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It is recognized by military historians and students of warfare that behavioral elements within each fighting force – morale, leadership, etc. – have a significant impact on battlefield outcomes. Such so-called "soft factors" can influence the battle towards victory or defeat. History is replete with examples of smaller, well-disciplined forces taking the fight to the enemy and being victorious. However, these elements of combat performance are seldom modeled explicitly in simulations at the campaign level. The Joint Warfare System (JWARS) is one of the few models that incorporate explicit behavioral soft factors that can influence battle outcome. During the Unified Vision 04 (UV04) wargame conducted by the US Joint Forces Command (JFCOM), the JWARS model was used in conjunction with a political-economic model to represent the interplay of morale and cohesion as it affected the enemy force "will to fight". Following the wargame, the Joint Experimentation Analysis Division conducted a series of examinations on the sensitivity of the JWARS model to various morale settings to further inform the analytical team as to the utility of this approach in future wargaming and modeling efforts. This paper describes the JWARS soft factors implementation and the results of that series of sensitivity experiments.

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ABSTRACT

It is recognized by military historians and students of warfare that behavioral elements within each fighting force – morale, leadership, *etc.* – have a significant impact on battlefield outcomes. Such so-called “soft factors” can influence the battle towards victory or defeat. History is replete with examples of smaller, well-disciplined forces taking the fight to the enemy and being victorious. However, these elements of combat performance are seldom modeled explicitly in simulations at the campaign level. The Joint Warfare System (JWARS) is one of the few models that incorporate explicit behavioral soft factors that can influence battle outcome. During the Unified Vision 04 (UV04) wargame conducted by the US Joint Forces Command (JFCOM), the JWARS model was used in conjunction with a political-economic model to represent the interplay of morale and cohesion as it affected the enemy force “will to fight”. Following the wargame, the Joint Experimentation Analysis Division conducted a series of examinations on the sensitivity of the JWARS model to various morale settings to further inform the analytical team as to the utility of this approach in future wargaming and modeling efforts. This paper describes the JWARS soft factors implementation and the results of that series of sensitivity experiments.

BACKGROUND AND MOTIVATION

In June 2004, the United States Joint Forces Command (US JFCOM) conducted a multinational wargame experiment called Unified Vision 04 (UV04). Unlike many of the experiments conducted by JFCOM, UV04 was not intended to validate or examine a specific operational concept. Instead, the primary goal of the event was to investigate the ability of two computer simulations to provide additional detail and support to the exercise participants. This was of interest since supporting major wargames and experiments is extremely labor intensive and once the event has been concluded there is often very little that can be examined parametrically “after the fact” as the players and support staff have gone on to other activities. Using structured models to support the exercise would not only have the potential of adding a degree of rigor to

the decisions of the event control group but would also provide a mechanism by which follow-on investigations could be conducted as player actions and intent would be incorporated in the simulation data as well as in the artifacts of the experiment itself.

The experiments at the JFCOM level of interest encompass the full spectrum of political and military actions, along with effects-based planning and operations, therefore any selected simulations needed to span the spectrum as well. The two models chosen for examination were the Synthetic Environment for Analysis and Simulation (SEAS) and the Joint Warfare System (JWARS). Together, these two models allow analysts to examine complex diplomatic, economic, military, and information (DIME) activities across the spectrum of interest to JFCOM.

The SEAS model is an agent-based simulation that concentrates on the non-military aspects of social interaction. Within the model it is possible to represent various groups, tribes, and factions as well as specific leaders and leader "types", *e.g.* labor leaders. When military actions are input to the model along with the other social activities, the results report the composite set of responses for the population being studied. This includes a country's "will to fight" with outputs signifying the strength of that behavior at the tactical, operational, and strategic levels. Thus, it is possible for a SEAS country entity to have a populace and military units in a tactical mode with strong willingness to fight while the political leadership may have its nerve being severely tested at the strategic decision-making level (or vice versa).

JWARS is a complete campaign-level combat model, playing forces flowing from garrison or other locations to the combat area, standing them up and employing and sustaining them in combat operations, all within one model. JWARS is intended to be used at high level organizations such as the Office of the Secretary of Defense (OSD) and Combatant Commanders (COCOMs) for Force Assessment, Contingency Planning, System Trade-offs, and Doctrine Assessment. In addition to fundamental combat, combat support, and combat service support and logistics activity, JWARS has the capacity to adjust the ability of the respective combatant forces by a variety of behavioral factors such as leadership, training, *etc.* These are referred to in JWARS parlance as "soft" factors in contrast to "hard" engineering and other more easily ascertained values used by the model.

The intent of the UV04 wargame was to play a standard JFCOM game, complete with Red, Blue, and White teams representing enemy, friendly, and control elements respectively. The White team would directly interface with the staff running the two models and provide relevant information and political-military results to the opposing Red and Blue teams. As each side reacted to the changing circumstances the White team would implement their actions in the two support models, thereby creating wargame artifacts and a record of player intent along with the simulation results. The linkage between the two supporting simulations was to be at the behavioral level in that the SEAS "will to fight" adjustments at the tactical and operational level would cause JWARS morale and cohesion values to be adjusted and consequent effects on the military campaign played out and fed back into the political context via SEAS.

UV04 was designated a multi-national event because of the presence of foreign nationals as both participants and observers. Consequently, security classification guidance was adopted to prevent the exposure of classified data to the players. The overall scenario (including the road

to war and all associated preparation materials) was developed as an unclassified exercise scenario. The data used by the SEAS model was all unclassified, not only because of the scenario parameters, but also because the model was run with staff from Simulex, Inc. (the developer) who had no security clearances. JWARS software is unclassified but JFCOM used a classified threat database and actual weapon data. This meant that results from JWARS had to be "scrubbed" such that there was no possible way to re-engineer actual classified values from the materials briefed to the wargame teams. This policy has been followed for this paper as well. The data presented, and other calculations, were done at either a theoretical group of settings or were extracted from the JWARS model using the same guidance that allowed the UV04 wargame to be conducted at an unclassified level. Furthermore, the UV04 scenario represents a battlefield situation that is hypothetical and is not based on any historical conflict. The use of military examples in this paper is intended to show military-model relevance and relationships and not to depict a particular real conflict.

In the week prior to the actual conduct of the UV04 wargame, the game parameters were changed due to some extraneous modeling issues dealing with run time and data reduction requirements. The flow of the game was modified such that the Red and Blue teams would no longer "step" their way through the scenario, with periodic updates from the White team. Instead, the scenario would be played out by the models in their entirety and reviewed by the participants. Changes to both Red and Blue operations would then be made and the models run again to provide refined output. As a consequence of this change, the planned feedback loop between the SEAS "will to fight" and the JWARS morale and cohesion parameters was removed, leaving questions about the degree of impact that modifications of these parameters would have on battle and other game outcomes. This generated a set of issues and investigations that are the primary topic of this paper.

ANALYTICAL ISSUES AND TASKING

Due to the adjusted flow of the wargame, three major questions related to the original game intent remained unanswered:

1. What is the impact of the "will to fight" on the combat outcomes?
2. How sensitive is JWARS to the morale and cohesion "soft" factor?
3. Is it worth the cost and effort to pursue establishing formal software linkages between JWARS and SEAS to represent the interplay of combat and sociological effects?

The deadline for this follow-on study was set for September 2004 in order to provide results that might be acted upon for the next major series of wargames. This established a three month period (July – September) to formalize the questions and conduct experiments with the JWARS model. Prior to initiating the formal investigation approximately six weeks were dedicated to refining the JWARS scenario with data updates and excursions into the last set of player instructions which were the final artifacts of the UV04 wargame itself. The author was the study lead and was able to call on efforts of various modeling support personnel that were part of the Joint Experimentation Directorate (J9) of JFCOM for matrixed support as required.

METHODOLOGY

A three-stage analytical approach was devised for the investigation.

1. Examination of the JWARS soft factors with emphasis on the elements related to morale and cohesion.
2. Address as much of the investigation as reasonable without running the JWARS model and the UV04 scenario.
3. Design and conduct appropriate simulation experiments for JWARS.

The first stage was the equivalent of a literature and software research phase. It would serve to insure that the proper elements of the JWARS model were later manipulated in a correct manner as well as provide insight as to proper interpretation of model activities and results. This was considered an essential element of the investigation because an ancillary intent was to train JFCOM J9 modelers on the JWARS system in addition to developing a response to the questions of interest. Consequently, detailed explanation of the JWARS soft factors was an integral part of the overall project.

The second stage of the approach was adopted for two major reasons. First, as already noted, there was the need for approximately six weeks of staff effort dedicated to refining the databases for formal studies. This included insuring that all data was correctly entered into the model and that all of the latest changes from the Red and Blue wargame teams had been properly represented and the scenario run for approximately twenty days of combat actions. The second reason for the use of non-simulation techniques was due to the model run-time. For the UV04 scenario the JWARS model was taking approximately seven hours of computer time to produce one replication of the event. As JWARS is a stochastic model, this meant that formal investigations would require multiple replications and the time to perform these could become prohibitive unless a focused approach was used.

Stage three would be to develop those conditions that could only be answered with actual scenario runs. Chronologically, these would be among the last items to be accomplished but, in the end, produced some of the most interesting results.

SOFT FACTORS IN JWARS

The JWARS version being used by JFCOM for this series of experiments was software release 1.5. In that version of the model there were five behaviors that could be modified as a result of applying different values to the soft factor components:

- Unit Rate of Direct Fire
- Unit Speed of Maneuver
- Unit Suppression of the Rate of Direct Fire
- Unit Suppression of the Speed of Maneuver
- Unit Breakpoints

Of these five behaviors, most are reasonably self-explanatory based on standard military terminology. The rate of direct fire controls how battlefield entities shoot in a direct fire engagement and the suppression behavior governs how that activity is reduced when under fire from an opponent. The speed of maneuver behavior controls how the organization conducts maneuver and the suppression behavior governs how that activity is reduced when under fire. The breakpoint behavior requires additional explication.

In the JWARS model there are two types of breakpoints for a unit, one called "temporary" and the other "permanent". The temporary breakpoint represents the phenomenon depicted when a unit engages in an activity and is temporarily stymied and must make an operational pause before attempting to resume its mission. For example, an infantry battalion in the attack may come under intense defender fire and make a brief pause, possibly even pulling back out of its opponent's range, to regroup and re-attack. Once the attack is resumed there could either be success in achieving the objective, or another temporary breakpoint or, in the extreme case, a permanent breakpoint. The latter is recognized by the fact that the unit no longer has the capacity or wherewithal to continue the original mission. Thus, the attacker shifts to a hasty defense and the tide of battle may turn.

Depending on the tactical situation, when one or more units reach some form of breakpoint, the battle may shift in a drastic and unforeseen manner. Thus, even if the equations governing the calculation of the soft factor are found to be well behaved mathematically, they can still cause seemingly chaotic effects when applied in the conflict.

Each of the five active behaviors in the model is determined by settings that reflect the influence of three sets of data. These will be addressed in the following order: a "country" factor; a "unit function" factor; and a "unit ranking" factor.

- Country Factor

The country factor is associated with the unit's nation or tribal situation and reflects national differences in the ability to wage war. The National Ground Intelligence Center (NGIC) rates foreign countries on a vector of sixteen attributes ranging across the spectrum of combat experience, ability to gather and apply intelligence, leadership, training, morale and cohesion, *etc.* The complete shorthand list of attributes is shown in Table 1.

Table 1. NGIC Country Attributes

Ability to Assimilate	Joint and Combined Operations
Air Defense	Leadership
Battle Command	Maneuver
Combat Experience	Mobility and Survivability
Combat Service Support	Morale and Cohesion
Combined Arms Operations	Power Projection
Fire Support	Readiness
Intelligence	Training

For our investigation, we were interested in the morale and cohesion attribute. However, it is important to note that when a user turns on the soft factors in JWARS it is an all-or-nothing

choice. All soft factors and data are activated even if one only wants a selected attribute. It is possible to adjust the data elements to eliminate this holistic approach but philosophically that would defeat the purpose of using the country factor (or any of the other factor components) if the analyst truly believes that different nationalities would fight differently.

Two important points require mention. First, NGIC does not rate United States forces, only those of foreign countries. Therefore, an analyst using JWARS must put in corresponding attribute values for US forces. For actual detailed studies it is possible to get a reasonable approximation of US force values since the NGIC methodology is unclassified and the analyst may apply the decision rules of the NGIC methodology for scoring US forces. The country results, once obtained, are subject to classification since intelligence information is used in developing the assessments. This study used the JWARS-supplied data since we were not attempting to change US morale and will to fight, only that of the opponent.

The second point is that each vector attribute is built up of sub-elements that result in the scoring for the overall vector component. The sub-elements for the morale and cohesion component are shown in Table 2. This is a simplified view of the sub-elements that are expanded in detail in the NGIC documentation.

Table 2. NGIC Morale and Cohesion Sub-Elements

Level	Service Officers & soldiers:	Pride	Risk Soldiers & leaders:	Discipline	Tension	Ldr. Sub Loyalty	Soldier Loyalty	Unit Morale	National Support	NGIC Factor
10	Serve in regiment or cohort	All units have pride	Share risk assumption	All units highly disciplined	Tensions within units almost non-existent	High degree	High degree	Very high	Very high degree	
9	Serve in same units	90%+ units have pride	Share risk assumption	90%+ units highly disciplined	Tensions within units almost non-existent	Reasonable degree	High degree	High in most units	Moderately high degree	
8	Serve in same units	Many units have pride	Share risk assumption	Many units highly disciplined	Tensions within units almost non-existent	Reasonable degree	Reasonable degree	Fairly good in most units	High degree	
7	Usually serve in same units	Many units have pride	Sometimes share risk assumption	Units generally disciplined	Tensions within units minimal	Some degree	Reasonable degree	Good in elite units; others fair	Mostly supports	
6	Often serve in same units	Some units have pride	Sometimes share risk assumption	Units generally disciplined	Tensions within units minimal	Some degree	Some degree	Fair in most units	Mostly supports; some dissidents do not	
5	Sometimes serve in same units	Some units have pride	Sometimes share risk assumption	Units generally disciplined	Some tensions within units	Little degree	Some degree	Low in some units	Nation supports; many dissidents do not	
4	Sometimes serve in same units	Few units have pride	Sometimes share risk assumption	Units generally disciplined	Some tensions within units	Little degree	Little degree	Low in most units	Nation tends to support; large minority does not	
3	Sometimes serve in same units	Few units have pride	Risk assumption between soldiers & leaders unusual	Units frequently lack discipline	Some tensions within units	Little to no degree	Little degree	Low in all units	Nation divided	
2	Seldom serve in same units	Few units have pride	Risk assumption between soldiers & leaders unusual	Units frequently lack discipline	Frequent tensions within units	Little to no degree	Little to no degree	Low in most units; low desertion rate	Nation does not support; some groups do	
1	Seldom serve in same units	Virtually all lack pride	Risk assumption between soldiers & leaders almost non-existent	Absence of discipline	Frequent tensions within units	Little to no degree	Little to no degree	Low in most units; high desertion rate	Nation has no respect for military	
Score	8	6	3	7	5	7	6	7	9	6.4

The ovals in the table illustrate the methodology applied to developing the morale and cohesion vector component score. There are nine sub-elements to be evaluated (the columns) against the level (the row number). The intelligence analyst applies the latest estimates and

known data, in essence establishing a numerical level for each of the nine sub-elements. This numerical score is shown at the bottom of each column and corresponds to the circled row-column intersection. The overall value of this component is then the unweighted arithmetic mean of the column scores. In this unclassified example the value for morale and cohesion that would be entered into the JWARS database would be 6.4, as shown in the circled block in the bottom right corner of the table.

At this point we can note that many of the contributing sub-elements to the morale and cohesion value are not likely to change in a short period of time. Characteristics such as the amount of time soldiers and leaders serve together (column 1), unit pride (column 2), unit discipline (column 4), leader-to-subordinate loyalty (column 6), soldier-to-soldier loyalty (column 7), and unit morale (column 8) may shift during the course of combat but are unlikely to change dramatically barring some catastrophic circumstances. Thus, for the short scenario used in UV04 (twenty days of combat), it is unlikely that this factor would have a significant change in value. However, even small movements might have large results depending on model sensitivity so we were not able to call an early halt to our investigation based solely on this fact.

- Unit Function Factor

The unit function factor reflects the fact that what a unit is supposed to do on the battlefield will affect its overall performance with respect to the five active behaviors involved in fighting. JWARS currently uses one of three selectable settings for a unit: combat, combat support, and combat service support. This factor can take on values between zero and one. The usual condition is that combat forces are rated at 1.0 and the other two categories are less than that in the relation $\text{value}(\text{combat}) > \text{value}(\text{combat support}) > \text{value}(\text{combat service support})$. This reflects the general condition that combat forces are more likely to behave at full capacity under fire than units organized and trained for other purposes. This value set can be manipulated for special-case situations but the general description is what was used for this study.

An important point to note here is that there is no standard methodology for the assignment of values to these settings. While intelligence estimates may allow for the classification of a unit into one of the categories, the value set is strictly under the control of the analyst studying the problem at hand. For the UV04 scenario and this study we used the JWARS-supplied settings for this input variable.

This factor is global for all JWARS units, *i.e.*, a combat unit on the Red side has the same value as a combat unit on the Blue side with respect to the unit function factor. Thus, an Iraqi combat infantry battalion will have the same $\text{value}(\text{combat})$ as a US combat infantry battalion. To the extent that there are behavioral differences between these two units, these are represented in either the country factor (Iraqi versus US differences) or in unit ranking (discussed next).

- Unit Ranking Factor

The unit ranking factor takes into consideration that some units are better than others within the same nationality or tribal grouping. JWARS currently uses one of three selectable settings for a unit: elite, standard, and militia. As with the unit function factor, this one also

takes on values between zero and one where elite units are typically set equal to 1.0 and the others are less. The general relation is $\text{value}(\text{elite}) > \text{value}(\text{standard}) > \text{value}(\text{militia})$. This value set can be manipulated for special-case situations but the general description is what was used for this study.

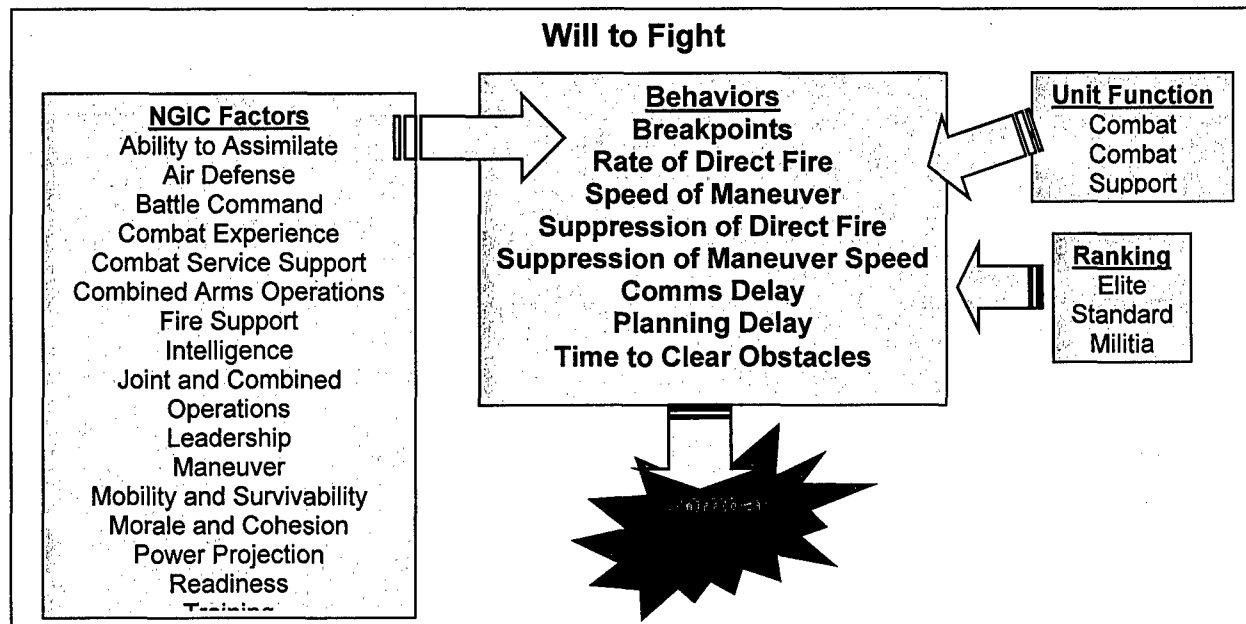
An important point to note here is that there is no standard methodology for the assignment of values to these settings. While intelligence estimates may allow for the classification of a unit into one of the categories, the value set is strictly under the control of the analyst studying the problem at hand. For the UV04 scenario and this study we used the JWARS-supplied settings for this input variable.

This factor is global for all JWARS units, *i.e.*, an elite unit on the Red side has the same value as an elite unit on the Blue side with respect to unit ranking. Thus, an Iraqi elite armor battalion will have the same $\text{value}(\text{elite})$ as a US elite infantry battalion. To the extent that there are behavioral differences between these two units, these are represented in either the country factor (Iraqi versus US differences) or in unit function (discussed previously).

- Example Application

The process of setting the ultimate value of the behavioral soft factor for each of the five active behaviors is shown in Figure 1.

Figure 1. Soft Factors and the Will to Fight



The applicable equation for each behavior is:

$$SF_{Behavior} = (1 - (N_{\%} * (1 - N))) * (1 - (R_{\%} * (1 - R))) * (1 - (F_{\%} * (1 - F)))$$

Of the variables in the soft factor equation we have discussed N, R, and F as they relate directly to the NGIC Country factor (N), the Unit Ranking factor (R), and the Unit Function

factor (F). However, three additional inputs need to be described, *i.e.*, those variables with the % subscript. In the application of the three elements of influence – the country, function, and ranking factors – the analyst must decide just how much influence that element has with respect to the behavior being calculated. Thus, the variables with the % subscript can be thought of as representing the size of the arrows in Figure 1 where the value of 1.0 means that full influence is given to that element and a value of zero would mean that the particular factor has no direct bearing on the behavior of interest.

What we have now is an equation for each of our behaviors of interest that requires six input variables each having a value between zero and one. While complex to deal with, there are some mathematical patterns in the equation that will permit us to reduce the problem set to something more manageable. Note that in the soft factor equation the variables are clustered into three sets of nested parentheses each pertaining to one of the factor values and its corresponding degree of influence. Since our item of interest is focused on the “will to fight” and the morale and cohesion element we can take advantage of the fact that this setting is isolated in the first nested set of parentheses on the N variable. Furthermore, if we, for the moment, concentrate solely on elite combat units, such that the values of R and F are 1.0 each, then the equation reduces to:

$$SF_{Behavior} = (1 - (N_{\%} * (1 - N)))$$

This equation is amenable to calculating in a spreadsheet as shown in Figure 2.

N _%											
N	0.0000	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
0.0000	1.0000	0.9000	0.8000	0.7000	0.6000	0.5000	0.4000	0.3000	0.2000	0.1000	0.0000
0.1000	1.0000	0.9100	0.8200	0.7300	0.6400	0.5500	0.4600	0.3700	0.2800	0.1900	0.1000
0.2000	1.0000	0.9200	0.8400	0.7600	0.6800	0.6000	0.5200	0.4400	0.3600	0.2800	0.2000
0.3000	1.0000	0.9300	0.8600	0.7900	0.7200	0.6500	0.5800	0.5100	0.4400	0.3700	0.3000
0.4000	1.0000	0.9400	0.8800	0.8200	0.7600	0.7000	0.6400	0.5800	0.5200	0.4600	0.4000
0.5000	1.0000	0.9500	0.9000	0.8500	0.8000	0.7500	0.7000	0.6500	0.6000	0.5500	0.5000
0.6000	1.0000	0.9600	0.9200	0.8800	0.8400	0.8000	0.7600	0.7200	0.6800	0.6400	0.6000
0.7000	1.0000	0.9700	0.9400	0.9100	0.8800	0.8500	0.8200	0.7900	0.7600	0.7300	0.7000
0.8000	1.0000	0.9800	0.9600	0.9400	0.9200	0.9000	0.8800	0.8600	0.8400	0.8200	0.8000
0.9000	1.0000	0.9900	0.9800	0.9700	0.9600	0.9500	0.9400	0.9300	0.9200	0.9100	0.9000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Figure 2. Soft Factor Values for Elite Combat Units

Graphing the results shows the surface of soft factor values in Figure 3. The graph on the left is the standard default when using Microsoft Excel 2003 as the spreadsheet and graphing tool. The surface shows the maximum possible level for the soft factor since we used R=F=1.0 to lock down the full equation. Since all other values of R or F will produce smaller values of the final soft factor, this layer being graphed is the top surface in a family of the same shape, much like the top layer of an onion which, when peeled back, reveals additional layers.

The surface on the right side of the figure is the same graph rotated by 260 degrees and elevated by 30 degrees. It reveals that the simple picture on the left is actually a twisted surface. This means that the results of the soft factor calculation will be extremely hard to anticipate when actualized in the simulation.

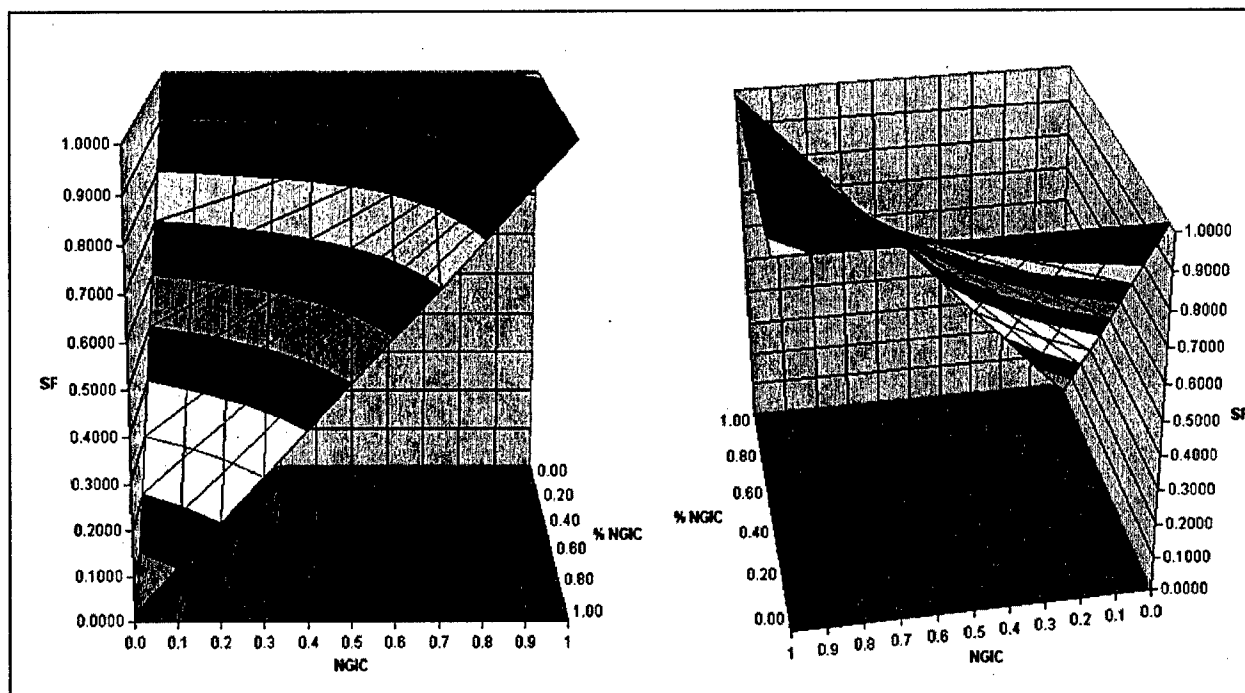


Figure 3. Soft Factor Surface - Default (Left) and Rotated (Right)

INITIAL EXPERIMENTS

Upon the conclusion of the fundamental soft factor research as described in the previous section, the study team was prepared to conduct some initial investigations regarding the sensitivity of the JWARS model to actual changes in the soft factor values based on modifying the values associated with the morale and cohesion attribute of the Country factor.

The first set of screening experiments was conducted by artificially setting each of the behavior soft factor values to the same level as shown in Figure 4.

$$SF_{BPT} = SF_{RDF} = SF_{SM} = SF_{SupRDF} = SF_{SupSM}$$

Unit Ranking		Unit Function	NGIC Rating	
100		100	100	
		Combat Service		
		Combat	Combat Support	Support
1.0	Elite	1.000	0.600	0.300
0.7	Standard	0.700	0.420	0.210
0.4	Militia	0.400	0.240	0.120

Figure 4. Initial Maximum Soft Factor Test Settings

The abbreviations in the equation are defined as follows:

SF	= Soft Factor, where the subscript indicates the specific behavior
BPT	= Breakpoint
RDF	= Rate of Direct Fire
SM	= Speed of Maneuver
SupRDF	= Suppression of Rate of Direct Fire
SupSM	= Suppression of Speed of Maneuver

The matrix of values shows the settings when the %-subscripted variables are each set to full contribution (1.0 or 100%) and the Ranking values are as shown on the left of the matrix. The unit Function values are not shown explicitly but can be deduced from the matrix by noting that for the "elite" row the only way to depart from 1.0 is to multiply by the value shown under the respective Function.

Using this structured approach, an entire family of settings, each represented by a similar matrix, can be calculated such that the matrix shown here is the most effective set of values for a composite force. Subsequent matrices were produced in increments of 0.1 using the upper left corner cell (Elite-Combat) as the index when discussing the individual matrix. This is analogous to our common manner of speaking when we say that the 10th Mountain Division is occupying the town of Najaf. We do not necessarily mean that every soldier in the division is in the town, but that the division has control and enough force in the town to maintain control. In this manner, when we talk of the soft factor setting for a force in JWARS we must recognize that the force is made of a mixture of units with potentially different functions and ranks (and possibly even different nationalities, depending on our level of aggregation). Thus, the upper left corner serves as our "unit guidon" for indicating which groups of settings are under discussion or use.

The first set of simulation runs was designed to determine if the JWARS model was sensitive enough to the soft factor values to warrant additional investigation. To that end, the study team initially conducted a set of five replications each at the best possible setting of soft factor values (shown in Figure 4) and the worst set, where the index flag was 0.1 indicating an extremely ineffective force. The rationale was that if no important differences were discernable between these extreme settings, there would be no need to continue with simulation runs. The results of these first ten replications showed that it would be worthwhile to complete the family of runs across the spectrum from a soft factor maximum of 1.0 to the minimum of 0.1. The main measure of outcome was set to be Blue and Red personnel casualties as this scenario was focused on light force interactions rather than heavily armored or otherwise equipped units.

Figure 5 shows the Loss Exchange Ratio, here defined as Red Losses divided by Blue Losses, with a curve with a significant bend at about the force soft factor setting of 0.3. The geometric mean was used to calculate the single curve shown for the five replications since we were dealing with fractional calculations. To the left of that value, Blue forces inflict serious casualties with little consequence to their forces. To the right of the shift, the Red forces put up a strong fight. The range of factor settings as actually played in the UV04 scenario is shown within the boxed area. This helps to explain the wargame finding that the Red force was

showing unexpected strong reaction to the Blue force, an action that was counter-intuitive to the beliefs actual exercise participants.

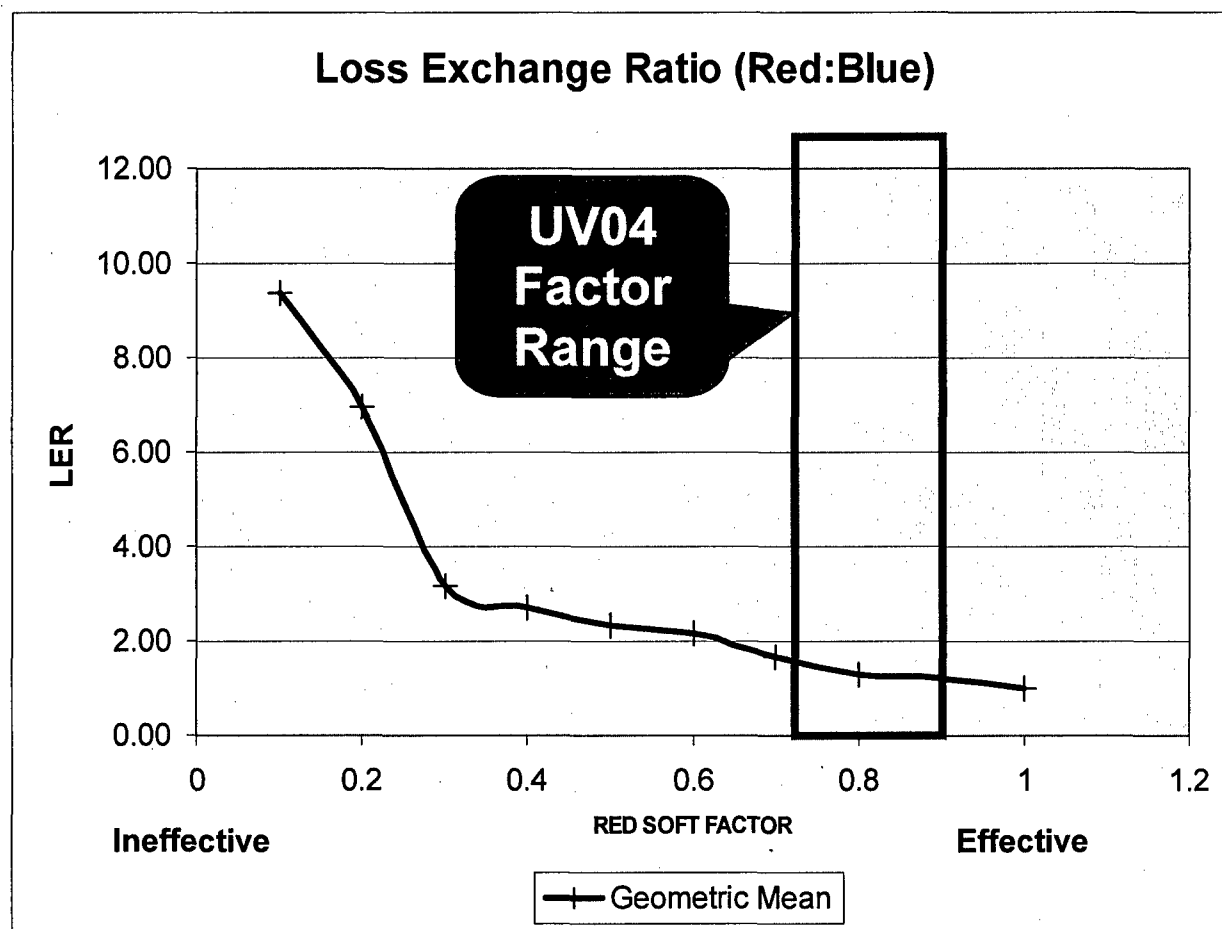


Figure 5. Loss Exchange Ratio by Red Soft Factor Setting

Since measures of merit such as loss exchange ratios obscure some of the information available in the data, the team also examined the raw casualty figures. Figure 6 shows the results of graphing both the Red and Blue troop losses over the spectrum of the soft factor settings. An unusual condition is shown on the graph. One would expect that as the Red force increased in effectiveness (soft factors of higher value) there would be greater casualties on the Blue force but that the Red casualties might be reduced. This is belied by the graph of the results.

Looking into the details of the replications, it was noted that at the low soft factor settings (*i.e.*, 0.3 or lower) the Red force very often cut and ran. Thus, as their effectiveness was increased due to the higher settings, their casualties rose as more units did not hit their permanent breakpoints and flee from the battle. Blue casualties, as expected, rose as Red became more effective. However, the "ripple" effect at the higher soft factor settings was not so easily explained. Each of the individual replications showed this ripple pattern so we knew that we were not examining a data outlier that was simply skewing the mean. This called for further investigation, as there were no changes in any other settings by which to explain this result. The

team suspected that it might be a complex interaction effect between the various behaviors that was causing this unexplained rise and fall in the combat losses as the soft factor varied near the tip of its range for the five behaviors.

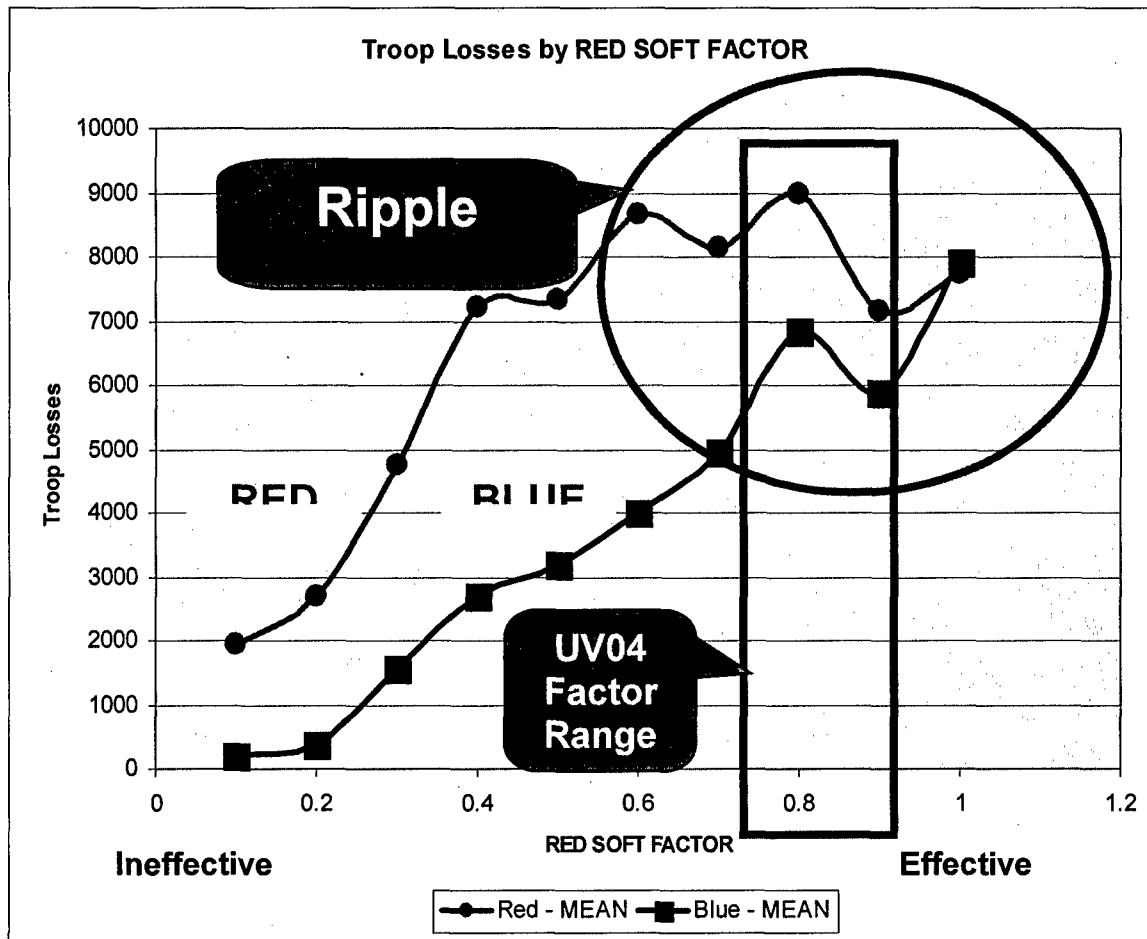


Figure 6. Troop Losses by Red Soft Factor

FINAL EXPERIMENTAL DESIGN

In order to investigate the ripple effect discovered in the basic investigation the team decided to do a full factorial design on the five active behaviors that use the soft factor settings. Because of the run-time issue and the number of runs required (a minimum of 32 runs for a full design) the process was staged so that the first set of runs would be a proper half-replicate. In that way, if the team reached its study deadline before being able to perform all of the required runs for a full design we would still have some reasonable estimation on the primary behaviors. As circumstances allowed, however, we were able to complete the full factorial design before the deadline was reached.

To determine the settings to use for the high and low points for each of the five behaviors to be examined the team used the Excel spreadsheet matrix calculations to determine the highest setting within the window of interest as well as the lowest setting. This allowed the team to

concentrate on the area surrounding the ripple pattern and the base UV04 factor range that directly impacted the wargame results and not waste runs on areas that were not of immediate interest.

For the full factorial design the significance level was set at $\alpha = 0.05$. The troop casualties resulting from direct fire, indirect fire, and air-to-ground weapons were the primary measures for both Blue and Red. This selection was based on the details of the forces in the scenario. Since this was still a screening/investigative series of experiments the team selected one replication at each of the 32 settings. Table 3 shows the design matrix and run results in canonical form. All calculations for the formal design of experiments (DOE) phase were performed with Design-Expert® version 6 by Stat-Ease. This is the official JFCOM DOE software for formal experimentation.

Table 3. Canonical Design for Full Factorial Experiment in Five Factors

Behavior Design		Break point	Rate-DF	Spd-Man	Sup-DF	Sup-ManSp	Troop	Kills
STD	RUN	A	B	C	D	E	RED	BLUE
8	1 Block 1	1	1	1	-1	-1	7515	6250
10	2 Block 1	1	-1	-1	1	1	10490	6203
5	3 Block 1	-1	-1	1	-1	-1	7316	5945
2	4 Block 1	1	-1	-1	-1	-1	10256	5788
7	5 Block 1	-1	1	1	-1	1	6135	5792
3	6 Block 1	-1	1	-1	-1	-1	8528	5715
1	7 Block 1	-1	-1	-1	-1	1	8763	5882
9	8 Block 1	-1	-1	-1	1	-1	9481	5609
13	9 Block 1	-1	-1	1	1	1	8439	4836
4	10 Block 1	1	1	-1	-1	1	10615	6078
11	11 Block 1	-1	1	-1	1	1	8736	6488
15	12 Block 1	-1	1	1	1	-1	7221	6433
14	13 Block 1	1	-1	1	1	-1	7501	6257
6	14 Block 1	1	-1	1	-1	1	8636	6203
12	15 Block 1	1	1	-1	1	-1	9732	6049
16	16 Block 1	1	1	1	1	1	8524	5789
21	17 Block 1	1	1	-1	1	1	10028	6115
20	18 Block 1	-1	-1	1	1	-1	7721	5781
31	19 Block 1	1	-1	-1	-1	1	10430	5795
30	20 Block 1	-1	1	-1	-1	1	8850	5786
17	21 Block 1	1	1	1	1	-1	7857	6537
32	22 Block 1	-1	-1	-1	-1	-1	8573	5510
24	23 Block 1	-1	-1	-1	1	1	8708	5751
19	24 Block 1	1	-1	1	1	1	8530	5184
18	25 Block 1	-1	1	1	1	1	6127	6133
28	26 Block 1	-1	-1	1	-1	1	5860	5959
29	27 Block 1	1	1	-1	-1	-1	9736	5206
27	28 Block 1	1	-1	1	-1	-1	8037	6836
25	29 Block 1	1	1	1	-1	1	8801	5673
26	30 Block 1	-1	1	1	-1	-1	7309	5812
23	31 Block 1	1	-1	-1	1	-1	9966	5127
22	32 Block 1	-1	1	-1	1	-1	8642	5853

STATISITCAL DIAGNOSTICS

After the runs were completed a series of diagnostic tests were conducted to confirm that the results met the requirements of the design and to identify if there were any outliers. Among the tests performed were developing the Normal Plot of residuals, examining the residuals versus the design predicted error, examining the residuals by run number, and outlier tests based on Outlier-T and Cook's Distance. For brevity, only the normal plot of the residuals and the Outlier-T test results are shown in Figures 7 and 8 for both the Red and Blue casualties. The

plots show that the fit of the model to the design was good and there were no outliers that would skew further analysis.

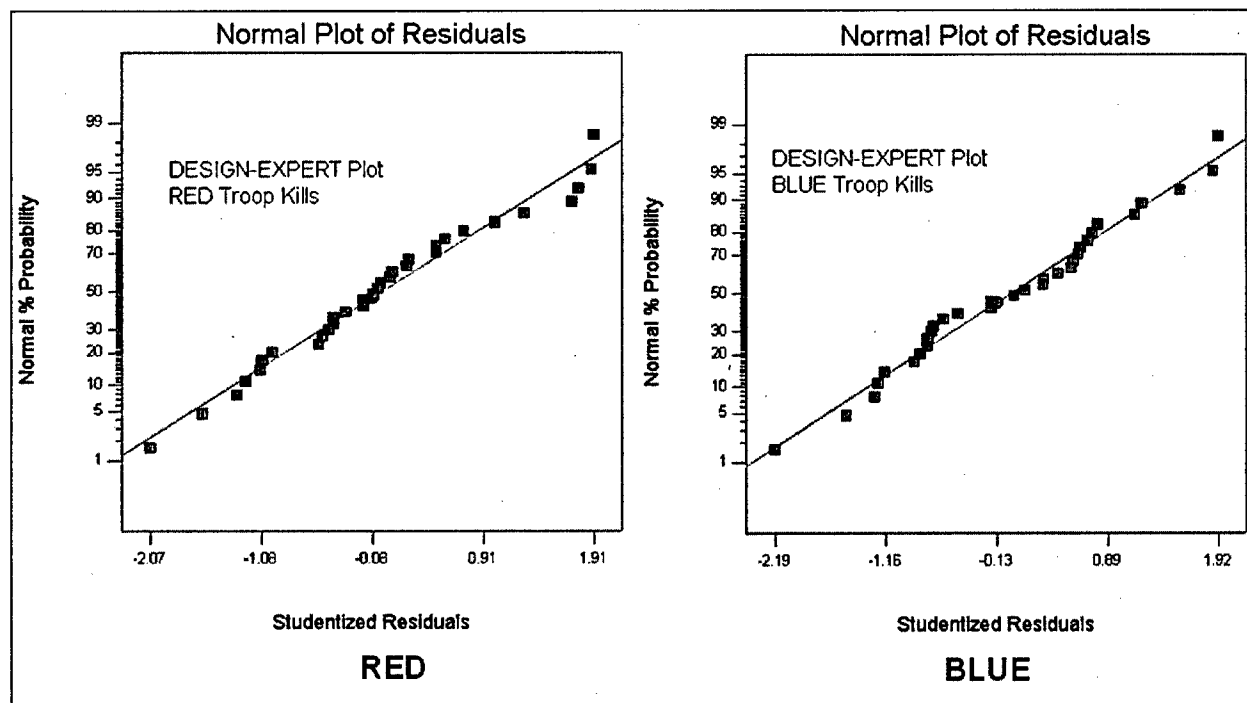


Figure 7. Normal Plot of Residuals for Red and Blue Troop Losses

The plot of the studentized residuals for both the Red and Blue troop losses shows a very good fit to a "normal" line, indicating that the assumption of the normality of the error term in the model is reasonable.

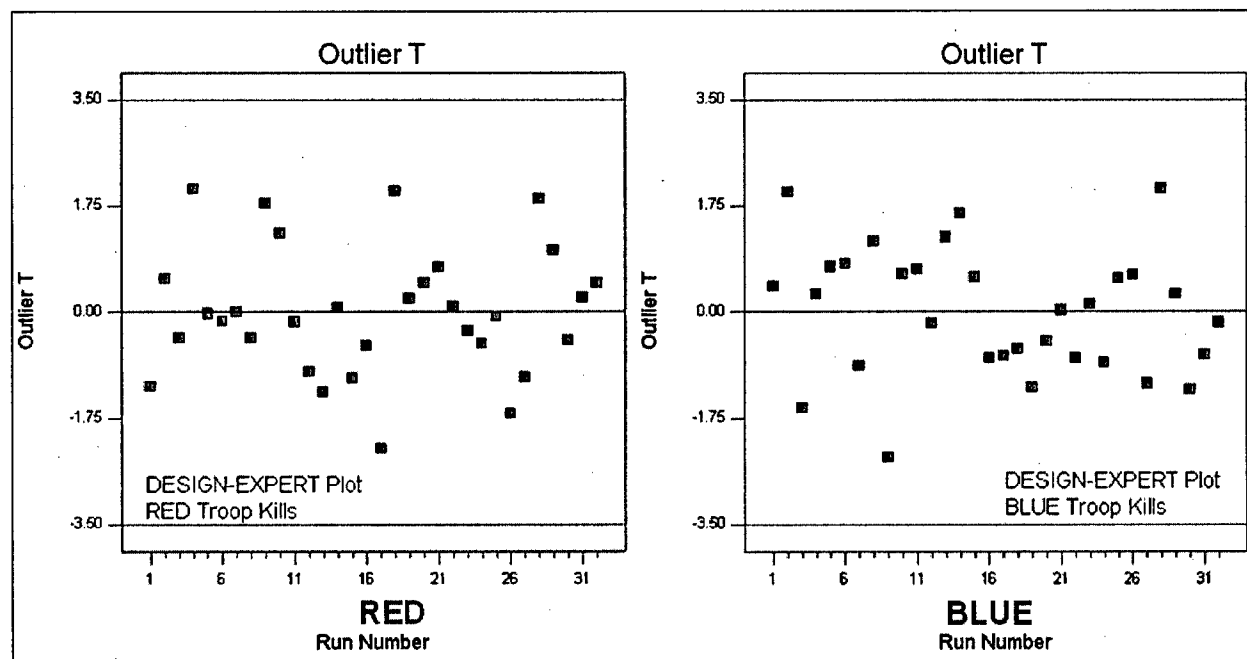


Figure 8. Outlier T Plots for Red and Blue Troop Losses

Both of the plots in Figure 8 show that there are no outliers based on this set of calculations. It is interesting to note that during the first stage of data reduction, while the analysis team was examining the results of the half-replicate and still running the remainder of the replications, an outlier was discovered. Further investigation revealed that it was not, in fact, a simulation outlier. Instead, the team uncovered a data reduction error and was able to correct the calculations before reaching the phase where assessments and conclusions would be affected by the erroneous calculations.

EXPERIMENTAL RESULTS

Figure 9 shows the significant effects as revealed by the Half Normal plot.

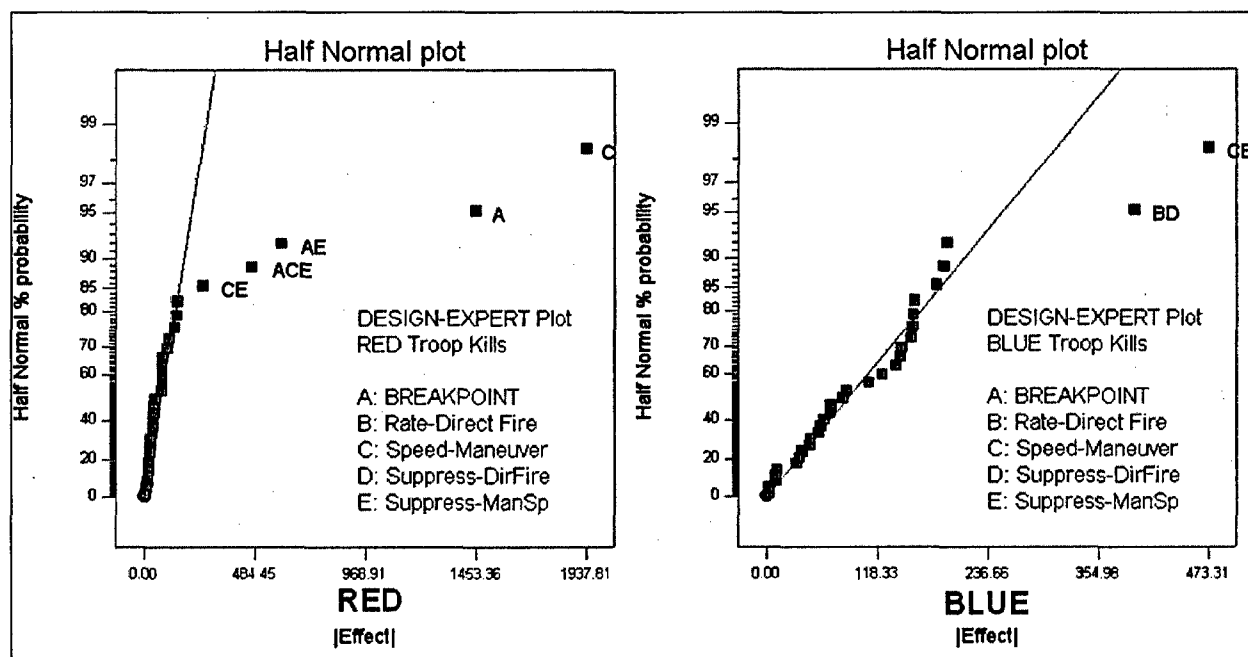


Figure 9. Significant Effects for Red and Blue (Half Normal Plot)

For the Red forces the most significant effects are caused by (in order) the Speed of Maneuver (C), Breakpoint (A), and the interactions of those two behaviors with the Suppression of Maneuver Speed (E) in both 2-way and 3-way interactions. For the Blue force, a completely different set of relations is revealed, none of which involves a pure primary effect but only interactions between the operationally related behaviors of the Speed of Maneuver (C) and the suppression thereof (E) and the Rate of Direct Fire (B) and the suppression thereof (D). This difference of significant behavioral effects between the Red and Blue forces was a totally unexpected result. Deeper investigation into the scenario revealed that Blue forces never reached a breakpoint, thus the only behavioral effects that were possible were those related to the other factors. On the other hand, Red forces had a large number of breakpoint triggers that affected various runs and the consequent flow of the battles they portrayed.

This graphical representation of significance is also shown in the two Analysis of Variance (ANOVA) tables shown below. In each table the shaded regions are the variables showing statistical significance.

Table 4. Analysis of Variance Results for Red (L) and Blue (R)

ANOVA for Selected Factorial Model						ANOVA for Selected Factorial Model					
Analysis of variance table [Partial sum of squares]						Analysis of variance table [Partial sum of squares]					
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	52202222.22	7	7457460.32	182.57	< 0.0001	Model	3568335.44	6	594722.57	6.94	0.0002
A	16885313.28	1	16885313.28	413.38	< 0.0001	B	298957.78	1	298957.78	3.49	0.0735
C	30040938.28	1	30040938.28	735.45	< 0.0001	C	197663.28	1	197663.28	2.31	0.1413
E	51280.03	1	51280.03	1.26	0.2736	D	38.28	1	38.28	0.00	0.9833
AC	15268.78	1	15268.78	0.37	0.5467	E	37196.28	1	37196.28	0.43	0.5160
AE	2896222.78	1	2896222.78	70.90	< 0.0001	BD	1242282.03	1	1242282.03	14.50	0.0008
CE	533286.28	1	533286.28	13.06	0.0014	CE	1792197.78	1	1792197.78	20.92	0.0001
ACE	1779912.78	1	1779912.78	43.58	< 0.0001	Residual	2141881.03	25	85675.24		
Residual	980327.75	24	40846.99			Cor Total	5710216.47	31			
Cor Total	53182549.97	31									

DESIGN-EXPERT
RED Troop Kills

A: BREAKPOINT
B: Rate-Direct Fire
C: Speed-Maneuver
D: Suppress-DirFire
E: Suppress-ManSp

DESIGN-EXPERT
BLUE Troop Kills

A: BREAKPOINT
B: Rate-Direct Fire
C: Speed-Maneuver
D: Suppress-DirFire
E: Suppress-ManSp

Further investigations were conducted graphically with the Design Expert© software to observe the manner of the interactions and glean additional insights. Figure 10 shows the single factor significant effects for the Red force.

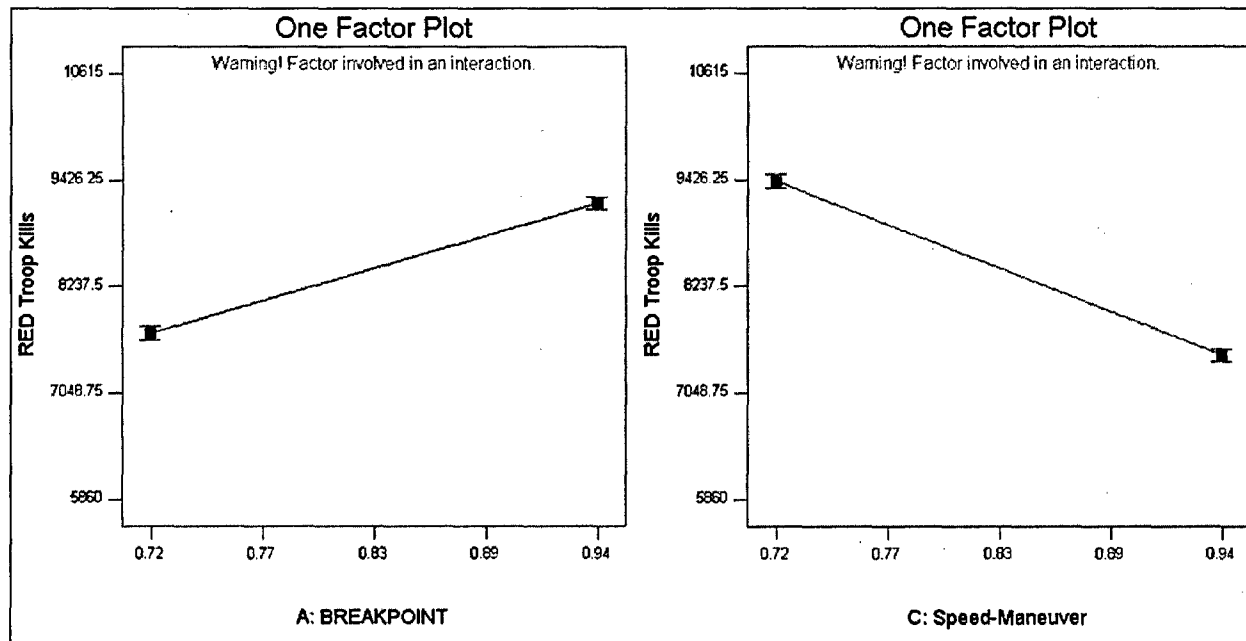


Figure 10. Single factor Effects for the Red Force Losses

The single factor effects for the Red force make sense operationally. As the soft factor controlling the breakpoint behavior (the left plot) increases in effectiveness (meaning that troops are more likely to stay and fight rather than run away) the Red force incurs greater casualties. Conversely, as the speed of maneuver behavior is improved the Red force takes fewer casualties due to better tactical behavior on the battlefield.

Turning our focus to the interaction graphs for the Red force, we can see the strength of the interaction due to suppression of maneuver speed and where the shift in behavior occurs.

Since both plots in Figure 11 are scaled the same we note that the stronger interaction is that on the left, between the breakpoint behavior and the suppression of maneuver speed, as the angle between the two crossing lines is greater than for that for the angle on the right. This is confirmed by the values in the ANOVA table that show the F statistic is larger for the AE interaction than for the CE interaction.

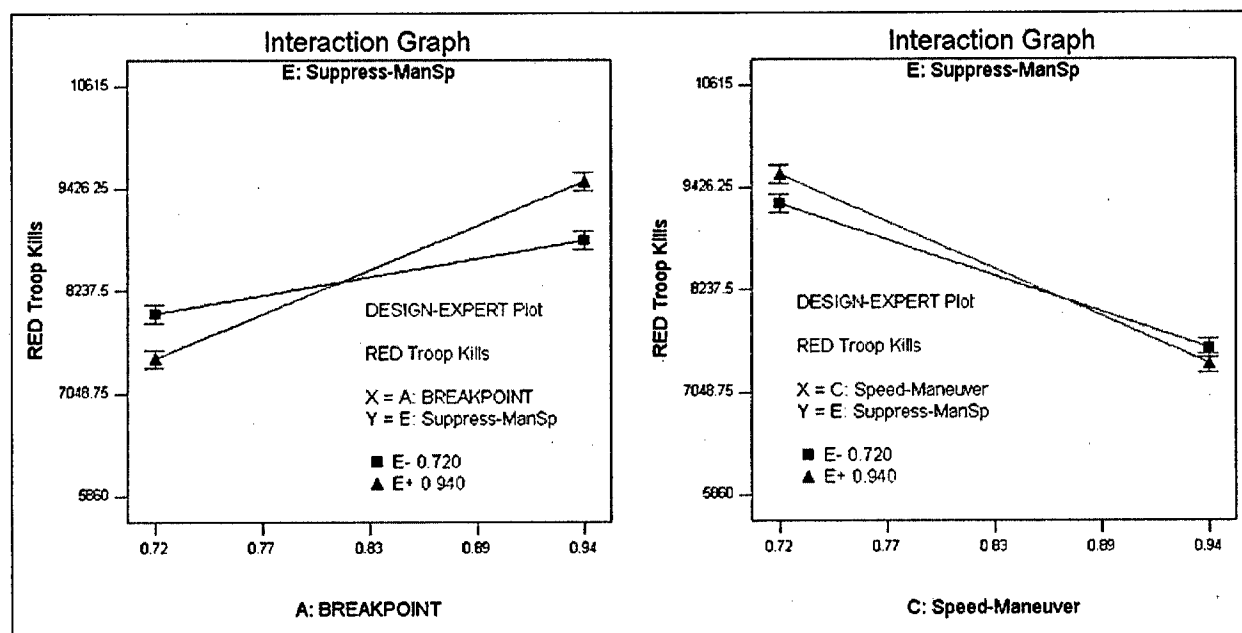


Figure 11. Interaction Effects for the Red Force Troop Losses

The effect of the suppression of maneuver speed on the breakpoint behavior is such as to strengthen the response. The greater the suppressive effect (the line with the triangle symbol at the end points) causes greater casualties when the Red force is more willing to engage in battle because they are less capable in their maneuvering yet willing to remain under fire. Likewise, the suppressive effect on maneuver speed also yields greater casualties when maneuver speed itself is already at a poorer level of performance (left side of the right-hand plot). Operationally, this makes sense. Suppressing a basic capability of a fighting force yields poorer performance. What is unique here is that in this series of experiments we actually have a measure of what degree of influence is exerted upon the forces in the engagement rather than just the military semantics to rely upon.

One of the capabilities of the Design-Expert® software is to permit the analyst to rotate the response surface in three dimensions. Just as rotating the initial soft factor surface in the Excel spreadsheet showed unexpected curvature, we are also able to examine our interaction surfaces in a similar manner. Figure 12 shows the standard 3-D view that is produced by the software on the left side. The "selected" icon in the lower left corner is the rotation tool, which allows the analyst to change the angle of elevation and rotation by using the gimbal device. The two rotated views on the right of the figure show the effect of the interaction on the overall response surface where the upper surface is the result when all the other soft factor behaviors are at their high settings and the lower surface shows the results when they are at their lower settings. An immediate observation is that the suppression effect is more pronounced when all of the other soft factor behaviors are at their higher effective settings. When they are lower, the

suppressive effects blend into the composite and are lost among all the other lower-effect settings and results.

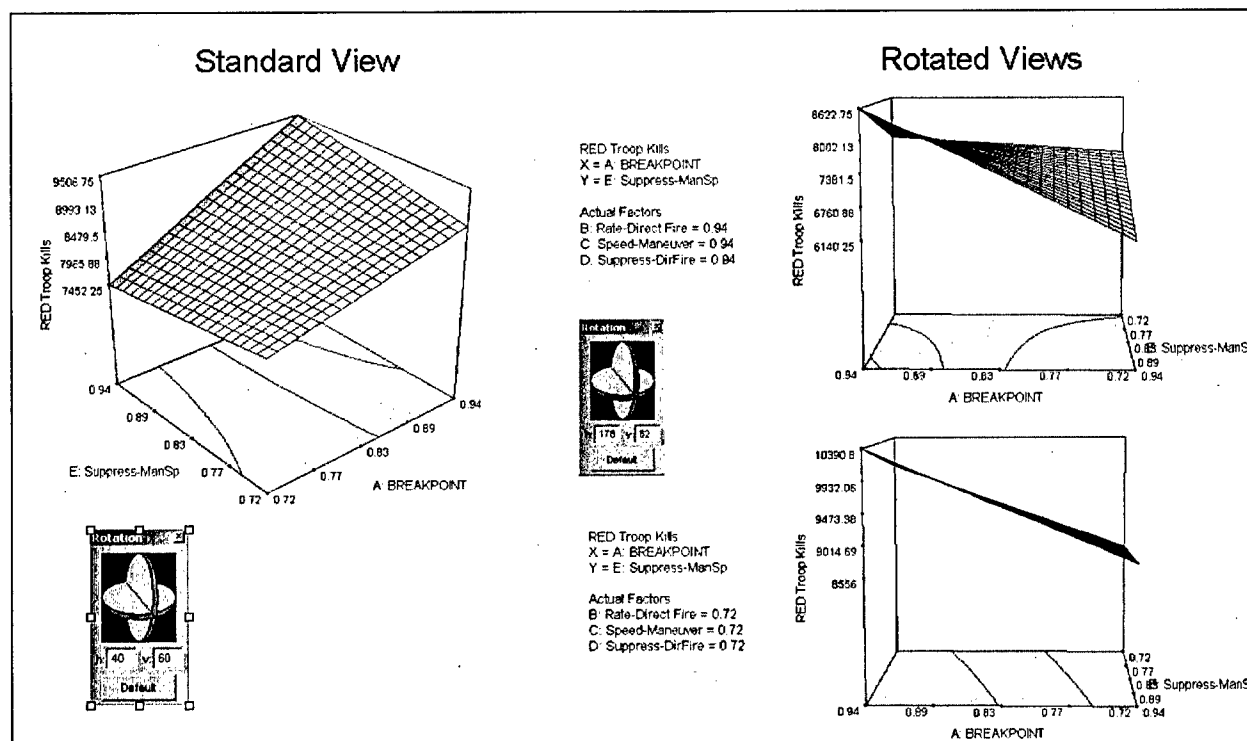


Figure 12. 3-D Response Surface for Breakpoint - Suppression of Maneuver Speed Interaction

Multiple views, both two- and three-dimensional, were generated as part of the examination of the effects data. Only a selected subset has been extracted from the full project report for this paper. Furthermore, the number of settings that are possible is subject to the time and interest of the analyst as the rotation tool in Design-Expert® is capable of an immense number of combinations.

SUMMARY – ANSWERING THE QUESTIONS

Wrapping up, we return to the questions that generated this project and attempt to provide some answers and insights as a result of the activities that have been pursued and reported upon.

1. What is the impact of the “will to fight” on the combat outcomes?

Combat outcomes vary significantly, both statistically and militarily, as the will to fight takes on different values. Even more important for the analyst is the fact that these effects are strongly non-linear and evidenced primarily as interactions. This means that tracing cause-and-effect will be extremely difficult in the battles produced by the model, just as much as it is in real historical and operational analysis. The search for answers will be more time consuming rather than quick due to this level of complexity.

2. How sensitive is JWARS to the morale and cohesion “soft” factor?

We found that the morale and cohesion factor in the JWARS formulation of the "will to fight" could produce statistically and militarily significant effects as it was varied over the spectrum of its potential settings. Furthermore, confining the investigation just to a limited range of parameters, *i.e.*, those in the UV04 scenario setting, still yielded an immense difference in battlefield performance that affected both Red and Blue forces. JWARS is a complex, non-linear, dynamic, stochastic model. Simple measure and statistics will not likely serve well and analysts using this model must be prepared to invest significant effort to trace results to full cause and effect relationships.

3. Is it worth the cost and effort to pursue establishing formal software linkages between JWARS and SEAS to represent the interplay of combat and sociological effects?

The team found that would be premature to link the models in a complete sense. Referring back to the NGIC criteria shown in Table 2 and noting that many of the morale and cohesion components did not necessarily vary much over short time intervals was one reason for this finding. A second important reason for not developing a full linkage at this point is based on the fact that numerous aspects of the JWARS soft factor implementation, other than the NGIC Country factor, have no firm foundation upon which to base their current values. The study team recommended a series of steps that could be taken to develop a reasonable, defensible set of parameters for the unit function and unit ranking factors along with the weights that they should be given for each of the active behaviors. That recommendation is currently under review by the Joint Experimentation Directorate of JFCOM.

A final note regarding the utility of JWARS to support wargaming is in order as it relates to this study and the use of the model at JFCOM. As of October 2005 JFCOM has not only continued to use and work with the JWARS model, they have assumed management responsibility for the configuration control of JWARS from the Program Analysis and Evaluation division of OSD.

List of Acronyms

ANOVA	Analysis of Variance
COCOM	Combatant Commander
DIME	Diplomatic, Informational, Military, Economic
DOE	Design of Experiments
JFCOM	Joint Forces Command
JWARS	Joint Warfare System
NGIC	National Ground Intelligence Center
OSD	Office of the Secretary of Defense
SEAS	Synthetic Environment for Analytical Simulation
UV04	Unified Vision 2004

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Descriptors

Behavioral Factors
Design of Experiments
Joint Warfare System (JWARS)
Morale and Cohesion
Unified Vision 2004 (UV04)