	REPL	R:B	ATK	DEF
# BLUE VEH/BLUE UNIT	-1.561	-.309	.151	-.885	-.246	-.582	-.130	.292	-.034	-.345
DESIRED ATK FORCE RATIO	.820	.065	-.009	.594	.001	.072	.006	-.006	.025	.021
%FIRERS-DIRECT FIRE	-.459	-.024	-.022	-.277	-.056	-.157	-.036	.186	-.002	-.101
TARGET ACQUISITION TIME	.692	.047	.016	.506	-.006	.183	.040	-.203	.015	.104
C^3 ERROR (min %)	.146	.000	.005	.061	.002	.109	.005	-.020	.003	.027
INTELLIGENCE ERRORS	.606	.006	.012	.124	.047	.184	.011	-.049	.001	.042
C^3 ERROR BY ENEMY EW	-.076	-.005	.006	-.032	-.022	-.029	-.005	.021	-.002	-.017
10% Level - (Absolute Value)	1.137	.113	.161	.607	.201	.033	.065	.331	.019	.192

can be shown to be dominated by interactions. The general result of applying this method to many inputs suggests there is no evidence to reject the hypothesis that MOSCOW produces results which meet with expectations. A complete listing of all main effects as calculated from the results of all factorial experiments is in Appendix K.

The remaining two inputs, Desired Blue Attacking Force Ratio and Percentage of Blue Firers Using Direct Fire are examples of inputs which do not lend themselves to this type of analysis since no clear intuition exist about the behavior of these inputs. However, all the main effects for the first of these inputs are dominate and consistent with the hypothesis that an increase in attacking force ratio is not favorable for Blue. For the last input, all main effects except for the R:B force ratio in the Attack scenario are dominate. This suggest that increasing the numbers of direct fire weapons is favorable for Blue. If the objective of analysis was to explore whether or not MOSCOW was producing results which are consistent with other models, these types of comparisons may be of value.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

As seen in the previous section, this analysis has identified only two areas where obvious problems appear to exist within MOSCOW's algorithms. The first problem involves the unexpected model sensitivity to changes in engineer attributes. The second problem is the unexplained sensitivity to the amount of command and control errors induced by enemy electronic warfare. Where intuition exists, changes in other inputs appear to influence the model in a manner that agrees with expectations.

With the above deficiencies corrected, there is no evidence showing that MOSCOW could not be calibrated to agree with the results of a higher resolution model, such as Vector-In-Commander. MOSCOW could then explore scenarios which result from small percentage changes of inputs. This would be the case as long as the proportion of direct and indirect fire weapons remains relatively constant.

B. RECOMMENDATIONS

The assumption that the proportions of direct and indirect fire combatants will remain constant for the duration of combat represents MOSCOW's fundamentally limiting assumption. The exact scope of this limitation, stemming from the model's underlying square law formulation, is unknown. Future research should evaluate this limitation in comparison with other formulations, such as that proposed by Helmbold [Ref. 3]. This investigation may discover an attrition methodology which proves better able to handle a wider variety of situations, yet does not increase the model's complexity or number of inputs by a significant amount. Pursuing the answers to these questions will determine which method is the "best" to use as a basis for the attrition calculations within MOSCOW.

APPENDIX A. LIST OF ABBREVIATIONS USED IN MOSCOW

Currently, MOSCOW's output screens are restricted to a width of 80 columns. A consequence of this restriction and the large amount of information contained in MOSCOW's output is that many nonstandard abbreviations are used to make output readable. The following is a list of common abbreviations used in MOSCOW.

AMMO	Ammunition
AMT REQD	Amount Required
ATK	Attack
AVG	Average
AVE/DAY	Average per Day
BLUE	Blue units -- Friendly Units
CUM	Cumulative
DEF	Defense
ENG	Engineer Unit
ENGMENT	Engagement
HQs	Headquarter(s)
LIFT	Supply Transport Capability
MIN	Minimum
MVR	Maneuver Unit -- Combat Unit
MVR-EQ/D	Maneuver Unit Equivalent per Day
MVR+EQVS	Standing Forces plus Replacements
MVRS	Maneuver Units -- Combat Units
OTHER	Other supplies requirement (food, water, etc.)
PEAK/DAY/MVR	Maximum rate of Personnel Casualties per Day per Maneuver Unit
PERS/DAY	Personnel per Day
POL	Petroleum and Lubricants

RED	Red Units -- Enemy Forces
REPL	Replacements (Soldiers who take the place of casualties)
#S VEH	Number of Supply Vehicles
# HQs	Number of Headquarters Elements Required for Combat Operations

APPENDIX B. DESCRIPTION OF MODEL INPUTS

The inputs used in describing land combats scenarios in MOSCOW belong to one of six general categories. This grouping is described in section 4.3.5, A New Approach for the Design and Evaluation of Land Defense Concepts, RAND Corp report R-3643-A, Philip J. Romero.

A. TERRAIN

MOSCOW requires that the user provide some process which quantifies the trafficability, defense strength, and target availability within the zone. These values are then averaged across the zone to represent a uniform characterization of a scenario's terrain.

B. LIMITS FOR BLUE

These inputs represent the resource constraints for the Blue (friendly) force expressed in terms of total maneuver units available, personnel casualties sustainable, replacements of personnel and equipment available (total and daily rate), and supplies. These values are only used for comparisons against resource requirements.

C. RED THREAT AND ZONE GEOGRAPHY

These inputs describe the size of the Red (enemy) force and the rectangular dimensions of the geographic zone the campaign is fought. This geographic description also includes the average dimensions and number of choke points which limit Red operations and the number of engineer units which support Red's tactical/operational plan.

D. SUCCESS CRITERIA AND OPERATIONAL-LEVEL POLICY FOR BLUE

These inputs define the Blue force tactical objective which is the number of Red units which will be allowed to survive. Additional inputs define the deployment of Blue forces in the zone of operations, the amount of supporting engineer units, aggressiveness, and linearity of combat operations.

E. LIMITS FOR BLUE

These inputs specify an upper bound on the resources which Blue can use during the battle. They do not enter into MOSCOW's attrition calculation, but are used to compare model outputs with user defined maximum resource limit. As such, these inputs are set to arbitrary levels.

F. MANEUVER UNIT DESCRIPTION

This class of input broadly defines the combat characteristics of Red and Blue forces. As such, it contains specifications which describe both unit capabilities and aggregate vehicle characteristics.

G. SUPPORTING AIR, ARTILLERY, AND ENGINEER CAPABILITIES

These define the quantity of air support available to both sides. This definition includes the quantity of aircraft (fixed wing and helo) which supports each side, how these assets are allocated between close air support and air interdiction missions, their lethality, and a rough measure of the attrition effects of air defenses. Supporting engineer assets are described by scaling coefficients which quantify Blue engineers' ability to delay Red and Red engineers' ability to enhance Red mobility. Artillery inputs are not useful and are omitted from these input sets.

H. LISTING OF SPECIFIC INPUTS

This paper uses the unclassified inputs developed by TRAC-FLVN as a starting point for experimental investigation into the sensitivity of MOSCOW to selected inputs. The methodology used to generate these inputs and specific details of the scenarios represented are in draft technical report, A Methodology for Estimation MOSCOW Inputs, James C. Hoffman, 1988. Broadly speaking, these inputs attempt to demonstrate a method of generating suitable model inputs which represent the attack, using airland battle doctrine, of a U.S. Corps to destroy the lead echelon of an opposing Combined Arms Army employing Soviet type equipment. The same methodology is also used to produce inputs representing the defense of this Corps against a Combined Arms Army's deliberate attack. Both scenarios occur on the same type of terrain in NORTHAG.

1. Attack Scenario Inputs

TERRAIN FEATURES IN ZONE (2 screens)

COVER	GRADIENT	MOVEMENT RATE coeff.	DEFENSE STRENGTH coeff.	TARGET AVLBTY coeff.	FRACTION OF ZONE
Clear	Flat	1.00	1.00	1.00	0.34
Mixed	Flat	0.86	1.05	0.83	0.11
Forest	Flat	0.54	1.27	0.52	0.13
Urban	(N/A)	0.64	2.90	0.42	0.09
Clear	Rolling	0.88	1.05	1.00	0.17
Mixed	Rolling	0.78	1.09	0.67	0.02
Forest	Rolling	0.64	1.31	0.52	0.09
Clear	Hills	0.83	1.13	0.94	0.01
Mixed	Hills	0.00	0.00	0.00	0.00
Forest	Hills	0.66	1.38	0.46	0.01
Clear	Broken	0.00	0.00	0.00	0.00
Mixed	Broken	0.00	0.00	0.00	0.00
Forest	Broken	0.00	0.00	0.00	0.00
Clr/Mixd	Marsh	0.17	1.03	0.83	0.03
Jungle	Marsh	0.00	0.00	0.00	0.00
Clear	Mountains	0.00	0.00	0.00	0.00
Mixed	Mountains	0.00	0.00	0.00	0.00
Desert	Flat/Rolling	0.00	0.00	0.00	0.00
Desert	Hills/Mtns	0.00	0.00	0.00	0.00
Arctic	Flat/Rolling	0.00	0.00	0.00	0.00
Arctic	Hills/Mtns	0.00	0.00	0.00	0.00
Tropical	Flat/Rolling	0.00	0.00	0.00	0.00
Tropical	Hills/Mtns	0.00	0.00	0.00	0.00

RED THREAT SCENARIO: ZONE GEOGRAPHY AND FORCE SIZE

ZONE WIDTH	50.00	km
ZONE LENGTH	200.00	km
#CHOKE AREAS	10.00	# areas where traffic is confined
CHOKEAR FRONTG	7.50	Average choke area width (km)
CHOKEAR DEPTH	5.00	Average choke area depth (km)
HRS/DAY USBLE	24.00	hrs/day usable for operations
BLUE WARNING	1.00	days
# RED MVR	4.00	# Red maneuver units (rmvrs)
# FRNT LN DIVS	2.00	# rmvrs in front line
# RED HQs	1.00	# Red Headquarters (HQs)
# RED ENG UNITS	4.33	# Red engineer units
% RMVRS-ATK	0.86	% rmvrs assigned atk mission
RED DIV SEPRTN	65.00	Average dist between rmvrs (km)
RMVR AGGRSV-ATK	0.80	Dist toward enemy/tot dist moved
RMVR AGGRSV-DEF	0.10	Dist toward enemy/tot dist moved (+1.0=forw; -1.0=away; 0=static)

BLUE SUCCESS CRITERIA AND THEATER-LEVEL POLICY (2 screens)

SUCCESS CRITERIA

RED PEN LIMIT	50.000	km Red allowed to penetrate zone
RED SURVIVORS	1.340	# rmvrs allowed to survive
MAXPEN PRE-INT	25.000	km max pen before must eng Red

TIME OBJECTIVE

DELAY	1.000	campaign-days added by Blue ops

DEPLOYMENT

FORW BNDRY	0.000	km to border --
REAR BNDRY	50.000	km to border --
%ATKOPS-LINEAR	0.100	% Blue atks using linear ops
%of ZONEW DEFD	1.000	% zone frontage covered by Blue

MVR TACTICAL AGGRESSIVENESS

MVR AGGRSV-ATK	0.800	Dist toward enemy/tot dist moved
MVR AGGRSV-DEF	0.800	Dist toward enemy/tot dist moved
		(+1.0=forw; -1.0=away; 0=static)

MVR MISSION ASSIGNMENTS

%MVRs-ATK KILS	0.800	% rmvrs to be killed by atk mvrs
%MVRs-DEF KILS	0.200	% rmvrs to be killed by def mvrs

HQ CAPABILITIES

# HQs AVAIL	4.000	# Blue HQs in zone
HQ SPAN-#MVRs	4.000	# mvrs controllable by Blue HQs
HQ RADIUS-KM	50.000	Max dist an HQ can control an mvr
# ENG UNITS AVAIL	12.000	# Blue engineer units in zone

LIMITS OF BLUE FORCES AND RESOURCES FOR ZONE (2 screens)

CATEGORY	RESOURCE	AVAIL.	
TOTAL MVR AVAILABLE	INITIAL	21.80	mvrs
MAXIMUM CASUALTIES	TOT CASLTY	250000	pers
	AVG CASLTY/DAY	5000.0	pers/day
REPLACEMENT STOCKS AVAILABLE	PERSONNEL	200000	pers
	VEHICLES	12000	veh
	AMMO (TONS)	7.0E+05	tons
	POL (TONS)	5.0E+06	tons
	OTHER (TONS)	1.0E+05	tons
	LIFT (TONS)	1.5E+06	tons
DAILY REPLACEMENTS AVAILABLE	PERSONNEL	4000.0	pers/day
	VEHICLES	400.0	veh/day
	AMMO (TONS)	2.0E+04	tons/day
	POL (TONS)	4.0E+05	tons/day
	OTHER (TONS)	4.0E+03	tons/day
	LIFT (TONS)	1.1E+04	tons/day
SUPPLY & HQs AVAILABLE	SUPP. VEHS	100000	# vehs
	TOLERANCE LEVEL:	110%	Reqd/avail

MANEUVER UNIT DESCRIPTION AND OPERATIONAL POLICY (7 screens)

	Red	Blue	
SIZE OF MANEUVER UNIT (MVR)			
TECH/ORG			
VEH/MVR	266.000	369.000	# vehicles per maneuver unit
GENERAL			
TECH/ORG			
DISENG %AGE-ATK	NA	0.750	% of engagement
DISENG %AGE-DEF	NA	0.750	% of engagement
% NON-MV/CBT	0.330	NA	%time not moving or fighting
POLICY & NORMS			
TAC PWR-ATK	4.500	3.000	Ratio: Attack to defend cbt power
RED ATTR-BLATK	0.150	0.020	%desired/engagement
BLUE ATTR-RATK	0.020	0.150	%desired/engagement
MOBILITY			
TECH/ORG			
MVMT/HR-ADMIN	21.500	22.500	km/hr
MVMT/HR-BATTL	7.500	7.500	km/hr
VEH DASH SPD	40.000	60.000	km/hr
VEH BRKDWNS	0.050	NA	% vehicles that breakdown per day
POL CONS/KM	NA	1.460	gals/km
TIME-CHNG FORM	20.000	20.000	minutes to change formation type
POLICY & NORMS			
%MVMT-ADM FORM	0.500	0.500	% of mvmt time in adm. formation
TAC STA PD-ATK	1.000	10.000	minutes stationary when attacking
TAC STA PD-DEF	50.000	25.000	minutes stationary when defending
DIS/TAC MV-ATK	200.000	400.000	meters moved per dash in attack
DIS/TAC MV-DEF	2500.000	750.000	meters moved per dash on defense
IF %OPNL MOVE	0.110	0.110	IF aggrss as % of DF aggrss.

LETHALITY

TECH/ORG

% FIRERS-ADMIN	0.330	0.330	% firing veh in adm. formation
% FIRERS-BATTL	0.670	0.670	% firing veh in btl. formation
MAX IF RATE-S	0.240	0.340	max rnds/min of IF while statnry
MAX IF RATE-M	0.000	0.000	max rnds/min of IF while moving
MAX DF RATE-S	2.300	3.540	max rnds/min of DF while statnry
MAX DF RATE-M	2.300	3.540	max rnds/min of DF while moving
IF RANGE-MAX	20.000	19.600	km
IF RANGE-MIN	1.000	5.000	km
DF RANGE-MAX	1.168	1.630	km
DF RANGE-MIN	0.100	0.100	km
HITS/RND-S/S	0.950	0.950	P(h/rd): sta DF, sta tgt @min rng
HITS/RND-S/M	0.950	0.950	P(h/rd): sta DF, mov tgt @min rng
HITS/RND-M/S	0.950	0.950	P(h/rd): mov DF, sta tgt @min rng
HITS/RND-M/M	0.950	0.950	P(h/rd): mov DF, mov tgt @min rng
HIT DEGRD-MAXR	0.690	0.670	Degradation of P(h/rd) at max rng
KILLS/HIT	0.500	0.500	Prob. of vehicle kill given hit
ANTI-PERS COEF	0.250	0.250	Pr. dismtd kill given veh kill
IF HITS/R COEF	0.00060	0.00320	Degradation of P(hit/rnd) for IF

POLICY & NORMS

ACT IF RATE-S	0.240	0.340	actual IF rnds/min while statnry
ACT IF RATE-M	0.000	0.000	actual IF rnds/min while moving
ACT DF RATE-S	2.300	3.540	actual DF rnds/min while statnry
ACT DF RATE-M	2.300	3.540	actual DF rnds/min while moving
ACT IF RANGE-HI	20.000	19.600	km
ACT IF RANGE-LO	1.000	5.000	km
ACT DF RANGE-HI	1.168	1.630	km
ACT DF RANGE-LO	0.100	0.100	km
IF DIST-FLOT-HI	70.000	25.000	km
IF DIST-FLOT-LO	1.000	6.700	km
DF DIST-FLOT-HI	40.000	10.000	km
DF DIST-FLOT-LO	0.100	0.100	km
% FIRERS DF	0.730	0.860	% veh firing in DF mode
% PERS DISMTD	0.030	0.020	% personnel acting as dismtd infy
VEH DIS%-DEF	0.060	0.060	max dis betw veh as % of avg rng
DESIRD FRNTAGE	10.000	10.000	km
MISC LETH MU-AT	0.800	1.000	x Friendly lethality
MISC LETH MU-DE	0.500	1.000	x Friendly lethality
% ATKRS-1st ECH	0.670	NA	% of atk veh in 1st ech

VULNERABILITY

TECH/ORG

HARDNESS-FRONT	0.460	0.560	x hardness assumed in enemy P(k)
HARDNESS-SIDE	0.310	0.370	x hardness assumed in enemy P(k)
CONCLMT-ADMIN	0.250	0.250	% veh concealed from enemy
CONCLMT-BATTL	0.100	0.400	% veh concealed from enemy
MAX ATTR/DAY	0.300	0.300	% pers attr/day for unit to break
BREAKPOINT	0.500	0.500	% pers cum attr for unit to break

POLICY & NORMS

SHADOW DIS-ATK	NA	15.000	km
SHADOW DIS-DEF	NA	10.000	km
DEFENSE PREP%	NA	0.170	% of max preparations
VEH DIS-ATK	50.000	100.000	min dist betw veh--m
MISC VULN MU-A	1.000	0.800	x Enemy lethality
MISC VULN MU-D	1.000	0.500	x Enemy lethality

C3IEW

TECH/ORG

ACQ TIME-S TGT	50.000	50.000	secs. reqd to acq stationary tgt
STGT#SHOTS-ACQ	2.000	2.000	# of tgt's shots to acq sta tgt
C-3 ERROR	0.050	0.050	min % errors in C-3 system
C-3 REGEN/DAY	0.500	1.000	daily reduc. in C-3 err from regen
MAX C-3 ERR	0.750	0.500	max % errors in C-3 system
INTEL ERROR	0.250	0.250	min % errors in Intel system
EW EFFNESS	1.000	1.500	x Blue/red C-3 err due to EW
ATK PREP&RECOV	3.000	NA	Prep&recov time mult of atk time
DEF PREP&RECOV	3.000	NA	Prep&recov time mult of def time

BASIC LOAD & LOGISTICS

TECH/ORG

PERS/VEH	8.200	6.800	passengers and crew per veh
AMMO/VEH	40.000	41.000	rounds per veh
POL/VEH	NA	265.000	gals POL per veh
OTH/VEH	NA	680.000	lbs. other resources per veh
VEH WEIGHT	NA	34.700	tons / veh weight
PERS WEIGHT	NA	140.000	lbs./person
AMMO WEIGHT	59.000	59.000	lbs./round
POL WEIGHT	NA	7.200	lbs./gallon
PERS REGEN/DAY	NA	89.000	# non cbt casualties recov/day
VEH REGEN/DAY	1.250	10.000	# veh losses recoverable/day
CAS REGEN COEF	NA	0.740	Cbt cas recov / non cbt cas recov

POLICY & NORMS

%REPL/ATK CYC	0.300	0.500	% veh loss repl. by next engmt
%REPL/DEF CYC	0.300	0.500	% veh loss repl. by next engmt
DIS-EXCHPT-DEF	NA	0.500	km from def engmt to supply pt
DIS-EXCHPT-ATK	NA	5.000	km from atk engmt to supply pt
% REST	NA	0.250	% of time spent resting
%REPRBL LOSS-M	NA	0.800	% of losses repairable by mvr
%REPRBL LOSS-T	NA	0.000	% of losses repairable by theater
% REPRD-M	NA	0.120	% of reprbl losses reprd by mvr
LOAD RATE	NA	976.200	tons supplies loaded/hr
SUPP VEH MOVEF	NA	150.000	km/day that a supply veh can move
CAP/SUPP VEH	NA	10.000	tons capacity per supply veh
CAP DEGRDN/KM	NA	0.000	tons cap degrdn per km total dist

FIRE, AIR AND ENGINEER SUPPORT ALLOCATION (5 screens)

	Red	Blue	
CLOSE AIR SUPPORT (PLANES AND HELOS)			
TECH/ORG			
STARTING CAS	50.000	250.000	initial CAS aircraft
SORTIES/DAY	3.500	3.000	sorties/day
AIR ATTRITION	0.100	0.100	Attrition rate per sortie
TONS ORD/S	0.750	1.480	tons ordnance per sortie
HITS/TON	0.750	1.480	# vehicles hit per ton of ordnance
KILLS/HIT	0.330	0.210	Prob. vehicle killed given hit
PERCENTAGE ALLOCATION			
% ATTK	1.000	1.000	% of aircraft supporting atk mvrs
HEADQUARTERS ARTILLERY			
TECH/ORG			
TONS/D/HQ	0.000	0.000	tons ammo fired per day per HQ
HITS/TON	0.000	0.000	veh hits per ton ammo fired
KILLS/HIT	0.000	0.000	Prob. vehicle killed given hit
TONS SUPPD/T	0.000	0.000	tons enemy HQ fire suppressed/ton
PERCENTAGE ALLOCATION			
% ATTK	0.000	0.000	% of HQs supporting attk mvrs
%COUNTERHQ	0.000	0.000	%of HQs in counterfire agnst HQs
ENGINEERS			
TECH/ORG			
DEL/D/ENG	NA	0.400	Rmvr-days delay/Blue eng-unit-day
ACCEL/ENG	0.250	NA	Rmvr-days accel/Red eng-unit-day
AIR INTERDICTION			
TECH/ORG			
INITIAL AI	0.000	50.000	initial AI aircraft
SORTIES/DAY	0.000	3.000	sorties/day
AIR ATTRITION	0.100	0.100	Attrition rate per sortie
TONS ORD/S	8.000	8.000	tons ordnance per sortie
AI ATTRITION MISSION			
TECH/ORG			
HITS/TON	0.130	0.130	# vehicles hit per ton of ord
KILLS/HIT	1.000	1.000	Prob. vehicle killed given hit

AI DELAY MISSION

TECH/ORG			
HITS/TON	0.130	0.130	target hits/ton of ordnance
KILLS/HIT	1.000	1.000	Prob. target killed given hit
DELAY/KILL	5.000	10.000	mins. mvr delay per target killed

AI DISRUPTION MISSION

TECH/ORG			
C3 ERR/TON	0.005	0.005	Incr. in mvr C3 error/ton ord

AI COUNTER HQ MISSION

TECH/ORG			
TONS SUPPD/T:	0.000	0.000	tons enemy HQ fire suppressed/ton

AI SUPPLY MISSION

TECH/ORG			
S VEH HITS/TON	0.250	NA	Supply veh hits per ton ordnance
S VEH KILS/H	1.000	NA	Prob. supply veh killed given hit
VEH REIN HITS/T	NA	0.250	Reinforcement veh hits/ton ord
VEH REINF K/H	NA	1.000	Prob. reinf veh killed given hit

POLICY AND NORMS:	PERCENTAGE ALLOCATION		
% ATTRIT	1.000	0.330	% AI sorti assigned attrition msn
%DELAY	0.000	0.330	% AI sorti assigned delay mission
%DISRUPT	0.000	0.330	% AI sorti assigned disrpt msn
%COUNTER HQ	0.000	0.000	% AI sorti assigned counterHQ msn

2. Defense Scenario Inputs

TERRAIN FEATURES IN ZONE (2 screens)

COVER	GRADIENT	MOVEMENT RATE coeff.	DEFENSE STRENGTH coeff.	TARGET AVLBTY coeff.	FRACTION OF ZONE
Clear	Flat	1.00	1.00	1.00	0.34
Mixed	Flat	0.86	1.05	0.83	0.11
Forest	Flat	0.54	1.27	0.52	0.13
Urban	(N/A)	0.64	2.90	0.42	0.09
Clear	Rolling	0.88	1.05	1.00	0.17
Mixed	Rolling	0.78	1.09	0.67	0.02
Forest	Rolling	0.64	1.31	0.52	0.09
Clear	Hills	0.83	1.13	0.94	0.01
Mixed	Hills	0.00	0.00	0.00	0.00
Forest	Hills	0.66	1.38	0.46	0.01
Clear	Broken	0.00	0.00	0.00	0.00
Mixed	Broken	0.00	0.00	0.00	0.00
Forest	Broken	0.00	0.00	0.00	0.00
Clr/Mixd	Marsh	0.17	1.03	0.83	0.03
Jungle	Marsh	0.00	0.00	0.00	0.00
Clear	Mountains	0.00	0.00	0.00	0.00
Mixed	Mountains	0.00	0.00	0.00	0.00
Desert	Flat/Rolling	0.00	0.00	0.00	0.00
Desert	Hills/Mtns	0.00	0.00	0.00	0.00
Arctic	Flat/Rolling	0.00	0.00	0.00	0.00
Arctic	Hills/Mtns	0.00	0.00	0.00	0.00
Tropical	Flat/Rolling	0.00	0.00	0.00	0.00
Tropical	Hills/Mtns	0.00	0.00	0.00	0.00

RED THREAT SCENARIO: ZONE GEOGRAPHY AND FORCE SIZE

ZONE WIDTH	50.000	km
ZONE LENGTH	200.000	km
#CHOKE AREAS	20.000	# areas where traffic is confined
CHOKEAR FRONTG	15.000	Average choke area width (km)
CHOKEAR DEPTH	10.000	Average choke area depth (km)
HRS/DAY USBLE	24.000	hrs/day usable for operations
BLUE WARNING	1.000	days
# RED MVR	4.000	# Red maneuver units (rmvrs)
# FRNT LN DIVS	2.000	# rmvrs in front line
# RED HQs	1.000	# Red Headquarters (HQs)
# RED ENG UNITS	15.000	# Red engineer units
% RMVRS-ATK	0.950	% rmvrs assigned atk mission
RED DIV SEPRTN	190.000	Average dist between rmvrs (km)
RMVR AGGRSV-ATK	0.500	Dist to enemy/total dist moved
RMVR AGGRSV-DEF	-0.100	Dist to enemy/total dist moved (+1.0=forw; -1.0=away; 0=static)

BLUE SUCCESS CRITERIA AND THEATER-LEVEL POLICY (2 screens)

SUCCESS CRITERIA

RED PEN LIMIT	250.000	km Red allowed to penetrate zone
RED SURVIVORS	1.230	# rmvrs allowed to survive
MAXPEN PRE-INT	50.000	km max pen before must eng Red

TIME OBJECTIVE

DELAY	1.000	campaign-days added by Blue ops

DEPLOYMENT

FORW BNDRY	0.000	km to border --
REAR BNDRY	200.000	km to border --
%ATKOPS-LINEAR	0.100	% Blue atks using linear ops
% ZONEW DEFD	0.850	% zone frontage covered by Blue

MVR TACTICAL AGGRESSIVENESS

MVR AGGRSV-ATK	0.100	Dist to enemy/total dist moved
MVR AGGRSV-DEF	-0.200	Dist to enemy/total dist moved (+1.0=forw; -1.0=away; 0=static)

MVR MISSION ASSIGNMENTS

%MVRs-ATK KILS	0.250	% rmvrs to be killed by atk mvrs
%MVRs-DEF KILS	0.750	% rmvrs to be killed by def mvrs

HQ CAPABILITIES

# HQs AVAIL	1.000	# Blue HQs in zone
HQ SPAN-#MVRs	4.000	# mvrs controllable by Blue HQs
HQ RADIUS-KM	100.000	Max dist an HQ can control an mvr
# ENG UNITS AVAIL	12.000	# Blue engineer units in zone

LIMITS OF BLUE FORCES AND RESOURCES FOR ZONE (2 screens)

CATEGORY	RESOURCE	AVAIL.	
TOTAL MVR AVAILABLE	INITIAL	21.80	mvrs
MAXIMUM CASUALTIES	TOT CASLTY	250000	pers
	AVG CASLTY/DAY	5000.0	pers/day
REPLACEMENT STOCKS AVAILABLE	PERSONNEL	200000	pers
	VEHICLES	12000	veh
	AMMO (TONS)	7.0E+05	tons
	POL (TONS)	5.0E+06	tons
	OTHER (TONS)	1.0E+05	tons
	LIFT (TONS)	1.5E+06	tons
DAILY REPLACEMENTS AVAILABLE	PERSONNEL	4000.0	pers/day
	VEHICLES	400.0	veh/day
	AMMO (TONS)	2.0E+04	tons/day
	POL (TONS)	4.0E+05	tons/day
	OTHER (TONS)	4.0E+03	tons/day
	LIFT (TONS)	1.1E+04	tons/day
SUPPLY & HQs AVAILABLE	SUPP. VEHS	100000	# vehs
	TOLERANCE LEVEL:	110%	Reqd/avail

MANEUVER UNIT DESCRIPTION AND OPERATIONAL POLICY (7 screens)

	Red	Blue	
SIZE OF MANEUVER UNIT (MVR)			
TECH/ORG			
VEH/MVR	979.000	1108.000	# vehicles per maneuver unit
GENERAL			
TECH/ORG			
DISENG %AGE-ATK	NA	0.500	% of engagement
DISENG %AGE-DEF	NA	0.500	% of engagement
% NON-MV/CBT	0.330	NA	%time not moving or fighting
POLICY & NORMS			
TAC PWR-ATK	4.500	3.000	Ratio: Attack to defend cbt power
RED ATTR-BLATK	0.080	0.160	%desired/engagement
BLUE ATTR-RATK	0.080	0.020	%desired/engagement
MOBILITY			
TECH/ORG			
MVMT/HR-ADMIN	21.500	22.500	km/hr
MVMT/HR-BATTL	7.500	7.500	km/hr
VEH DASH SPD	40.000	60.000	km/hr
VEH BRKDWNS	0.050	NA	% vehicles that breakdown per day
POL CONS/KM	NA	1.460	gals/km
TIME-CHNG FORM	120.000	120.000	minutes to change formation type
POLICY & NORMS			
%MVMT-ADM FORM	0.500	0.500	% of mvmt time in adm. formation
TAC STA PD-ATK	1.000	10.000	minutes stationary when attacking
TAC STA PD-DEF	50.000	25.000	minutes stationary when defending
DIS/TAC MV-ATK	200.000	400.000	meters moved per dash in attack
DIS/TAC MV-DEF	2500.000	750.000	meters moved per dash on defense
IF %OPNL MOVE	0.110	0.110	IF aggrss as % of DF aggrss.
LETHALITY			
TECH/ORG			
% FIRERS-ADMIN	0.330	0.330	% firing veh in adm. formation
% FIRERS-BATTL	0.670	0.670	% firing veh in btl. formation
MAX IF RATE-S	0.280	0.340	max rnds/min of IF while statnry
MAX IF RATE-M	0.000	0.000	max rnds/min of IF while moving
MAX DF RATE-S	2.300	3.540	max rnds/min of DF while statnry
MAX DF RATE-M	2.300	3.540	max rnds/min of DF while moving
IF RANGE-MAX	18.300	19.600	km
IF RANGE-MIN	1.000	5.000	km
DF RANGE-MAX	0.653	1.609	km

DF RANGE-MIN	0.100	0.100	km
HITS/RND-S/S	0.950	0.950	P(h/rd): sta DF, sta tgt @min rng
HITS/RND-S/M	0.950	0.950	P(h/rd): sta DF, mov tgt @min rng
HITS/RND-M/S	0.950	0.950	P(h/rd): mov DF, sta tgt @min rng
HITS/RND-M/M	0.950	0.950	P(h/rd): mov DF, mov tgt @min rng
HIT DEGRD-MAXR	0.690	0.670	Degradation of P(h/rd) at max rng
KILLS/HIT	0.500	0.500	Prob. of vehicle kill given hit
ANTI-PERS COEF	0.250	0.250	Pr. dismtd kill given veh kill
IF HITS/R COEF	0.0006	0.0032	Degradation of P(hit/rnd) for IF
POLICY & NORMS			
ACT IF RATE-S	0.280	0.340	actual IF rnds/min while statnry
ACT IF RATE-M	0.000	0.000	actual IF rnds/min while moving
ACT DF RATE-S	2.300	3.540	actual DF rnds/min while statnry
ACT DF RATE-M	2.300	3.540	actual DF rnds/min while moving
ACT IF RANGE-HI	18.300	19.600	km
ACT IF RANGE-LO	1.000	5.000	km
ACT DF RANGE-HI	0.653	1.609	km
ACT DF RANGE-LO	0.100	0.100	km
IF DIST-FLOT-HI	20.000	50.000	km
IF DIST-FLOT-LO	1.000	6.700	km
DF DIST-FLOT-HI	15.000	30.000	km
DF DIST-FLOT-LO	0.100	0.100	km
% FIRERS DF	0.800	0.860	% veh firing in DF mode
% PERS DISMTD	0.030	0.020	% personnel acting as dismtd infy
VEH DIS%-DEF	0.110	0.060	max dis betw veh as % of avg rng
DESIRD FRNTAGE	10.000	25.000	km
MISC LETH MU-AT	0.250	1.000	x Friendly lethality
MISC LETH MU-DE	0.200	1.000	x Friendly lethality
% ATKRS-1st ECH	0.670	NA	% of atk veh in 1st ech
VULNERABILITY			
TECH/ORG			
HARDNESS-FRONT	0.500	0.560	x hardness assumed in enemy P(k)
HARDNESS-SIDE	0.330	0.370	x hardness assumed in enemy P(k)
CONCLMT-ADMIN	0.250	0.250	% veh concealed from enemy
CONCLMT-BATTL	0.100	0.600	% veh concealed from enemy
MAX ATTR/DAY	0.300	0.300	% pers attr/day for to unit break
BREAKPOINT	0.500	0.500	% pers cum attr for to unit break

POLICY & NORMS

SHADOW DIS-ATK	NA	8.000	km
SHADOW DIS-DEF	NA	4.000	km
DEFENSE PREP%	NA	0.330	% of max preparations
VEH DIS-ATK	50.000	75.000	min dist betw veh--m
MISC VULN MU-A	1.000	0.250	x Enemy lethality
MISC VULN MU-D	1.000	0.200	x Enemy lethality

C3IEW

TECH/ORG

ACQ TIME-S TGT	50.000	50.000	secs. reqd to acq stationary tgt
STGT#SHOTS-ACQ	2.000	2.000	# of shots reqd to acq sta tgt
C-3 ERROR	0.050	0.050	min % errors in C-3 system
C-3 REGEN/DAY	0.500	0.500	daily reduc. in C-3 err by regen
MAX C-3 ERR	0.250	0.500	max % errors in C-3 system
INTEL ERROR	0.250	0.250	min % errors in Intel system
EW EFFNESS	3.000	1.000	x Blue/red C-3 err due to EW
ATK PREP&RECOV	3.000	NA	Prep time as mult of atk time
DEF PREP&RECOV	3.000	NA	Prep time as mult of def time

BASIC LOAD & LOGISTICS

TECH/ORG

PERS/VEH	8.200	6.800	passengers and crew per veh
AMMO/VEH	40.000	41.000	rounds per veh
POL/VEH	NA	265.000	gals POL per veh
OTH/VEH	NA	680.000	lbs. other resources per veh
VEH WEIGHT	NA	34.700	tons / veh weight
PERS WEIGHT	NA	140.000	lbs./person
AMMO WEIGHT	59.000	59.000	lbs./round
POL WEIGHT	NA	7.200	lbs./gallon
PERS REGEN/DAY	NA	89.000	# non cbt casualties recov/day
VEH REGEN/DAY	20.000	110.000	# veh losses recoverable/day
CAS REGEN COEF	NA	0.580	Cbt cas recov / non cbt cas recov

POLICY & NORMS

%REPL/ATK CYC	0.100	0.200	% veh loss repl. by next engmt
%REPL/DEF CYC	0.100	0.200	% veh loss repl. by next engmt
DIS-EXCHPT-DEF	NA	0.500	km from def engmt to supply pt
DIS-EXCHPT-ATK	NA	5.000	km from atk engmt to supply pt
% REST	NA	0.250	% of time spent resting
%REPRBL LOSS-M	NA	0.800	% of losses repairable by mvr
%REPRBL LOSS-T	NA	0.000	% of losses repairable by theater
% REPRD-M	NA	0.460	% of reprbl losses reprd by mvr
LOAD RATE	NA	976.200	tons supplies loaded/hr
SUPP VEH MOVEF	NA	200.000	km/day that a supply veh can move
CAP/SUPP VEH	NA	10.000	tons capacity per supply veh
CAP DEGRDN/KM	NA	0.000	tons cap degrdn per km total dist

FIRE, AIR AND ENGINEER SUPPORT ALLOCATION (5 screens)

	Red	Blue	
CLOSE AIR SUPPORT (PLANES AND HELOS)			
TECH/ORG			
STARTING CAS	100.000	250.000	initial CAS aircraft
SORTIES/DAY	3.500	3.000	sorties/day
AIR ATTRITION	0.150	0.100	Attrition rate per sortie
TONS ORD/S	1.480	1.480	tons ordnance per sortie
HITS/TON	1.480	1.480	# vehicles hit per ton of ord
KILLS/HIT	0.210	0.210	Prob. vehicle killed given hit
PERCENTAGE ALLOCATION			
% ATTK	1.000	1.000	% of aircraft supporting atk mvrs
HEADQUARTERS ARTILLERY			
TECH/ORG			
TONS/D/HQ	0.000	0.000	tons ammo fired per day per HQ
HITS/TON	0.000	0.000	veh hits per ton ammo fired
KILLS/HIT	0.000	0.000	Prob. vehicle killed given hit
TONS SUPPD/T	0.000	0.000	tons enemy HQ fire suppressed/ton
PERCENTAGE ALLOCATION			
% ATTK	0.000	0.000	% of HQs supporting attk mvrs
%COUNTERHQ	0.000	0.000	%of HQs in counterfire agnst HQs
ENGINEERS			
TECH/ORG			
DEL/D/ENG	NA	0.310	Rmvr-days delay/Blue eng-unit-day
ACCEL/ENG	0.040	NA	Rmvr-days accel/Red eng-unit-day
AIR INTERDICTION			
TECH/ORG			
INITIAL AI	150.000	50.000	initial AI aircraft
SORTIES/DAY	3.500	3.000	sorties/day
AIR ATTRITION	0.150	0.150	Attrition rate per sortie
TONS ORD/S	8.000	8.000	tons ordnance per sortie
AI ATTRITION MISSION			
TECH/ORG			
HITS/TON ordnance	0.130	0.130	# vehicles hit per ton of
KILLS/HIT	1.000	1.000	Prob. vehicle killed given hit

AI DELAY MISSION

TECH/ORG			
HITS/TON	0.130	0.130	target hits/ton of ordnance
KILLS/HIT	1.000	1.000	Prob. target killed given hit
DELAY/KILL	5.000	10.000	mins. mvr delay per target killed

AI DISRUPTION MISSION

TECH/ORG			
C3 ERR/TON	0.005	0.005	Incr. in mvr C3 error/ton ord

AI COUNTER HQ MISSION

TECH/ORG			
TONS SUPPD/T:	0.000	0.000	tons enemy HQ fire suppressed/ton

AI SUPPLY MISSION

TECH/ORG			
S VEH HITS/TON	0.250	NA	Supply veh hits per ton ordnance
S VEH KILS/H	1.000	NA	Prob. supply veh killed given hit
VEH REIN HITS/T	NA	0.250	Reinforcement veh hits/ton ord
VEH REINF K/H	NA	1.000	Prob. reinf veh killed given hit

POLICY AND NORMS:	PERCENTAGE ALLOCATION		
% ATTRIT	0.330	0.330	% AI sorti assigned attrition msn
%DELAY	0.330	0.330	% AI sorti assigned delay mission
%DISRUPT	0.330	0.330	% AI sorti assigned disrpt msn
%COUNTER HQ	0.000	0.000	% AI sorti assigned counterHQ msn

APPENDIX C. DERIVATION OF MODEL METHODOLOGY

Fundamental modeling assumptions for MOSCOW provide a way to reduce a complicated system of differential equations to a simple Lanchester "square law" form.

Assume the following system of equations which describes the attrition interactions between two combatants, both using direct and indirect fire weapons.

$$dX_D/dT = -(a_1 Y_D + b_1 Y_I X_D) \quad (1)$$

$$dX_I/dT = -(a_2 Y_D + b_2 Y_I X_I) \quad (2)$$

$$dY_D/dT = -(a_3 X_D + b_3 X_I Y_D) \quad (3)$$

$$dY_I/dT = -(a_4 X_D + b_4 X_I Y_I) \quad (4)$$

X_D and Y_D refer to the respective numbers of direct fire weapons on each side while X_I and Y_I correspond to indirect fire systems. The a_i are the usual "square law" attrition coefficients; the b_i are attrition coefficients given in the "linear law" case. The dimensionality of these coefficients is:

a units = S-killed / (R-firer)(unit time)

b units = S-killed / (S-target)(R-firer)(unit time)

Clearly, this formulation accounts for typical tank vs tank, artillery vs tank, tank vs artillery, and artillery vs artillery engagements. MOSCOW reduces this complicated system of equations to the traditional "square law" case by assuming the rate at which targets become available to indirect fire is constant for the duration of battle. This assumption implies that artillery can only "see" a constant number of targets independent of the actual size of the opposing force. This assumption also implies that neither side approaches annihilation. By defining the following constant terms, equations 1 - 4 can be reduced to a traditional square law formulation as follows:

Define constants:

$$c_1 \ll X_D (t)$$
$$c_2 \ll X_I (t)$$
$$c_3 \ll Y_D (t)$$
$$c_4 \ll Y_I (t)$$

Then, by substitution,

$$dX_D/dT = -(a_1 Y_D + b_1 c_1 Y_I) \quad (5)$$
$$dX_I/dT = -(a_2 Y_D + b_2 c_2 Y_I) \quad (6)$$
$$dY_D/dT = -(a_3 X_D + b_3 c_3 X_I) \quad (7)$$
$$dY_I/dT = -(a_4 X_D + b_4 c_4 X_I) \quad (8)$$

Summing pairs of equations 5,6 and 7,8:

$$d(X_D+X_I)/dT = -(a_1 + a_2)Y_D - (b_1\ c_1 + b_2\ c_2)Y_I \qquad (9)$$

$$d(Y_D+Y_I)/dT = -(a_3 + a_4)X_D - (b_3\ c_3 + b_4\ c_4)X_I \qquad (10)$$

By assuming the proportion of direct and indirect fire systems as a fraction of the total force remains constant, then:

$$X(t) = X_D(t) + X_I(t)$$

$$Y(t) = Y_D(t) + Y_I(t)$$

Then define such constants d_1, d_2, d_3, d_4 so that:

$$X_D = d_1\ X \quad \text{and} \quad X_I = d_2\ X$$

$$Y_D = d_2\ Y \quad \text{and} \quad Y_I = d_4\ Y$$

Substituting into equations 9 and 10 and collecting terms gives:

$$dX/dT = -[(a_1 + a_2)d_3 + (b_1\ c_1 + b_2\ c_2)d_4]Y \qquad (11)$$

$$dY/dT = -[(a_3 + a_4)d_1 + (b_3\ c_3 + b_4\ c_4)d_2]Y \qquad (12)$$

These equations are equivalent to the square law case.

APPENDIX D. ATTRITION CALCULATION EQUATIONS

As derived by Hartman [Ref 2, chapter 7, sec 5], the following equations result from the Lanchesterian square law formulation of attrition and explicitly determine the duration of such a battle where:

X_o and Y_o are initial force levels

a = coefficient of Y force attrition

b = coefficient of X force attrition

X_{bp} = "Break point" for X force

t_{xpb} = time required to reach X_{bp}

s = 1/2, exponential parameter

The "break point" is the point, in terms of force size, that a combatant will chose to disengage from combat so as not to sustain further losses. A symmetric pair of equations exist to express these relationships for the Y force.[27]

$$X_{bp} = \frac{1}{2}\left\{\left[X_o-(a/b)^s Y_o\right]e^{(a/b)^s t_{xbp}} + \left[X_o-(a/b)^s Y_o\right]e^{-(ab)^s t_{xbp}}\right\}$$

[27] The expressions for the Y force can be obtained by switching the definitions of variables, substituting Y for X, a for b, and visa versa.

$$t_{xbp} = (ab)^{-s} \ln \left\{ \frac{X_{bp} - \left[X_{bp}^2 - X_o^2 + (a/b)Y_o^2\right]^{-s}}{X_o - \left[(a/b)Y_o\right]^s} \right\}$$

Taken together, these equations represent the mechanism MOSCOW uses to compute either the time required for combat or the amount of attrition which results from combat. As solutions of a differential system of equations with specified initial conditions, the evaluation of these equations must result in unique solutions. Hence, transformations which are not identity relations cannot represent solutions of the original differential system. Since an change of the exponential parameter, s, to any value other than 1/2 is not an identity transformation, the result of such changes will be to fundamentally change the nature of MOSCOW's attrition relationship. This means that the possibility of changing the exponential parameter to values other than 1/2, as proposed by Romero [Ref. 1, figure C-15], will result in an attrition relationship which is different from the "square law" formulation.

APPENDIX E. AIR-GROUND ATTRITION EQUATIONS

Current descriptions of MOSCOW's algorithms do not elaborate on the algorithm used to compute the total number of aircraft sorties flown in any given campaign. Clues, however, exist in the code of the model and the inputs required for its computations. Apparently, this algorithm assumes a constant rate of attrition which decreases the number of aircraft which are available over time using the relation:

$$S_i = (1-P)^u X_o$$

where S_i = # of sorties available in period u

P = rate of aircraft attrition

X_o = initial number of aircraft available

The sortie period is a time index defined by the relation:

$$u = aT_b$$

where a = sortie rate measured in sorties/day

T_b = length of the battle in days

By treating this as a continuous process, the total number of sorties available in a battle of length (t) and sortie rate (a) is simply:

$$S = \int_{0}^{u} (1-P)^{r} X_{o} \, dr$$

$$S = [X_o/\ln(1-P)] \; [(1-P)^{u} - 1]$$

since $\qquad u = aT_b$

then,

$$S = [X_o/\ln(1-P)] \; [(1-P)^{aT_b} - 1]$$

APPENDIX F. FACTORIAL EXPERIMENT RESPONSE CALCULATION

The following method to calculate the effects produced by changing the levels of variables in a 2^n factorial experiment is an adaptation of a tabular approach attributed to F. Yates[28]. Using this method to compute the main effect of a single variable reduces to calculating the difference between the average output of all trials where the variable is at a high level and the average output when the variable is at a low level. To accomplish this, suppose a level coding vector X_i, containing 2^n elements, is used to record the levels of the variable X_i in all trials of an experiment. Within this vector, the k^{th} element contains 1 or -1. A "1" corresponds to trials with the variable at a high level; "-1" corresponds to trials at a low level. If the results of all trials for a single model output, Q_j are collected in a vector Q_j, then these two vectors, X_i and Q_j, can be used to compute the main effect of a variable by evaluating the expression:

$$\text{Main Effect } X_i = \frac{\sum_{k=1}^{2^n} X_{ik}\, Q_{jk}}{2^{n-1}}$$

[28] See Davies, Section 7.45, p. 263

The interaction between two variables is defined as half of the difference between the average output when the variables are at similar levels and the average when they are at dissimilar levels. As demonstrated in Davies[29], the previous method of recording the levels of variables in any trial can be used to compute these interactions by observing that, for two variables with corresponding vectors X_1 and X_2, the two-way interaction is:

$$X_1\ X_2 \text{ Interaction} = \frac{\sum_{k=1}^{2^n} (X_{1k}\ X_{2k})\ Q_{jk}}{2^{n-1}}$$

Similarly, the three-way interaction of variables X_1, X_2, and X_3 is:

$$X_{123} \text{ Interaction} = \frac{\sum_{k=1}^{2^n} (X_{1k}\ X_{2k}\ X_{3k})\ Q_{jk}}{2^{n-1}}$$

At this point it is easy to observe that, for a given interaction, multiplying the level codings for each interacting variable in trial will result in a level coding

[29] See Davies, Section 7.441, p. 262

vector corresponding to the interaction. Yate's method first calculates the level coding vectors for all interactions and then uses these vectors to compute main effects and interactions. These vectors are usually computed in "standard order" where all level coding vectors corresponding to the main effects and interactions of n-1 variables are combined with the level coding vector of the X_n variable to determine the coding vectors of all interactions with the X_n variable.

Thus, the order of computation is:

$$X_1,\ X_2,\ X_{12},\ X_3,\ X_{13},\ X_{23},\ X_{123},\ X_4,\ X_{14},\ X_{24},\ X_{124},\ X_{34},\ldots$$

This algorithm effectively generates all distinct combinations of main effects and interactions. The total number of such calculations [Ref. 7, sec 24.11, p. 822] is:

$$\sum_{k=1}^{n} \binom{n}{k} = 2^n - 1$$

Consequently, an algorithm using this technique has complexity order $O(2_n)$.

APPENDIX G. LISTING OF SENSITIVITY EXPERIMENT INPUTS

This appendix list the grouping of variables which comprise individual experiments in both the attack and defend scenarios. Code letters are used to correlate variable description with the results for each experiment. Input code identifies a particular input during data analysis

Experiment 1: Single Inputs of Interest

CODE	INPUT
A	HRS/DAY USABLE
B	%RED UNITS ATTACKING
C	# RED ENGINEER UNITS
D	% BLUE ATTACK OPS LINEAR
E	RED PENETRATION LIMIT
F	# RED UNITS ALLOWED TO SURVIVE
G	# BLUE ENGINEER UNITS

Experiment 2: Red Maneuver Unit Description and Operational Policy

CODE	INPUT
A	# RED VEHICLES/RED MANEUVER UNIT
B	DESIRED ATTACK FORCE RATIO
C	% FIRERS USING DIRECT FIRE
D	TARGET ACQUISITION TIME

CODE	INPUT
	(seconds)
E	C^3 ERROR (minimum %)
F	INTELLIGENCE ERRORS (minimum %)
G	C^3 ERRORS DUE TO ENEMY ELECTRONIC WARFARE

Experiment 3: Blue Maneuver Unit Description and Operational Policy

CODE	INPUT
A	# RED VEHICLES/RED MANEUVER UNIT
B	DESIRED ATTACK FORCE RATIO
C	% FIRERS USING DIRECT FIRE
D	TARGET ACQUISITION TIME (seconds)
E	C^3 ERROR (minimum %)
F	INTELLIGENCE ERRORS (minimum %)
G	C^3 ERRORS DUE TO ENEMY ELECTRONIC WARFARE

Experiment 4: Logistic and Maintenance Attributes of Interest

CODE	INPUT
A	BLUE PERSONNEL REGENERATION (persons/day)
B	RED VEHICLE REGENERATION (veh/day)
C	BLUE VEHICLE REGENERATION (veh/day)
D	BLUE CASUALTY REGENERATION COEFFICIENT
E	% RED VEHICLE LOSSES REPLACED

	BY NEXT ATTACK CYCLE
F	% BLUE VEHICLE LOSSES REPLACED BY NEXT ATTACK CYCLE
G	% RED VEHICLE LOSSES REPLACED BY NEXT DEFENSE CYCLE
H	% BLUE VEHICLE LOSSES REPLACED BY NEXT DEFENSE CYCLE
I	DISTANCE TO BLUE SUPPLY EXCHANGE POINT IN DEFENSE
J	DISTANCE TO BLUE SUPPLY EXCHANGE POINT IN ATTACK

Experiment 5: Aggregate Red Weapons Attributes of Interest

CODE	INPUT
A	ACTUAL RATE OF INDIRECT FIRE (stationary firer)
B	ACTUAL RATE OF DIRECT FIRE (both stationary and moving)
C	ACTUAL MAXIMUM INDIRECT FIRE RANGE (km)
D	ACTUAL MAXIMUM DIRECT FIRE RANGE (km)
E	PROBABILITY OF KILL GIVEN HIT
F	PROBABILITY OF INDIRECT FIRE HIT SCALING FACTOR
G	COEFFICIENT OF FRONTAL ARMOR HARDNESS
H	COEFFICIENT OF SIDE ARMOR HARDNESS

Experiment 6: Aggregate Blue Weapons Attributes of Interest

CODE	INPUT
A	ACTUAL RATE OF INDIRECT FIRE (stationary firer)
B	ACTUAL RATE OF DIRECT FIRE (both stationary and moving)
C	ACTUAL MAXIMUM INDIRECT FIRE RANGE (km)
D	ACTUAL MAXIMUM DIRECT FIRE RANGE (km)
E	PROBABILITY OF KILL GIVEN HIT
F	PROBABILITY OF INDIRECT FIRE HIT SCALING FACTOR
G	COEFFICIENT OF FRONTAL ARMOR HARDNESS
H	COEFFICIENT OF SIDE ARMOR HARDNESS

Experiment 7: Scaling Inputs of Interest

CODE	INPUT
A	MISCELLANEOUS LETHALITY MULTIPLIER (Red attack)
B	MISCELLANEOUS LETHALITY MULTIPLIER (Blue attack)
C	MISCELLANEOUS LETHALITY MULTIPLIER (Red defense)
D	MISCELLANEOUS LETHALITY MULTIPLIER (Blue defense)
E	MISCELLANEOUS VULNERABILITY MULTIPLIER (Red attack)
F	MISCELLANEOUS VULNERABILITY MULTIPLIER (Blue attack)
G	MISCELLANEOUS VULNERABILITY MULTIPLIER (Red defense)

H	MISCELLANEOUS VULNERABILITY MULTIPLIER (Blue defense)
I	RED MOBILITY DECREASE PER BLUE ENGINEER UNIT
J	RED MOBILITY INCREASE PER RED ENGINEER UNIT

Experiment 8: Red Organization for Combat, Morale, and Concealment

CODE	INPUT
A	MAXIMUM ATTRITION (per day) BEFORE UNIT BREAKS
B	CUMULATIVE ATTRITION BEFORE UNIT BREAKS
C	AVERAGE VEHICLE SPEED IN ADMINISTRATIVE MOVEMENT (km/hr)
D	AVERAGE VEHICLE SPEED IN BATTLE (km/hr)
E	% OF VEHICLES WHICH CAN FIRE IN ADMINISTRATIVE FORMATIONS
F	% OF VEHICLES WHICH CAN FIRE IN BATTLE FORMATION
G	% VEHICLES CONCEALED IN ADMINISTRATIVE FORMATION
H	% VEHICLES CONCEALED IN BATTLE FORMATION

Experiment 9: Blue Organization for Combat, Morale, and Concealment

CODE	INPUT
A	MAXIMUM ATTRITION (per day) BEFORE UNIT BREAKS
B	CUMULATIVE ATTRITION BEFORE UNIT BREAKS

C	AVERAGE VEHICLE SPEED IN ADMINISTRATIVE MOVEMENT (km/hr)
D	AVERAGE VEHICLE SPEED IN BATTLE (km/hr)
E	% OF VEHICLES WHICH CAN FIRE IN ADMINISTRATIVE FORMATIONS
F	% OF VEHICLES WHICH CAN FIRE IN BATTLE FORMATION
G	% VEHICLES CONCEALED IN ADMINISTRATIVE FORMATION
H	% VEHICLES CONCEALED IN BATTLE FORMATION

Experiment 10: Attack/Defend Paired Scenario Inputs

CODE	INPUT
A	RED UNIT AGGRESSIVENESS IN ATTACK
B	RED UNIT AGGRESSIVENESS IN DEFENSE
C	BLUE UNIT AGGRESSIVENESS IN ATTACK
D	BLUE UNIT AGGRESSIVENESS IN DEFENSE
E	% RED UNITS TO BE KILLED BY BLUE ATTACKS
F	% RED UNITS TO BE KILLED BY BLUE DEFENSES

Experiment 11: Red Attack/Defend Paired Maneuver Unit Description and Operational Policy

CODE	INPUT
A	% RED KILLED BY EACH BLUE ATTACK ENGAGEMENT
B	% RED KILLED BY EACH BLUE DEFENSE ENGAGEMENT
C	TIME STATIONARY IN ATTACK
D	TIME STATIONARY IN DEFENSE
E	AVERAGE DISTANCE MOVED BETWEEN HALTS IN THE ATTACK
F	AVERAGE DISTANCE MOVED BETWEEN HALTS IN THE DEFENSE

Experiment 12: Blue Attack/Defend Paired Maneuver Unit Description and Operational Policy

CODE	INPUT
A	% OF ATTACK ENGAGEMENTS ENDED AT A TIME CHOSEN BY BLUE
B	% OF DEFENSE ENGAGEMENTS ENDED AT A TIME CHOSEN BY BLUE
C	% BLUE KILLED BY EACH RED ATTACK ENGAGEMENT
D	% BLUE KILLED BY EACH RED DEFENSE ENGAGEMENT
E	TIME STATIONARY IN ATTACK
F	TIME STATIONARY IN DEFENSE
G	AVERAGE DISTANCE MOVED BETWEEN HALTS IN THE ATTACK
H	AVERAGE DISTANCE MOVED BETWEEN HALTS IN THE DEFENSE

I	SEPARATION FROM RED UNITS THAT BLUE CAN MAINTAIN IN THE ATTACK (SHADOW DISTANCE)
J	SEPARATION FROM RED UNITS THAT BLUE CAN MAINTAIN IN THE DEFENCE (SHADOW DISTANCE)

APPENDIX H. ESTIMATING RECALCULATION REQUIREMENTS

A consequence of the simultaneity within MOSCOW is that, by fixing input parameters and then successively recalculating the MOSCOW spreadsheet, model outputs converge to specific values. Although Romero [Ref. 1] proves MOSCOW's algorithms will converge, his explanation gives no information on the path this convergence takes or the points at which numerical limitations present computational difficulties[30]. Until this information is provided, model users face the problem of finding some reasonable way to estimate the number of recalculations required to move the point of output convergence of an initial set of input values to a new point defined by a specific change in these initial inputs. One way to approach this problem is to assume that, with no information to the contrary, the number of recalculations required to obtain convergence for changes in inputs which result in "small" changes of outputs is less than or equal to the number of recalculations need to produce convergence for those changes in inputs which produce "large" changes in outputs. With this idea, the

[30] The possibility exist that certain ranges of input values may not result in convergence as a result of excessive truncation, overflow, or underflow conditions which result from the inherent limitation of computers.

following heuristic approach was used to determine the number of recalculations required to produce a satisfactory level of convergence:

1. Double the numbers of Red forces while leaving all other inputs at a fixed level.
2. Recalculate the model 256 times. (Experience has shown this will produce convergence to at least 12 decimal places.)
3. Return Red force levels to their original values.
4. Perform 256 successive recalculations of the model, recording the resulting levels for those outputs of interest at each recalculation.
5. Assume that model outputs converge to the values obtained in the final recalculation.
6. Compute the difference between the output levels observed on each recalculation and those of the last recalculation.
7. Select as the recalculation requirement the number of recalculations which will guarantee convergence to within a desired amount.

For this investigation, the accuracy requirements defined in Section IV lead to the following calculations:

1. Attack Scenario Convergence Limit
   Since a Blue unit in the Attack scenario contains 369 combat vehicles, the accuracy requirement, A_{atk}, is:

$$A_{atk} = (.5)(1/369)$$
$$= 1.355 \times 10^{-3} \text{ Blue Units}$$

2. Defense Scenario Convergence Limit
Since a Blue unit in the Defense scenario contains 1108 combat vehicles, the accuracy requirement, A_{def}, is:

$$A_{def} = (.5)(1/369)$$

$$= 4.513 \times 10^{-4} \text{ Blue Units}$$

Performing the above heuristic procedure using the inputs for the Attack and Defend scenarios in Appendix B and comparing the resulting levels of convergence for both "Standing" and "Replacement" Blue unit outputs with the appropriate accuracy requirement leads to the conclusion that 21 recalculations achieve desired convergence in the Attack scenario while 15 suffice in the Defense. Figures 1-4 show the levels of convergence for these cases. Results of this procedure also indicate that MOSCOW's algorithm converges by oscillating about the limiting value for each output. While an interesting observation, this characteristic of convergence may not be true in general.

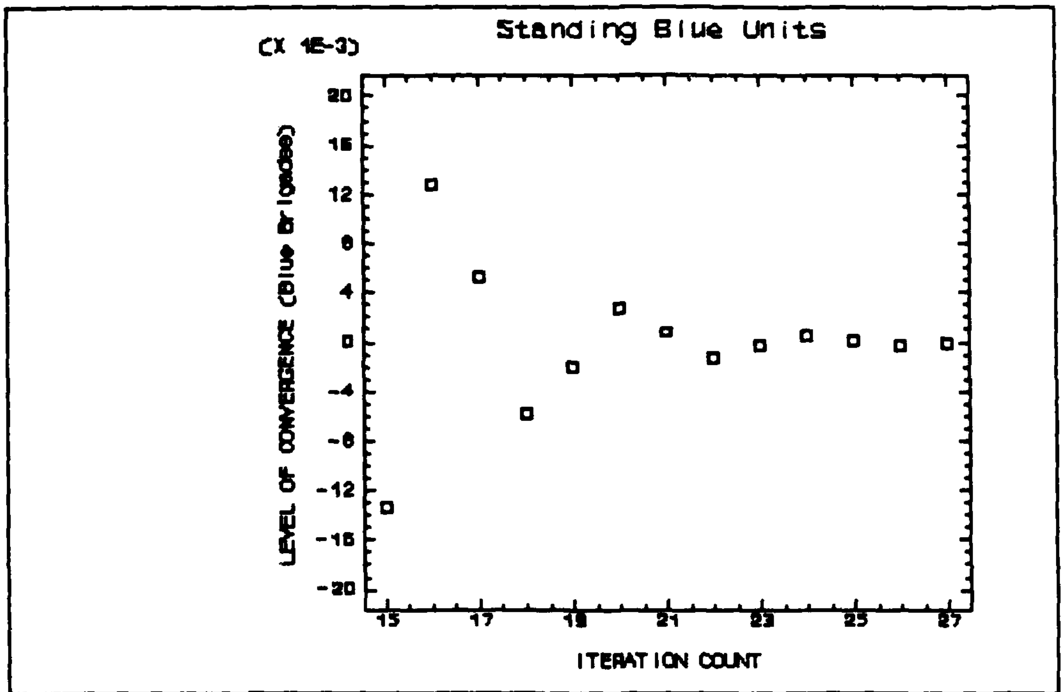

Figure 1 Convergence of Attack Scenario, Standing Blue Units Required.

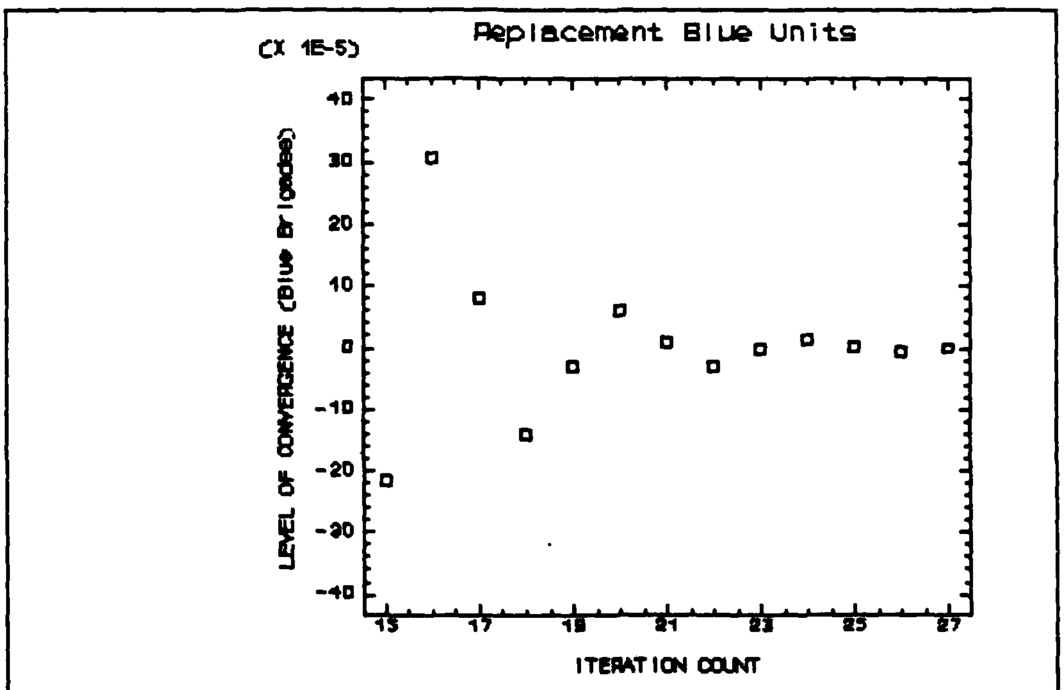

Figure 2. Convergence of Attack Scenario, Replacement Blue Units Required.

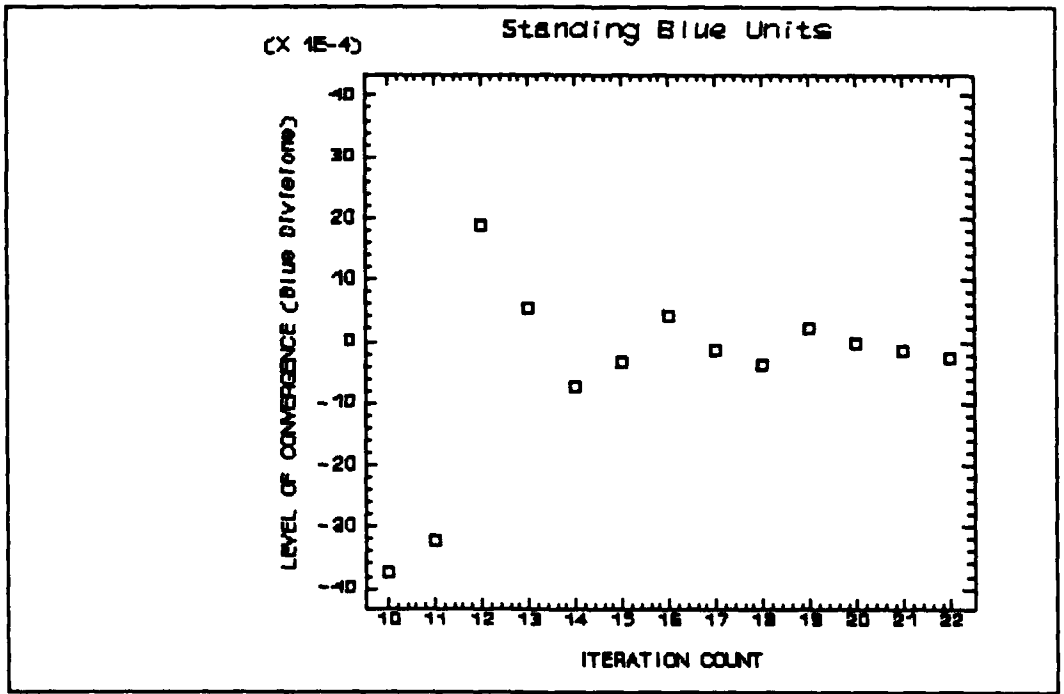

Figure 3. Convergence of Defense Scenario, Standing Blue Units Required.

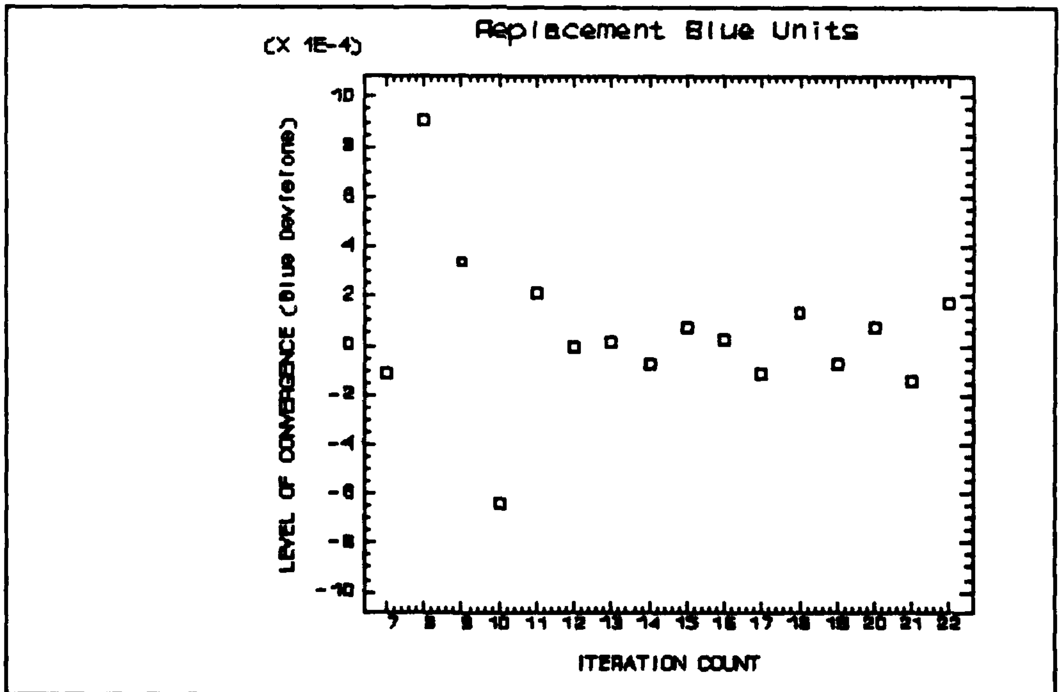

Figure 4. Convergence of Defense Scenario, Replacement Blue Units Required.

APPENDIX I. FACTORIAL EXPERIMENT MACRO LISTING

The following listings are examples of those incorporated into the MOSCOW spreadsheet in order to perform factorial experiments. Two different, but essentially equivalent programs were used. This was necessary to overcome the LOTUS 1-2-3, ver 2, macro limitation on the number of nested loops which can be imbedded within a macro. This limitation restricts the efficiency of experiments using nine or more inputs.

Each macro has three elements. The first section contains variable declarations which specify the changes in levels of specific inputs. The next section contains a control section that implements a 2^n factorial design as a series of nested loops. Recalculation of the spreadsheet is called by this section. The specific number of recalculations performed must be declared in the spreadsheet iteration counter prior to macro execution. Upon completion of the specified number of iterations for each trial, this section writes the results to a table which contains indicators of the levels for all experimental variables (inputs) and the resulting levels for five model outputs. One row of the results table corresponds to one trial of the experiment. A "1" in a column associated with a variable indicates that the input was at the high level during that trial. Zeros indicate inputs at the low level. The last program section writes the results of each trial to an output file. Due to memory limitations, results were written in 128 record blocks. The output files GROUP1, GROUP2, ..., GROUP8 are the destinations of these results. These files must exist prior to macro execution.

1. MACRO listing for 10 variable experiment.

```
                    COMPLETE TWO LEVEL FACTORIAL EXPERIMENT OF UP TO 10 FACTORS

CONSTANTS    DELTA= 0.10   (The percentage difference of the lower level from the upper level
.........

                          VAR 1                    VAR 2                    VAR 3

VARIABLES
.........                 RED MISC LETH MU-AT      BLUE MISC LETH MU-AT     RED MISC LETH MU-DE
          Counter         CTR1=        0           CTR2=        0           CTR3=        0
          Test value      TVL1=     0.80           TVL2=     1.00           TVL3=     0.50
          Increment       INC1=    -0.08           INC2=    -0.10           INC3=    -0.05


                          VAR 4                    VAR 5                    VAR 6

                          BLUE MISC LETH MU-DE     RED MISC VULN MU-AT      BLUE MISC VULN
MU-AT

          Counter         CTR4=        0           CTR5=        0           CTR6=        0
          Test value      TVL4=     1.00           TVL5=     1.00           TVL6=     0.80
          Increment       INC4=    -0.10           INC5=    -0.10           INC6=    -0.08


      VAR 7                     VAR 8                    VAR 9                    VAR 10

RED MISC VULN MU-DE       BLUE MISC VULN MU-DE         DEL/D/ENG                ACCEL/ENG

CTR7=        0            CTR8=        0           CTR9=        0           CTR10=        0
TVL7=     1.00            TVL8=     0.50           TVL9=     0.40           TVL10=     0.25
INC7=    -0.10            INC8=    -0.05           INC9=    -0.04           INC10=    -0.03


MACRO PROGRAM
.............

\J        {LET COUNTER,0}{VAR1}              Initialize iteration counter to ZERO

VAR1      {FOR CTR1,0,1,1,VAR2}
```

```
VAR2    {FOR CTR2,0,1,1,VAR3}

VAR3    {FOR CTR3,0,1,1,VAR4}

VAR4    {FOR CTR4,0,1,1,VAR5}

VAR5    {FOR CTR5,0,1,1,VAR6}

VAR6    {FOR CTR6,0,1,1,VAR7}

VAR7    {FOR CTR7,0,1,1,VAR8}

VAR8    {FOR CTR8,0,1,1,COMPUTE}


COUNTER      0.00

{LET CTR9,0}{LET CTR10,0}
{LET GI279,TVL1+INC1*CTR1;VALUE}
{LET GJ279,TVL2+INC2*CTR2;VALUE}
{LET GI280,TVL3+INC3*CTR3;VALUE}
{LET GJ280,TVL4+INC4*CTR4;VALUE}
{LET GI298,TVL5+INC5*CTR5;VALUE}
{LET GJ298,TVL6+INC6*CTR6;VALUE}
{LET GI299,TVL7+INC7*CTR7;VALUE}
{LET GJ299,TVL8+INC8*CTR8;VALUE}
{LET GJ393,TVL9+INC9*CTR9;VALUE}
{LET GI394,TVL10+INC10*CTR10;VALUE}
{LET COUNTER,COUNTER+1}
{CALC}
{GOTO}TABLE~
/RV{END}{RIGHT}~
{END}{DOWN}{DOWN}~
{LET CTR9,0}{LET CTR10,1}
{LET GI279,TVL1+INC1*CTR1;VALUE}
{LET GJ279,TVL2+INC2*CTR2;VALUE}
{LET GI280,TVL3+INC3*CTR3;VALUE}
{LET GJ280,TVL4+INC4*CTR4;VALUE}
{LET GI298,TVL5+INC5*CTR5;VALUE}
{LET GJ298,TVL6+INC6*CTR6;VALUE}
{LET GI299,TVL7+INC7*CTR7;VALUE}
{LET GJ299,TVL8+INC8*CTR8;VALUE}
{LET GJ393,TVL9+INC9*CTR9;VALUE}
{LET GI394,TVL10+INC10*CTR10;VALUE}
{LET COUNTER,COUNTER+1}
{CALC}
{GOTO}TABLE~
/RV{END}{RIGHT}~
{END}{DOWN}{DOWN}~
{LET CTR9,1}{LET CTR10,0}
{LET GI279,TVL1+INC1*CTR1;VALUE}
{LET GJ279,TVL2+INC2*CTR2;VALUE}
{LET GI280,TVL3+INC3*CTR3;VALUE}
{LET GJ280,TVL4+INC4*CTR4;VALUE}
{LET GI298,TVL5+INC5*CTR5;VALUE}
{LET GJ298,TVL6+INC6*CTR6;VALUE}
{LET GI299,TVL7+INC7*CTR7;VALUE}
{LET GJ299,TVL8+INC8*CTR8;VALUE}
{LET GJ393,TVL9+INC9*CTR9;VALUE}
{LET GI394,TVL10+INC10*CTR10;VALUE}
{LET COUNTER,COUNTER+1}
{CALC}
{GOTO}TABLE~
```

```
/RV{END}{RIGHT}~
{END}{DOWN}{DOWN}~
{LET CTR9,1}{LET CTR10,1}
{LET GI279,TVL1+INC1*CTR1;VALUE}
{LET GJ279,TVL2+INC2*CTR2;VALUE}
{LET GI280,TVL3+INC3*CTR3;VALUE}
{LET GJ280,TVL4+INC4*CTR4;VALUE}
{LET GI298,TVL5+INC5*CTR5;VALUE}
{LET GJ298,TVL6+INC6*CTR6;VALUE}
{LET GI299,TVL7+INC7*CTR7;VALUE}
{LET GJ299,TVL8+INC8*CTR8;VALUE}
{LET GJ393,TVL9+INC9*CTR9;VALUE}
{LET GI394,TVL10+INC10*CTR10;VALUE}
{LET COUNTER,COUNTER+1}
{CALC}
{GOTO}TABLE~
/RV{END}{RIGHT}~
{END}{DOWN}{DOWN}~
{GOTO}TABLE~{DOWN 2}
{IF COUNTER=128}/FXVGROUP1.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=256}/FXVGROUP2.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=384}/FXVGROUP3.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=512}/FXVGROUP4.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=640}/FXVGROUP5.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=768}/FXVGROUP6.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=896}/FXVGROUP7.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=1024}/FXVGROUP8.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
```

Output table containing levels of variables:

LEVELS of VARIABLES

VAR 1	VAR 2	VAR 3	VAR 4	VAR 5	VAR 6	VAR 7	VAR 8	VAR 9	VAR 10
0	0	0	0	0	0	0	0	0	0

Output table containing levels of measures of effectiveness for each trial:

MEASURES OF EFFECTIVENESS

MOE 1 STANDING	MOE 2 REPL	MOE 3 RED:BLUE GRND	MOE 4 ATK CYCLES	MOE 5 DEF CYCLES
11.3706413	1.3070730	1.6099078	6.0713466	2.0052472

2. MACRO listing for eight variable experiment

COMPLETE TWO LEVEL FACTORIAL EXPERIMENT OF UP TO 8 FACTORS

CONSTANTS DELTA= 0.10 (The percentage difference of the lower level from the upper level

VARIABLES

	VAR 1		VAR 2		VAR 3 ACT IF RATE-S	
Counter	CTR1=	0	CTR2=	0	CTR3=	0
Test value	TVL1=	0.00	TVL2=	0.00	TVL3=	0.340
Increment	INC1=	0.00	INC2=	0.00	INC3=	0.00

	VAR 4 ACT DF RATE-S/M		VAR 5 ACT IF RANGE-HI		VAR 6 ACT DF RANGE-HI	
Counter	CTR4=	0	CTR5=	0	CTR6=	0
Test value	TVL4=	3.540	TVL5=	19.600	TVL6=	1.609
Increment	INC4=	0.00	INC5=	0.00	INC6=	0.000

VAR 7 KILLS/HIT		VAR 8 IF HITS/R COEF		VAR 9 HARDNESS-FRONT		VAR 10 HARDNESS-SIDE	
CTR7=	0	CTR8=	0	CTR9=	0	CTR10=	0
TVL7=	0.500	TVL8=	0.0032	TVL9=	0.560	TVL10=	0.370
INC7=	0.00	INC8=	0.0000	INC9=	0.00	INC10=	0.00

MACRO PROGRAM

```
\J        {LET COUNTER,0}{VAR3}                  Initialize iteration counter to ZERO

VAR1      {FOR CTR1,0,1,1,VAR2}

VAR2      {FOR CTR2,0,1,1,VAR3}

VAR3      {FOR CTR3,0,1,1,VAR4}

VAR4      {FOR CTR4,0,1,1,VAR5}

VAR5      {FOR CTR5,0,1,1,VAR6}

VAR6      {FOR CTR6,0,1,1,VAR7}

VAR7      {FOR CTR7,0,1,1,VAR8}

VAR8      {FOR CTR8,0,1,1,VAR9}

VAR9      {FOR CTR9,0,1,1,VAR10}

VAR10     {FOR CTR10,0,1,1,COMPUTE}

COUNTER      0.00

COMPUTE   {LET     ,TVL1+INC1*CTR1;VALUE}
          {LET GI263,TVL3+INC3*CTR3;VALUE}
          {LET GI265,TVL4+INC4*CTR4;VALUE}
          {LET GI266,TVL4+INC4*CTR4;VALUE}
          {LET GI267,TVL5+INC5*CTR5;VALUE}
          {LET GI269,TVL6+INC6*CTR6;VALUE}
          {LET GI258,TVL7+INC7*CTR7;VALUE}
          {LET GI260,TVL8+INC8*CTR8;VALUE}
          {LET GI286,TVL9+INC9*CTR9;VALUE}
          {LET GI287,TVL10+INC10*CTR10;VALUE}
          {LET COUNTER,COUNTER+1}
          {CALC}{OUTPUT}
          {IF @MOD(COUNTER,128)=0}{FILE}
          {RETURN}
          {GOTO}TABLE~
          /RV{END}{RIGHT}~
          {END}{DOWN}{DOWN}~
          {RETURN}
```

Subprogram to write output files:

```
{GOTO}TABLE~{DOWN 2}
{IF COUNTER=128}/FXVGROUP1.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=256}/FXVGROUP2.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=384}/FXVGROUP3.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=512}/FXVGROUP4.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=640}/FXVGROUP5.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=768}/FXVGROUP6.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=896}/FXVGROUP7.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{IF COUNTER=1024}/FXVGROUP8.WK1~{END}{DOWN}{END}{RIGHT}~R/RE{END}{DOWN}{END}{RIGHT}~{RETURN}
{QUIT}
```

Output table headings:

LEVELS of VARIABLES

VAR 1	VAR 2	VAR 3	VAR 4	VAR 5	VAR 6	VAR 7	VAR 8	VAR 9	VAR 10
0	0	0	0	0	0	0	0	0	0

MEASURES OF EFFECTIVENESS

MOE 1	MOE 2	MOE 3	MOE 4	MOE 5
STANDING	REPL	RED:BLUE GRND	ATK CYCLES	DEF CYCLES
3.3243906	0.6491045	3.3061550	0.1920200	1.9240636

APPENDIX J. INPUT SENSITIVITY PROGRAM LISTING

This APL program computes the main effects and levels of interaction for a sensitivity experiment using the LOTUS macro program in Appendix I. Lotus format output files must be merged and converted into a STATGRAPHICS file using the file conversion facilities within version 6.4. This program will read these files and interactively compute a results file which contains all resulting main effects and levels of interaction. Once results for a given experiment have been calculated, the results are saved for further analysis. The user is given the option of replaying results at user selected levels of significance or requesting a rank ordering of the magnitudes of all interactions and main effects. This ordering can be used to determine the dominance of main effects vice corresponding interactions.

```
      ∇FINT[⎕]∇
[0]  FINT;F;N;R;FAC;K;COUNT;M;T;TEMP;OLD;OLDINDEX;TEMPINDEX;J;MOE;I;VARI;INX;SOR
[1]  LOUT:'REVIEW PREVIOUSLY COMPUTED INTERACTIONS ? (Y/N)' ◇ ANS←⍞
[2]   →('Y'=1↑ANS)ρL13
[3]   'COMPUTE INTERACTIONS OF NEW DATA FILE ? (Y/N)' ◇ ANS←⍞
[4]   →('N'=1↑ANS)ρ0 ⍝ If 'N', then abort program
[5]   'INPUT NAME OF NEW "asf" DATA FILE' ◇ ANS←⍞
[6]   ANS ⎕FTIE 90
[7]   F←90
[8]   'INPUT THE NUMBER OF VARIABLES' ◇ N←⎕
[9]   'INPUT THE NUMBER OF MEASURES OF EFFECTIVENESS' ◇ R←⎕
[10]  'INPUT THE FACTOR OF SIGNIFICANCE FOR RESULTS' ◇ FAC←⎕
[11]
[12]  ⎕←'CREATE FILES' ◇ ''
[13]  'INDEX' ⎕FCREATE 98
[14]  'EFFECTS' ⎕FCREATE 99
[15]
[16]  K←11-N
[17]  COUNT←0
[18]  VARI←'ABCDEFGHIJ'
[19]
```

```
 ⎕←'PROCESSING DATA' ◇ '' ◇ '     VARIABLE:'
L1:K←K+1
 COUNT←COUNT+1
 M←(⎕FSIZE 99)[2]-1
 T←⎕FREAD(F,K)
 TEMP←(T=0)+(¯1×T) ⍝Convert data to string of 1's and ¯1's
 C←TEMP ⎕FAPPEND 99 ⍝Save result in EFFECTS file
⍝SET INDEX
 TEMPINDEX←1↑VARI
 D←TEMPINDEX ⎕FAPPEND 98
 ⎕←'                    ',TEMPINDEX
⍝SET REMAINING INDICIES
 VARI←1↓VARI
 →(COUNT=1)⍴L1 ⍝First variable has no interactions
⍝COMPUTE INTERACTIONS
 J←1
L2:OLD←⎕FREAD(99,J)
 OLDINDEX←⎕FREAD(98,J)
 C←(OLD×TEMP)⎕FAPPEND 99
 D←(OLDINDEX,TEMPINDEX)⎕FAPPEND 98
 J←J+1
 →(J≤M)⍴L2
⍝CHECK FOR MORE VARIABLES
 →(COUNT<N)⍴L1
 C←(⎕FSIZE 98)[3]+(⎕FSIZE 99)[3]
 ⎕←'' ◇ 'TOTAL FILE STORAGE REQUIRED:  ',(⍕C),' bytes'
⍝  READ THE MOE RESULTS DATA VECTORS
 (R=1)⍴(MOE←⎕FREAD(F,K+1)) ⍝  If only one MOE, then special case
 (R=1)⍴L4
⍝Else:
 J←1
 MOE←(R,(2*N))⍴0
L3:MOE[J;]←⎕FREAD(F,K+J)
 J←J+1
 →(J≤R)⍴L3
⍝  COMPUTE THE VALUE OF MAIN EFFECTS AND INTERACTIONS FOR ALL MOE'S
 ⎕←'' ◇ 'COMPUTING MAIN EFFECTS AND INERACTIONS'
 I←1
 INTR←(((2*N)-1),R)⍴0
 INDEX←(((2*N)-1),10)⍴' '
 SORTVEC←(((2*N)-1),1)⍴0
L4:TEMP←⎕FREAD(99,I)
 INX←⎕FREAD(98,I)
 SORTVEC[I;1]←⍴INX
 INDEX[I;]←INX,(10-SORTVEC[I;1])⍴' '
 J←1
L5:INTR[I;J]←(+/MOE[J;]×TEMP)÷(2*(N-1))
 J←J+1
 →(J≤R)⍴L5
 I←I+1
 →(I≤((⎕FSIZE 99)[2]-1))⍴L4
```

```
⍝  SORT RESUTING INTERACTION:  MAIN EFFECTS, TWO-WAY, THREE-WAY, ETC.
 INTR[;]←INTR[⍋SORTVEC;]
 INDEX[;]←INDEX[⍋SORTVEC;]
 ⎕←'' ⋄ 'EFFECTS COMPUTED.  MEMORY REQUIRED:  ',(⍕(284416-⎕WA)),' bytes'
 NAME←ANS
⍝  SAVE COMPUTED LEVELS OF INTERACTION FOR LATER ANALYSIS
 '' ⋄ 'SAVE RESULTS? (Y/N) ' ⋄ ANS←⍞
 →('Y'≠1↑ANS)⍴SKIP
 ('E',NAME)⎕FCREATE 80
 ('I',NAME)⎕FCREATE 81
 C←N ⎕FAPPEND 80
 C←R ⎕FAPPEND 80
 C←INTR ⎕FAPPEND 80
 C←(R,1)⍴MOE[;1]⎕FAPPEND 80
 D←INDEX ⎕FAPPEND 81
 ⎕FUNTIE 80 81
 'INDEX' ⎕FERASE 98
 'EFFECTS' ⎕FERASE 99
SKIP:⎕←'' ⋄ 'RESULTS FOLLOW'
⍝  COMPUTE LEVELS OF SIGNIFICANCE FOR EACH MOE AT DESIRED FACTOR
 BL←MOE[;1] ⍝  BASE LEVEL (ALL FACTORS AT LOW LEVEL) OF MOE'S
L6:SIG←BL×FAC
 I←1
L7:'' ⋄ '' ⋄ ''
 '          SIGNIFICANT INTERACTIONS FOR MEASURE OF EFFECTIVENESS ',⍕I
 '                    (Level of significance = ±',(⍕SIG[I]),')'
 '' ⋄ ''
 J←1
 L←0
L8:→((|INTR[J;I])<SIG[I])⍴L9
 ⎕←(INDEX[J;]),⍕(INTR[J;I])
 L←1
L9:J←J+1
 →(J≤((2*N)-1))⍴L8
 →(L=0)⍴L11
L12:I←I+1
 →(I≤R)⍴L7
 '' ⋄ '' ⋄ 'NEW LEVEL OF SIGNIFICANCE? (Y/N) ' ⋄ ANS←⍞
 →('Y'=1↑ANS)⍴L10
 ⎕FUNTIE ⎕FNUMS
 →0
L10:'' ⋄ 'ENTER NEW LEVEL OF SIGNIFICANCE'
 FAC←⎕
 →L6
L11:'               ****** NO SIGNIFICANT INTERACTIONS ******' ⋄ ''
```

```
 →L12
L13:'ENTER NAME OF RESULTS FILE (Do not include "asf" extension)' ⋄ NAME←⍞
 ('E',NAME)⎕FTIE 80
 ('I',NAME)⎕FTIE 81
⍝  DECODE THE NUMBER OF VARIABLES AND MOE IN THESE DATA FILES
 N←⎕FREAD 80 1
 R←⎕FREAD 80 2
 INTR←⎕FREAD 80 3
 BL←⎕FREAD 80 4
 INDEX←⎕FREAD 81 1
 ⎕FUNTIE 80 81
 'FILES READ'
 ''
 'RANK ORDER OF MAIN EFFECTS AND INTERACTIONS?  (Y/N)' ⋄ ANS←⍞
 →('Y'=1↑ANS)⍴L14
 →L10
L14:'' ⋄ '' ⋄ 'ENTER DEPTH OF RANKING TO DISPLAY  (Integer > 0) ' ⋄ LIM←⎕
 I←1
L15:J←1
 '' ⋄ ''
 'RANK ORDER FOR MAIN EFFECTS AND INTERACTIONS ',⍕I
 '' ⋄ ''
 RI←⍒INTR[;I]
 RINTR←INTR[RI;I]
 RINDEX←INDEX[RI;]
L16:⎕←(RINDEX[J;]),(⍕RINTR[J])
 J←J+1
 →((J≤((2*N)-1))∧(J≤LIM))⍴L16
 I←I+1
 →(I≤R)⍴L15
 →LOUT
```

APPENDIX K. COMPUTED MAIN EFFECTS

The following tables contain the main effects for all inputs as computed from factorial experiments. Main effects for those inputs marked with an asterisk were used in comparisons with a priori predictions of how a small (10 percent) increase in input level should influence model output. All cases where such expectations do not agree with observation appear in instances where the main effect term is dominated by interactions with other inputs.

Single Inputs of Interest

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
HRS/DAY USABLE	1.144	.070	-.107	.502	.313	.358	.004	-.040	-.006	.234
*%RED UNITS ATTACKING	.056	.004	-.001	.041	-.002	-.101	-.015	.074	-.021	-.043
*# RED ENGINEER UNITS	1.286	.018	-.001	.659	.258	.295	.014	-.071	.010	.179
*%BLUE ATTACK OPS LINEAR	.003	.000	.000	.003	.000	.005	.011	-.061	.000	.003
*RED PENETRATION LIMIT	-1.123	-.019	.001	-.573	-.227	-.463	-.017	.076	-.018	-.276
*# RED UNITS SURVIVING	-.519	-.075	.000	-.260	-.110	-.192	-.035	.019	-.008	-.114
*# BLUE ENGINEER UNITS	-1.861	-.029	.002	-.950	-.376	-1.616	-.056	.248	-.065	-.965
10% Level - (Absolute Value)	1.137	.113	.161	.607	.201	.332	.065	.331	.019	.192

Red Maneuver Unit Description and Operational Policy

Input	Attack Scenario STAND	REPL	R:B	ATK	DEF	Defense Scenario STAND	REPL	R:B	ATK	DEF
*# RED VEH/RED UNIT	1.332	.252	-.264	.651	.300	.237	.095	-.444	.029	.167
DESIRED ATK FORCE RATIO	.209	.135	-.425	-.111	.261	.065	.059	-.565	-.003	.089
*%FIRERS-DIRECT FIRE	.703	.189	-.446	.338	.165	.136	.052	-.434	.022	.022
*TARGET ACQUISITION TIME	.061	.001	-.001	.044	.000	.004	.002	-.010	.000	.004
*C^3 ERROR (min %)	-.023	-.006	.014	-.005	-.012	-.028	-.002	.019	.000	-.029
*INTELLIGENCE ERRORS	-.814	-.049	.093	-.528	-.054	-.043	-.016	.113	-.005	-.015
C^3 ERROR BY ENEMY EW	.218	.015	-.033	.129	-.011	6.233	1.181	7.244	.342	3.616
10% Level - (Absolute Value)	1 137	.131	.161	.607	.201	.332	.065	.331	.019	.192

Blue Maneuver Unit Description and Operational Policy

Input	Attack Scenario STAND	REPL	R:B	ATK	DEF	Defense Scenario STAND	REPL	R:B	ATK	DEF
*# BLUE VEH/BLUE UNIT	-1.561	-.309	.151	-.885	-.246	-.582	-.130	.292	-.034	-.345
DESIRED ATK FORCE RATIO	.820	.065	-.009	.594	.001	.072	.006	-.006	.025	.021
*%FIRERS-DIRECT FIRE	-.459	-.024	-.022	-.277	-.056	-.157	-.036	.186	-.002	-.101
*TARGET ACQUISITION TIME	.692	.047	.016	.506	-.006	.183	.040	-.203	.015	.104
*C^3 ERROR (min %)	.146	.000	.005	.061	.002	.109	.005	-.020	.003	.027
*INTELLIGENCE ERRORS	.606	.006	.012	.124	.047	.184	.011	-.049	.001	.042
*C^3 ERROR BY ENEMY EW	-.076	-.005	.006	-.032	-.022	-.029	-.005	.021	-.002	-.017
10% Level - (Absolute Value)	1.137	.113	.161	.607	.201	.033	.065	.331	.019	.192

Red Organization for Combat, Morale, and Concealment Factors

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
MAX DAILY ATTRITION	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
*MAX CUMULATIVE ATTRITION	.447	.059	-.078	.279	.039	.099	.021	-.147	.023	.040
*VEHICLE SPEED (Admin)	.604	.021	-.015	.292	.138	.188	.004	-.017	.009	.111
*VEHICLE SPEED (Battle)	.209	.006	-.003	.103	.046	.068	.003	-.017	.003	.040
*%VEH FIRING (Admin)	.230	.061	-.102	.091	.073	.084	.019	-.136	.010	.044
*%VEH FIRING (Battle)	.180	.048	-.079	.076	.052	.007	-.002	.014	.001	.004
*%VEH CONCEALED (Admin)	.076	.007	.000	.047	.007	.070	.015	-.118	.000	.044
*%VEH CONCEALED (Battle)	.015	.002	.000	.008	.002	.003	.000	-.001	.000	.002
10% Level - (Absolute Value)	1.137	.113	.161	.607	.201	.332	.065	.331	.019	.192

Blue Organization for Combat, Morale, and Concealment Factors

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
MAX DAILY ATTRITION	.000	.000	.000	.000	.000	-.001	.000	.000	.000	.000
MAX CUMULATIVE ATTRITION	.000	.000	.000	.000	.000	-.001	.000	.000	.000	.000
*VEHICLE SPEED (Admin)	-.382	-.020	.000	-.263	-.010	-.035	-.003	.000	-.010	-.012
*VEHICLE SPEED (Battle)	-.128	-.007	.000	-.088	-.003	-.012	-.001	.000	-.003	-.004
*%VEH FIRING (Admin)	-.347	-.014	-.027	-.285	.038	-.141	-.027	.152	-.001	-.089
*%VEH FIRING (Battle)	.038	.020	-.036	.005	.022	.068	.008	-.050	-.004	.048
*%VEH CONCEALED (Admin)	-.109	-.021	.024	-.068	-.010	-.144	-.030	.157	-.003	-.089
*%VEH CONCEALED (Battle)	-.003	-.002	.002	-.002	-.001	-.059	-.015	.051	-.001	-.037
10% Level - (Absolute Value)	1.137	.131	.161	.607	.201	.332	.065	.331	.019	.192

Aggregate Red Weapons Attributes

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
*INDIRECT FIRE RATE	.017	.002	-.003	.004	.008	.001	.000	.000	.000	.000
*DIRECT FIRE RATE	.411	.092	-.150	.172	.121	.052	.011	-.071	.011	.022
*INDIRECT FIRE MAX RANGE	.022	.003	-.005	.007	.009	.000	.001	-.001	.003	-.003
*DIRECT FIRE MAX RANGE	-.001	.000	.000	-.001	.000	.001	.000	.000	.000	.000
*DF PROB KILL GIVEN HIT	.431	.094	-.153	.186	.122	.053	.010	-.069	.011	.022
*INDIRECT FIRE HIT PROB	-.037	-.003	.006	-.010	-.016	.000	.000	-.001	.000	.000
*FRONTAL ARMOR COEF	.240	.013	-.003	.171	.000	.037	.009	-.067	.000	.024
*SIDE ARMOR COEF	.209	.001	.036	.112	.037	.045	.008	-.059	.004	.025
10% Level - (Absolute Value)	1.137	.131	.161	.607	.201	.332	.065	.331	.019	.192

Aggregate Blue Weapons Attributes

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
*INDIRECT FIRE RATE	-.001	.000	-.001	-.002	.001	-.007	-.001	.005	-.002	-.003
*DIRECT FIRE RATE	-.259	-.012	-.019	-.175	-.010	.026	.070	-.285	-.001	.017
*INDIRECT FIRE MAX RANGE	-.002	.000	-.001	-.003	.001	.007	.005	-.014	.002	.002
*DIRECT FIRE MAX RANGE	.000	.000	.000	-.001	.001	.158	.063	-.202	.009	.092
*DF PROB KILL GIVEN HIT	-.298	-.018	-.015	-.201	-.011	.203	.070	-.234	.013	.117
*INDIRECT FIRE HIT PROB	.018	.000	.001	.012	.001	.002	-.004	.011	.001	.000
*FRONTAL ARMOR COEF	-.124	-.010	.006	-.088	-.001	.019	-.001	.005	.001	.012
*SIDE ARMOR COEF	-.633	-.138	.174	-.280	-.170	.106	.009	-.017	.008	.060
10% Level - (Absolute Value)	1.137	.131	.161	.607	.201	.332	.065	.331	.019	.192

Lethality, Vulnerability, and Mobility Scaling Inputs

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
MISC LETHALITY (Red atk)	.727	.129	-.209	.368	.150	.183	.029	-.157	.011	.106
MISC LETHALITY (Blue atk)	-.111	.001	-.024	-.109	.030	-.003	-.001	.000	-.008	.006
MISC LETHALITY (Red def)	.030	.004	-.005	.020	.001	.003	.000	.000	.002	.000
MISC LETHALITY (Blue def)	-.062	.000	-.004	.016	-.061	-.161	-.026	.150	.001	-.104
MISC VULN (Red atk)	-.051	.000	-.004	.023	-.060	-.161	-.026	.150	.001	-.104
MISC VULN (Blue atk)	.033	.004	-.006	.022	.001	.003	.000	.000	.002	.000
MISC VULN (Red def)	-.136	.002	-.029	-.129	.032	-.001	.000	-.003	-.007	.006
MISC VUNL (Blue def)	.659	.131	-.220	.330	.140	.169	.029	-.155	.011	.097
*COEF BLUE ENG ABILITY	-1.825	-.021	-.004	-.887	-.414	-1.414	-.037	.150	-.056	-.846
*COEF RED ENG ABILITY	1.078	.002	.022	.542	.226	.208	.002	-.003	.009	.124
10% Level - (Absolute Value)	1.137	.131	.161	.607	.201	.332	.056	.331	.019	.192

Logistic and Maintenance Attributes

Input	Attack Scenario					Defense Scenario				
	STAND	REPL	R:B	ATK	DEF	STAND	REPL	R:B	ATK	DEF
BLUE PERS REGENERATION	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
*RED VEHICLE REGEN	.009	.001	.000	.006	.001	.019	.004	.000	.002	.010
*BLUE VEHICLE REGEN	-.148	-.003	.000	-.009	-.096	-.046	-.002	.000	.000	-.029
BLUE CASUALTY REGEN	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
%RED VEH LOSS REPL ATK	.004	.000	.000	.003	.000	.000	.000	.000	.000	.000
%BLUE VEH LOSS REPL ATK	-.007	-.001	.000	-.006	.000	.000	.000	.000	.000	.000
%RED VEH LOSS REPL DEF	.041	.004	-.001	.031	-.002	.000	.000	.000	.000	.000
%BLUE VEH LOSS REPL DEF	.001	.000	-.001	.000	.001	.000	.000	.000	.000	.000
BLUE EXCH PT DIST DEF	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
*BLUE EXCHPT DIST ATK	.041	.001	.000	.031	-.002	.001	.000	.000	.001	.000
10% Level - (Absolute Value)	1.137	.131	.161	.607	.201	.332	.065	.331	.019	.192

Attack/Defend Paired Scenario Inputs

Input	Attack Scenario STAND	Attack Scenario REPL	Attack Scenario R:B	Attack Scenario ATK	Attack Scenario DEF	Defense Scenario STAND	Defense Scenario REPL	Defense Scenario R:B	Defense Scenario ATK	Defense Scenario DEF
RED AGGRESSIVENESS (Atk)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
RED AGGRESSIVENESS (Def)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
BLUE AGGRESSIVENESS (Atk)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
BLUE AGGRESSIVENESS (Def)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
%RED KILLED BY BLUE ATK	.049	.090	-.128	.396	.110	-.094	-.011	.079	.014	-.036
%RED KILLED BY BLUE DEF	.010	.068	-.138	-.043	.168	-.063	.015	-.094	.001	.068
10% Level - (Absolute Value)	.137	.131	.161	.607	.201	.332	.065	.331	.019	.192

Red Attack/Defend Paired Maneuver Unit Description and Operational Policy Inputs

Input	Attack Scenario STAND	Attack Scenario REPL	Attack Scenario R:B	Attack Scenario ATK	Attack Scenario DEF	Defense Scenario STAND	Defense Scenario REPL	Defense Scenario R:B	Defense Scenario ATK	Defense Scenario DEF
%RED KILLED BY EACH ATK	-.812	-.067	.040	-.599	.020	-.017	-.002	.011	-.002	-.009
%RED KILLED BY EACH DEF	.000	-.003	.005	.000	.000	-.164	-.010	-.007	.001	-.106
TIME STATIONARY IN ATK	-.990	-.044	-.080	-.757	.052	-.238	-.049	.247	-.029	-.123
TIME STATIONARY IN DEF	.254	.020	-.007	.185	-.004	-.008	-.001	.008	.003	-.008
DIST BETWEEN HALTS (Atk)	.028	.016	-.028	.030	-.011	-.099	-.019	.110	.001	-.064
DIST BETWEEN HALTS (Def)	-.150	-.019	.013	-.113	.006	-.016	-.002	.006	-.002	-.008
10% Level - (Absolute Value)	1.137	.131	.161	.607	.201	.332	.065	.331	.019	.192

Blue Attack/Defend Paired Maneuver Unit Description and Operational Policy Inputs

Input	Attack Scenario STAND	REPL	R:B	ATK	DEF	Defense Scenario STAND	REPL	R:B	ATK	DEF
%ATK ENGMENT END BY BLUE	1.050	.104	-.074	.752	-.005	-.002	-.001	.001	-.002	.000
%DEF ENGMENT END BY BLUE	-.088	-.038	.064	.029	-.091	.156	.012	-.018	-.001	.101
%BLUE KILLED BY EACH ATK	-.029	-.003	.003	-.017	-.004	-.009	.000	-.004	-.004	-.001
%BLUE KILLED BY EACH DEF	-.210	-.085	.138	.060	.210	-.162	-.027	.146	.002	-.105
TIME STATIONARY IN ATK	.030	.007	-.010	.013	.008	.004	.000	-.002	.001	.002
TIME STATIONARY IN DEF	.000	-.001	.002	.002	-.002	.003	.000	-.002	.000	.002
DIST BETWEEN HALTS (Atk)	-.004	.000	-.001	-.001	-.002	.003	.000	-.002	.000	.002
DIST BETWEEN HALTS (Def)	.008	.001	-.003	.001	.005	.003	.000	-.002	.000	.002
BREAK CONTACT DIST (Atk)	.223	.012	.001	.171	-.013	.006	.000	-.002	.002	.002
BREAK CONTACT DIST (Def)	.027	.002	.000	-.008	.027	.023	.002	.000	.000	.015
10% Level - (Absolute Value)	1.137	.131	.161	.607	.201	.322	.065	.331	.019	.192

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