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THESIS

**ASCERTAINING VALIDITY IN THE ABSTRACT REALM
OF PMESII SIMULATION MODELS: AN ANALYSIS OF
THE PEACE SUPPORT OPERATIONS MODEL (PSOM)**

by

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June 2009

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SIMULATION MODELS: AN ANALYSIS OF THE PEACE SUPPORT
OPERATIONS MODEL (PSOM)**

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ABSTRACT

The Department of Defense has recently declared that irregular warfare is as strategically important as traditional warfare. Unfortunately, there is a dearth of mature training and analysis tools that can be used to support contemporary military operations. One popular wargaming simulation is the campaign-level Peace Support Operations Model (PSOM). This thesis provides a quantitative analysis of PSOM. The results are based on over 75,000 simulated runs of an Operation Iraqi Freedom scenario. The study concludes with the identification of the critical factors within PSOM, recommended potential uses for the model, an accuracy assessment, and an assessment of the risks assumed by using the model. Results indicate that the critical factors within the model are indicative of contemporary operations. PSOM should be used for its original purpose, as a wargame to further study the societal implications of modern military operations. As a wargame, PSOM has strong potential as a high-level staff and leader training tool and as a planning aid for course of action development. Within the confines of this study, the model proved limited in its ability to model changes in force capabilities. Due to its limited ability to model uncertainties in irregular warfare without the human-in-the-loop, or give multiple potential outcomes, further development and analysis is required before the model is used for large scale analysis.

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LIST ACRONYMS AND ABBREVIATIONS

AIF	Anti-Iraqi Forces
AOR	Area of Responsibility
AQI	Al Qaeda in Iraq
COIN	Counter Insurgency
CSV	Comma Separated Values
DIME	Diplomatic Information Military Economic
DIMEFIL	Diplomatic Information Military Economic Financial Intelligence Law
DoD	Department of Defense
DSTL	Defense Science Technology Laboratory
GUI	Graphical User Interface
UN IGO	United Nations Inter Governmental Organization
IW	Irregular Warfare
JAM	Jaysh al-Mahdi
JIEDDO	Joint Improvised Explosive Device Defeat Organization
MND	Multi-National Division
MOE	Measure of Effectiveness
NOLH	Nearly Orthogonal Latin Hypercube
OIF	Operation Iraqi Freedom
NPS	Naval Postgraduate School
OSD-SAC	Office of Secretary of Defense Simulation Analysis Center
PMESII	Political, Military, Economic, Social, Information, Infrastructure
PSOM	Peace Support Operations Model
ROE	Rules of Engagement
SEED	Simulation Experiments Efficient Designs
VV&A	Verification, Validation, and Accreditation
XML	Extensible Markup Language

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EXECUTIVE SUMMARY

This research addresses the Department of Defense's (DoD's) need to accurately model strategic level contemporary military operations. In the simplest form, the purpose is to gain a basic understanding of the Peace Support Operations Model (PSOM). In doing so we provide a methodology which should be incorporated into the VV&A (verification, validation, and accreditation) process for complex combat models that incorporate the Political, Military, Economic, Social, Infrastructure, and Information (PMESII) aspects of irregular warfare. This summary explains the need for such a model and hence the methodology, the steps taken during the analysis of PSOM, and the conclusions and recommendations toward the future use of PSOM and the study of PMESII models. The following document provides the DoD insights into the potential use of PSOM as a wargame and as an analytic tool.

As the United States Military's focus shifts from conventional warfare toward irregular warfare, interest has progressively grown in the development of models that can simulate social behavior as it pertains to military operations. Populations, whether broken into smaller social groups, granulated into individuals, or studied as an aggregate of social groups, are often the determinate of success in modern combat. According to the most recent U.S. Army doctrine:

The integration of civilian and military efforts is crucial to successful COIN [Counter Insurgency] operations. All efforts focus on supporting the local populace and the H[ost] N[ation] government. Political, social and economic programs are usually more valuable than conventional military operations in addressing the root causes of conflict and undermining an insurgency. *FM 3-24 Counterinsurgency*

The military uses models for course of action analysis, training and rehearsal, and evaluation for acquisition. If these models are not indicative of contemporary operations, they are not only lacking in utility, they are potentially harmful. Therefore, the military's interest in modeling social cognition has grown out of necessity. To date there has not been a validated model designed for irregular warfare that covers the instruments of national power: Diplomatic, Information, Military, Economic (DIME) or the Political,

Military, Economic, Social, Infrastructure, and Information (PMESII) indicators on which progress in irregular warfare is based. Figure 1 illustrates the complex causal relationship between DIME and PMESII factors. As one can imagine, the development of such a model is not trivial. According to the Defense Modeling and Simulation Analysis Committee, the data to instantiate such a model is either nonexistent or woefully inaccurate, and the validation process of such a model would have to be completely rethought.

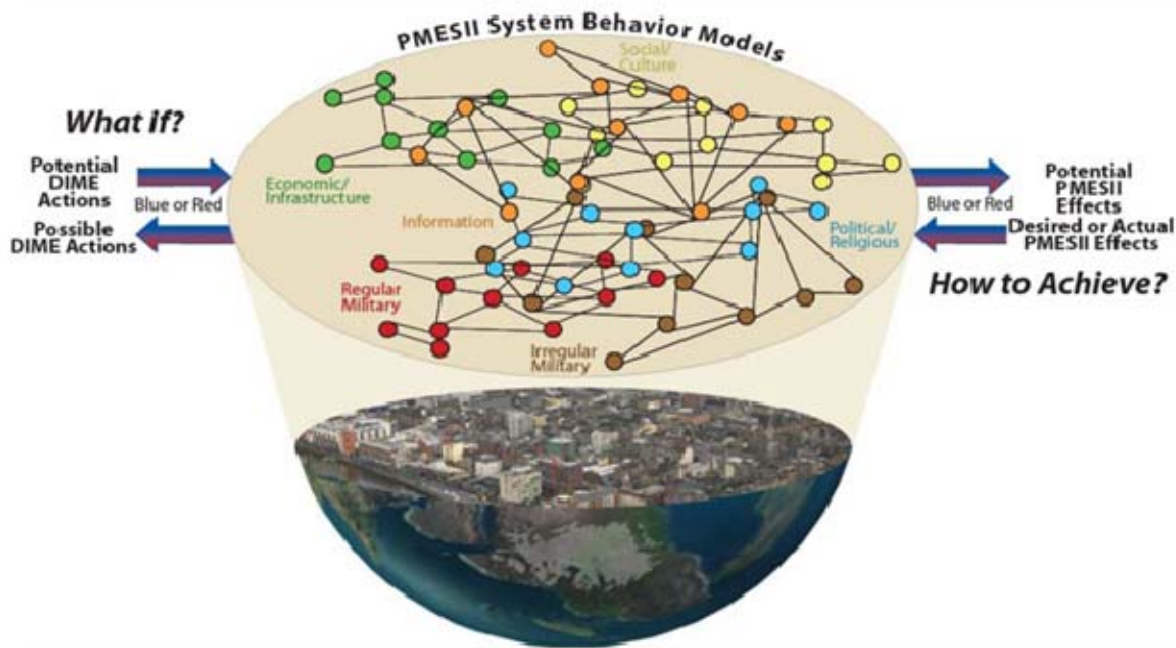


Figure 1. The complexity of the PMESII Environment [From (Allen 2004)]

One new model that addresses the operational focus on the population is the Peace Support Operations Model (PSOM). PSOM is a campaign level, simulation based, human-in-the-loop wargame which portrays the civilian populace as agents within the model. The model's metrics are both quantitative and qualitative in nature, providing results which are analogous with irregular warfare. Many of the Measures of Effectiveness offered by PSOM, such as attrition, are easily understood. However, much of the output is a cultural representation of the uncertain effects military and political actions have on the population.

This analysis defines a logical methodology to assess PSOM as a potential tool to:

- Quantitatively measure the limitations and constraints of PSOM and, more importantly, identify the appropriate context for interpreting PSOM results.
- Assess the accuracy of PSOM in regards to current doctrine.
- Make recommendations toward the potential use of PSOM.
- Define a methodology for the much needed VV&A process of PMESII models.

In order to address the fore mentioned issues, this study follows the data farming process (Horne 2004). Our implemented data farming process entails a four step procedure: Define factors of interest, create a design of experiment (DOE), run the simulation experiments in parallel on a computing cluster, and conduct data mining. By leveraging thoughtful experimental design with powerful computation capabilities we are able to change over 100 parameters within PSOM while conducting over 50,000 simulations of operations in the current Multi-National Forces Iraqi Area of Responsibility. This immense number of simulation runs allows us to quantifiably analyze over 5,000 design points consisting of well over 500,000 data files covering a large portion of the model's response space. By covering such a vast space of possible outcomes, we are able to use a variety of methods to investigate the model's behavior.

The analysis of this data set focused on three doctrinally essential measures of effectiveness (MOEs) provided by PSOM in a current Iraq based scenario. These measures are the Sunni Population's consent toward the Coalition forces, the Sunni Population's consent toward the Iraqi Government, and the security level of the nation. The results of our research are telling.

PSOM provides players a tremendous amount of flexibility in choosing their operational tasks (stances). Our analysis shows that the stances players (factions) choose have a significant effect on both the consent and security of the population, which is what one would expect based on current doctrine. There are also intuitive interactions between the stances of multiple factions. The rules of engagement status and risk level of a unit in conjunction with the unit's stance also prove important choices throughout the game.

For example, a violent ROE in conjunction with an aggressive stance will result in a loss of consent, especially if another faction proves more cautious and focused on the population.

We found the consent metric to be more intricate than the security metric. It seems consent is difficult, but not impossible, to increase toward both the coalition and the Iraqi government. It is arguable that this difficulty is actually a strength of the game. Changing the opinion of a society is a particularly difficult task; just as in PSOM, it can be done, but not without deliberate effort.

The initial conditions and assumptions made in scenario design are of particular importance. The simulation's results can be dominated by some of these assumptions. For example, the underlying assumptions that are used to create the population are absolutely critical in the determination of consent in the game. In accordance with doctrine and the PSOM developers, the outcomes of PSOM are especially population centric. Because of this, if underlying assumptions about the population are not strongly supported, the game should be played multiple times, changing population assumptions to ensure a considerable range of possible outcomes is covered.

The game is not very sensitive to many of the non-scenario specific parameter settings. Of particular focus within this study are those of unit capabilities. Therefore, we recommend PSOM should not be used as a decision tool for equipment manning or force manning until this aspect of the game is studied further. Those settings to which we found the game to be sensitive are mentioned within the thesis.

The model should be used for its original purpose, as a wargame to further study the societal implications of modern military operations. As a wargame, PSOM has strong potential as a high-level staff and leader training tool and as a planning aid for course of action development for stability operations. Within the confines of this study, the model proved limited in its ability to model changes in force capabilities. Also, due to its inability to model uncertainties in irregular warfare, or give multiple potential outcomes further development and analysis is required before the model is used for large scale analysis.

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However, none of this analysis would have been possible without the tremendous work ethic and technical competences of SEED research associate Adam Larson. Not only did Adam create the various tools we needed to make this entire experiment possible, but he was a constant sounding board. Our many discussions about PSOM, simulation, and experimental design are interwoven into much of the writing and analysis in this thesis.

I would also like to thank Nathan Hanley, one of the primary developers of PSOM. Nathan has been openly supportive of this research and very responsive to all questions. More importantly, Nathan and his team at DSTL have made tremendous steps forward in the developing field of irregular warfare modeling. Modeling social implications in military operations is a tremendous task, and it is clear that DSTL has put remarkable effort into solving this complex problem.

The teams at OSD-SAC and J-8 WAD have been a huge help throughout this process. The ability to reach out to such professionals with questions or for advice kept this research moving in a forward direction.

Finally, I must thank my wife, Heidi, for her unwavering support while I impaled myself on this thesis and the entire OA curriculum at NPS. There is no doubt that without her support I would not be where I am today.

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I. INTRODUCTION

At an earlier time, a commander could be certain that a future war would resemble past and present ones. This enabled him to analyze appropriate tactics from past and present. The troop commander of today no longer has this possibility. He knows only that whoever fails to adapt the experiences of the last war will surely lose the next one.

German Gen. Franz Uhle-Wettler (1985)

A. OVERVIEW

As the focus of the United States military shifts from conventional warfare toward irregular warfare, interest has progressively grown in the development of models that can simulate social behavior as it pertains to military operations. The contemporary operating environment, as reflected in Iraq and Afghanistan, shows the critical role the population plays in modern combat. Populations, whether broken into smaller social groups, granulated into individuals, or studied as an aggregate of social groups, are often the determinate of success in modern combat. Therefore, the military's interest in modeling social cognition has grown out of necessity. The military uses models for course of action analysis, training and rehearsal, and evaluation for acquisition. If these models are not indicative of contemporary operations, they are not only lacking in utility, but are potentially harmful.

One new model that combines conventional warfare with the modern focus on the population is the Peace Support Operations Model (PSOM). PSOM is a simulation-based wargame, that portrays the populace and displays the effects military and political actions have on the population and its emersion of social organizations. During preliminary use of PSOM at the Joint Staff Warfighting Analysis Division and the Office of the Secretary of Defense, PSOM has shown potential as an analytic and training tool; however, to date the model has not been taken through any sort of verification, validation and accreditation (VV&A) process. VV&A is an important prerequisite, ensuring models with flaws or biases to not become mainstream tools. The lack of appropriate vetting can prove detrimental due to the tremendous risk inherited from using a model which may provide

inconsistent or inaccurate results. This study quantifiably analyzes PSOM using design of experiments and data farming to quantitatively measure the limitations and constraints of the model.

B. BACKGROUND

Warfare changes with society. Over the past fifty years we have seen a shift from maneuver warfare where nonlinear tactics could determine victory (German blitzkrieg), to irregular warfare where the objective is the support of a population (Mao Tse-tung and the Protracted People's War). Irregular warfare is a violent struggle among state and non-state actors for legitimacy and influence over the relevant population (Department of Defense [DoD] Directive 3000.07, 2007). The Department of Defense's policy is to "Recognize that IW [irregular warfare] is as strategically important as traditional warfare" (DoD, 2007). Irregular warfare contains many subsets, including unconventional warfare, foreign internal defense, counter insurgency (COIN), counterterrorism, and stability operations.

The United States military continues to transform to meet the current and upcoming challenges of national security. Although the United State military must remain able to defend the country and defeat a robust enemy in a conventional war, the military now must conduct the complete taxonomy of irregular warfare to ensure America's security. In doing so, the military focus is split between the destruction of enemy armies and the development of "indigenous capacity for securing essential services, a viable market economy, rule of law, democratic institutions, and robust civil society" (DoD Directive 3000.05, 2005); the latter obviously being the far more difficult to plan. As C.E. Callwell states in *Small Wars* (1906):

But when there is no king to conquer, no capital to seize, no organized army to overthrow, and when there are no celebrated strongholds to capture, and no great centers of population to occupy, the objective is not so easy to select. (p. 40)

Colonel Callwell continues by explaining how an attacking force must destroy and deprive the defending population using techniques that are inhumane and not accepted under today's laws of war. Contemporary doctrine enforces the mitigation of civilian casualties and collateral damage.

The role of the military has become extremely complex, interwoven with other governmental and non-governmental agencies. Current war spans political, economic, social and military aspects of humanity (Hammes, 2008). The military has published new doctrine and leaders have been quick to change their mindset. As young men and women gain experience in this emerging warfare, it has become the norm rather than the exception for warfighters to leverage the political, economic, social, and military aspects of war. The result is a military composed of people ready to meet the irregular warfare challenges and accomplish the mission in stride. This trend will continue as junior leaders become senior leaders with a wealth of modern-day experience and knowledge which will in turn become wisdom.

As the paradigm of the military's role changes, the plans, training, and force structure must be dynamic as well. Unfortunately, a key part of the planning process, training structure, and military decision making process has yet to be transformed. This key ingredient is the modeling and simulation of war. Whether manifested in a wargame, simulation, or experiment, simulation modeling has become a critical part of the decision making process. An example is the critical role that modeling takes in DoD's development of the Analytic Agenda (Stevens, 2003).

According to the Committee on Modeling and Simulation for Defense Transformation, "DoD needs MS&A appropriate to complex dynamic, adaptive systems because such systems pervade military combat, other aspects of military operations, and other political, military, economic, social, infrastructure, and information phenomena of interest" (Committee on Modeling and Simulation for Defense Transformation, 2006). DoD's Transformation Planning Guidance (2003) states "a new generation of M&S is needed to support concept development linking together many types of simulations from aggregate and detailed computer models to simulators and man in the loop hardware components."

The Department of Defense defines validation as the process of determining the degree to which a model, simulation, or federation of models and simulations, and their associated data are accurate representations of the real world from the perspective of the intended use(s) (DoD, 2008). To date there has not been a validated model designed for irregular warfare that covers the instruments of national power, Diplomatic, Information, Military, Economic (DIME) or the Political, Military, Economic, Social, Infrastructure, and Information (PMESII) indicators that progress in irregular warfare is based. Figure 2 illustrates the complex causal relationship between DIME and PMESII factors. As one can imagine, the development of such a model is not trivial. According to the Defense Modeling and Simulation Analysis Committee, the data to instantiate such a model is either nonexistent or woefully inaccurate, and the validation process of such a model would have to be completely rethought (Committee on Modeling and Simulation for Defense Transformation, 2006).

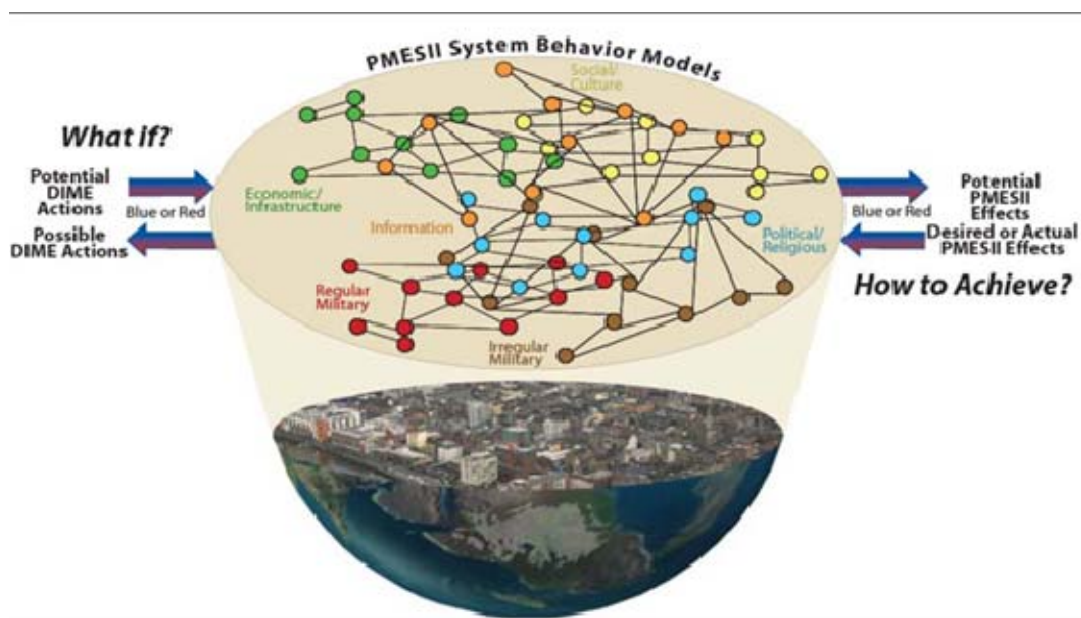


Figure 2. The Complexity of the PMESII Environment [From (Allen, 2004)] [Best viewed in color]

Gropman (1986) states a popular position in the development of mathematical models pertaining to human social interaction as:

Psychological dimensions: their uncertainty, their variety, their inconsistency and their lack of utility in modeling future conflict should make one reluctant to expend resources pursuing them, leaving the community the time and money to quantify better the quantifiable. (p. 16)

When modeling warfare, especially on a macro level, much of the information about human behavior is either assumed or discarded, often resulting in a gross simplification of the situation we wish to model (Perla, 1990, p. 276). This problem is amplified when attempting to model irregular warfare. In FM 3-07, the newest Army Manual on Stability Operations, LTG Caldwell states:

The lines separating war and peace, enemy and friend have blurred and no longer conform to the clear delineations we once knew. At the same time, emerging drivers of conflict and instability are combining with rapid cultural, social, and technological change to further complicate our understanding of the global security environment. (Army, 2008)

This statement alone depicts the modeling of irregular warfare as a great problem to even comprehend let alone attack.

Our military has become dependent on models. Traditionally the military has used computational models for analysis and forecasting for planning, simulation for training rehearsal, and design and evaluation for acquisition (Committee on Organizational Modeling, 2008, p. 23). However, we are now fighting a war that many deem extremely difficult to model, much less model in a way that would fit traditional validation techniques. Due to the dependence on models and simulation, the DoD has attacked this problem with vigor, and the modeling community has answered the call to develop what are now being called PMESII models.

There are many models being developed to meet the need to understand the contemporary battlefield. Currently these models fall into multiple categories such as agent based, system dynamic, or analytic. These models differ in their underlying designs used to generate outputs. However, they are similar in that they are a step in the

direction of modeling the asymmetric battlefield where “civilians are the targets, objectives to be won, as much as an opposing force” (Smith, 2007). One such model is the Peace Support Operation Model v2 (PSOM 2).

PSOM was developed by the United Kingdom (UK) to first study and then understand stabilization operations. Model development began in 2004 at the Defense Science and Technology Laboratory, United Kingdom. The model is built by an allied institution which has already encouraged inter-agency use of the simulation. The model is a time stepped human-in-the-loop semi-automated campaign level wargame. PSOM uses over eighty algorithms, which are primarily deterministic with a number of stochastic elements, to take into account the DIME interventions and PMESII indicators in determining outcomes of friendly unit actions (Body, 2008). These outcomes are representative of required results from irregular warfare where seized terrain and causality counts cannot determine a victor or even positive results.

A critical underlying assumption of PSOM is that current UK and U.S. doctrine represent the best strategy in Peace Support Operations. This assumption is difficult to validate due to the changing nature of irregular warfare, and doctrine is being developed and improved on a regular basis. However, the developers of the model support this assumption stating that the contemporary environment is being debated and that PSOM is “an endorsed understanding of the Contemporary Operating Environment” (Body, 2008). This statement is not meant to be a catch-all for every assumption in which the model is based, but rather a candid explanation of those areas of “deep uncertainty,” which can derive from social modeling.

The PSOM 2 model allows for the interaction of multiple factions amongst themselves and the population. This is key because the model assumes that the Contemporary Operating Environment (COE) is one in which the population is the point of emphasis. The modelers understand that irregular warfare uses a range of approaches including political, military, economic, and social to persuade the enemy leadership that their strategic goals are either unachievable or not cost effective. Therefore, a tremendous emphasis in PSOM is its ability to represent both the political will of the population and the changes both friendly and enemy forces have on this will. In order to

model these interactions, PSOM allows each player or faction to choose a stance for each time step. The stances are similar to current doctrinal operations and specific tactical tasks and are directed toward other factions or the population. For example, a maneuver battalion in Iraq could have the stance of secure being directed at the Sunni Population.

PSOM gives multiple measures of effectiveness (MOEs) and metrics that can be used to determine success or lack thereof. The model is analogous with U.S. doctrine in that political legitimacy is a key outcome of stability operations. Legitimacy is assessed by the indicators of security, consent, rule of law, and provision of essential services. The primary MOEs presented by PSOM are security, consent, stability and fear. These MOEs coincide with the strategic framework described in FM 3–07, which states the end state conditions for a stability operation are a safe and secure environment, established rule of law, social well being, stable governance and a sustainable economy. Although economy is not a stated MOE in PSOM, economic conditions play a role in all the aforementioned MOEs and multiple economic metrics are available.

For all of its strengths, to date this model has not been through any particular VV&A process. The J–8 Warfighting Analysis Division along with the Office of Security of Defense Simulation Analysis Center (OSD-SAC) have used PSOM in an exploratory manner with debatable results. Currently, the staff at DSTL are conducting a large-scale multiple course of action wargame to test PSOM. However, PSOM has not been put through the rigors of the DoD’s Modeling and Simulation accreditation process.

C. RESEARCH QUESTIONS

The intent of this research is to conduct a quantitative analysis of the Peace Support Operations Model. This analysis is not meant to be a complete VV&A process. However, the following issues are addressed:

- Identify the factors which most dramatically change PSOMs output. Identifying the critical factors quantitatively measures the limitations and constraints of PSOM, and, more importantly, identify the appropriate context for interpreting PSOM results.
- Attempt to assess the accuracy of the Peace Support Operation Model.

- Make recommendations toward the potential use of the Peace Support Operation Model.
- Conduct a risk analysis of the Peace Support Operation Model.

D. BENEFITS OF STUDY

This study provides the Department of Defense a thorough analysis of PSOM. In doing so it aids decision makers in selecting potential uses of PSOM as a wargame and analytic tool. Concurrently, we have developed an analytic procedure for evaluating complex PMESII models. This procedure provides analysts a reference in the validation and verification of models that take into account the importance of societal implications. This study demonstrates that the use of large scale data farming, combined with thoughtful design of experiments, can provide useful insight into the complexities of social modeling.

E. METHODOLOGY

This thesis uses quantitative analysis to explore the capabilities of PSOM. Because the parameter space in a campaign level model such as PSOM is quite large, the study is based on the leveraging of high performance computing and efficient design of experiments to run the model many times. This process allows for the exploration of a very large parameter space in a limited amount of time (Barry and Koelher, 2004). Efficient design of experiments and statistical analysis permits us to determine which parameters and interactions are significant in PSOM and what the corresponding responses are to a particular set of parameters. Once the significant factors are identified, further exploration into particular sets of parameters permits analysis of the response accuracy in accordance with current doctrine.

The scenario used to test the model is the ongoing war in Iraq as of 2004. This model was developed by DSTL in 2008 and has been vetted through multiple U.S. Army officers who served in the Iraqi theater during this period of time. The design of experiments focus on the underlying assumptions about the Iraqi population, the capabilities and attributes of coalition and insurgent forces, the operational courses of action taken by coalition forces, and the systematic settings of PSOM. The responses

analyzed are primarily the changes in security in the nation and the population's consent towards its own government and coalition forces (when needed, other outputs are taken into account). The resulting statistical analysis of the simulated data is then used to gain insight into the vast space of possible PSOM inputs and their corresponding outputs.

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II. PSOM BACKGROUND

The modeling of cognition and action by individuals and groups is quite possibly the most difficult task humans have yet undertaken.

(Committee on Organizational Modeling, 2008, p. 20)

A. BACKGROUND

This next chapter is a combination of first person user experience with the model, the 2008 PSOM 2 Functional Specifications, and the 2008 PSOM Philosophy. The purpose of this chapter is to provide the reader a basic understanding of the PSOM model and software. This is not meant to be a standalone user's manual, but rather an introduction to the framework of the model. By understanding many of the specifications, the data required, the setup of the model, and the execution of the simulation the reader can see not only what the model is intended to do, but how it accomplishes it.

The Peace Support Operations Model is a human-in-the-loop, time stepped semi-automated wargame (Parkman, 2008). The definition of a wargame is a model or simulation not involving actual military forces, in which the flow of events is affected by, and in turn affects, decisions made during the course of those events by players representing opposing sides (Perla, 1990, p. 274). PSOM is a campaign level model that represents irregular warfare at the Policy, Strategic and Operational Levels (Body, 2008). It was designed by and is still in active development at the Defense Science and Technology Lab of the UK Ministry of Defense in order to test policy guidance and provide campaign context for lower level modeling. PSOM 2 models irregular warfare as defined by the Department of Defense. Because the results of an irregular warfare campaign rest on the will of the population, PSOM shows the causal effects of the players' actions primarily through their effect on the population. The model is analytical and based on the assumption that current U.S. and UK irregular warfare doctrine represent the solutions to irregular warfare (Body, 2008). The designers acknowledge the

significance of this assumption, but also accept that there is no universally accepted validated answer to irregular warfare. So, until combat models can be tied into an agreed upon anthropological model, DSTL has moved forward with PSOM.

PSOM is written in Visual Basic and is non-proprietary. For this study and future studies, analysts are not just allowed to “look under the hood” but encouraged to do so. PSOM is built from a series of algorithms and sub-models which are interwoven to represent the DIMEFIL and PMESII aspects of irregular warfare. In this aspect it is possible to classify PSOM as a system dynamics model. In addition, the emersion of social groups within the civilian population is portrayed by independent agents whose actions and attitudes are determined by simple decision rules, thus giving PSOM a pseudo agent based characterization. One key aspect is PSOM supports the interaction of multiple organizations that are representative of IW. PSOM uses over eighty algorithms to drive the unit interaction and state functionality systems. These interactions and functionality systems allow for 3rd and 4th level actors, such as non-governmental organizations, to have effects on outcomes.

B. SPECIFICATIONS AND CAPABILITIES OF PSOM

The PSOM wargame is designed with a two-level hierarchy: the high level game (HLG) and the operational game. The high level game is designed to simulate the political and strategic levels of conflict. This is where relationships between factions are represented and international cooperation is accounted for. The high level game is very much the “grey beard” game.

The operational level game is just that, operational. It is representative of the campaigns and actions required to support the strategic objectives. This resolution is the level at which Brigade Combat Teams, terrorist organizations, and local government organizations are played. By creating this ontology the developers have attempted to represent the importance of the political and strategic influences with regards to the operational levels of irregular warfare.

The PSOM 2 wargame model can be split into four categories: scenario design, underlying data and settings, game play, and results.

C. SCENARIO DESIGN

In the development of social models the represented environment is dynamic and the model's structure is often derived from logical, rather than only mathematical, specifications (Gilbert, 2005, p. 15). PSOM's scenario design accounts for this dynamic behavior. The scenario design is the point at which the modeler develops the specific initial conflict setting. In a basic wargaming analogy, this is where we pick the layout of the game board, the attributes of the pieces, and the mindset of the population. Many of the basic assumptions about the social model are inputted into the scenario design. An abridged version of the basic inputs required for the scenario follows.

1. Factions

A faction is defined as any political entity that has an effect on the scenario. These are the key players in the game. Faction examples are military organizations, the host nation government, NGO's, and terrorist organizations. A significant characteristic in the makeup of a faction is its ideology. Factions have ideologies represented by the Nolan Chart, which uses scores for economic and personal freedom to determine the faction's political and social inclination. Figure 3 shows the Nolan Chart and gives the explanation from the PSOM Manual. Other inputs for each faction are type of unit or organization (there are many pre-set unit types), size in number of people, expectations, wealth level, etc.

The Nolan chart is used to determine a faction's political views. A faction is assigned a number based on the importance of political freedom versus economic freedom. Where prior tools determined if an individual's views were to the right or left on a line, the Nolan chart is a plane. The Nolan chart was developed by the libertarian party and its role in PSOM has drawn criticism due to its bias and lack of scientific support (Turnley, 2008).

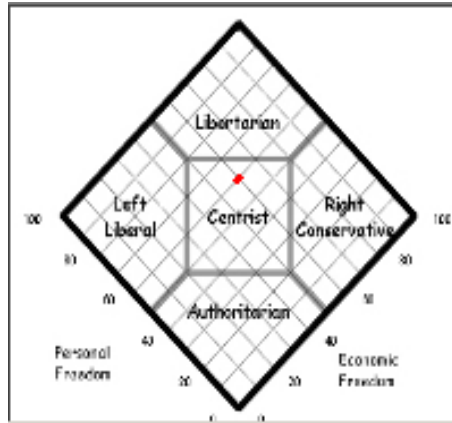


Figure 3. An Example of a Nolan Chart Taken from the PSOM User Manual (Draft)

2. Ethnic Groups

This category represents the attributes of groups of similar people within the population. For the model, ethnic groups can be used for more than just ethnicities, but also social views (Parkman, 2008). Ethnic groups also use the Nolan Chart to determine political ideology. However, ethnic groups are assigned marginal gains coefficients. Marginal gains coefficients represent the importance of a particular good or service (to include security) to the corresponding ethnicity. These marginal gain coefficients are used to determine consent in the operational game. Other inputs into the ethnic group category are starting values of population size, age groups, etc. As the aggregate of ethnic groups create a population agent, the assumptions that create an ethnic group should prove to be of the utmost importance.

3. Nationalities

Every faction has a nationality. This attribute allows the game to look at the homeland consent based on activities particular to the individual nations.

4. Map

The map plays an important role in the PSOM. The user downloads the map of the area of concern. Then the map is divided by grid squares representing a user

determined geographic size. The user then gives each square particular attributes based on physical terrain data, population level, infrastructure level, and human capital.

5. Population Agents

By using the input of map data and ethnic group data, population agents are formed. These are “Semi Autonomous groups of ‘similar’ people of a defined size based on proximity. An agent may make a number of decisions based on the conditions and environment surrounding it” (Parkman, 2008, p. 41). The population agents gain the attributes of their respective ethnic group with a predetermined user defined variance.

6. Relationships

PSOM allows the user to define overarching relationships between factions. These relationships can be updated throughout the game, but are initialized in the scenario design. The relationships are depicted below in Table 1.

Combative Relationship	Intelligence Relationship
Shooting	Sharing
Shooting	Not Sharing
Not Shooting	Sharing
Not Shooting	Not Sharing

Table 1. Explanation of Relationships in PSOM

7. Units

These are the conventional military forces, nonconventional military forces, insurgent or terrorist forces, and governmental and non-governmental agencies. The user can give units particular leadership values, experience values, stances, etc. This is where you build the hierarchy of units and commanders and assign the units to their initial location. This also allows for the building of battle groups.

D. DATA AND SETTINGS

The underlying data and settings for the model establish the basic characteristics and assumptions that can be generalized over multiple scenarios. These characteristics are predominately independent of the scenario, but can be updated to reflect scenario specific requirements.

1. Unit Abilities

Under data and settings, the user is able to prescribe unit abilities. This category allows the user to assign both descriptive and subjective values to multiple attributes for each unit type. These values determine the unit's ability to accomplish particular tasks. As above, a unit is any organization that participates in the scenario. Figure 4 shows that the unit abilities sub category can be separated into military values and reconstruction values. The displayed unit is a health team, and therefore has relatively high values for healthcare under the reconstruction values, and relatively low military kinetic values.

The screenshot shows the 'Data and Settings Editor' window with the 'Unit Abilities' tab selected. The unit type is 'Health Team (Small)'. The interface is divided into 'Military Values' and 'Reconstruction Values' sections.

Military Values:

- Name: Health Team (Small)
- Domain: Land
- Mobility: 30
- Firepower: 0
- Change Attitude: 0
- Protection: 10
- Crime: 0
- Sensors: 30
- Policing: 0
- Intelligence: 10
- Collateral Damage: 0
- Social Camouflage: 1
- Physical Camouflage: 1
- Manpower: 20
- Max Footprint Size: 0
- Logistics Cost: 0
- Logistics Provision: 0

Domain Modifiers:

- Land: 0
- Air: 0
- Maritime: 0

Reconstruction Values:

Economic Sector	Infrastructure	Human Capital	Palliative
Income	0	0	0
Power	0	0	0
Sanitation	0	0	0
Potable Water	0	0	0
Education	0	0	0
Healthcare	3.3E-05	0.0059	3.33
Shelter	0	0	0
Information	0	0	0
Internal Order	0	0	0
Administration	0	0	0
Food	0	0	0
Transport	0	0	0
Military	0	0	0
Politics	0	0	0
Oil	0	0	0

Figure 4. Example of Unit Abilities in PSOM

2. Stances

Stances provide a catalog of actions that a unit or faction can take toward another entity in the game. Stances are broken in categories based on a main stance, and each main stance has one or more sub stances. The stances are similar to the operations and the sub stances are similar to tactical tasks. For example, a main stance can be attack and the sub stances are the multiple types of attacks, such as ambush or indirect fires. This category allows the user to add main stances and sub stances and make changes to the numeric values that create the particular stance array. A unit's stance determines the intensity of combat tasks, information operations, humanitarian tasks, or logistical support. Figure 5 is a screen shot from the stance "attack" with sub stance "ambush-direct fire." So a unit given this stance, regardless of unit type, has the corresponding values. Also provided in Figure 4 is a list of the main stances available to all units. Special units (e.g., air and sea) have specific stances.

Data and Settings		Main Stances (Coalition Units)
Save/Load Settings Unit Abilities Stances Goods Details Descriptors Population Agents Pre-Set Unit Types Terrain Display Colours Combat Modifiers Outputs Weather Main Stance: Attack/Enforce Add Main Stance Remove Main Stance Sub Stances - Occupy Infrastructure - Destroy Infrastructure - Clear Ambush - Direct Fire - Indirect Fire/Harassment - Attack Logs - Destroy Human Capital (Covert) - Destroy Infrastructure (Covert) - Ambush - IED - Anti-Air - Support Fires Add Sub Stance Remove Sub Stance Effort Modifiers Name: Ambush - Direct Fire Attack Attack Infrastructure: 0 Attack Units: 1 Attack Population: 0 Attack Human Capital: 0 Attack Logs: 0 Defend Guard Units: 0 Guard Infrastructure: 0 Guard Population: 0 Reconstruction Build Human Capital: 0 Build Infrastructure: 0 Provide Aid: 0 Other Military Tasks Train Units: 0 Receive Training: 0 QRF: 0.3 Recce/Intel Gathering: 0.2 Crime and Policing Traffik: 0 Extortion: 0 Counter-Crime: 0 Other Logs Provision: 0 Modify Perceptions: 0.2 Max No Contacts per Man Day: 0.015 Logs Cost: 1 C2 Cost: 1 Average Size of Force on Stance: 30 OK		Build Humanitarian Aid Attack/Enforce Control/Stabilize Transition Information Operations Reconnaissance Logistics/Headquarters Counter-transition

Figure 5. Example of Stance Setting in PSOM

3. Goods and Services

This category allows for categorical costs, production details, and population expectations of provided goods and services. Goods and services can be provided by participating factions as any combination of palliative aid, infrastructure, and human capital. Different types of goods can be added to the model, some common examples of which are power, sanitation, food, and security. The modeler can assign values such as cost per person for palliative aid, maintenance costs, production details, and the population expectation for a particular good or service. A population's expectations compared to what is provided effects the population's consent toward particular factions. The effect of a particular good or service provided in PSOM on population consent is based on public choice theory (Body, 2008, p. 45).

4. Terrain

PSOM can represent different types of terrain. Unit firepower, protection, detection ability, and mobility are all modified by terrain settings.

5. Population Agents

Agents are "Semi Autonomous groups of 'similar' people of a defined size. An agent may make a number of decisions based on the conditions and environment surrounding it" (Parkman, 2008, p. 41). This category is used to create generalizations about the overall population. The number of people in a particular agent (population resolution), group decision actions (decision radius), and criminality (average time in prison for crime) settings are examples of attributes in a population agent.

6. Combat Modifiers

These settings allow for generalizations about combative units. These are often averages that are used in later calculations. Examples are average distance moved, planning delay, average leadership values, and comparative values for conscripts versus

veterans, and typical fire control status (ROE). These values provide a sort of base case or expected values for military or paramilitary unit types using subjective subject matter expert inputs.

7. Outputs

PSOM provides a wealth of deterministic metrics that can be displayed via the graphical user interface (GUI) or sent to a comma separate value file (CSV) for analysis. Multiple metrics relating to PMESII can be extracted from the outputs tab. This is important because in irregular warfare success is often subjective and there is no clean list which provides the conditions for victory. Rather, many metrics are interwoven and dependent on one another. There is more discussion on this topic in the results section.

E. GAME PLAY

PSOM is designed to be a human-in-the-loop wargame. By definition a wargame is a tool for the modeling and exploration of human decisions processes in the content of military action (Perla 1990 p. 261).

An action model that is disconnected from the decision maker's intuition and from the concepts he or she is familiar with does not permit interplay between the decision maker and the model. In short, complicated, non-intuitive action models require decision makers to accept the implications of the model on blind faith. Action models should aid decision makers not replace them. (Committee on Organizational Modeling: From Individuals to Societies, 2008, p. 321).

Therefore, the way in which the game is played is critical. The game should be intuitive in how it is played so as to ensure the semantics of game play do not interfere with player decisions and lessons learned from game play. PSOM is implemented by two separate installations, one server and multiple clients. Clients represent the multiple factions and units involved in the wargame. Figure 6 was taken from the PSOM specification manual and displays this.

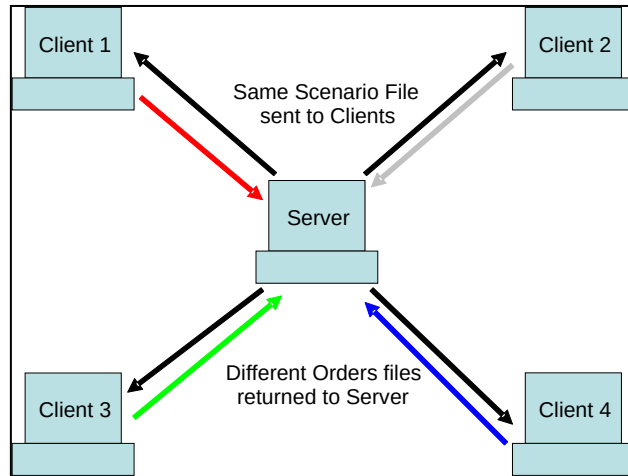


Figure 6. Setup of Game Play [From (PSOM Specification Manual)]

The client interface shown in Figure 7 is the primary means in which the players implement unit orders. Prior to each time step the client updates the client interface. The client can determine the unit's stance and sub-stance toward particular factions, initiate movement, loosen or tighten the unit ROE, change the unit's force protection level, along with other faction-specific updates. Once the player (client) has updated this interface for all units within the corresponding faction, the player sends his complete order to the server. It is possible for a client's order to be scripted as well. For example, the game director can submit a predetermined order for a new insurgent group to attack a target on a particular turn.

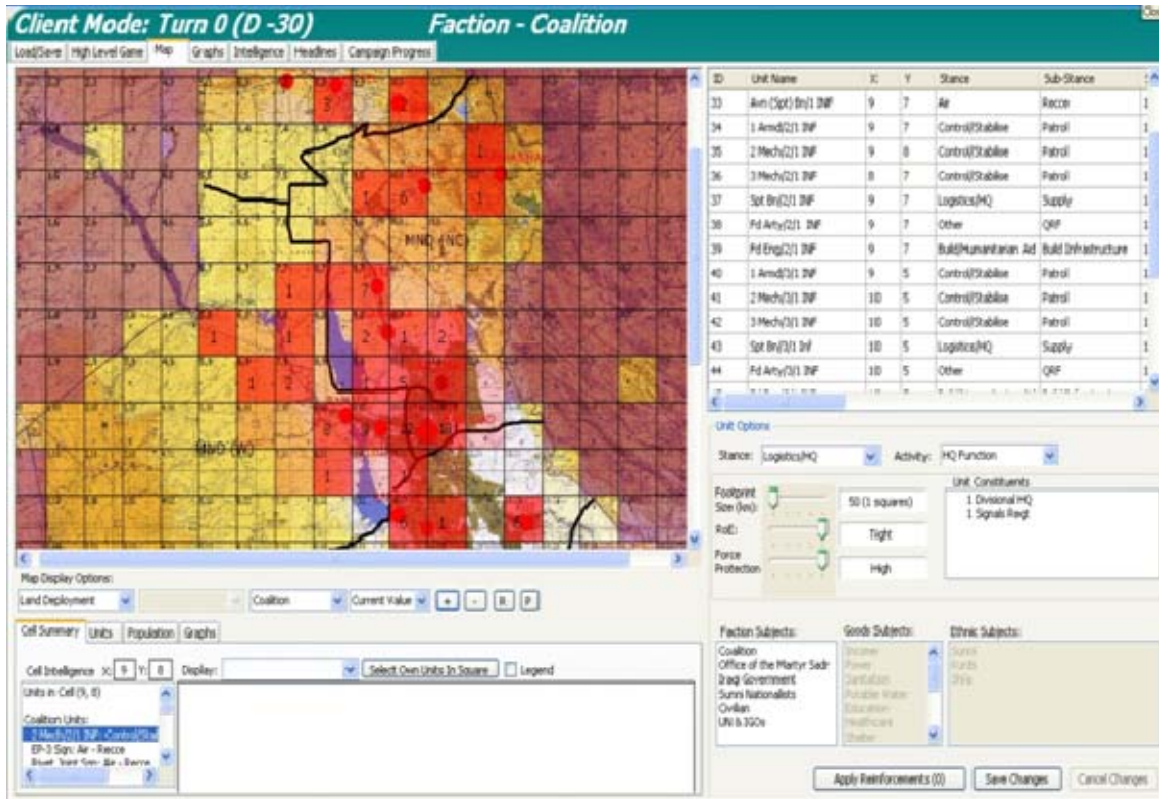


Figure 7. PSOM Player Interface [Best viewed in color]

Similar to the client interface for factions, the higher level game interface shown in Figure 8 is used to update the political and strategic environment the game.

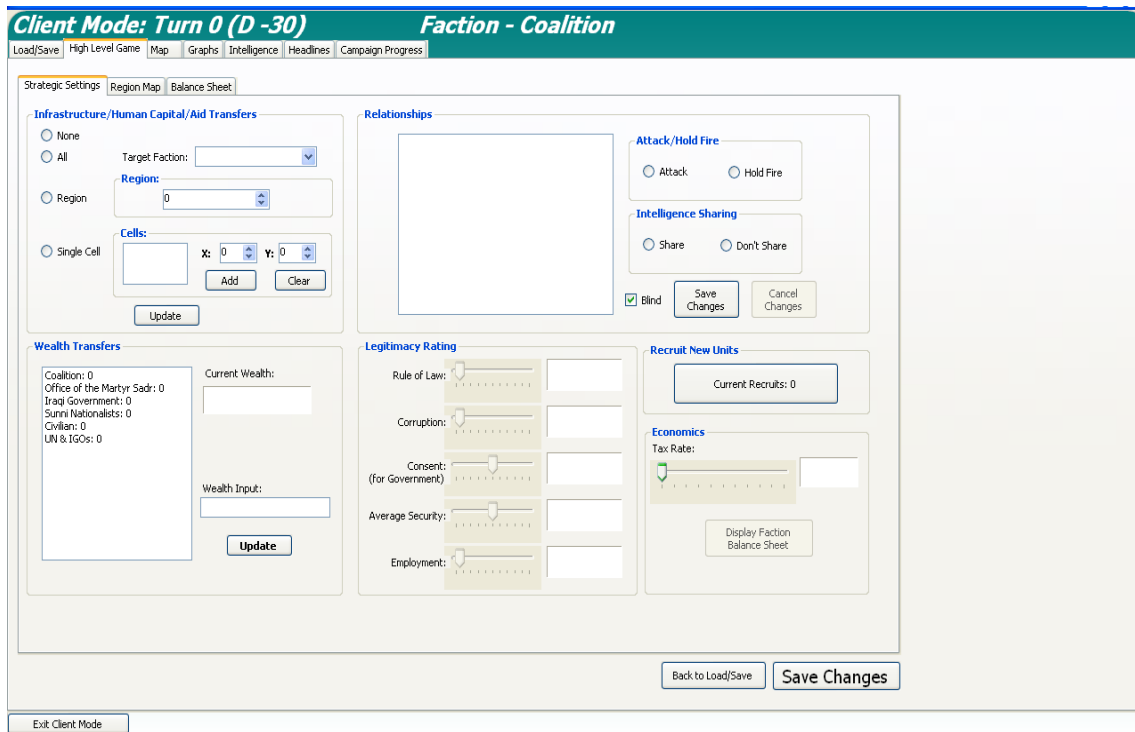


Figure 8. High Level Game Interface

Once all of the clients/players have sent their updated orders to the server, the next time step for the game can be run and the outcomes of the previous actions are provided. At this time the game turn process is completed again.

Time steps for the wargame can be variable; however, a normal time step is thirty days. Therefore, all contacts, humanitarian actions, policy changes, training missions, population actions, and IW considerations for thirty days will be played out between each turn. Faction activities will influence the population, resulting in changes in population support, HUMINT, crime, etc. These will all play out during the thirty-day period and have effects on the status of the host nation in which the war is being fought at the end of the time step.

F. OUTPUT

PSOM can output a tremendous amount of data as output from each turn of the game. This is imperative because “No definitive list can be developed due to the somewhat subjective nature of success” (Body, 2008, p. 16). Because of the interaction between factions, many measures of effectiveness are explained in regards to a relationship between factions and the population. This level of detail allows particular factions to know how their conduct effects the population and other factions. With careful analysis of the multiple outputs a faction can determine the causality of actions by subordinate units. However, these relationships are not often apparent with the basic outputs displayed between turns and take some experience with PSOM to find. PSOM does not provide a list of stochastic possibilities that units could take in regards to faction actions.

In approximate accordance with military doctrine, the primary MOEs for PSOM are security and consent (Stability Operations, 2008, pp. 1–33, 1–77). Both of these measures relate to the population and are represented on a scale ranging from 1 to 10. In the philosophy documentation (Body H. , 2008), security is defined as the key MOE in PSOM. Security tracks the perceived risk of violent death of a population agent in a scenario. This MOE is applied only to the population agents in regard to factions. It is an aggregate of the security amongst all ethnic groups within that population’s grid square. The security MOE is subject to a memory effect in that perception takes time to catch up with reality. It is calculated from deaths to an ethnic group within a cell while accounting for the size of that ethnic group. If a faction actively provides security to a population the metric will credit the faction with the security provided.

The consent MOE depicts the degree to which the population supports and submits to the will of a faction (Jon Parkman, 2008). Unlike the security MOE, consent is not an aggregate of ethnic groups; rather, it is based on the perception of a particular ethnic group toward a faction. So, for example, one ethnic group can have a high consent toward the national government while another ethnicity is the opposite. The consent MOE is subject to memory effects and it is modified by the ideological differences

represented by the Nolan Chart. The value of consent in regard to each faction is a function of the level of goods and services provided, the marginal gain coefficients, and the population agents' expectations. This approach is supported by the standard rational choice theory. "The basic idea behind rational choice theory is that people do their best under prevailing circumstances" (Green, 2002, p. 5). Although these are the primary outputs, Table 2 shows the PMESII indicators and their equivalent PSOM output.

PMESII Indicator	Corresponding PSOM Output
Political Legitimacy	Population Consent toward own Government, Security, Rule of Law, Corruption, Provision of Essential Services
Military	Casualties, Contacts
Economic	Production, Reconstruction, Income, Human Capital, Growth Rate
Social	Fear, Rule of Law, Economic Factors
Information	HUMINT, Headlines
Infrastructure	Infrastructure, Economic Production, Human Capital

Table 2. PMESII Indicators in Relation to PSOM Output

PSOM also provides the user a headlines function which is intended to highlight activities that would most likely become open source press releases. Such topics as civilian deaths, enemy deaths, and terrorist attacks are general headlines.

The taxonomy of the parameters and the responses for the Peace Support Operations Model provides a logical and intuitive environment to simulate contemporary warfare. As explained earlier in this chapter, the inputs required to design and execute a simulation in PSOM cover a vast space from combat capabilities to social behaviors. This study is able to take advantage of this design to create an experiment that will evaluate the model based on its underlying categorical blueprint. By initially completing multiple designs of experiments based on the model's categorical setup, we can then determine and aggregate the influential factors to further explore the model in its entirety.

III. SCENARIO DESIGN

One of the most important jobs of wargame developers is to assess the validity of the game's results and processes in light of the real world.

(Perla, 1990)

A. INTRODUCTION

In evaluating military simulation models it is critical to use a realistic and accurate scenario that is pertinent to current military operations. This chapter describes the macro level military, political, and societal scenario used for all experimentation. The chapter then describes the focus areas of the experimentation with more resolution. This includes a description of factions, coalition military units, and ethnic groups that are critical in the analysis. The chapter concludes with a summary of the measures of effectiveness, units employed, and stances in use.

B. SCENARIO CHOICE

1. Overview

Because of the considerable complexity of a campaign level wargame that portrays the importance of the population, the first priority is using a scenario that is based on thorough research and factual data. Secondly, the scenario should describe a military situation that is relatively well understood, thus allowing intuitive and doctrinal analysis. Therefore, we used a scenario developed by DSTL based on Iraq in the time frame of 2004 onward. DSTL developed this scenario to test PSOM and has conducted multiple wargames and considerable adjustments to ensure scenario accuracy. Also, PSOM is a fairly new model with minimal documentation and thousands of possible inputs; therefore, for this study, we felt it best to use a scenario designed by developers who actually understand the simulation.

Although the scenario encompasses all of Iraq in the given time frame, in order to allow focused quantitative analysis this study primarily concentrates on the coalition forces, the Sunni Nationalists, and the Sunni Ethnic Group Population Agents. All factions and ethnic groups are discussed in this section; however, the emphasis is on the aforementioned groups.

2. The Macro Level Scenario

As previously stated, the scenario used is Iraq 2004 onward. The force structure of coalition forces closely matches that of mid 2004 to 2005. The enemy force structure is loosely based on known information, and the population's attributes are also reflective of this geo-spatial information. Table 3 describes the factions in play and their respective sub-factions. For the majority of simulation runs, twelve 30-day time steps, equivalent to one year of combat, are played. Therefore, the game is a terminating scenario.

Coalition	Office of the Matyr Sadr	Iraqi Governemnt	Sunni Nationalists	UN, IGO's
Combined Air Operations Center	Jaish al-Mahdi Commander	New Iraqi Army	Ba'athist	United Nations Assistance Mission for Iraq
Combined Joint Special Operations Task Force		Police Service	Al-Qaeda in Iraq	
Multi National Division (B)		Facility Protection Service	Tribal Militias	
Multi Nation Division (NC)		Development Center		
Multi Nation Division (CS)		Shi'a Militias		
Multi National Division (SE)		National Police		
Multi National Division (W)				
Coalition Provisional Authority				
Multi National Forces Iraq Corps Assets				

Table 3. Breakdown of Iraq Scenario Factions

The population consists of three primary ethnic groups (using the PSOM definition of ethnic group): Sunni, Shi'a, and Kurds. During Saddam Hussein's reign these ethnic groups separated themselves across the country, creating geo-ethnic areas throughout the entire nation. For this particular scenario the coalition defined areas of responsibility closely align with these ethnic divides. This is shown below in Figure 9. Due to the sheer size and complexity of this scenario, we have focused our emphasis on Sunni civilians, the Sunni Nationalist factions, and the coalition forces that are assigned to the areas in which Sunni's and the Sunni Nationalists live and operate. Figure 9 displays the Office of the Martyr Sadre Faction (JAM), the Sunni Nationalist Faction, and the population of ethnic groups by region at simulation time step zero.

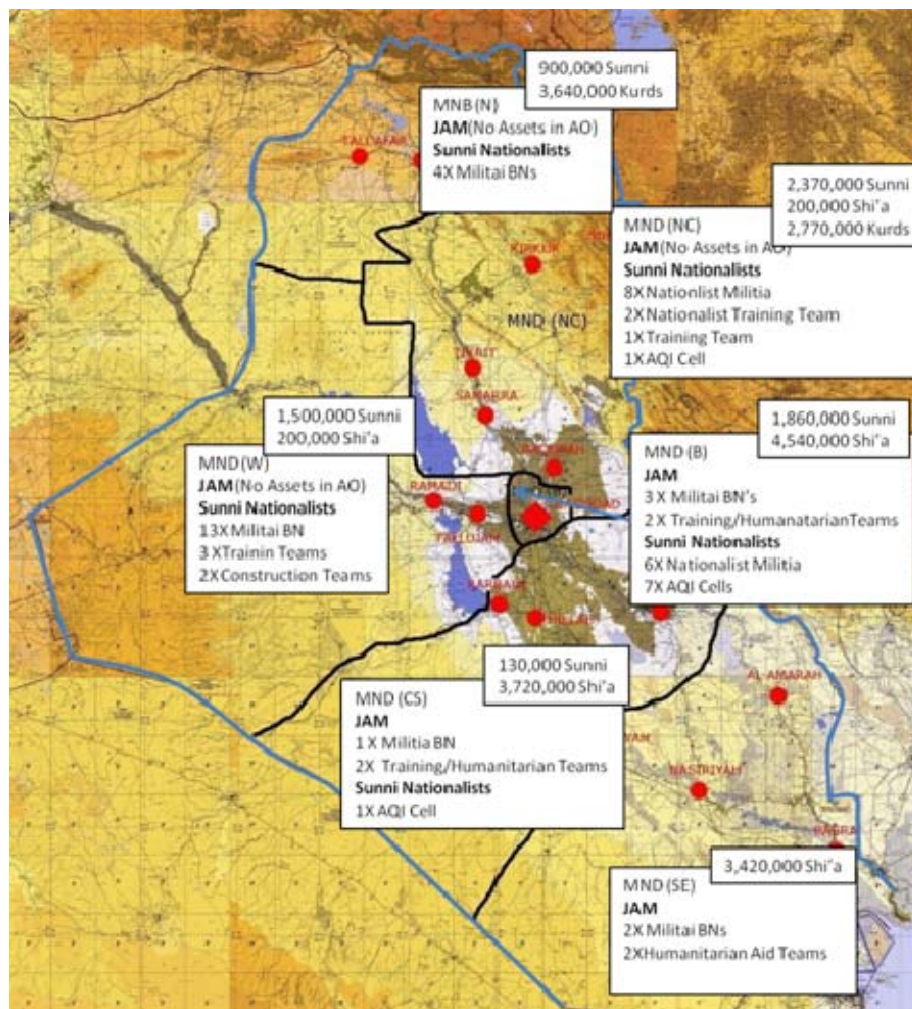


Figure 9. Break Down of Population, JAM, and Sunni Nationalists by AOR [Best viewed in color]

Figure 10 shows the Map of Iraq broken down by Area of Responsibility used for this study.

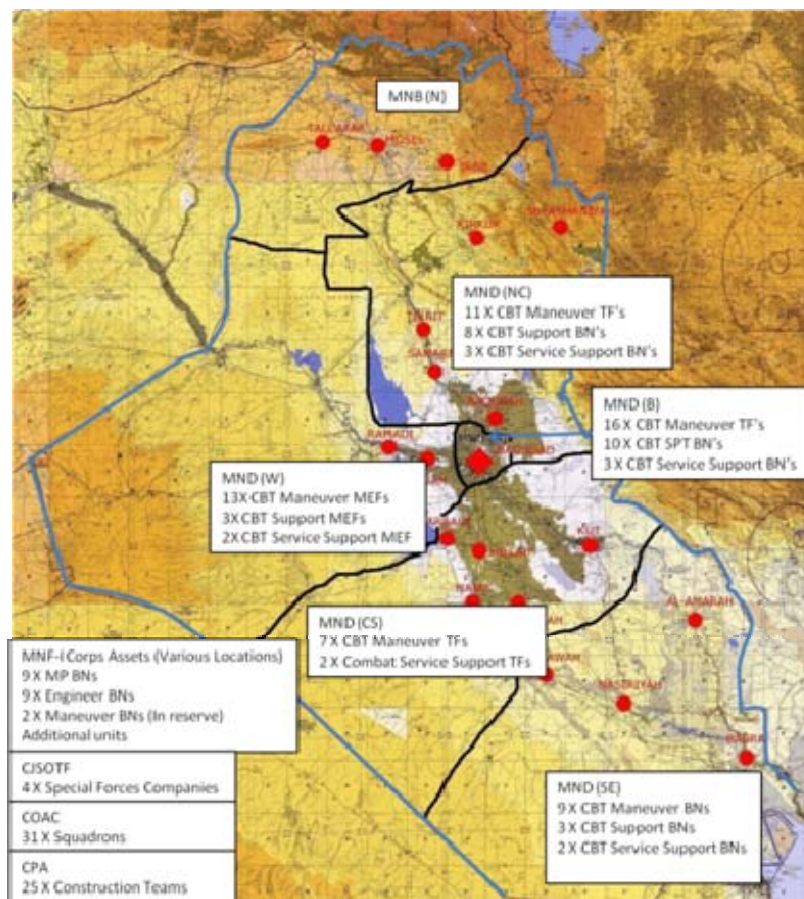


Figure 10. Coalition Force Structure by Area of Responsibility [Best viewed in color]

C. SITUATION

By late 2004, coalition forces were well established with over 150,000 troops in Iraq. Although the new Iraqi government has control over the country, the population's support is questionable across the nation. The growth of Al Qaeda in Iraq (AQI) has been noted throughout the country and increased violence between ethnic groups has many feeling a civil war is inevitable. At the same time, a tremendous emphasis has been put forth by the coalition to build Iraqi Security Forces and the Iraqi Army is starting to take shape. The country's infrastructure is still weak, proven by a lack of continuous power and potable water throughout the country.

1. Factions

a. Coalition Forces

The faction of coalition forces consists of over sixty combat maneuver battalions and the required combat support and service support. These forces are spread throughout the country with the majority focused on Baghdad and MND(NC). In addition to the combat units, numerous air wings, indigenous force training teams, and reconstruction teams support the coalition mission. The coalition's primary stances during this phase of the war are to provide security and assist in the rebuilding of the war-torn nation.

b. Sunni Nationalists

The faction of Sunni Nationalists consists of the emersion of Al-Qaida in Iraq (AQI) and tribal militias. AQI consists of ten cells each with approximately forty members. Their primary focus is either attacking the coalition forces or the Iraqi government through the destruction of infrastructure. As can be seen in Figure 9, the majority of these forces are in Bagdad or the surrounding areas. The majority of the Sunni Nationalists are the nine tribal militias which consist of approximately 700 troops each. These units are primarily anti-coalition and anti-Iraqi government as well. The Sunni Nationalists also maintain a small number of training and reconstruction teams which operate in the central to northern portions of the country.

c. Office of the Martyr Sadr

The faction of the Office of the Martyr Sadr (JAM) consists of fourteen militia battalions, but for purposes of this scenario only seven are activated and seven are in hiding. In addition, JAM has seven training units and seven construction units to help win populace consent. As can be seen in Figure 8, the only area where JAM and Sunni Nationalists both operate is in Bagdad; the remaining JAM units focus primarily in MND(CS) and MNS(SE). JAM's primary stance in this game is to protect the Shi'a population from both the Sunni Nationalists and the coalition forces.

d. *Iraqi Government*

The faction representing the Iraqi government primarily consists of security forces. The Iraqi Security Forces are comprised of forty police Battalions, forty facility protection service (FPS) groups, five construction teams, five training teams, twelve Militia Battalions, twenty-seven national police battalions, and some additional recruiting and information operations units. These units are primarily focused on the security of the nation.

e. *United Nations and Inter-governmental Organizations (UN, IGO)*

The UN and IGOs faction consists of thirty-three humanitarian aid teams spread throughout the nation. Their primary role is to provide aid in the form of medical assistance, education, subsistence, and infrastructure to the population.

2. *Population*

a. *Sunni Ethnic Group*

In this scenario the Sunni population comprises approximately 25% of Iraq's total population (see Figure 8). As a group, the Sunni do not approve of the coalition forces and have only a slightly higher opinion of the current Iraqi government than of the coalition forces. However, the Sunni population has very strong consent for the Sunni Nationalists and their cause. The Sunni population holds the Office of the Martyr Sadr in contempt and fears JAM and coalition forces equally. The population primarily lives in the north central areas of Iraq and except for in Baghdad is segregated from the Shi'a populace.

b. Shi'a Ethnic Group

In the given scenario the Iraqi population is 48% Shi'a. As a group, the Shi'a accept coalition forces with consent equivalent to the Office of Martyr Sadr. The Shi'a generally support the current Iraqi government, but condemn the Sunni Nationalists. The Shi'a primarily reside in Baghdad and southern Iraq.

c. Kurd Ethnic Group

The Kurd ethnic group provides for the remaining 25% of the Iraqi population. They primarily live in the most northern areas of Iraq and support both the coalition forces and the Iraqi government. The Kurds are impartial toward the Office of the Martyr Sadr, but hold the Sunni Nationalists in contempt.

3. Game Execution

a. Overview

Normally, the intent of the coalition faction in this wargame is to actually play the PSOM Iraq scenario with the goal of creating an independent, secure Iraq with lucrative economic conditions and a legitimate government fully supported by the population. However, this is not the case for this experiment. Rather, our goal is to test the realm of possible outcomes received by the users of PSOM. For this we focus on the security levels and consent levels throughout the country as we change faction activities and scenario parameters.

The majority of simulations executed represent one year of combat. Starting conditions were not changed within simulation runs, so if a faction begins the year with an aggressive stance and a relaxed set of ROE, these characteristics are maintained for the entire year. This is an identified limit of the study. The human-in-the-loop technique allows for factions to adapt to reactions of the population and other factions. Unfortunately, in using the pre-scripted batch technique to run the scenario we cannot adjust the factions' actions throughout the year. This also pertains to unit movement. Therefore, a unit could not move out of its initial allotted footprint. This

being said, because each time step represents thirty days of combat, results of the previous month are carried over to the current month's fight. For example, civilian and military casualties, population reaction, and infrastructure growth all are determined time step by time step throughout the game.

b. Measures of Effectiveness

The primary measures of effectiveness addressed are the consent of the Sunni population toward the coalition forces, the consent of the Sunni population toward the Iraqi government, and the security level throughout the country. PSOM displays these outputs in 50km X 50km grid squares (see Figure 11). This system results in 135 separate responses as the game is played. To allow for analysis, the responses are aggregated by coalition Area of Responsibility and the entire country. This allows for regional averages for the MOEs, and therefore reduces 135 outputs for three metrics to seven outputs for the three metrics. However, these metrics are based on geo-spatial representation and not the quantity of people within the cell.

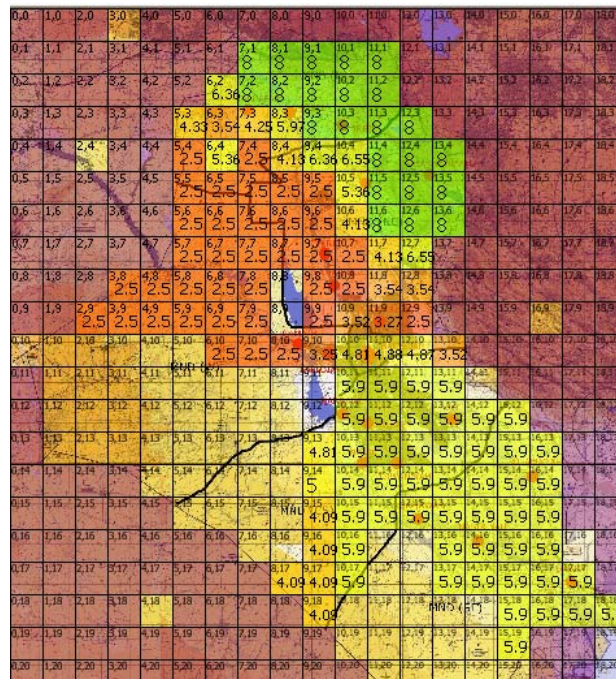


Figure 11. The Graphical Display of Ethnic Groups Consent for the Coalition from the Peace Support Operations Model [Best viewed in color]

c. Units Played

Due to the nature of a campaign level model, the number of maneuverable units can overwhelm analysis, causing excessive noise and confounding. To prevent this, the study focuses on varying the attributes and actions of selected units and population agents. A total of thirty-seven coalition maneuver battalions which are located in MND(B), MND(NC), and MND(W) are played, seventy-five Sunni Nationalist units are played, forty-seven UN IGOs are played, and 535 Sunni population agents, which represent 5.35 million Sunni civilians, are the population focus.

d. Unit Stances

The complete taxonomy of stances and sub stances in this scenario ranges the possible set of doctrinally defined operational and tactical tasks. For this study, coalition forces are limited to the following stances: providing aid, securing, attacking, and withdrawn. Sunni Nationalists are either attacking coalition forces, attacking Iraqi infrastructure, or withdrawn. IGO's are either providing aid or withdrawn. The stances are uniform across the units mentioned in the previous paragraph. So, if a particular design point includes coalition stances with a stance of "withdrawn," all thirty-seven coalition maneuver battalions are withdrawn. This is a noted limitation to this particular study and should be examined further in a follow-on study.

D. SUMMARY

The contemporary Iraq scenario used for this study was developed and thoroughly evaluated and updated by the Defense Science Technology Lab UK, who also developed the Peace Support Operation Model. It is the most robust scenario developed for PSOM and the best for this study. This is of significant importance due to the tremendous amount of social parameters that a PMESII model must account for. Due to the number of parameters and units the study narrows the scope of concern to primarily the Sunni population, the Sunni Nationalist Faction, and the coalition maneuver battalions operating in the areas where the Sunni population exists. By narrowing this area of focus the study can use intelligent Design of Experiment in conjunction with modern computing power and basic data mining to analyze the PSOM's output.

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IV. EXPERIMENTAL DESIGN

Everything should be made as simple as possible, but not simpler.

Albert Einstein 1933

A. INTRODUCTION

In the simplest form the purpose of this research is to gain a basic understanding of the Peace Support Operation Model. In particular, we need to determine which factors are significant in the model and how they affect the responses (Kelton, 1991, p. 657). In order to quantifiably analyze PSOM, this study follows the data farming process described by Horne (2004). Our implemented iterative data farming process entails a four step procedure: Define factors of interest, create a design of experiment (DOE), run the simulation experiments in parallel on a computing cluster, and conduct data mining. The initial definition of interesting factors is a research and subject matter centric step to begin the process. The use of DOE allows us to gain “detailed insight into the model’s behavior” (Kleijnen, 2005, p. 266), control the bias and confounding of factors, and explore a tremendous number of possible parameter combinations efficiently. Data mining is then used to analyze responses from the created vast parameter space (Phillip Barry & Koehler, 2004). This is essential as a low-resolution model which encompasses social implications has no closed form solution. We can then take this large data set and develop relatively simple formulas that act as a proxy for the actual simulation (Kelton, 1991). These “meta models” can then be used to determine which factors are significant within PSOM and what effects their manipulation might have.

This chapter describes in detail the variables selected as factors in the experiment, the methodology used to create the DOEs, and the tools created at the Naval Post-graduate School to take the PSOM wargame and convert it into a data farmable simulation. Next, the design of experiments processes used are discussed, providing the

reader insight into how the study efficiently tests a large space of possible combinations of input parameters (Horne, 2004). We then discuss the meta modeling techniques used to data mine the tremendous amount of output collected from the experiments.

B. FACTOR SELECTION AND METHODOLOGY

1. Overview

In analyzing the variables and comparing results, factor selection proves vital to an efficient and worthwhile study. PSOM is a complex model and the number of factors used to build the Iraq scenario is too immense to study in its entirety. For example, there are twelve factors used to describe each particular unit and there are an additional thirty-three attributes used to create each unit type. For example, A/1–26 IN has twelve specific settings and every generic infantry company has thirty-three attributes in common with all infantry companies. Therefore, any one of the 200 coalition units has forty-five variables which describe its totality. In addition to the number of factors, there is no published PSOM user’s manual (there is a draft manual cited throughout this work), and many of the variables are not constrained to particular numeric ranges. Naively selecting the factors without regard to their appropriate ranges would result in a design where important factors are washed out by noise or dominated by unknown limits on parameters. This section explains the tactics used and factors selected in building the experiment.

As previously stated, the scope of the study is limited by the focus on geographical areas inhabited by the Sunni. To further narrow the scope, we looked to the opinion of subject matter experts on irregular warfare, combat modeling, PSOM, and the DoD’s needs in IW modeling for the first stages of the experimental design. Although this reduces the number of factors tremendously, multiple designs were needed to create practical experiments. These experiments are categorized by scenario design and settings design. Finally, because this is an iterative process, the emersion of results, analysis, and expert opinion creates a cumulative design of experiment.

2. Scenario Specific Design of Experiment

The scenario specific design of experiment analyzes the parameters found in the scenario file. These factors are either set during scenario development or changed by players during the game. Many of these factors are crucial assumptions made about either population agents or factions. Of note, not all factors are quantitative in nature. For example, a unit's stance is an action from a list of possible tactical or operational tasks. These categorical factors increase the number of design points tremendously and are therefore limited in scope. Table 4 shows the list of scenario design categorical factors, their experimental ranges, and brief descriptions. Stance changes affect all units in the area of game play at the beginning of the game and they maintain these stances for the entire 12-month period.

Factor	Level 1	Level 2	Level 3	Level 4	Description
Coalition Stance	Combat Units Attacking Sunni Nationalists–	CBT Units Securing	CBT Units Providing Humanitarian Aid	CBT Units Withdrawn	37 Coalition maneuver BN's in Sunni inhabited regions take this stance
Sub Stance	Clear	Patrol	Build Infrastructure		
Sunni Nationalist Stance	Attacking U.S.	Attacking Iraqi Government	Withdrawn		75 Sunni Nationalist Units (AQI and Militia) in Sunni inhabited regions take this stance
Sub Stance	Ambush	Destroy Infrastructure			
IGO Stance	Withdrawn	Provide Humanitarian Aid			47 IGOs throughout Iraq take this stance
Coalition Shares Intelligence with Sunni Nationalist	Yes	No			Determines if the coalition and Sunni Nationalist share information

Table 4. Categorical Factors used in the Scenario DOE

Table 5 is a list of all the quantitative factors in the scenario DOE, their experimental range, and a short description.

Factor	Experimental Range	Description (Parkman, 2008)
Coalition ROE Level	1–5	1 (Loose) and 5 (Tight) representing the degree to which the unit is willing to cause civilian casualties in order to complete its task.
Coalition Force Protection Level	1–5	An integer between 1 (Low) and 5 (High) representing the degree to which the unit is willing to suffer its own casualties in order to complete its tasks.
Sunni ROE Level	1–5	See above.
Sunni Force Protection Level	1–5	See above.
Sunni Political ideology	0–100	This is a value between 0 and 100, which give the Faction’s ideology. based on its views on personal freedom, through the Nolan chart system, as shown below.
Sunni Marginal Gains	0.3–0.6	These values, one for each Good Type, control the level of importance that the group places on the provision of that good type.
Sunni Marginal Gains Security	0.3–0.6	This value controls the level of importance that the ethnic group places on Security.
Sunni Initial Consent Coalition	2–8	These values set the initial levels of Consent towards each Faction that are possessed by the generated Agents at the start of play.
Sunni Initial Threat toward coalition	2–8	This value sets the initial level of threat that a population agent feels toward each faction.
Coalition Casualty tolerance	0–100	Casualty tolerance value, which controls how many casualties the unit will bear each turn before the deterrence function begins to have an effect.
Coalition Leadership	0–100	The level of competence in the leadership of the unit.
Coalition Experience	0–100	The level to which the Unit is trained and experienced in conducting operations in a PSO type situation.
Coalition Reputation	0–100	The degree to which the population perceives that the unit is unwilling to conduct offensive operations against them.
Coalition Turns at Location	0–12	The values for calculating the unit’s familiarity with the local environment.

Table 5. Continuous Factors used in the Scenario DOE [From (Jon Parkman, 2008)]

3. Explanation of Factors

a. Stance

The stance that a faction takes determines the actions of that faction. Therefore, the choice of stance is critical. This experimental design emphasizes the different initial stances and the resulting responses. If the players' actions do not provide reasonable reactions from the game, then its use is questionable. We expected to see considerable interaction between the coalition and Sunni Nationalist stances. This thesis looks into the stances of the coalition forces, Sunni Nationalists, and the IGOs. These factors are normally controlled by the players.

b. Rules of Engagement

The players also set each unit's ROE. This provides the player the ability to designate the degree in which each unit is willing to cause civilian casualties in order to accomplish its mission. A setting of 1 is a very loose ROE and would be indicative of a VBIED detonated in a civilian populated area, where as an ROE of 5 represents a sniper who would only engage upon positive identification of an enemy.

c. Force Protection

Force protection is similar to ROE in that the players control this setting for each unit on a scale from 1–5. A unit's force protection describes its willingness to assume risk to accomplish its mission. A value of 1 is low risk and a value of 5 is high risk.

d. Political Ideology

Political ideology is a population agent attribute which falls on a scale of 1–100 (see Chapter II). This ideology is important in the development of population agents and therefore should play a role in the population's consent toward factions. Ideologies are defined in the scenario setup.

e. Marginal Gains for Goods

Marginal gains determine the importance of a particular good for each ethnic group. Marginal gains are on a scale of 0–1 and are a primary characteristic in the building of population agents during scenario development. Because these play a key role in the population’s development and rules it is essential to understand their impact on the game. During the initial iterations this factor proved very powerful to game outcomes, so the experimental range was limited to 0.3–0.6.

f. Marginal Gains for Security

The security marginal game is similar to that for goods. In this study its value was changed separately because a society’s concern for security is more likely to be influenced based on combat actions. Thus, the consent corresponding to marginal gain security is changed based on security provided as opposed to goods production. During the initial iterations this factor proved very powerful to the game outcome so the experimental range was limited to 0.3–0.6.

g. Initial Consent

The initial consent an ethnic group feels toward a faction is a tremendous assumption in scenario development. As with consent, this factor is on a scale from 0 to 10. With any scenario it is crucial to understand how initial conditions can affect simulation execution.

h. Initial Threat

The initial assumption of threat an ethnic group feels toward a faction is similar to initial consent, and its implications should be explored.

i. Coalition Casualty Tolerance

Coalition casualty tolerance controls how many casualties the unit will bear each turn before the deterrence function begins to have an effect. This value is on a

scale of 1 to 100 and is used to describe each unit during scenario development. Often in irregular warfare numerically small levels of casualties can create strategic implications.

j. Coalition Leadership

Coalition leadership describes the level of competence in the leadership of a particular unit. This value is on a scale of 1 to 100 and is used to describe each unit during scenario development. The United States relies heavily on leadership, making this factor an essential assumption.

k. Coalition Reputation

Coalition reputation describes the perception the population has on a particular unit. This value is on a scale of 1 to 100 and is initialized during scenario development. In warfare, dealing with the populace the reputation of a unit should have a direct effect on the collection of HUMINT, coalition freedom of movement, and trust.

l. Turns at Location

Coalition turns at location describes the number of time steps which a unit has been in a particular location and thus how familiar it is with that area. This value is on a scale of 0 to 100 and is initialized during scenario development. This factor has implications in the strategic emplacement of units and deployment timelines.

4. Setting Specific Design of Experiment

The settings design of experiments focuses completely on the settings factors in the Peace Support Operation Model. These factors are primarily generic in nature in that they are descriptions of units, populations, and conditions by type rather than tied to the particular scenario. The settings describe broad unit abilities, dictate stance attributes, and create values used to modify mathematical functions within the simulation. For example, these parameters can be used to provide insight on increasing unit manpower or mobility, giving combat units the ability to provide humanitarian aid, make combat more aggressive in nature, or determine if a patrolling unit acts to protect civilians or gain intelligence.

Because of the large number of these factors (sixty-six) and their similar nature, it is best to describe the purpose of their exploration upfront and give only a brief description of each. First off, it is crucial to understand the parameters used in any model prior to using it as a decision aid or training tool. Many of these parameters are not well defined in any literature, nor do they have limits to their values. Using an intelligent DOE we can explore the space of these factors and determine which, if any, will have a profound effect on the simulations outcome. This can only lead to better use of the model as a training wargame and analytic tool. Secondly, many of these attributes are quantitative descriptions of unit types. Often military comparative studies are used to modify unit attributes in determining fielding and acquisition questions. If PSOM can provide such comparative analysis in the world of irregular warfare it can prove a useful simulation. In order to mitigate any one factor from dominating the experiment, these factors are varied $\pm 20\%$ from the original values in the scenario developed by DSTL. Table 6 lists all the factors used in the settings DOE.

Factor	Experimental Range	Description
Unit abilities set attributes of the particular unit types. These were cast across maneuver companies.		
Unit Fire Power	64–96	Level of firepower per man
Unit Protection	80–120	Level of armor per man
Unit Sensor	40–60	Level of sensors per man
Unit Intelligence	16–24	The ability per man to recognise and classify
Unit Physical Camouflage	0.8–1.2	Level to which the element can blend in surroundings
Unit Social Camouflage	0.8–1.2	As above but in social population
Unit Mobility	24–36	Average speed in km/h the element moves
Unit Change Attitude Ability	2.4–3.6	Ability to change the attitude of the population
Unit Crime	1.6–2.4	Ability per man in the element to commit crimes
Unit Policing	2.4–3.6	The ability per man in the element to counter crime
Unit Collateral Damage	5.6–8.4	The level of expected collateral damage by unit
Unit Size	72–108	Number of men in the unit
Unit Palliative Aid Ability	0.24–0.36	Unit's ability to provide palliative aid
Stance settings describe the attributes of a particular stance. These were applied to stance <i>Secure/Patrol</i> .		

Factor	Experimental Range	Description
Stance Attacks Unit	0.24-0.36	Proportion of time in the turn spent attacking
Stance Protect Population	0.32–0.48	Proportion of time in the turn spent protecting
Stance Provide Aid	0.16-0.24	Proportion of time in turn providing aid
Stance Modify Perception	0.32–0.48	The level to which the population will be reassured or intimidated by the Unit's actions
Stance Extort	0-0.3	Proportion of time which a unit extorts
Stance Counter Crime	0.24–0.36	Proportion of time which a unit counters crime
Stance Intel Gather	0.4-0.6	Level which a unit's actions allow it to gather intel
Stance QRF	0.32–0.48	Proportion of time which a unit is on QRF
Stance Average Size	24-36	Average size of unit on stance
Stance Protection Modifier	0.64–0.96	Modifier to units protection value while on stance
Stance Mobility Modifier	0.8-1.2	Modifier to units mobility value while on stance
Stance Detectability Modifier	0.96–1.44	Modifier to units detectability value while on stance
Stance Detection Modifier	1.2-1.8	Modifier to units detection value while on stance
Stance Recognition Modifier	0.8–1.2	Modifier to units recognition value while on stance
Settings that control the generation of the population. These are applied to the entire population		
Population Decision Radius	40-60	Distance in km that an agent will look across to find a better location
Population Memory Coefficient	2.4–3.6	Half life (in turns) of the current consent value
Population Consent Political MScaler	-0.64–0.96	Controls the effect of ideology differences on Consent (gradient)
Population Consent Political CScaler	0.08–0.12	Controls the effect of ideology differences on Consent (intercept)
Population Average Term In Prison	2.4-3.6	Average length (in turns) of a custodial sentence
Population Self Presenters	0.4–0.6	% of a population that will self-present at a hospital–outbreak
Population Police Clear Rate	0.2-0.3	Gradient of the police clear rate
Population Infection MargGains	0.16–0.24	Related to the infection variable
The following are time variables used in the PSOM queuing algorithm		
Combat Mod Que Decay Rate	0.012-0.018	Intelligence decay rate
Percent Force on Duty	0.24–0.36	Proportion of a military unit on duty at any one time
Planning Delay	4.8-7.2	Length of time in hours that it takes to plan operation
Operation Time	3.2–4.8	Length of time in hours that it takes to carry out a small operation

Factor	Experimental Range	Description
Recuperation Time	8–12	Length of time in hours the portion of a unit in contact should be unavailable
Avg Distance Traveled	6.4–9.6	Average distance that a force will have to move within a square to prosecute a contact
Max Fatigue	0.64–0.96	Unused
Fatigue Drop Off Factor	3.2–4.8	Unused
Force Protection Mean	2.4–3.6	The mean of the force protection scale
Force Protection K Value	0.24–0.36	Calibration factor
Force Protection Mod	0.24–0.36	Level to which force protection actually impacts casualties
Mean ROE	2.4–3.6	Mean of the ROE scale
ROE K Value	0.24–0.36	Calibration factor
ROE Mod	0.24–0.36	Level to which rules of engagement actually impact civilian casualties
Max Leadership Mod	1.6–2.4	Maximum modifier possible with ∞ leadership
Min Leadership Mod	0.16–0.24	Minimum modifier possible with no leadership
Leadership Drop Off Factor	0.016–0.024	Value controlling the rate at which the value of the Leadership modifier curves
Familiarization Stranger	0.4–0.6	Modifier on the performance gathering of a person who is unfamiliar with his surroundings
Familiarization Native	1.6–2.4	Modifier on the performance gathering of a person who is familiar with his surroundings
Familiarization Learning	0.08–0.12	Control on the curve between the above factors
Experience Conscript	0.16–0.24	Modifier on the performance of a new recruit
Experience Vet	1.6–2.4	Modifier on the performance of an experienced troop
Experience Learning Factor	0.0712–0.1068	Control on the curve between the above factors
Inter Unit Base Casualties ATT	0.08–0.12	Level of casualties caused to the instigator of a contact
Inter Unit Base Casualties DEF	0.08–0.12	Level of casualties caused to the defender of a contact
Inter Unit Base Contact Size	24–36	Baseline combined size of the attacking and defending forces in contact
The following factors are relevant to each particular good.		
Goods Expected	0.4–0.6	Population requirement for goods
Good Protection Value Power	8000–12000	Protection score of power
Good Protection Value Water	56–84	Protection score of water

Factor	Experimental Range	Description
Good Protection Value Education	56–84	Protection score of education
Good Protection Value HealthCare	120–180	Protection score of healthcare

Table 6. Factors used for the Settings DOE [From (Parkman, 2008)]

5. Cumulative Design of Experiments

The cumulative experiment is the aggregate of results from the previous experiments' analysis and a desire to explore new factors (see Chapter V). After completing the very first test run the concept of time step and time for the model came into question. We therefore introduced both time step increment and overall simulated time as factors on an individual experiment. The scenario DOE brought significant insight into both stances and marginal gains and the coalitions limited ability to increase consent. We therefore focus on the coalition stances in this design. In regards to marginal gains, the marginal gain values' ranges are very limited in this DOE, and are lowered to allow for a greater change in consent. Finally, after analysis of the settings DOE, further analysis of the unit capabilities was required. The unit attribute values are varied over a greater range in this experiment than the limited 20% deviation we used earlier. Table 7 explains the factors used in this DOE.

FACTOR	VALUES and RANGES
Coalition Stance	Humanitarian Aid or Secure by Patrol
Time Step	7, 30, 60 in days
Sunni MG Security	0.1–0.2
Sunni Marginal Gains	0.1–0.2
Unit Fire Power	50–150
Unit Protection	50–150
Unit Sensors	50–150

FACTOR	VALUES and RANGES
Unit Size	50–150
Unit Change Attitude Per Man	1–10
Unit Intelligence Ability	20–50

Table 7. Factors used for the Cumulative DOE

C. EXPERIMENTAL DEVELOPMENT AND TOOLS

1. Software Upgrades used to Expand PSOM

It is important to understand that PSOM is a wargame. It was developed to explore irregular warfare with human interaction. Unfortunately, this setup does not allow for quick turnover analysis. Adjusting thousands of parameters by hand and then executing twelve months of combat would lead to potential human error and an unfathomable amount of time. In 2008, when the Naval Postgraduate School first received PSOM 2.2.3, the batch mode was not flexible enough for large scale experimentation, and there was no way to interface PSOM with the current host data farming tools. Such an experiment had never been done. SEED center research associate Adam Larson created the tools needed to allow parallel runs of the simulation on a cluster of computers. These tools include a command line batch mode for PSOM allowing the simulation to run based on predetermined settings completely independent of the graphical user interface and a script converter which converts the scenario and settings data files to an XML format compatible with current data farming tools. Additional changes include the addition of direct control over the simulation's random seed allowing the reproduction of any particular run. Also, in order to allow for data extraction, we developed a PSOM post processor that pulls the non-normalized data for each individual run, transforms the data to the PSOM scale of 1 to 10, takes the mean of multiple runs if used, and determines the variance across the regions.

2. Designs of Experiment Used

A tremendous amount of insight can be obtained in a very efficient manner with a well designed experiment. In this thesis, as is often the case with design of experiment, the experiment is being used to primarily determine which factors are truly important (Sanchez, 2008). To ensure a comprehensive analysis, the experimental design should look at a widely ranging combination of factors while at the same time trying to avoid confounding to ensure causality can be explained. It is important for the reader to understand which design techniques were used throughout this study. However, these techniques are tools for analysis and not a subject of this thesis; therefore, they are only briefly explained in this chapter.

For the exploration of the scenario file, this thesis uses three techniques to construct an intelligent design of experiments. To account for the categorical variables we used an m^k factorial design. This design consists of:

$$4(\text{Coalition Stances}) \times 3(\text{Sunni Nationalist Stances}) \times 2(\text{IGO Stances}) \times 2(\text{Coalition to Sunni Relations}) = 48 \text{ design points}$$

A nearly orthogonal Latin hypercube (NOLH) DOE is used for the remaining fourteen factors. A design is nearly orthogonal if the maximum absolute pairwise correlation between any two input columns is less than .05. Latin hypercubes (LHs) provide a flexible way of constructing efficient designs for multiple quantitative factors (McKay et al. 1979). However, due to an inherent randomness in their construction, they can exhibit substantial correlations among the input variables—thus, inhibiting many statistical procedures with which we would like to use to analyze relationships between input and output variables. While specially constructed orthogonal LHs exist (see, for example, Ye 1998), they often have poor space-filling properties. A design with good space-filling properties is one in which the design points are scattered throughout the experimental region.

To address the dearth of space-filling orthogonal LHs, Cioppa (2002) used a computationally intense heuristic algorithm to generate and catalogue a set of NOLHs with good space-filling properties. These flexible designs allow for the efficient examination of many factors and their complex relationships with very low

correlations—thereby facilitating powerful statistical analysis (Cioppa & Lucas, 2007). For example, by using Professor Susan Sanchez’s NOLH spreadsheet implementation of Cioppa’s designs (see <http://harvest.nps.edu> for the spreadsheet), a DOE with sixty-five design points is sufficient to analyze the previously mentioned fourteen continuous factors throughout their entire ranges. A basic 2^k factorial design requires 16,384 design points and would only explore the extreme points of the factors. Finally, by using a Cartesian join to create a cross design of the full factorial design with the NOLH design, a DOE with 3,120 design points covers a plethora of possible combinations of the factors between the two designs, greatly reducing computing expense.

Each design point (also called an excursion) represents an individual run of the experiment at the distinctive parameter values. As discussed in the following chapters we found little variance in PSOM output; however, because of the slight stochastic nature of PSOM, each excursion was run five times with a different random number seed to account for variation due to randomness in the simulation for a total of 15,600 runs on the NPS SEED Center’s cluster of fourteen processors. A twelve time step excursion takes approximately one minute to run on a standard computer. This process took approximately fifteen hours of computing time or about 200 hours of processor time.

The settings design of experiment was driven by three separate characteristics of the parameters. First, all data was continuous in nature, so the NOLH seemed ideally suited. However, the NOLH’s described by Cioppa (2002) were limited to twenty-nine factors and we wanted to explore sixty-six. Fortunately, COL Alejandro Hernandez had developed a tool for his PhD dissertation, *Breaking Barriers to Design Dimensions in Nearly Orthogonal Latin Hypercubes* (Hernandez, 2008), which extends the limits of the NOLH far past the sixty-six we required. Finally, many of the settings values are not bounded nor well described in the PSOM draft documentation. Therefore, we manipulated original settings factors used by DSTL by $\pm 20\%$ to mitigate any parameter dominance. The result is a design of experiment with 1,000 distinct design points thoroughly covering the ranges of the parameters. Each excursion was run ten times (by

now we had seen PSOM ran rather quickly) for a total of 10,000 scenario runs. This process took approximately twenty-four hours to complete on the fourteen processor cluster.

The cumulative design of experiment consists of only ten factors, three of which are categorical while the remaining seven are continuous. For this experiment, we crossed a stacked NOLH for the seven continuous factors with a full factorial for the categorical variables, resulting in 792 design points. Each design point was run ten times for a total of 7,920 runs.

3. Data Mining and Meta Models

Data mining is defined by Hand, Mannila, and Smyth “as the analysis of observational data sets to find unsuspected relationships and to summarize the data in novel ways that are both understandable and useful to the data owner” (Hand, 2001). The primary approach used for assessing PSOM once the data is “grown” is the use of meta models. This study followed Kleijnen and Sargent’s procedure for fitting the meta model (Sargent, 2000). A meta model is an approximation of the input and output data within a simulation (Sargent, 2000). It is merely a simple function used to approximate a very complicated simulation.

By simplifying the simulation we can gain tremendous insight into the actual nature of PSOM. For example, this study uses tools such as polynomial regression models to simplify the very complex inner workings of PSOM. Because the meta models used are not meant as prediction models, but rather to gain inference on the model, the meta models overall accuracy is not the overall goal, but gaining insight is. The primary types of meta models used are least squares regression and logistic regression. For much of the validity measures of the meta model, absolute relative error and R-Squared are the primary measures used in determining usefulness. We also used neural networks as a second modeling technique to merely validate the regression models. We assess the significance of the regressors in the meta model and reduce the overall number of regressors using the concept of Occam’s Razor; remembering that although we can closely fit the model and minimize error, we can lose sight on which parameters are truly

influential to PSOM. After the meta model has shown light on key factors, further analysis into the raw data and the mathematical algorithms within PSOM can be conducted.

V. DATA ANALYSIS

Information is data that has been given meaning by way of relational connection.

(Ackoff, 1989)

By leveraging design of experiment with powerful data farming tools we are provided a tremendous amount of data which is not yet tractable for a simulation that has no true closed form solution. Although much of the “heavy lifting” is complete, we still need to put the tremendous amount of data into a manageable form and quantitatively describe its relevance. The purpose of this chapter is to describe the processes used to analyze the data. This analysis is formatted around gaining insight into the original questions posed in the beginning of this thesis. We demonstrate that by using data models and algorithmic models (neural networks) in conjunction with our experimental designs, valuable conclusions can be gained about very complex simulation models. At the conclusion of this process, key points about the nature of PSOM are presented. These conclusions are discussed in detail in Chapter VI, less the detailed mathematical analysis.

A. DATA COLLECTION

In line with its purpose as a human-in-the-loop wargame, the output for PSOM is primarily graphic in nature and meant to be displayed on a map of the area of operations. These briefing maps are color coded, and for the MOEs security and consent range from 0 to 10 (see Figure 11). Fortunately, PSOM does have the ability to output data by grid square across the area of concern. These data are output into a comma separated value file (CSV) in their raw form without having been transformed to the fore mentioned normalized scale. Each CSV file contains the output for an individual MOE by faction or ethnic group in a single run. Therefore, each design of experiment provides over 100,000 output files. Because the primary emphasis of this study is limited to the Sunni consent and security MOEs, the data concerning these values is an aggregate of the mean

response of each region based on coalition forces' areas of responsibility and the entire country. The following example describes the mean consent values of the Sunni toward the coalition forces across all of Iraq,

$$MeanSunniConsent_{Coalition,Iraq} = \frac{\sum_1^k \sum_1^n SunniConsent_{Coalition}}{k * n}$$

Where k = the total run number within the design point.

n =the number of grids squares in the scenario.

A similar method was used to look at the level of variance throughout each AOR and the entire country.

$$SunniConsentVariance_{coalition,Iraq} = \frac{\sum_1^k \sum_1^n (x_{i,j} - \bar{x}_{coalition,iraq})^2}{(k * n) - 1}$$

Where x is the consent for coalition in grid square i on run j and n , the total number of grid squares, is multiplied by k , the number of runs of the design point. This value provides insight into the overall volatile nature of the responses across the area of concern.

This technique allows for further analysis into the six regions of the country without the overwhelming resolution of 135 responses. This permits significant enough granularity in the outcomes to raise a flag when outcomes are interesting, ensuring further analysis when needed. At this point, either analysis can take place on specific region, individual grid squares, or the game can be played and observed with the interesting parameters from the specific corresponding design point.

Arguably this technique is not ideal. Measures of effectiveness are measured by geographic location and not by population. Therefore, there is no appropriate weighting for population size in a particular area. For example, region 4, which is the highly populated city of Baghdad, consists of only for two squares, which is the same number of squares as Samarra, which only has a 10% of the population of Baghdad. This is an acknowledged weakness in this study; however specific cells and regions were addressed when required (we played over 100 games step-by-step throughout this process).

Initially, this entire process was conducted on a small scale design. This provided initial insight into the stochastic nature of PSOM, and some initial factor analysis as well as verifying the functionality of the computational tools developed. Although the initial experiment was meant to be a test, some significant insight was gained. The focus of this design was to demonstrate the significance of time step and faction stance. The factors in this experiment are displayed in Table 8. In this case, each simulation was run for 12 time steps. So the simulation was two years, one year, or 12 weeks in simulation time.

	IGO Stance	Coalition Stance	Sunni Nationalist Stance	Time Step
Level 1	Active	Providing Aid	Providing	7 Days
Level 2	Withdrawn	Attacking	Attacking	30 Days
Level 3		Securing		60 Days

Table 8. Initial Test DOE Factors

Each design point was run 30 times to ensure variance could be accurately estimated. The results show that although variance exists between each of the 30 iterations, it is minimal. Table 9 shows the quantiles of mean Security and variance by grid squares for a randomly drawn excursion file. It is important to note is that although the security values cover a large portion of the 1 to 10 domain the variance between the 30 iterations by grid square is minimal. Consent results are similar.

Quantiles for Mean Security by Gridsquare N=135	Quantiles for Security Variance (σ^2) of 30 runs by GridSquare N=135																																																																								
<table><tr><th colspan="3">Quantiles</th></tr><tr><td>100.0%</td><td>maximum</td><td>9.5050</td></tr><tr><td>99.5%</td><td></td><td>9.5050</td></tr><tr><td>97.5%</td><td></td><td>8.2720</td></tr><tr><td>90.0%</td><td></td><td>8.0924</td></tr><tr><td>75.0%</td><td>quartile</td><td>8.0787</td></tr><tr><td>50.0%</td><td>median</td><td>7.5153</td></tr><tr><td>25.0%</td><td>quartile</td><td>5.3991</td></tr><tr><td>10.0%</td><td></td><td>5.3754</td></tr><tr><td>2.5%</td><td></td><td>3.9384</td></tr><tr><td>0.5%</td><td></td><td>2.1749</td></tr><tr><td>0.0%</td><td>minimum</td><td>2.1749</td></tr></table>	Quantiles			100.0%	maximum	9.5050	99.5%		9.5050	97.5%		8.2720	90.0%		8.0924	75.0%	quartile	8.0787	50.0%	median	7.5153	25.0%	quartile	5.3991	10.0%		5.3754	2.5%		3.9384	0.5%		2.1749	0.0%	minimum	2.1749	<table><tr><th colspan="3">Quantiles</th></tr><tr><td>100.0%</td><td>maximum</td><td>0.23809</td></tr><tr><td>99.5%</td><td></td><td>0.23809</td></tr><tr><td>97.5%</td><td></td><td>0.03529</td></tr><tr><td>90.0%</td><td></td><td>0.00209</td></tr><tr><td>75.0%</td><td>quartile</td><td>0.00200</td></tr><tr><td>50.0%</td><td>median</td><td>0.00166</td></tr><tr><td>25.0%</td><td>quartile</td><td>0.00067</td></tr><tr><td>10.0%</td><td></td><td>0.00041</td></tr><tr><td>2.5%</td><td></td><td>0.00034</td></tr><tr><td>0.5%</td><td></td><td>0.00031</td></tr><tr><td>0.0%</td><td>minimum</td><td>0.00031</td></tr></table>	Quantiles			100.0%	maximum	0.23809	99.5%		0.23809	97.5%		0.03529	90.0%		0.00209	75.0%	quartile	0.00200	50.0%	median	0.00166	25.0%	quartile	0.00067	10.0%		0.00041	2.5%		0.00034	0.5%		0.00031	0.0%	minimum	0.00031
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Table 9. Looking at the Means and Variance of PSOM Output for Security

The largest variance of .24 (Standard Deviation = .48) is from grid location (9,7), and although this value is large in comparison to the rest it is 5% of the overall range covered and arguably negligible when looking at the entire country of 135 squares.

Using a least squares quadratic linear regression with two-way interactions built by stepwise regression we created a meta model to determine the significance of the fore mentioned factors in respect to the response variable Iraq mean security. Our primary concern in this analysis is to ensure that 12 time steps, whether they equate to 2 years or 3 months do not provide similar results. The scaled estimate graph in Figure 12 shows the least square regression meta model and that time step is indeed the most significant factor of the three (stances are further analyzed in the following sections). The model shows that the 7-day time step has the most significant affect on security followed by the 30-day and 60-day time step. This provides more knowledge, in that as expected, the longer units are active in a particular area the less marginal impact they have on security. The model demonstrates the potential to reflect a point of diminishing returns.

Scaled Estimates of the Regression resulting in an R-Squared of .82 and Root Mean Squared Error of .41

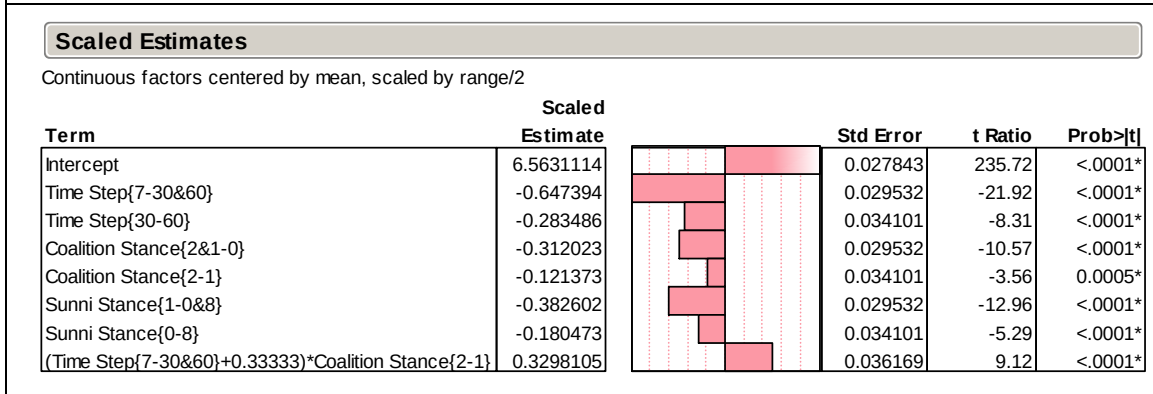


Figure 12. Explanation of the Test DOE Regression Model

Analyzing the data by the average security across Iraq against time step from PSOM we can see the significance of time step. Figure 13 shows the results of a Kruskal-Wallis Test comparison of security in regard to time step and a quantile plot of security by time step. The Kruskal-Wallis Test is a non parametric test for comparing multiple populations where the null hypothesis is the populations are equivalent. First, looking at the P-Value for the hypothesis test there is a statistically significant difference between security when subdivided by time step. The quantile plot visually depicts the test results. Figure 13 shows the substantial difference in security between a 7-day time step and a 30-day time step and just, as the meta model states, the difference is not as significant between the 30-day and 60-day time step. For a fixed number of steps, larger time steps results in greater security in this scenario.

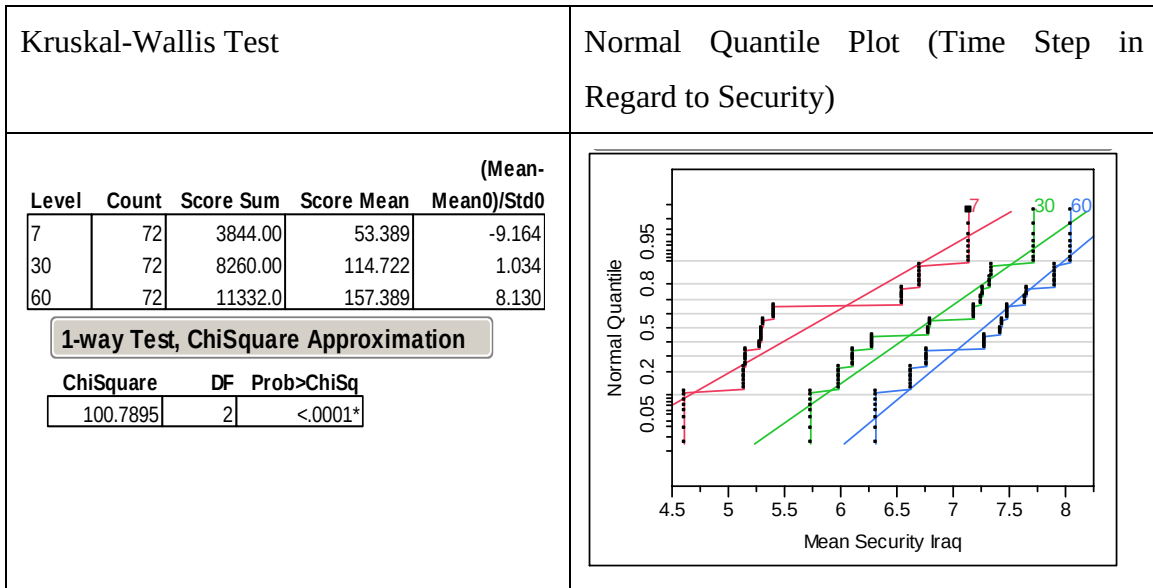


Figure 13. Difference in Security Determined by Time Step

B. SCENARIO SPECIFIC DESIGN OF EXPERIMENT

The scenario specific DOE covers those factors which are either underlying assumptions in the specific scenario or can be inputted by the players themselves as discussed in Chapter IV.

1. Consent

Consent is defined as the degree to which the population supports and submits to the will of a faction. It is a result of the difference between expectations of an ethnic group and the actual provision (including security) generated by a particular faction. Figure 14 is a correlation matrix which substantiates the use of the mean overall Sunni consent for coalition forces. The mean overall consent and the consent of each sub region show a very strong positive correlation.

Variable	By Variable	Correlation	Significance Prob
SUNNI_AVG_CoalitionConsent	Region 1 Mean	0.98	0
SUNNI_AVG_CoalitionConsent	Region 2 Mean	0.99	0
SUNNI_AVG_CoalitionConsent	Region 3 Mean	0.99	0
SUNNI_AVG_CoalitionConsent	Region 4 Mean	0.90	0
SUNNI_AVG_CoalitionConsent	Region 5 Mean	0.98	0

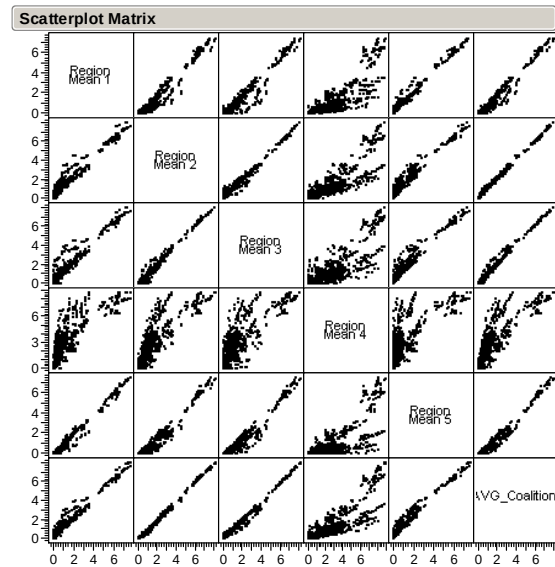


Figure 14. Correlation of Mean Consent by Region and Mean Consent of Iraq for the Sunni Population Agents toward the Coalition

Worth noting is the decreased correlation between the overall average consent in Iraq and that of Region 4. Region 4 is Baghdad, which due to its large population and larger amount of coalition units has a bit more extreme activity. Region 4 consent is isolated and analyzed later in this chapter.

Because initial consent is a factor in the experiment, the meta model response is the difference between the beginning and the end of the simulation run (*Consent Final-Consent Initial*). An initial look at this response variable (Figure 15), shows that regardless of factor settings mean Sunni consent for the coalition did not increase for any of the 3,120 design points. This was a troublesome point throughout the initial experiment. Consent toward a faction is a function of the goods created, to include security, by a particular faction and the corresponding marginal gains of the population agents. It took multiple iterations of the design process to actually create goods because goods production is a balance of infrastructure produced and human capital produced. Once this balance is met, which it was for this DOE, production increased.

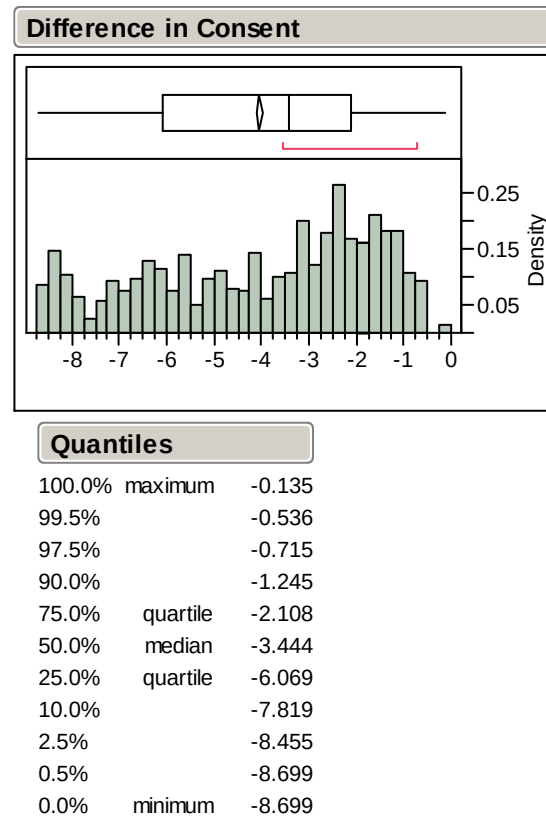


Figure 15. Histogram and Quantiles of the Difference in Initial Sunni Consent and Final Sunni Consent

The next step is to create a meta model to gain some insight into what factors are contributing to the change in Sunni consent toward the coalition. This meta model is a quadratic fit least squares model allowing for two-way interactions. Stepwise regression in JMP 7 resulted in an adequate model introducing relatively few factors. Figure 16 is comprised of three separate figures. The summary of fit shows an R-Square of .947, which is a statistic describing the proportion of the variance accounted for by the meta model. Because of the nature of the R-Square statistic this study carefully considers the number of factors in the model in conjunction with a particular R-Square with the goal being to explain as much variation in the model as possible with a minimum number of factors. Figure 16 shows that with an R-square of .94 and a mean square error of .35 our

model is clearly significant. The actual by predicted plot shows a fairly linear relationship, suggesting the meta model is sufficient for analysis of these factors and this response.

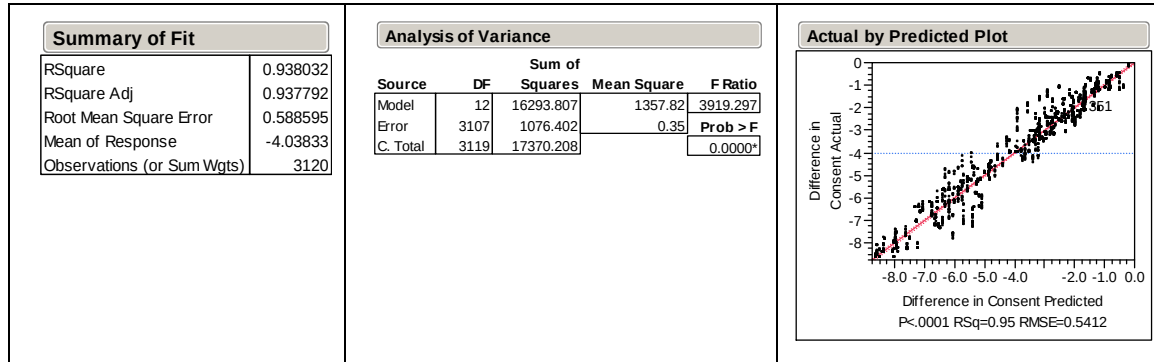


Figure 16. Summary Information of Consent Meta Model

Figure 17 displays the factors introduced into the meta model (less the intercept). The effects are sorted by the absolute value of the t-ratio, showing the most significant effects at the top. A bar graph shows the t-ratio, with a line showing the 0.05 significance level (JMP 7 Help).

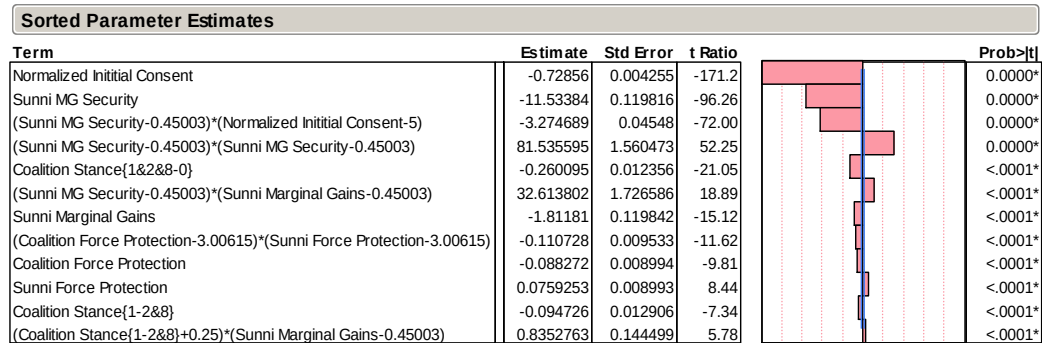


Figure 17. Scenario DOE Sorted Parameter Meta Model

For adjudication of our model, we also use the neural network variable importance tool from the Clementine software package. Figure 18 is developed using a Bayesian Neural Network. This technique is used throughout the thesis to ensure that we are focused on the significant factors. As can be seen by comparing Figures 16 and 17, in the two completely different modeling types the same factors (marginal gains, initial consent, and coalition stance) are significant.

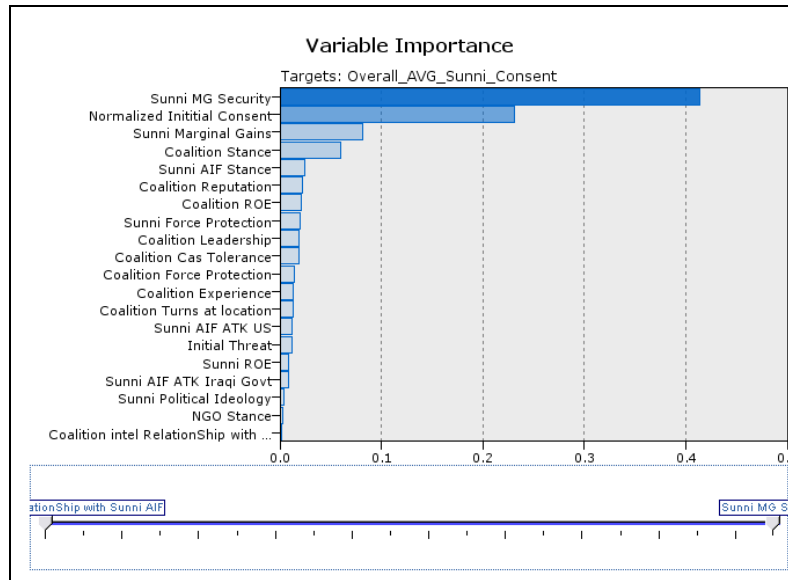


Figure 18. Variable Importance for the Response Consent from the Scenario DOE found from Using a Bayesian Neural Network Produced Using Clementine

From Figures 17 and 18 we can gain many insights about the consent MOE. First off, just looking at the factors without interactions, the initial consent is the most significant factor followed by the Sunni population's marginal gain for security. Sunni marginal gain for security also enters the model as a quadratic term indicating its importance to the model. Arguably this makes sense; however, these are both assumptions made in the scenario file which appear able to drive the game. Coalition stance is a significant factor; however, it is not nearly as influential as the previously mentioned assumptions. Sunni marginal gains for goods less security is also introduced as a significant factor. Finally, faction force protection values show significance.

Looking more closely into the relationship between initial consent and the Sunni marginal gain for security we see the significance of these two factors in relationship to the final average consent of the Sunni population to the coalition. Figure 19 is a contour plot with the Sunni marginal gain for security on the x-axis, normalized consent on the y-axis, and colors from red to blue representing the corresponding values of the final average Sunni consent toward the coalition at each design point.

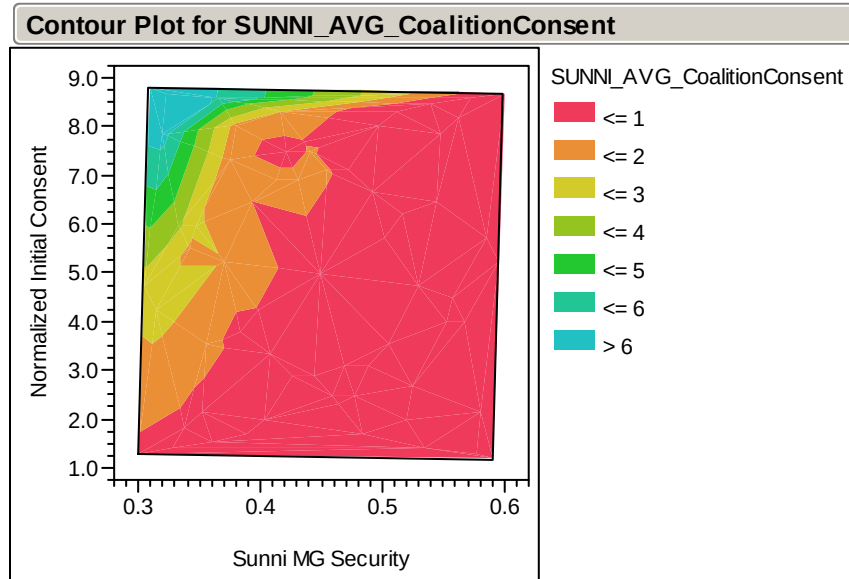


Figure 19. Contour Plot of Sunni Marginal Gain for Security and Initial Consent vs. Final Sunni Consent toward Coalition [Best viewed in color]

This is very interesting because, regardless of faction settings, if the Sunni MG for security is .5 or greater consent for the coalition will fall below 1 in this scenario. We can also see the significance of the initial assumption of consent. When the Sunni marginal gain for security is set at a relatively low value, greater initial consent results in greater final consent. Also of note is the relative jaggedness of the contour plot, which in part is caused by the influence of other factors.

When replaying parts of the game individually production does increase, which is directly tied to consent. This leads to the need for a more detailed analysis of consent in part 1(a) in this section. Consent has been the more complicated of the MOEs to look at. In PSOM it is largely a function of production level of the goods the population desires. It requires money, manpower, and effort put toward production. However, if consent is low, it is difficult to hire manpower.

The importance of the assumptions within the scenario is notable; however, PSOM is a wargame, and the influence the players have over consent is important. Figure 20 is a bar graph comparing final Sunni consent toward the coalition in regards to Sunni Nationalist stance and coalition stance. The graph shows that regardless of Sunni

Nationalist stance, coalition consent can reach its highest points when its stance is zero (providing humanitarian aid). But what is more surprising is that the coalition consent when withdrawn is equivalent regardless of Sunni Nationalists stance. Just as surprising is that whether the coalition is providing security or in an attacking stance we see about the same consent levels.

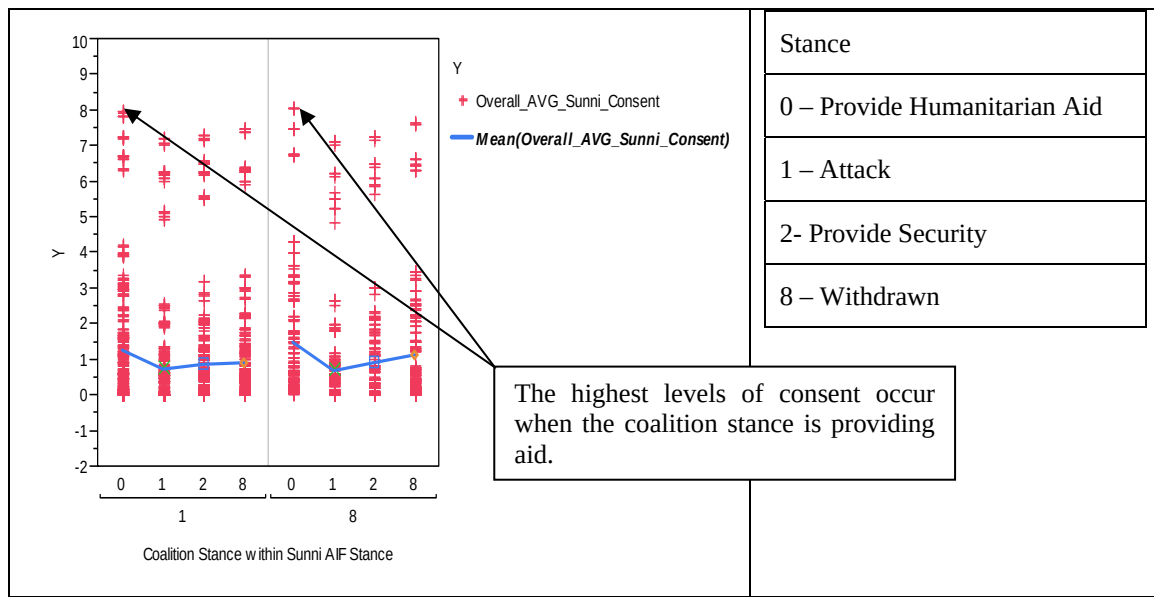


Figure 20. Final Consent for the Coalition with Respect to Sunni Nationalist and Coalition Stances

Figure 21 displays the consent toward coalition in regard to coalition stance. The green diamond provides a 95% confidence interval for the sample mean of consent at the particular stance. Conducting a non parametric Kruskal Wallis test to determine which stances matter, we see that stance 0 (provide humanitarian aid) has a significantly higher overall median than the other stances. This coincides with the definition of consent. However, the consent resulting from the other stances shows no significant difference. Therefore, it does not appear to matter whether all the coalition forces are securing, attacking, or withdrawn, which is surprising.

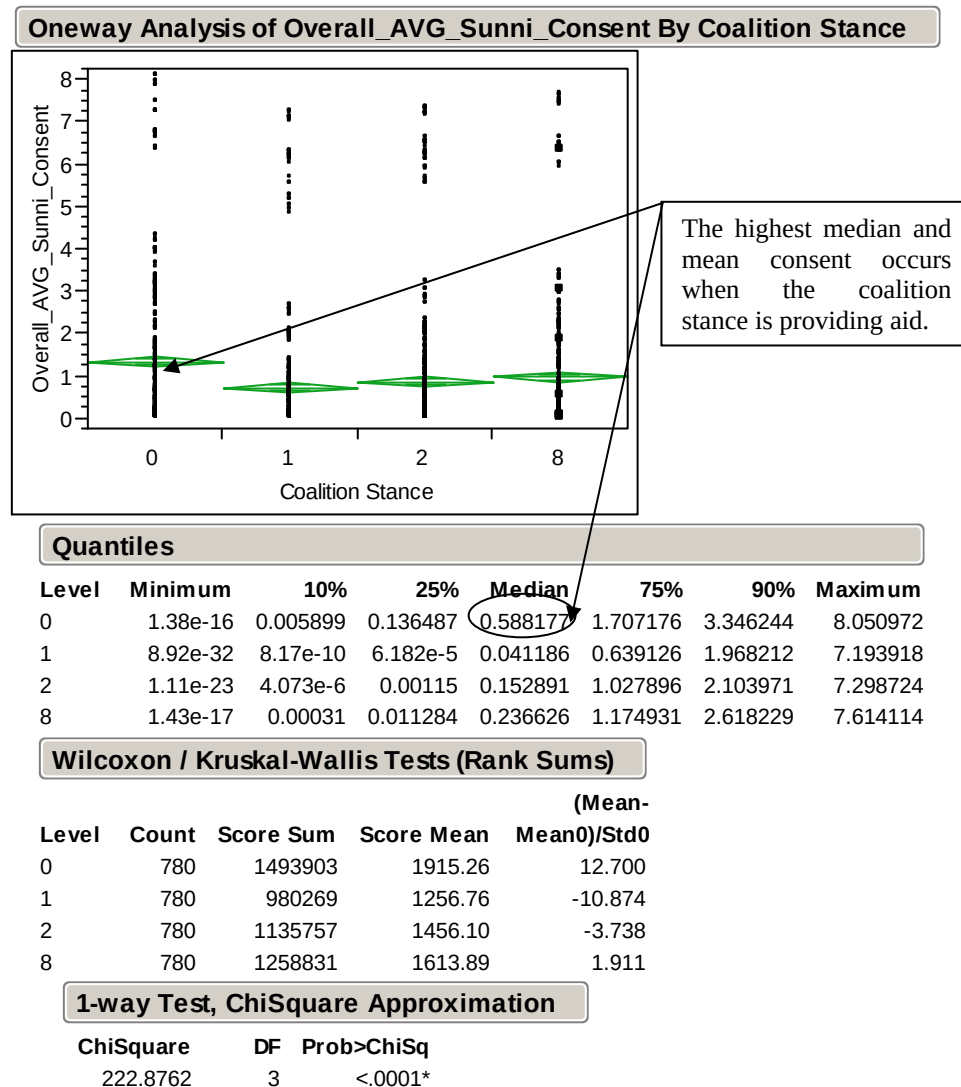


Figure 21. Means Diamond Plot of Sunni Consent toward Coalition in Regards to Coalition Stance and a Kruskal Wallis Test for Significances in the Factor Stance

a. Increasing Consent for Coalition

The fact that the average consent across Iraq never increased proves provoking and requires further attention. Looking at the separate regions of Iraq and then at the actual grid squares there are individual grid squares where consent increases. Focusing on Region 4, Baghdad, this becomes evident. There are 118 of the 3,120 total design points in which consent toward the coalition increased in Region 4. Figure 22 displays the histogram of change of consent toward the coalition in the region.

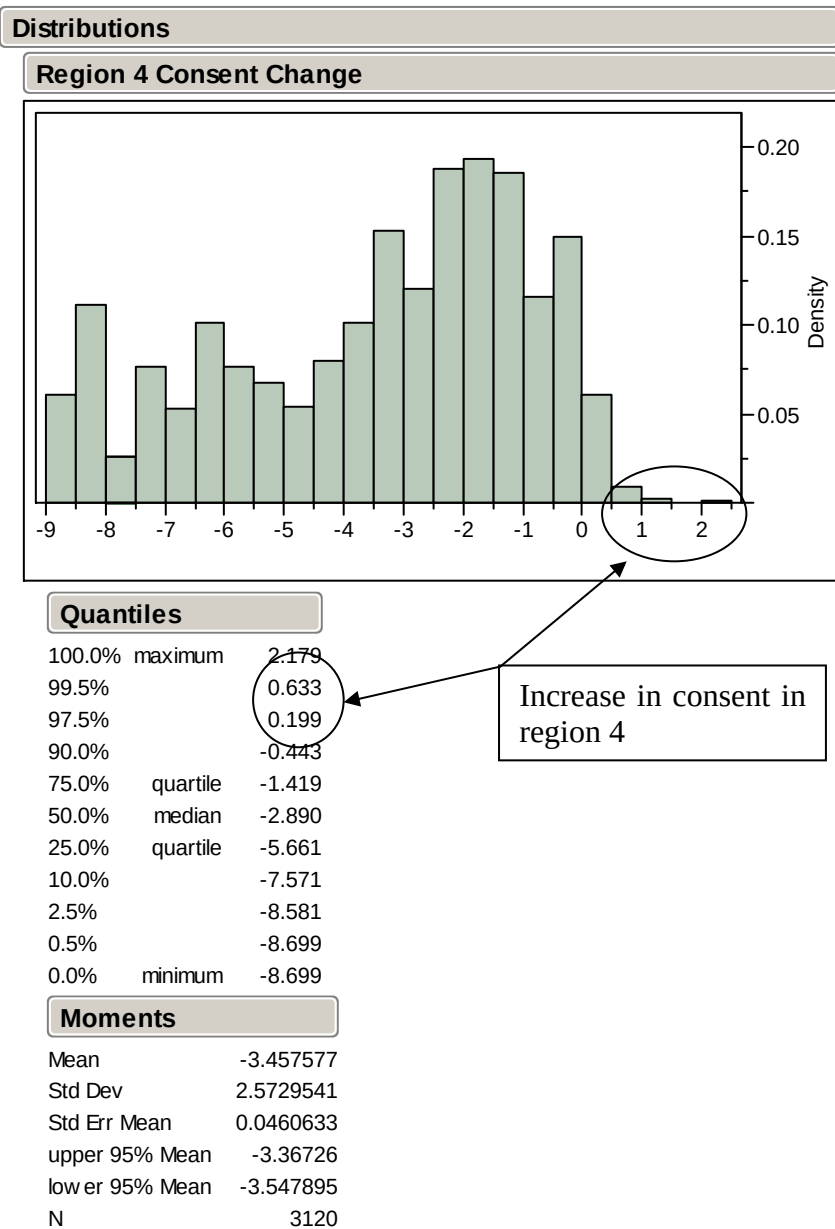


Figure 22. Region 4 (Baghdad) Difference in Initial and Final Consent

By replaying a few of these design points where consent increased it became evident that production also increased primarily in Region 4. Intuitively, this means that the coalition stance is set at 0 (humanitarian aid).

A nominal logistic regression meta model depicts the probability based on particular factors that the Sunni consent value in Region 4 increases or decreases. Because this model is only used to gain inference the focus is only on the factors currently known to be significant. The resulting meta model paints a picture of which factors are important to providing an increase in consent. From the parameter estimates below we learn that a coalition stance of 0 (humanitarian aid), combined with a high Sunni ROE (restrictive) and low Sunni marginal gains, will provide a high probability for increased consent.

Nominal Logistic Fit for Region 4 Binary				
Whole Model Test				
Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	277.85271	6	555.7054	<.0001*
Full	224.32584			
Reduced	502.17855			
RSquare (U)		0.5533		
Observations (or Sum Wgts)		3120		
Converged by Gradient				
Parameter Estimates				
Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Sunni AIF Stance[1]	1.18905319	0.1374393	74.85	<.0001*
Coalition Stance[0]	-7.6857738	1.1518985	44.52	<.0001*
Coalition Stance[1]	5.89511525	35.514447	0.03	0.8682
Coalition Stance[2]	5.89511525	35.514447	0.03	0.8682
Sunni ROE	-0.8161736	0.1248851	42.71	<.0001*
Sunni MG Security	19.0823207	2.0982498	82.71	<.0001*
Sunni Marginal Gains	9.82317705	1.5671129	39.29	<.0001*
For log odds of 0/1				

Figure 23. Nominal Logistic Regression Model Statistics for whether or not Consent Increased or Decreased in Baghdad

The prediction profiler in JMP 7 is an interactive tool that allows analysis of the response variable (consent) due to changes in the model's regressors. Figure 24 depicts the prediction profiler for the nominal logistic regression model with the above factors. The values in the y-axis are the probabilities of consent increase. Figure 24a shows that if the Sunni AIF stance is 1 (attack), regardless of coalition stance, the probability is very low that there will be an increase in consent. Figure 24b shows the drastic change in the probability of consent increase when the Sunni stance is changed to

withdrawn (all other factors are held constant). Figure 24c increases (tightens) only Sunni ROE, which in turn increases the probability of an increase in consent. Figure 24d shows the extreme effect that changing Sunni marginal gains security has on the model. With a slight increase in the factor the probability of increasing consent is marginal. Looking at Figure 24a and comparing Sunni marginal gains and Sunni marginal gains for security, we can see that the functions are similar and have similar effects on the model.

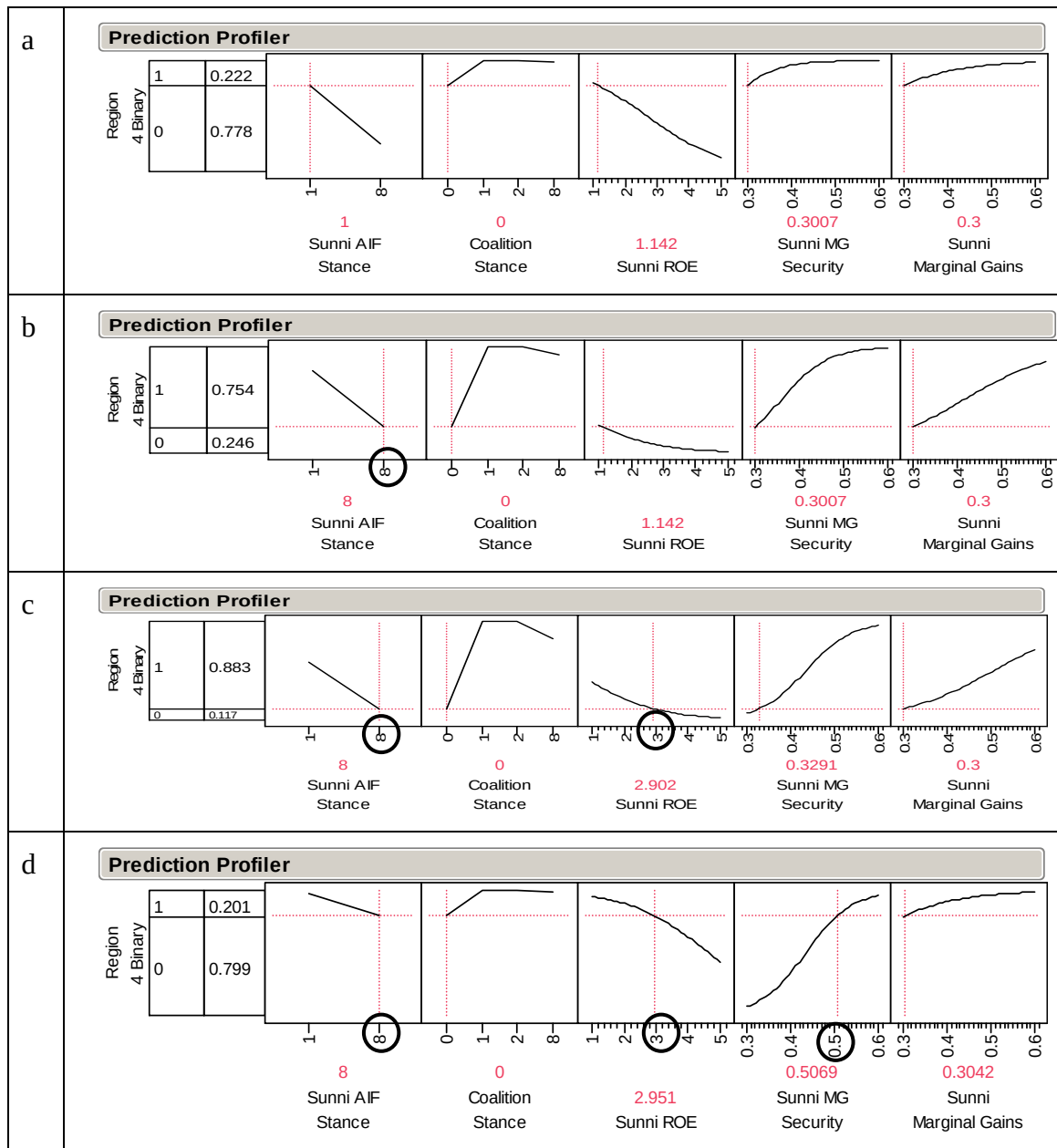


Figure 24. Effects Profiler for Logistic Regression Model Describing Probability Sunni Consent toward Coalition Increases Region 4

Now, looking back at the raw data for the change in Region 4 consent, we see that it matches our model. We primarily see consent increase when the coalition provides humanitarian aid while the Sunni Nationalists are withdrawn. Interestingly, the second best combination for the scenario is when the coalition is also withdrawn as shown in Figure 25.

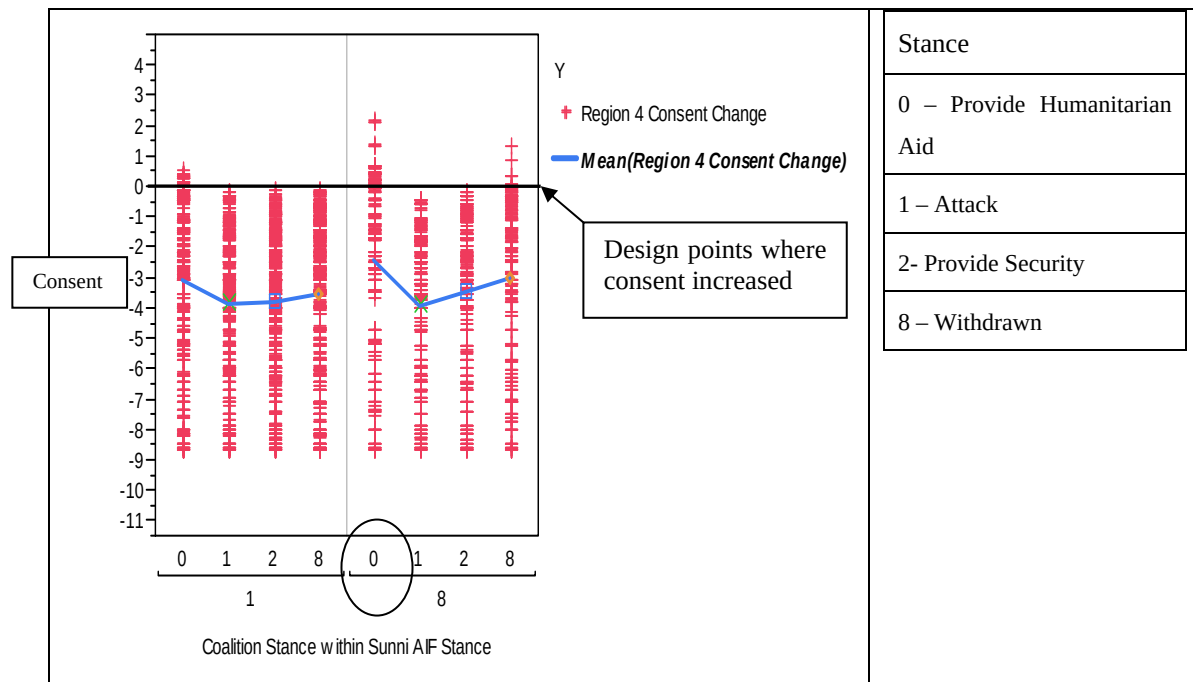


Figure 25. Region 4 Change in Sunni Consent toward the Coalition in Regards to Coalition and Sunni Nationalist Stance

Figure 26 is used to verify the accuracy of the model and to determine if the inference is correct about the Sunni marginal gains and Sunni marginal gains for security. The graphs are both histograms of the 118 data points in which consent for the coalition increased in Region 4. These same charts, if they were displayed using the original 3,120 design points, would be uniform. However, these histograms both tend toward the lower values of the factors. It is apparent that if a scenario is to be functional in the consent category, these values should be set relatively low. The exceptions to this conclusion are easily explainable after further analysis. In regards to Sunni marginal gains, there are twelve points on the histogram which have this factor at a higher level. The corresponding marginal gain for security for each of these design points is at its

lowest value of .3, which apparently is influential enough to offset the marginal gains. The few values at the Sunni marginal gains for security that are at the factor's higher level have the lowest level of initial consent, the Sunni Nationalists, withdrawn, and a very high Sunni ROE value which, when all align, allow for a very small (.16 on a scale of 1 to 10) increase in consent.

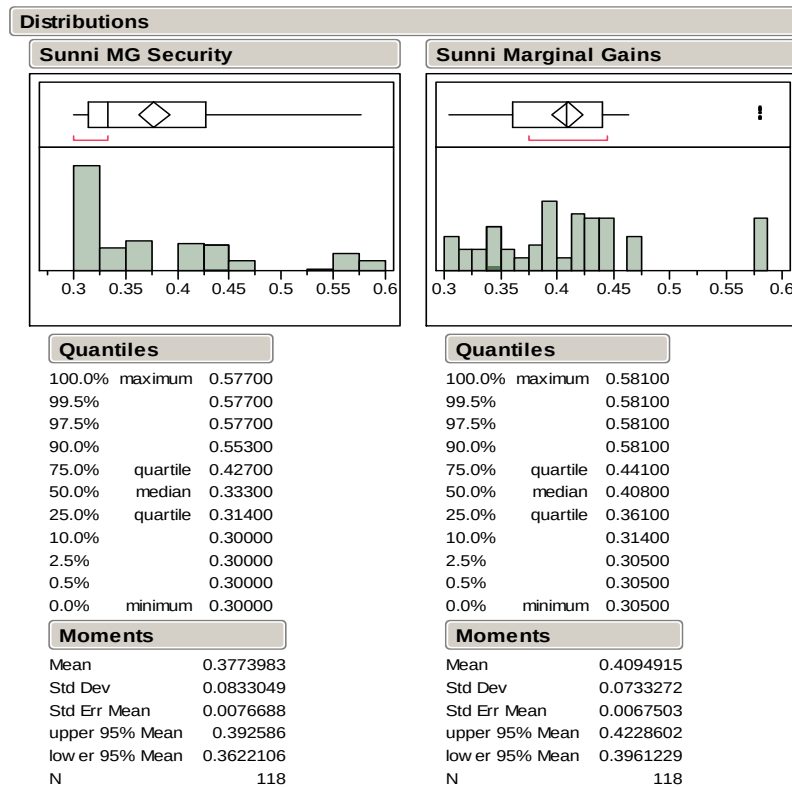


Figure 26. Histograms and Quantiles of Marginal Gains Values for 118 Points in which Consent Increased in Bagdad

b. Consent for the Iraqi Government

One of the key measures of a legitimate government is that it has the consent of the population (U.S. Army, 2006). It is important to see what effects the coalition can have on the consent of the Iraqi government remembering that all humanitarian aid by the coalition targeted the Iraqi government, giving the Iraqi government partial credit for the service.

A first look at the data (Figure 27) shows that 99% of the time consent dropped (starting value was 3.6); however, we were able to increase it a few times. It is also important to note that coalition consent often was driven to zero, but this was not the case for the government as shown in Figure 27.

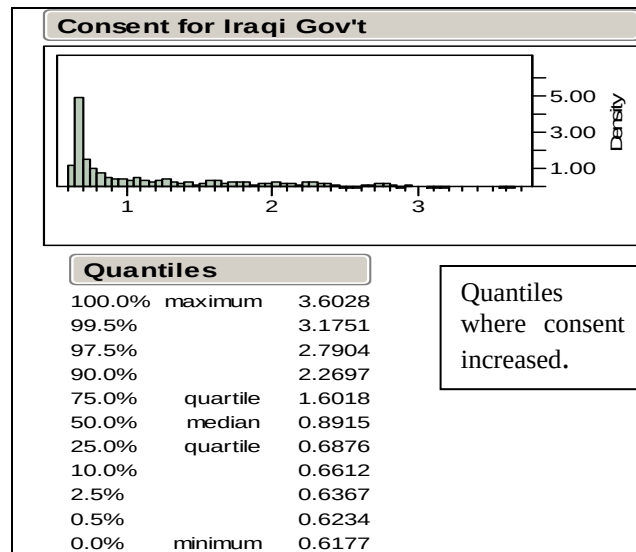


Figure 27. Histogram and Quantiles Sunni Consent Across Iraq toward Iraqi Government for Scenario DOE

Figure 28 shows the results of a quadratic least squares regression model allowing for two-way interactions with the response consent for the government. The model is limited to three factors: Sunni marginal gains security, Sunni marginal gains, and coalition stance, with a resulting R-squared value of 0.91.

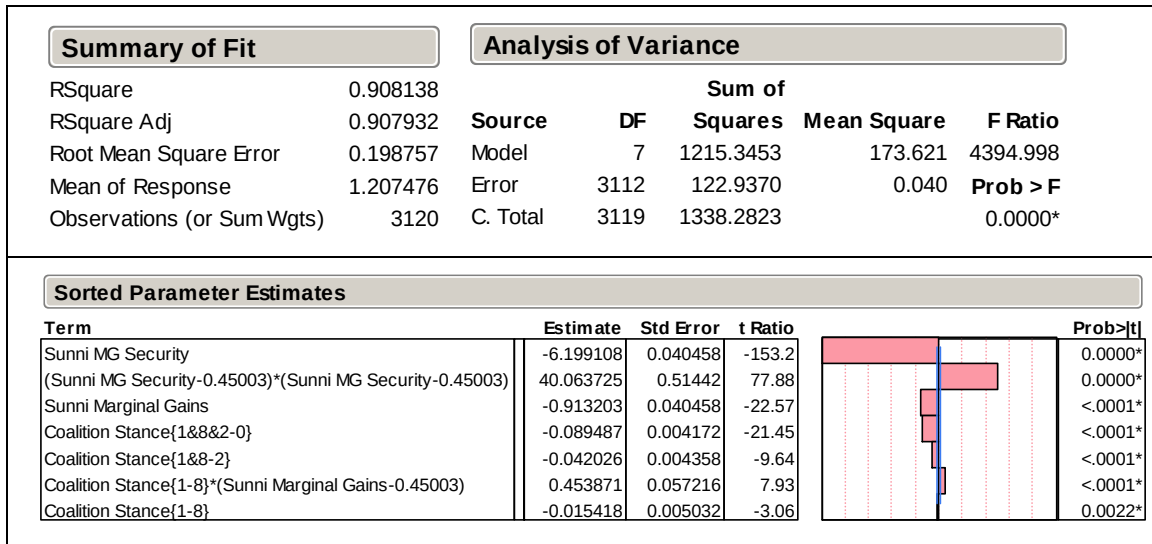


Figure 28. Regression Meta Model for Sunni Consent for the Iraqi Government

Once again, Sunni marginal gains for security prove to be the most significant factor. Looking at a contour plot of Sunni marginal gains for security and Sunni marginal gains (Figure 29), there is a strong relationship between consent for the Iraqi government and these factors. Sunni MG for security can dominate consent for the Iraqi government just as with the coalition.

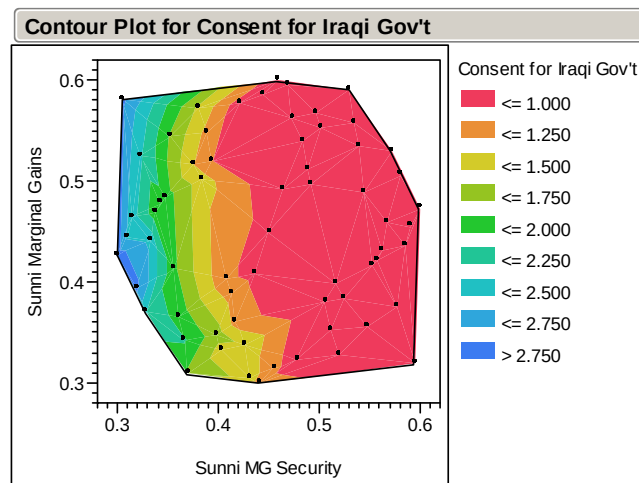


Figure 29. Contour Plot of Sunni Marginal Gain for Security and Sunni Marginal Gains for Good versus Final Consent for the Iraqi Government

The red line in Figure 30 is a quadratic fit of government consent in regards to only Sunni marginal gains for security. This factor alone accounts for 87% of the model's variation.

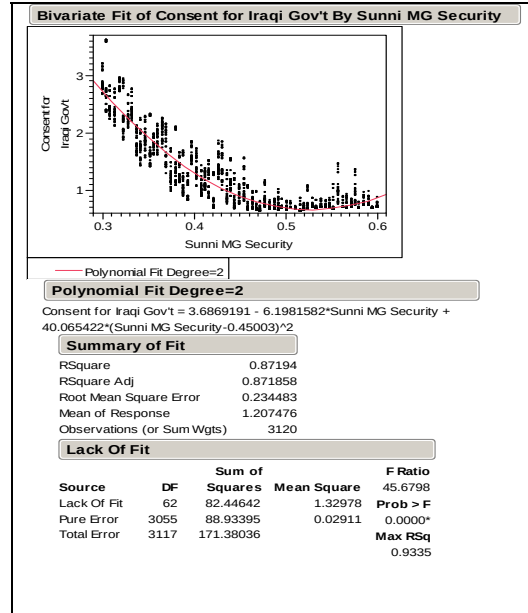


Figure 30. Bivariate Normal Fit: Sunni Consent toward Iraqi Government (Response) and Sunni Marginal Gains Security (Regressor)

Figure 31 shows a bar graph of Iraqi government consent in regards to coalition stance and the corresponding non parametric test for significance of the stances. The graph shows that the highest values of Iraqi consent occur when the coalition stance is 0 (humanitarian aid). This reflects a conscious decision in the scenario setup to credit the Iraqi government with coalition production proving this aspect of the game is effective. We also see that when the coalition is providing security (level 2) we are able to get a slightly higher consent toward the Iraqi government than when attacking (level 1) or withdrawn (level 8), which makes sense as well. Based on the non parametric test there is a statistically significant difference among the stances in regard to consent.

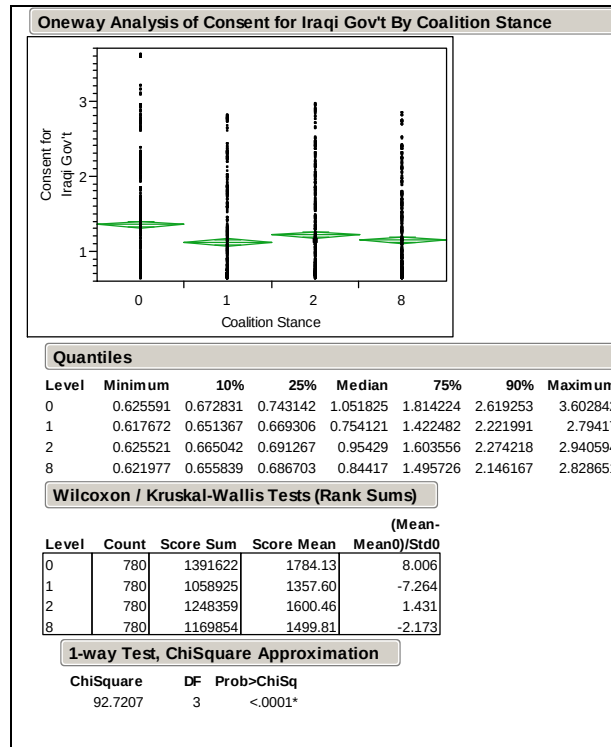


Figure 31. Iraqi Government Consent in Regards to Coalition Stance and the Corresponding Non Parametric Test for Significance of the Stances

The correlation between the change in coalition consent and Iraqi government consent is shown in Figure 32. It is substantial, which is logical, as the coalition and the Iraqi government are allies in this scenario.

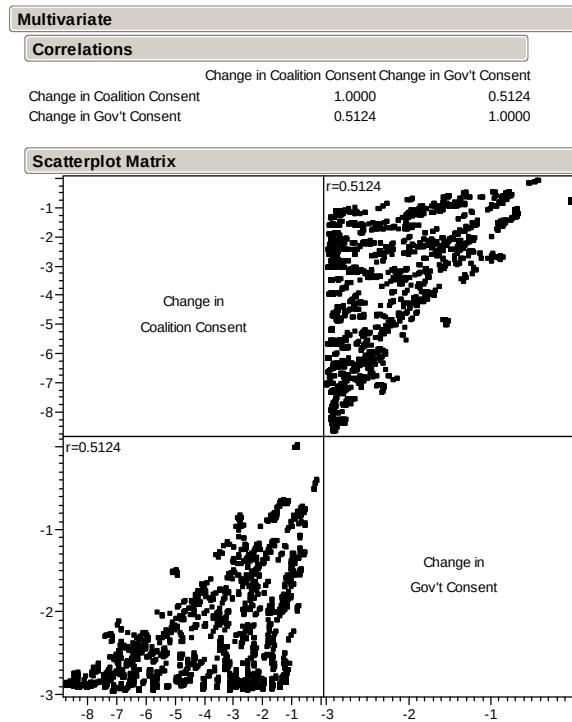


Figure 32. The Correlation between the Change in Coalition Consent and the Change in Iraqi Government Consent from the Sunni Population

2. Security

Security is defined as the perceived risk of violent death of a population agent. It is a function of the level of criminality, civilian casualties, and collateral damage. Looking at a scatter plot matrix, we see that security across the entire region of Iraq is correlated with each individual region, and therefore we can use the overall average as a good initial statistic for analysis. Although the overall average Iraqi security level is not as strongly correlated as consent, it is important to note that this includes the entire country and all ethnic groups. The lowest region correlation is .75, which is still significant enough to use the average security across Iraq as a response variable.

Correlations							
	Region Mean 1	Region Mean 2	Region Mean 3	Region Mean 4	Region Mean 5	Region Mean 6	AVG_Iraq Security
Region Mean 1	1.0000	0.9526	0.7393	0.7489	0.8386	0.7777	0.9362
Region Mean 2	0.9526	1.0000	0.8845	0.8548	0.8157	0.7228	0.9387
Region Mean 3	0.7393	0.8845	1.0000	0.8314	0.5938	0.4587	0.7581
Region Mean 4	0.7489	0.8548	0.8314	1.0000	0.6876	0.5957	0.7995
Region Mean 5	0.8386	0.8157	0.5938	0.6876	1.0000	0.9850	0.9634
Region Mean 6	0.7777	0.7228	0.4587	0.5957	0.9850	1.0000	0.9136
AVG_Iraq Security	0.9362	0.9387	0.7581	0.7995	0.9634	0.9136	1.0000

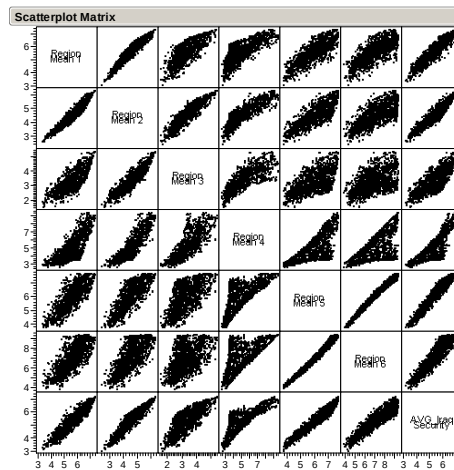


Figure 33. Correlations of Security by Region and the Overall Country of Iraq

Histograms of the security output show that security after twelve months has a substantial dispersion. Security started at 5.8 for this scenario, so it has both increased and decreased in this DOE.

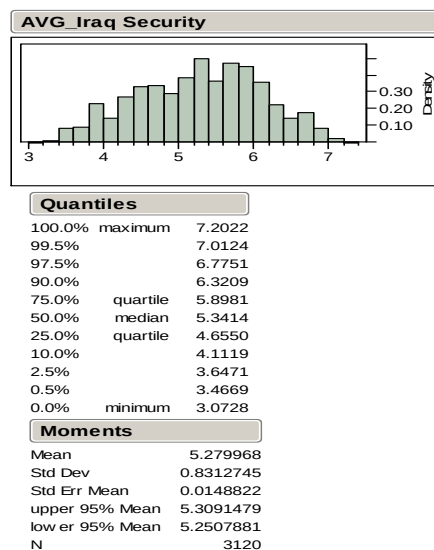


Figure 34. Histogram and Quantiles of Final Security in Iraq for Scenario DOE

Next, using a quadratic stepwise linear regression allowing for interactions, we get a telling model. Once again, we look for the point at which adding factors into the model yields minimal improvement. This results in an R-squared of 0.76, with only nine of the original twenty one factors entering the model. Figure 35a shows the summary of fit and Figure 35b is the scaled estimates description of the model from JMP 7. This output shows not only the model, but nicely displays the scaled effect each regressor has on the response (security). Bars that are to the left have a negative effect on the response and bars to the right have a positive effect.

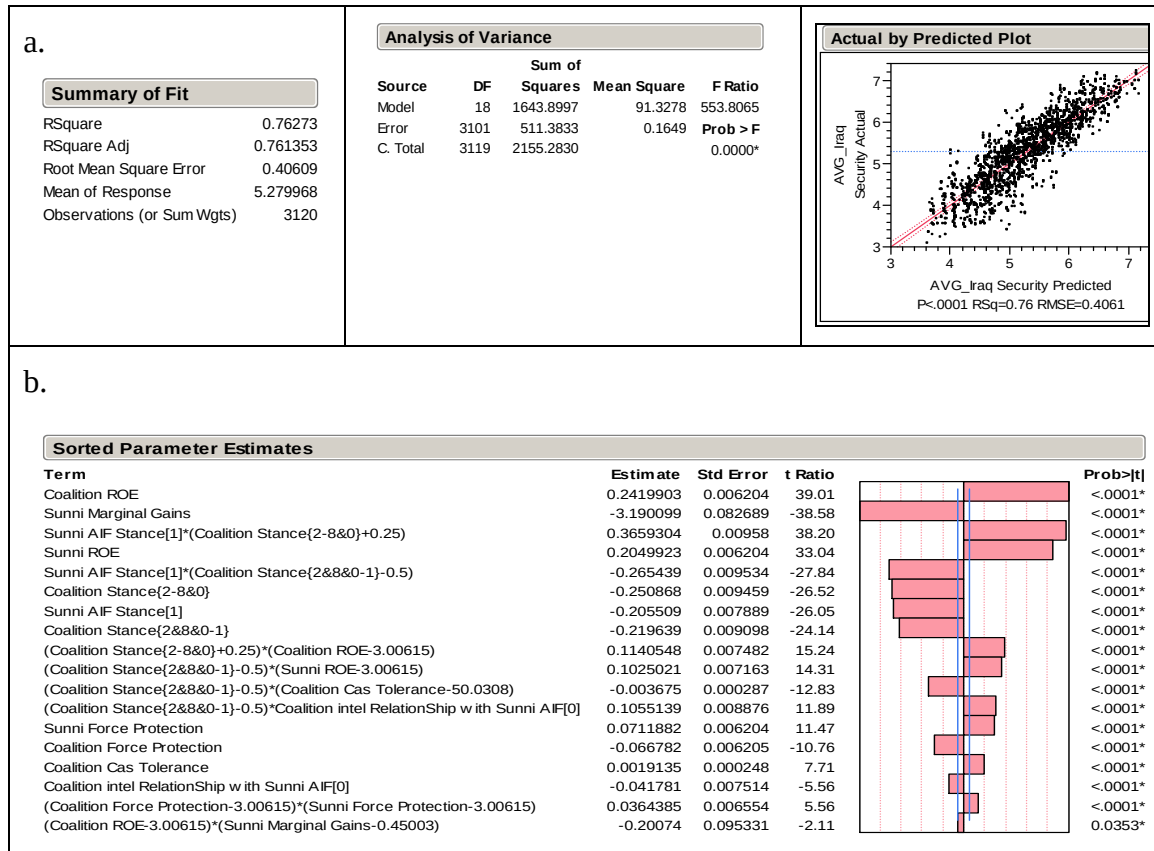


Figure 35. Meta Model Results for Scenario DOE in Regards to Security

Immediately, the significance of ROE for both the Sunni Nationalists and the coalition forces becomes evident. Figure 36 shows that although there are possible exceptions, we see an increase in overall security as both coalition and Sunni Nationalist ROE increase.

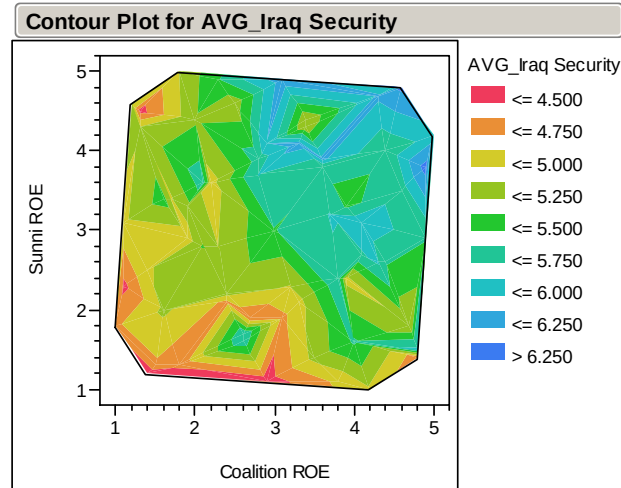


Figure 36. Contour Plot of Sunni Nationalist's ROE and Coalition ROE as a Function of Average Security in Iraq

The next factor of significant importance is that of marginal gains. What is non-intuitive is that the marginal gain for security is not found in this. Looking into the security algorithm we found that this is primarily because in this scenario we have fifteen marginal gains including security, so security only has one-fifteenth the influence in the population's decision making. Also, the marginal gains were limited between .3 and .6 to prevent extreme values of the parameter dominating the model.

Figure 37 displays this relationship through a bivariate fit of the response security in regards to marginal gains. There is a clear underlying linear relationship between marginal gains and security. The correlation between the two is $-.34$. This explains the significance in marginal gains and the importance of the assumptions which create these attributes in regard to the population. However, there is still considerable variability in this trend.

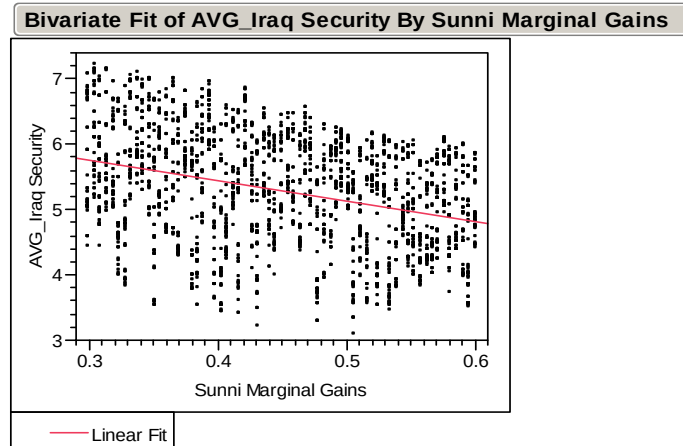


Figure 37. Bivariate Fit of Average Iraq Security (Response) in Regards to Sunni Marginal Gains (Regressor)

The importance of stances for both the coalition and the Sunni Nationalists are also evident in the meta model. This finding corresponds with the third value in Figure 35 which explains our meta model. Equally interesting is that the interaction of stances is more significant than the stances themselves.

Based on the meta model, coalition stance is much more significant toward the nation's security than toward consent. The plot of average security levels by coalition stances (Figure 38) provides insight into the model. The coalition stance attack (Level 1) provides the best security on average followed by humanitarian aid (0) and withdrawn (8), which are not significantly different from one another. Finally, the worst stance is coalition securing with patrols, which is statistically less than the others. The differences among the means are all statistically significant except for the differences between withdrawn and humanitarian aid. However, the highest values of security are found when the coalition is withdrawn or only providing humanitarian aid. This is a result of interactions between faction stances.

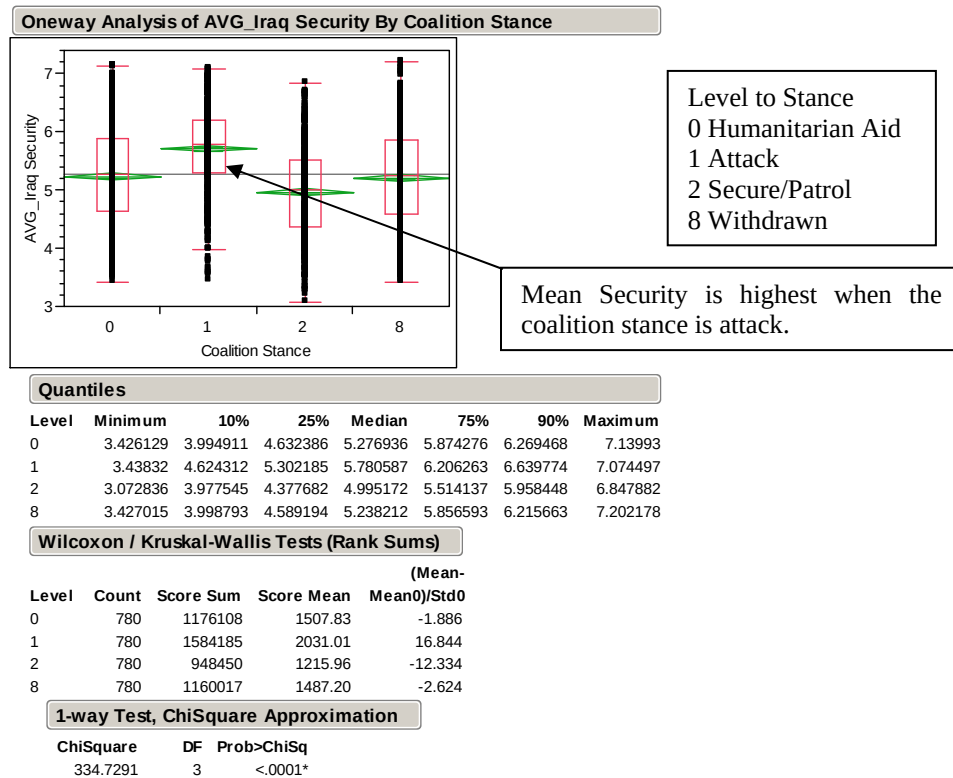


Figure 38. Means Diamond Plot of Iraq Security in Regards to Coalition Stance

Looking at just the Sunni AIF stance in Figure 39, we see that although the difference is not tremendous, there is a difference in security between when the Sunni Nationalists are withdrawn or present. The lack of a tremendous measured difference can be attributed to the actual game play and is discussed in detail in the conclusion.

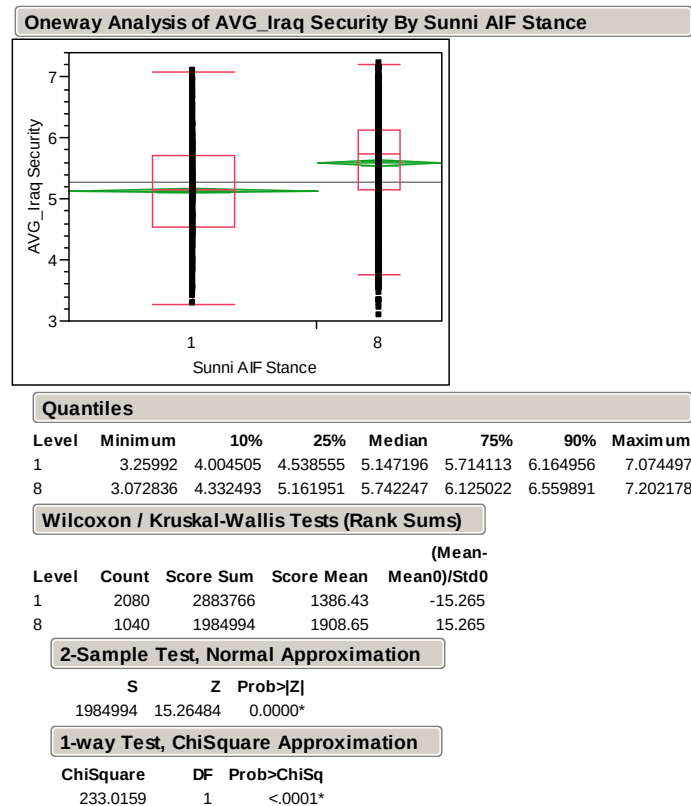


Figure 39. Means Diamond Plot of Average Iraq Security in Regards to Sunni Nationalist Stance

Looking back at the meta model, the interaction of stances is clearly significant. Figure 40 is an interaction plot for the factors in regards to the final level of security. The interaction plot provides two pieces of information. The steeper the regressors corresponding line, the more significant the factor, and if two regressors are not parallel, there is likely an interaction. Thus, when the lines are crossed this alludes to strong interactions between the regressors. This particular interaction plot shows strong interactions amongst the coalition stance and Sunni Nationalist stance factors.

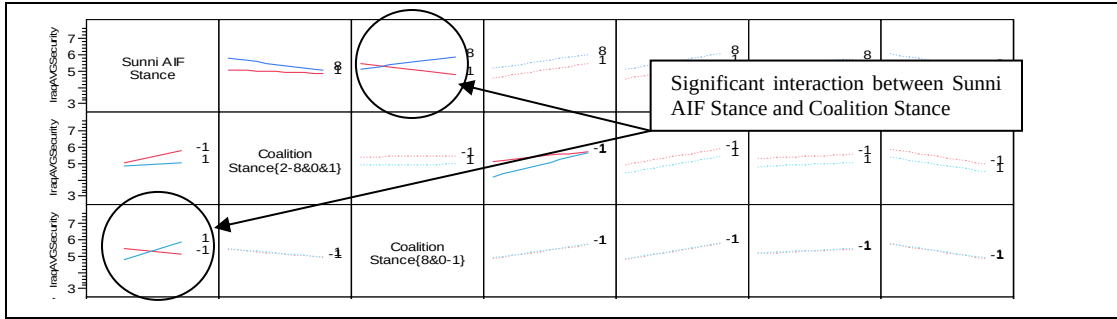


Figure 40. Interaction Plot of Coalition and Sunni Nationalist Stances in Regards to Iraq Security

The intent of Figure 41 is to tease out the significance of the interactions discovered in our model by a visual representation of the actual data. The graph is coalition stance within Sunni Nationalist stance in regards to security. We see that when the Sunni Nationalists are actively attacking (Stance 1) the coalition stances that increase security are 1 and 2 (attacking and securing respectively), which are both offensive stances. When the Sunni Nationalists withdraw (Stance 8) the coalition are best to either withdraw or provide humanitarian aid. We already know that coalition stance is significant in terms of the mean; however, looking at the highest security values per stance in Figure 40, we see this as well.

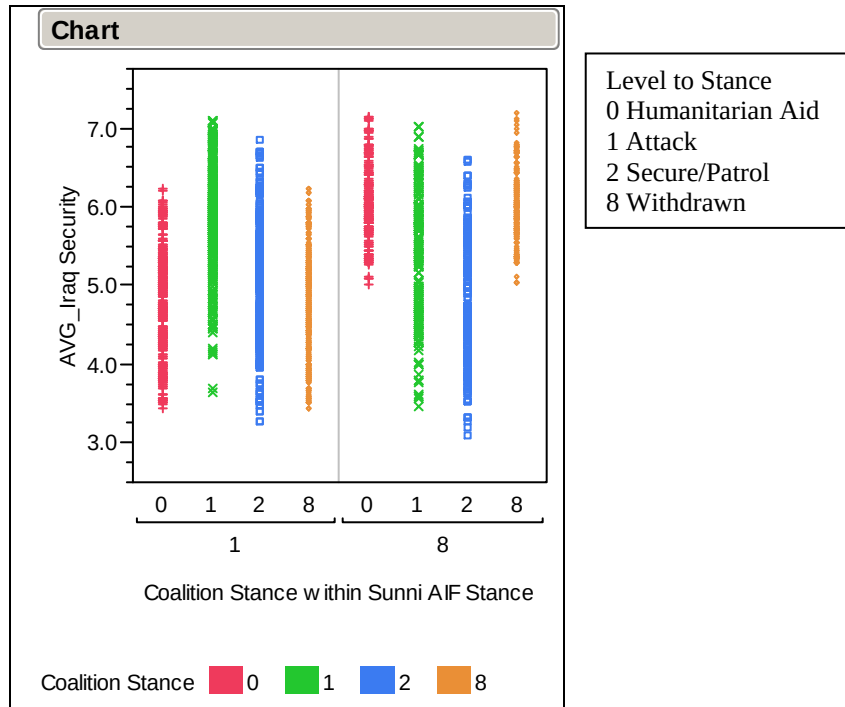


Figure 41. Interactions of Coalition and Sunni Nationalist Stances in Regards to Security [Best viewed in color]

Also of interest is the importance of the interaction for coalition stance and ROE. Figure 42 is a fitted plot of the security data with coalition stance held constant at securing (2) or attacking (1). There is a significant relationship which is also intuitive between ROE and security. Tighter ROE results in higher security for both offensive stances.

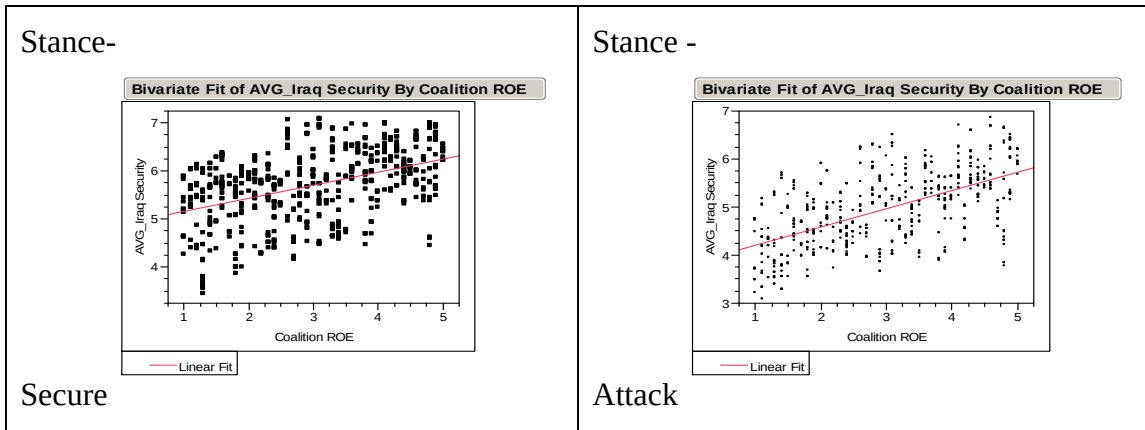


Figure 42. Fitted Plot of All the Security Data with Coalition Stance Held Constant at Securing (2) or Attacking (1)

The significance of force protection and casualty tolerance is also of note. Although not the most significant of variables, their introduction shows the depth of the security algorithm of PSOM. Force protection determines the risk a unit is willing to take in order to accomplish its mission. The meta model shows the greater the force protection level (which results in more aggressive contact) the lower the security value. However, casualty tolerance has a positive effect on security in our model. Casualty tolerance directly affects the enemy's ability to deter the coalition. Therefore, a high casualty tolerance will ensure the coalition continues its mission cycle in that unit's area of operations.

Finally, it is important to ensure that security and consent are truly different MOEs, although they should have some sort of relationship. Redundant MOEs can result in unwarranted reward for the wargame participants or irrelevant post analysis.

Figure 43 shows a correlation between the mean Iraqi consent and mean Iraqi security. There is a slightly positive correlation between the two responses, but inarguably they are different MOEs.

Correlations		
	AVG_Iraq Security	Sunni Consent toward Coalition
AVG_Iraq Security	1.0000	0.1137
Sunni Consent toward Coalition	0.1137	1.0000

Figure 43. Correlation between the Mean Iraqi Consent and Mean Iraqi Security

C. SETTINGS SPECIFIC DESIGN OF EXPERIMENT

The settings file encompasses all the underlying assumptions that are not scenario specific, such as the size of an infantry company, or the attributes of a particular stance. This design of experiments consists of sixty-six continuous factors. Each factor is adjusted to $\pm 20\%$ of the initial value used by DSTL when creating this particular settings file. This prevents any one factor from dominating the experiment. When looking at the settings file, focusing on only the contributing variables allows this research to explore particular mathematical models within PSOM. The primary goals in looking at the game settings are to determine if PSOM can be used to assess changes to unit's abilities and to determine if there are settings which, if not truly understood, can drive the game.

1. Consent

The first MOE used as a response is consent toward the coalition. Figure 44 is a scatter plot matrix showing once again that the overall average Sunni consent for coalition is correlated with the consent in each region and therefore is a good metric to use for initial analysis.

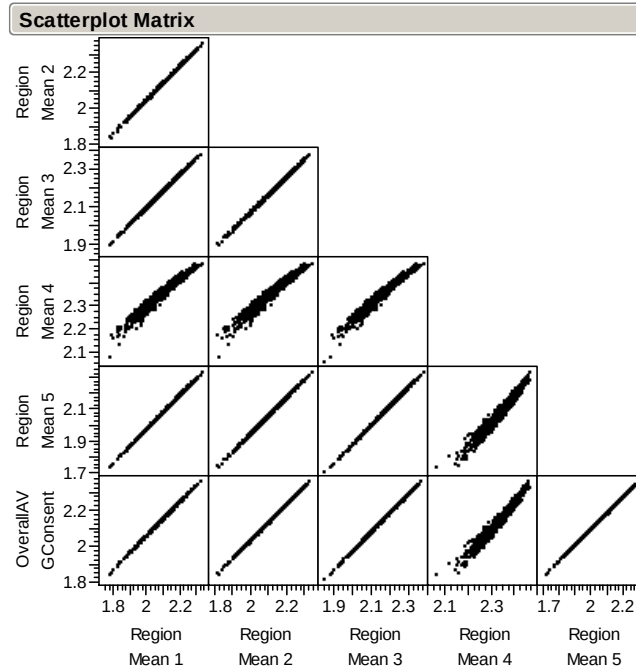


Figure 44. Scatter Plot Matrix Showing the Overall Average Sunni Consent for Coalition is Correlated with the Consent in Each Region

Looking at a histogram of the output, and remembering the starting condition for the scenario is the Sunni's having consent of 2.5 for the coalition, we see that regardless of settings consent does not increase. Also, the range for consent change is not very substantial in regards to the scale of possible outcomes. It appears that the overall outcome of the simulation is not particularly sensitive to the experimental factors.

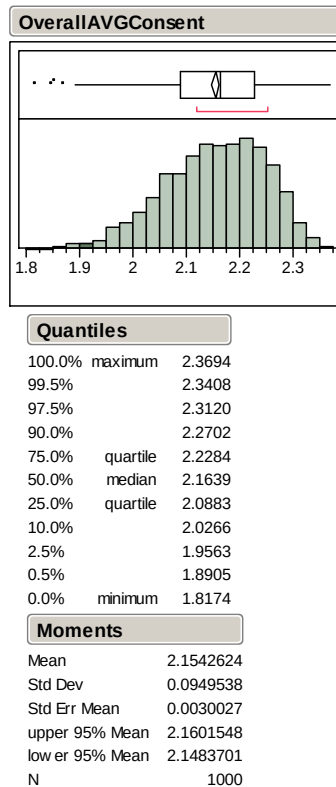
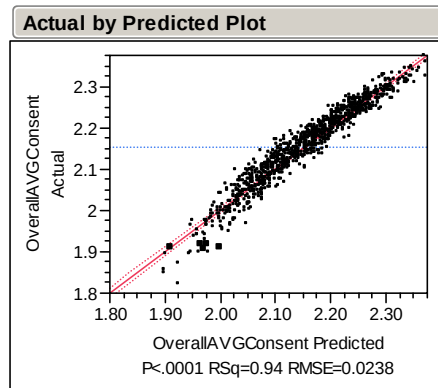


Figure 45. Histogram and Quantiles of Sunni Average Consent toward Coalition from the Settings DOE

Figure 46 shows the results of a stepwise least square regression meta model with two-way interactions. This model provides an initial look into the response of mean Iraq consent for the coalition based on the controlled settings factors. The most significant factor in the model is the mean ROE setting. This coincides with the importance of ROE throughout the model. Although not well defined, the author's understanding is the mean ROE can be related as the expected ROE of a particular area (otherwise, why make it variable). The recommended mean ROE is 3 (Parkman, 2008); however, varying this factor can have a substantial effect on consent. Secondly, the population memory coefficient is a significant factor in regards to consent. The greater this value, the less consent changes per time step. This makes sense; however, this value is a powerful assumption about the population.



(Adjusted R Squared .937)

Sorted Parameter Estimates			
Term	Estimate	t Ratio	Prob> t
MeanROE	-0.210931	-97.21	0.0000*
PopulationMemoryCoef	0.1076177	49.43	<.0001*
ROEMod	-0.634123	-29.22	<.0001*
ForceProtectionMean	-0.053347	-24.57	<.0001*
UnitProtection	0.0014413	22.10	<.0001*
UnitFirePower	-0.001788	-21.92	<.0001*
InterUnitBaseCasualtiesDEF	-1.296548	-19.87	<.0001*
UNitCollateralDamage	-0.013793	-14.84	<.0001*
(PopulationMemoryCoef-3.0006)*(MeanROE-3.0006)	0.0531651	8.45	<.0001*
(UnitFirePower-80.016)*(UnitProtection-100.02)	1.5352e-5	2.16	0.0309*
(ForceProtectionMean-3.0006)*(ROEMod-0.30006)	-0.024138	-0.38	0.7067
(UNitCollateralDamage-7.0014)*(InterUnitBaseCasualtiesDEF-0.10002)	-0.011726	-0.14	0.8851

Figure 46. Meta Model for Sunni Consent toward the Coalition

Looking at a contour plot of the two most significant factors identified from the meta model (Figure 47), we see that although other factors are having some effect, these primary two factors have a tremendous impact on consent. The lowest consent values are obtained with a low memory coefficient and a high mean ROE. The converse is true as well.

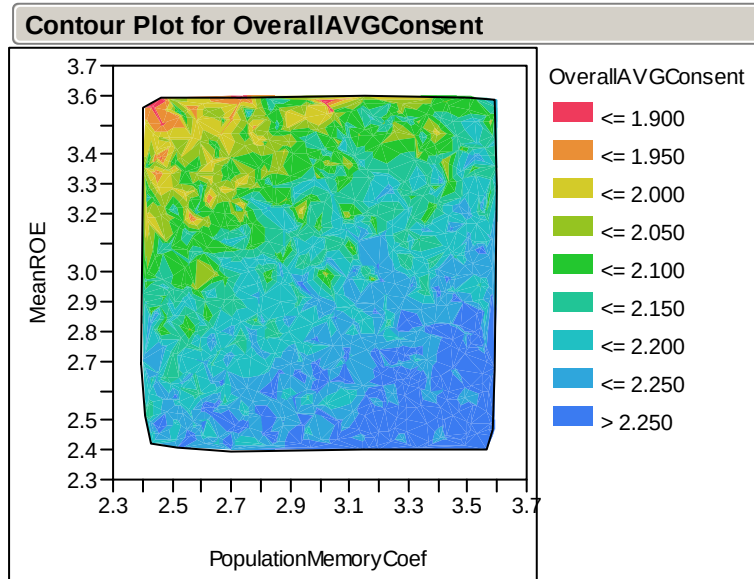


Figure 47. Contour Plot Showing Effects of Mean ROE and Population Memory on Consent [Best viewed in color]

A single factor least squares regression provides a more thorough understanding of the significance of mean ROE. Figure 48 shows we can obtain an R-squared of .59 with mean ROE as the only regressor. This shows the exceptional importance of this factor.

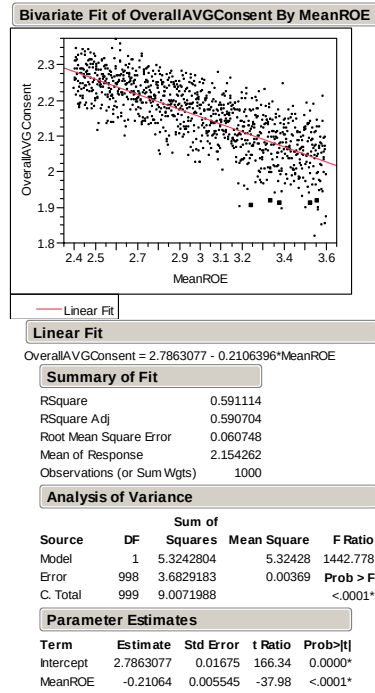


Figure 48. Linear Regression Meta Model for Consent using only Mean ROE as a Regressor

The importance of mean ROE suggests that it is worth looking into its use in the algorithms which determine civilian casualties. The following equations and their explanation are taken from Paragraph 167 of the Peace Support Operations Model Specifications Manual (Jon Parkman, 2008). These equations explain an important part of the combative algorithms in the simulation. The highlighted equations take into account the mean ROE and the ROE modifier which is used to control the level which rules of engagement actually impact civilian casualties (Jon Parkman, 2008). Mathematically μ_r (mean ROE) is used in an exponential role in determining the number of civilians killed due to combat.

$$FP = \left(e^{f_m(\mu_f - f_1)} \right) \left(e^{f_m(\mu_f - f_2)} \right)$$

$$C_1 = B_{Att} \cdot \left(\frac{S_1 + S_2}{B_C} \right) \cdot (F_2 \cdot T_f) \cdot \frac{1}{P_1 \cdot T_p} \cdot FP \cdot (1 - I)$$

$$C_2 = B_{DEF} \cdot \left(\frac{S_1 + S_2}{B_C} \right) \cdot (F_1 \cdot T_f) \cdot \frac{1}{P_2 \cdot T_p} \cdot FP$$

$$C_{Civ} = R_m \cdot \left(\left(e^{\mu_r - R_1} \cdot C_2 \right) + \left(e^{\mu_r - R_2} \cdot C_1 \right) \right)$$

Where:

FP = Contact Force Protection value of Units 1 and 2 ($0 \leq F \leq 1$)

f_m = Force protection modifier ($0 \leq f_m \leq 1$)

f₁, f₂ = Force protection values of Units 1 and 2 ($1 \leq f \leq 5$)

μ_f = Mean Force Protection value – (Typically 3)

C₁, C₂ = Casualties taken by Units 1 and 2 ($0 \leq C \leq \infty$)

B_{Att} = Average number of casualties taken in offensive operations of size B_c
(from HA, SIGACTS and other sources) (Constant)

B_{Def} = Average number of casualties taken in defensive operations of size B_c
(from HA, SIGACTS and other sources) (Constant)

B_c = Average size of contact (from HA, SIGACTS and other sources) (Constant)

S₁, S₂ = Size of force in contact from Units 1 and 2 ($0 \leq S \leq \infty$) – where Unit 2 may represent multiple defending units.

F₁, F₂ = Average Firepower values of Units 1 and 2 ($0 \leq F \leq \infty$)

P₁, P₂ = Average Protection values of Units 1 and 2 ($0 < P \leq \infty$)

T_b, T_p = Terrain modifiers on Firepower and Protection ($0 < T < 2$)

I = Indirectness level of Unit 1 ($0 \leq I \leq 1$)

R_m = RoE modifier ($0 \leq R_m \leq 1$)

R₁, R₂ = RoE levels of Units 1 and 2 ($1 \leq R \leq 5$)

μ_r = Mean RoE level – (typically 3)

C_{Civ} = Casualty level taken by civilians ($0 \leq C_{Civ} \leq \infty$)

In a real world situation, it makes sense that the casualty level of civilians should play a key part in the consent of a population. Furthermore, the ability to adjust the impact is important in designing the wargame. This also shows the importance of the value of security. Although it is not directly involved in consent, because the majority of coalition forces have assumed a stance that involves providing security in this scenario, the ways in which the coalition affects the marginal gain of security is key. In changing the settings file we have either increased or decreased the number of civilians killed and

therefore changed the civilian perception of security which has an impact on consent. This is a good example of the robustness of PSOM in regards to irregular warfare modeling. However, the mean ROE in this game is very sensitive and can outweigh a strategic plan in the game if allowed.

The memory coefficient is a scalar which determines the speed at which a population agent's consent can change. The following equation, taken from the PSOM manual, shows part of the consent algorithm and the memory coefficient's role:

$$C_f^t = \frac{(\Delta C_f + C_f^{t-1}(k^M - 1))}{k^M}$$

Where:

C_f^t = **The final consent rating for faction f in turn t**

C_f^{t-1} = **The consent rating for faction f in turn t-1.**

k^M = **The memory coefficient.** (Jon Parkman, 2008)

What becomes evident is that the larger the memory coefficient is, the less sensitive the change in consent will be. This includes even small changes such as the range covered in this experiment (2.4 to 3.6). The importance of this parameter makes sense because of its direct relationship with the final consent. It is crucial to understand that this value, if misused, can cause serious issues in the simulation. This implication is particularly true if model is used as a wargame over a short period of time. If players do not see the effects of their decisions, interest can be quickly lost.

Looking back at the meta model, the unit attributes of firepower and protection are significant in regards to consent. As unit firepower increases the consent goes down. This is most likely due to the number of civilians killed, which links directly to the marginal gain value of security. As seen in the previous equations, this is a very simplistic look at combat interactions. Just because a unit possesses a tremendous amount of firepower does not mean this firepower is projected, nor does it mean this firepower will result in civilian casualties.

As the protection attribute increases consent increases because this allows for more deliberate focus on the mission. The first reason is the less casualties a unit takes, the less likely they are to be deterred from the mission. More indirectly, but the above equations also show, that the greater the coalition protection the more coalition survive resulting in fewer civilian casualties because the coalition ROE is tight. The relationship between consent and the unit's collateral damage level is also negatively correlated, which is intuitive.

The limited effects of the unit attribute changes provide some key insights. Further analysis must be conducted to prove the hypothesis that PSOM can be used to gain information on force capability modification. Arguably, the addition or removal of 20% of a maneuver company's capability should have a significant effect. Unfortunately, only three of the ten attributes in the experiment proved significant when changed $\pm 20\%$. This is a bit disconcerting if the model is intended to test unit capabilities.

2. Security

Looking at the data we see that security does increase. It starts at 5.8 throughout the country in this scenario. Figure 49 is a histogram and analysis of the security output showing that security increased in over 95% of the design points. Also, even though security is on the same scale as consent (1 to 10), the security response variable covers a much greater range (from 5.7 to 7.7).

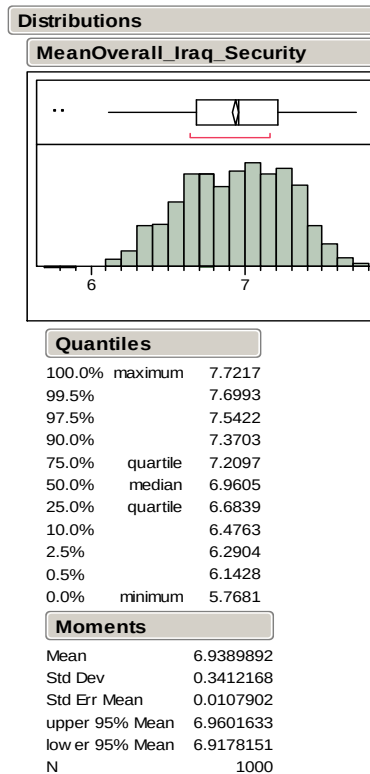


Figure 49. Histogram and Analysis of the Security Output

Figure 50 is the scaled estimate results of the least squares regression meta model with two-way interactions. Once again, mean ROE dominates followed by the ROE mod. Unit firepower and unit protection also prove significant.

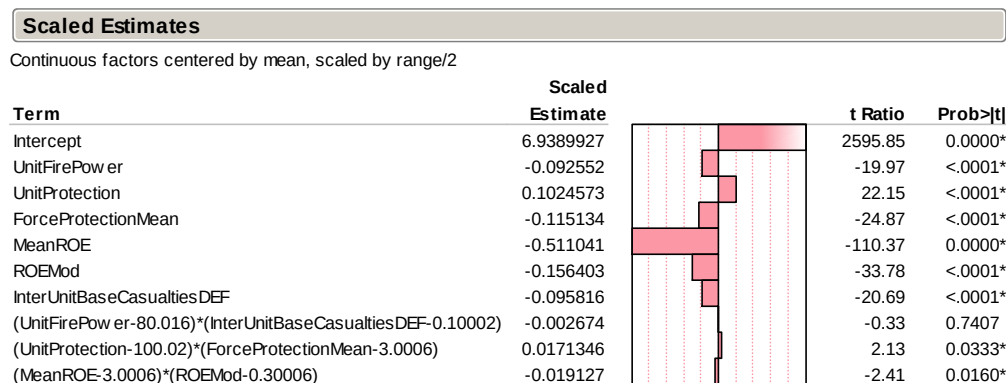


Figure 50. Non-ordered Scaled Estimates of Parameters of Settings File DOE in Regards to Security

Figure 51 is a contour plot of security in regards to the mean ROE and ROE modifier. Mean ROE clearly has a tremendous effect on security.

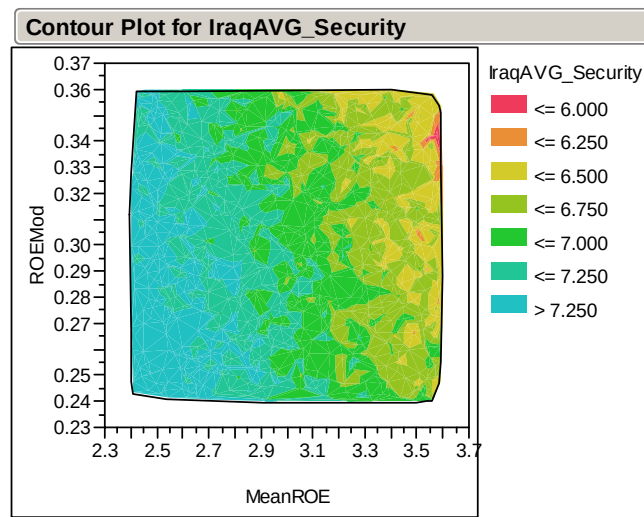


Figure 51. Contour Plot of Mean ROE and ROE Mod versus Security

Referring to the security meta model in Figure 49, and focusing on unit firepower and unit protection, we see the same results as from earlier with consent. An increase in a unit's firepower results in a lower-end state security, and an increase in protection results in an increase in security. This negative relationship between unit firepower and the responses creates a pattern in the model: the more firepower a unit has the more likely they are to use it.

Because the meta models for security and consent had such similar results, further analysis into the relationship between security and consent for this DOE proves beneficial. Figure 52 is a correlation scatter plot matrix for security and consent for the 1,000 design points in the settings file. With a correlation of .9, clearly there is a nearly linear relationship between security and consent for this experimental design. This can be attributed to the primary factor driving change throughout the experiment—mean ROE. Because most factors that have effects on functions other than the combative algorithms were not significant with the 20% interval used in this experiment, the combative functionality of PSOM can account for the majority of the variation in both security and consent.

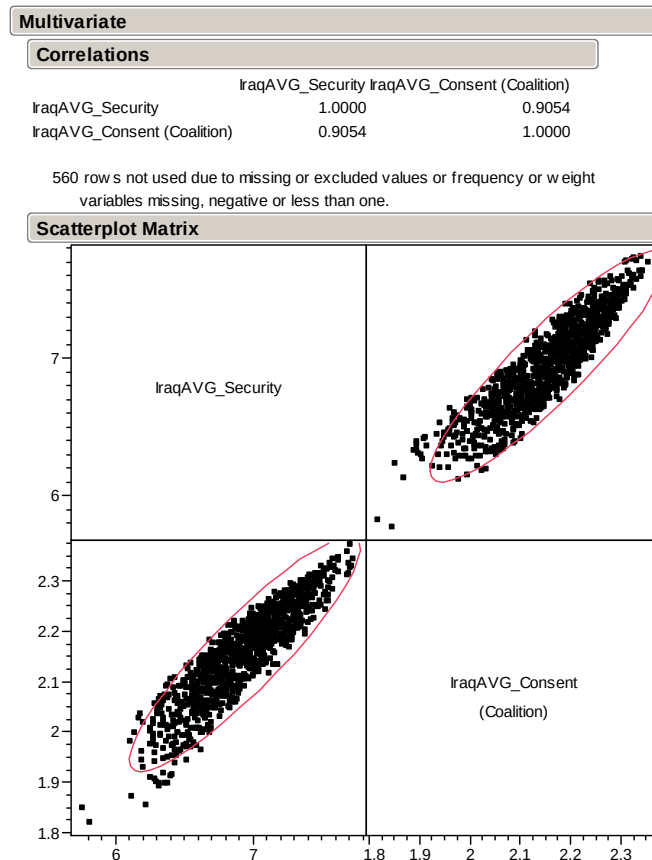


Figure 52. Scatter Plot Correlation Matrix of the Outputs Consent and Security in the Settings DOE

The settings files contribute to the underlying assumptions and factors of PSOM. Clearly, over sensitivity of these functions could prove problematic in the use of the model. Of the sixty-six setting factors changed, only a handful proved sensitive to a 20% change from the initial values. This provides some insurance that for the most part questionable settings will not ruin the validity of the game. This analysis has identified those factors which should be carefully manipulated. However, the lack of sensitivity to unit attributes could prevent PSOM from becoming a tool used for comparative analysis of unit equipment or force structure.

D. CUMULATIVE DOE

Using information gained over six months of studying PSOM and all the lessons learned from earlier analysis, we devised a cumulative experiment. In this experiment we focused on coalition stance, unit attributes, ethnic group characteristics, and time. It is important to remember this design used a scenario in which the Sunni Nationalists are actively attacking the coalition and Iraqi infrastructure.

1. Consent toward Coalition

In this case, consent outcomes toward the coalition are moderate compared to the previous experiments. Figure 53 also shows that consent increased in approximately 20% of data points (initial value is 2.5).

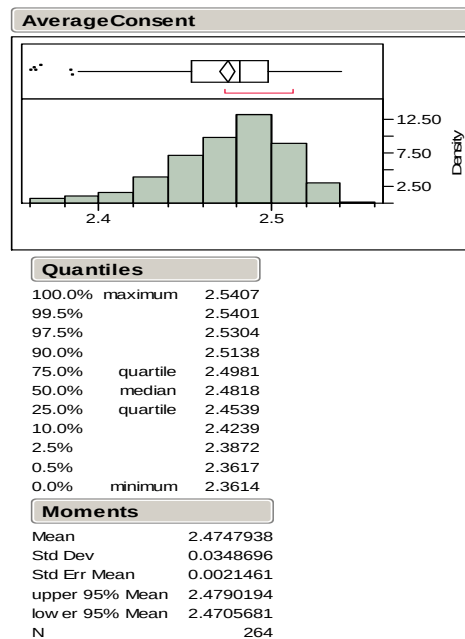


Figure 53. Histogram and Quantiles for the Cumulative DOE in Regards to Consent toward Coalition

Figure 54 displays a stepwise quadratic linear regression with two-way interactions with a very small mean square error and an R-squared of 0.95.

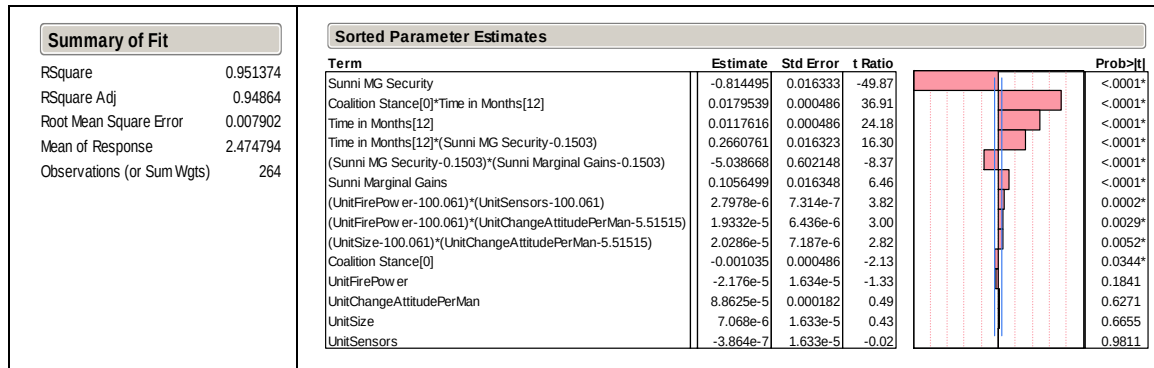


Figure 54. Least Squares Meta Model Results for the Cumulative DOE in Regards to the Response Consent

In this experiment we intentionally limited the range of Sunni marginal gain security to between .1 and .2. However, it remains a determining factor in this model.

The next interesting finding is the importance of the interaction of coalition stance and time in months. According to the model, consent toward the coalition is greater if the coalition is providing humanitarian aid over a 12-month period than if the coalition provides aid over a 24-month period. This seems counterintuitive. The increase in production directly increases consent and over twenty-four months there is more production than over twelve months. However, the lack of security provided by this tactic over the second year seems to decrease consent toward the coalition. This shows the dynamics of PSOM. From this telling analysis it appears that a faction cannot just “build” consent.

Analyzing the importance of time in regards to the data from the experiment, we see that, on average, a 12-month simulation results in a greater consent. Figure 55 (left side) shows a means diamond plot of consent toward the coalition at the end of both twelve and twenty-four months. We can see consent is greater at twelve months than at twenty-four. The right side of Figure 55 is a quantile plot where the red line shows each

data point for the 12-month design points, and the blue line shows the data point for each 24-month design point. For all but the 99% quantile twelve months has a higher consent toward coalition.

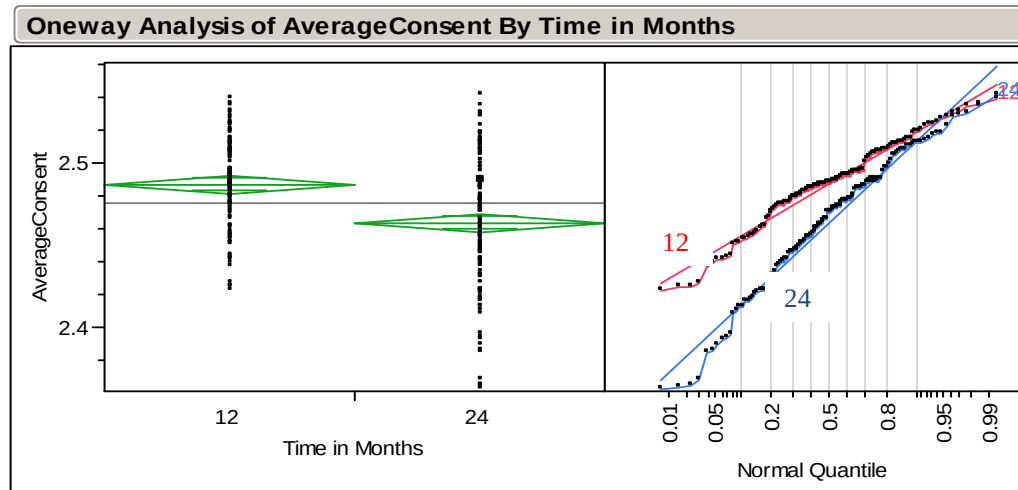


Figure 55. Consent versus Time in Months for the Cumulative DOE

Figure 56 shows the interaction between coalition stance and the simulation time in regards to consent. What is noticeable is that when the coalition is providing humanitarian aid (Stance 0) we see a decrease in consent from a one year simulation to a two year simulation. However, there is a slight increase in consent between year one and year two when the coalition is in a securing stance (Stance 2). This supports the meta model's (Figure 54) findings that providing just humanitarian aid is not a simple path to increased consent in PSOM.

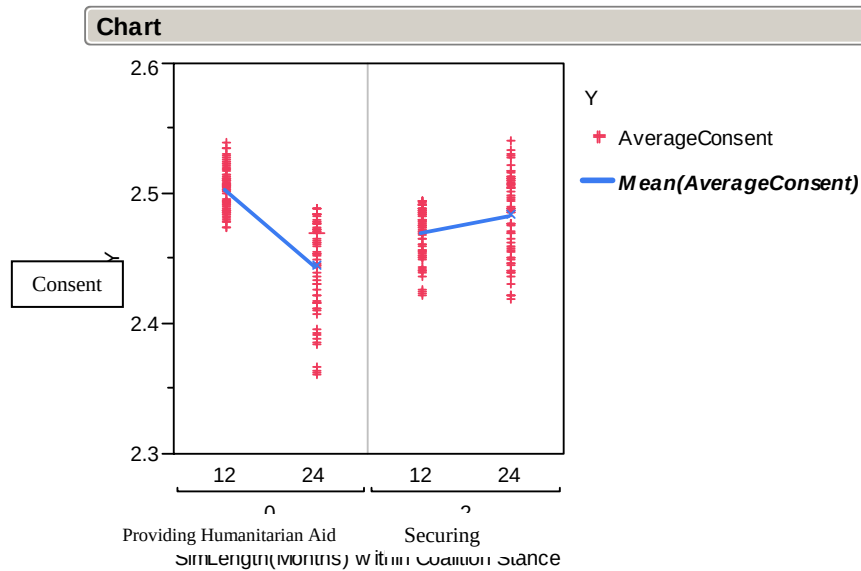


Figure 56. The Interaction between Time and Coalition Stance in Regards to Consent

Also, we now see the lack of significance of the unit descriptor variables (Figure 54). According to the regressor meta model the unit attributes are not significant alone. However, they are significant amongst themselves with interactions. These interactions seem intuitive. For example, the increase in unit size alone is not significant; however, when combined with increasing the unit's ability to change perception, we see significance in these parameters' interaction. It is important to remember these variables were changed with an exceptional range ($\pm 50\%$ the original value), which may not be representative of reality.

2. Security

Looking at the average security values for each design point in Figure 57 we see that security always increased throughout the country (the starting value was 5.8).

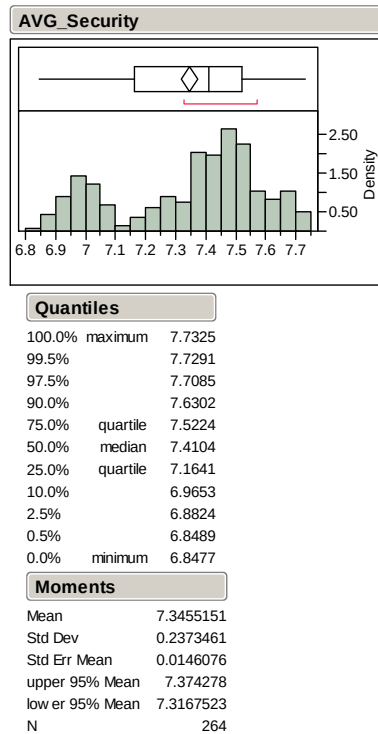


Figure 57. Cumulative DOE Histogram of Final Security Value

Figure 58 shows the results of the quadratic least squares meta model with security as the response variable. The factors we adjusted accounted for a very large portion of the variance within the simulation.

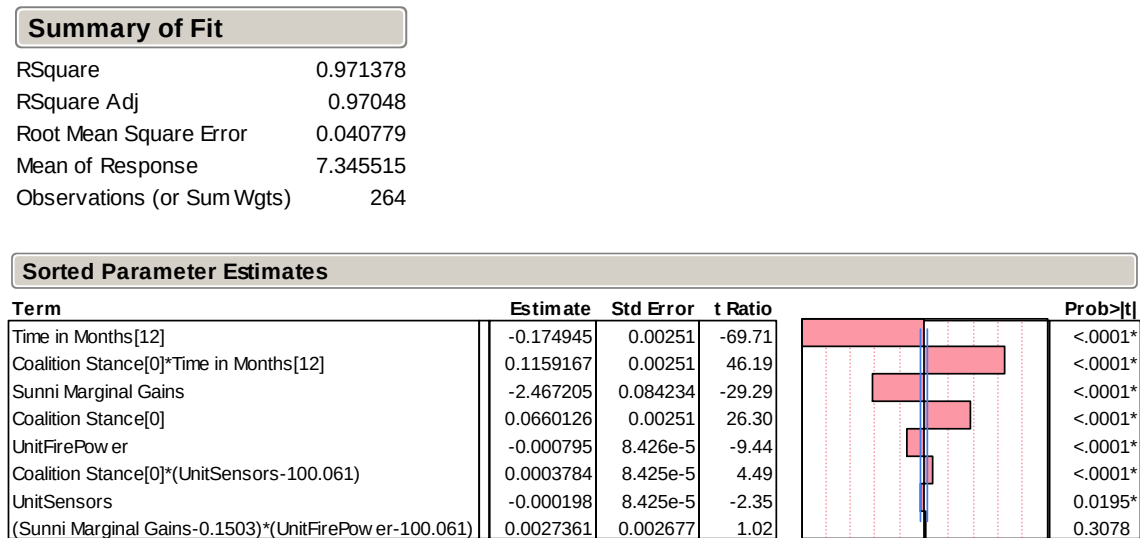


Figure 58. Regression Meta Model Results with Security as the Response Variable

From the parameter estimates it appears that, just as with consent, simulation time, coalition stance, and the Sunni marginal gains are significant factors within this experiment.

Figure 59 shows the means diamond plot of security in regards to time along with the normal quantile plot of both the 12-month design points and the 24-month design points. From this picture, security, unlike consent, seems to increase when the scenario is executed over two years.

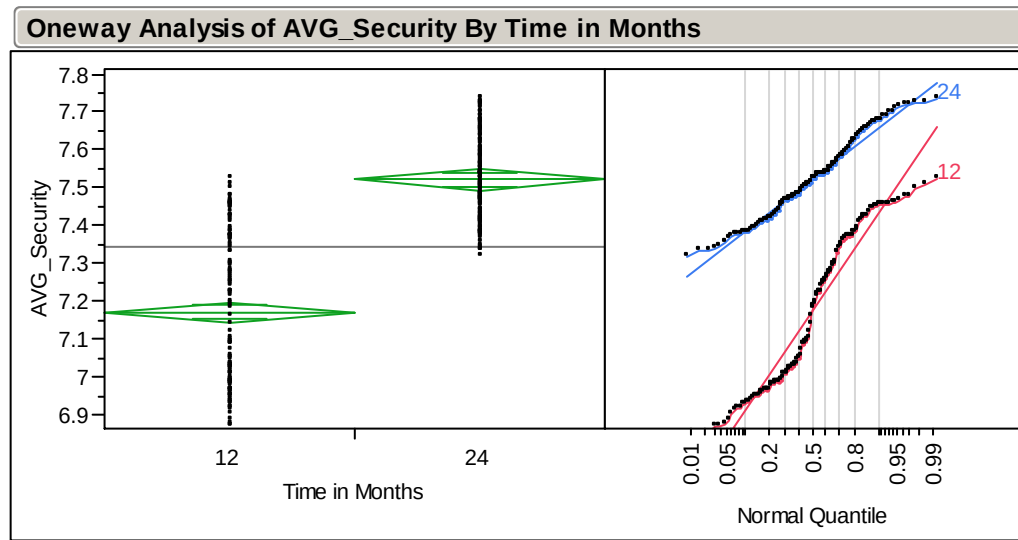


Figure 59. Means Diamond and Normal Quantile Plots of Security in Regards to Time

Figure 60 shows the same data, but introduces the interaction of unit stances. In both cases where the collation stance is either provide humanitarian aid (0) or secure through patrolling (2) security increases between the one-year design points and the two-year design points. However, we see a greater quantity in this increase when the coalition is securing. This agrees with the analysis of consent. It seems that although in the first year gains can be made through the use of humanitarian aid a faction must also focus on security.

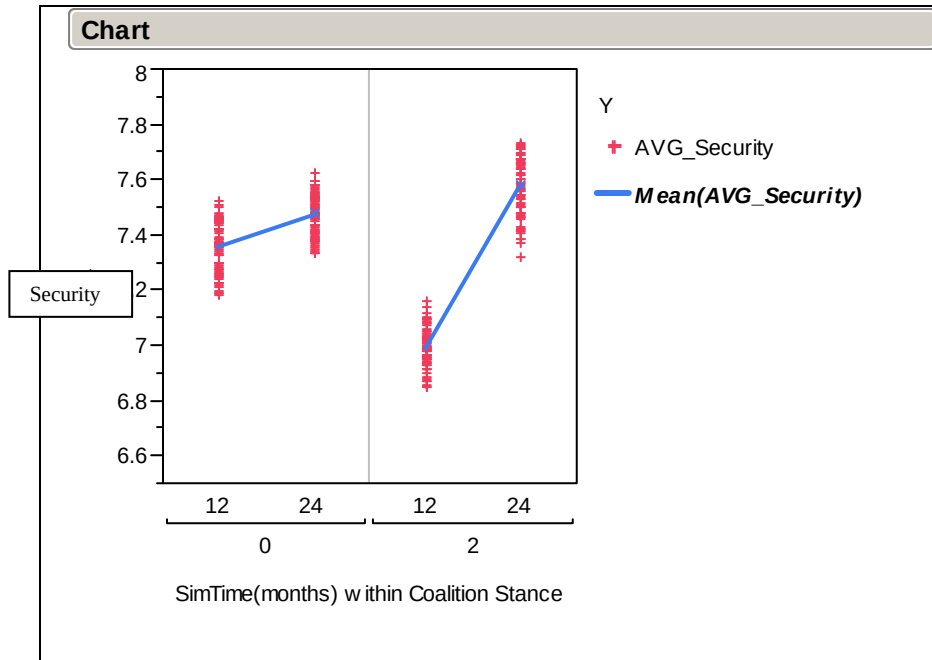


Figure 60. The Interaction between Time and Coalition Stance in Regards to Security

Looking just at marginal gains in regards to security (Figure 61) we see that there is a clear trend that when marginal gains are higher security is decreased. The space where there is no data is a result of the variables coalition stance and time. The darker points are the sixty-six points where the coalition forces are patrolling for the one-year time frame.

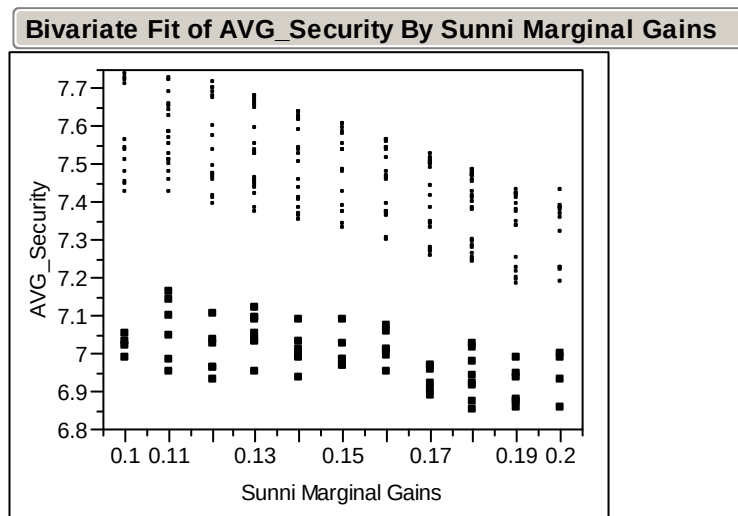


Figure 61. Bivariate Fit of Security by Sunni Marginal Gains

3. Time Step

The final bit of analysis conducted was to determine the stability of the model with respect to time step. For this experiment we simulated the initial Iraq scenario for one year of combat changing only the time step for each turn of the game. We found that, for consent, time step can have a substantial effect on the game as shown below in Table 10.

Time Step	Total number of steps	Sunni Consent for Coalition	Security
7 Days=1 time step	52	1.28	7.13
30 Days=1 time step	12	2.19	7.23
60 days = 1 time step	6	2.36	7.17

Table 10. Security and Consent Responses Resulting from Changing only Time Step

E. SUMMARY

By leveraging intelligent design of experiments with powerful computing we have been able to obtain a very robust scope of output from PSOM. Using some basic data mining techniques we can gain some tremendous insight into the simulation model. A synopsis of the results is as follows:

- The methodology used within this thesis proved a useful process to analyze social models and produce viable results.
- The initial assumptions made about the population can be a controlling factor of the game's outcome. This is especially true with respect to the ethnic group's marginal gains and initial levels of consent toward a particular faction.
- Although it is difficult to increase consent in the game, it is not impossible. A careful balance of productivity and security provided should result in increased consent.

- Although there is a stochastic aspect to PSOM, it is minimal. It is a wargame and variation primarily results from the human-in-the-loop aspect of the game.
- Time is an important contributor to the game. This applies to both the overall simulated time and time step between turns. There is a difference between twelve weeks of combat and twelve months, and this is represented.
- The total length of represented time is important within the simulation. When the coalition stance was either provide humanitarian aid or secure by patrolling, security MOEs were varied at the end of two years compared to the end of one year.
- Stances and the interactions of stances between factions have an impact on the game's results. This is more obvious when looking at security, but it is true in regards to consent as well.
- In this scenario consent for the Iraqi government is correlated with the consent for the coalition. They are not the same, however. This aspect was investigated directly and the game represents this well.
- Consent and security are quantitatively different MOEs. They are not just scaled differently; it is possible to increase one and decrease the other.
- Player set ROE and force protection can have tremendous implications in the scenario. A risk adverse unit with restrictive ROE will fare better in a stability focused scenario, especially in regards to increasing security.
- The game is not overly sensitive to the initial settings parameters (these are non-scenario dependent assumptions). However, this includes most unit attributes (excluding firepower and protection). These attributes have marginal effect when changed 20% and only a small effect when changed 50%.
- One should be very careful when manipulating the mean ROE value and the ROE modifier as they have a tremendous impact on the model.
- An increase in a unit's firepower will decrease consent. Regardless of the argument for or against this assumption, it is imperative that unit attributes in the settings support the unit's actual capabilities on the ground. For example, most armored units use HMMWV's in Iraq. Therefore, firepower should be reduced accordingly.
- Consent decreased in the two-year model compared to the one-year model when the coalition stance was set to provide humanitarian aid, and increased when the coalition stance was set to secure through patrolling. This shows that even though production increased, the lack of security dominated production in determining consent.

- The developers' recommendation of a 30-day time step should be adhered to. Although changing the length of the time step had minimal effect on security, it did result in different values in the consent MOE.
- Throughout this analysis many of the results proved statistically significant; however, the results might not be deemed practically significant. A 0.2 change in consent could easily be interpreted as irrelevant. From the author's experience with PSOM, this is primarily due to the normalizing of the final MOE values and could therefore be adjusted to show greater impact from the players' decisions.

VI. CONCLUSIONS

A. RESEARCH SUMMARY

This thesis set out to develop and subsequently implement a methodology to quantifiably analyze military models, which claim to meet the social implications of the modern battlefield. By using a well-vetted realistic scenario, multiple design of experiments, various data models, and cumulative statistical analysis the study focused on addressing some fundamental questions about the popular simulation model, the Peace Support Operations Model. The final results of these experiments and the corresponding analysis will provide multiple agencies within the Department of Defense substantial insight into PSOM and a solid foundation for further research of PMESII models. This chapter concludes the research and analysis conducted within this study.

B. RESEARCH QUESTIONS

In developing the purpose of this study we identified four fundamental concerns in the realm of PMESII models, into which PSOM falls:

- Identify the factors which most dramatically influence PSOM's output.
- Attempt to assess the accuracy of the Peace Support Operation Model.
- Make recommendations toward the potential use of the Peace Support Operation Model.
- Conduct a risk analysis of the Peace Support Operation Model.

This chapter discusses the results of our analysis regarding each of these initial issues. Many additional insights were gained through this process and the more significant ones are addressed.

1. Important Factors

Over 100 factors covering the space of multiple factions, units, population agents, settings, and courses of action were explicitly explored in this study. Of significant importance are the factors that the players of the game can control. These factors, as they

should, have tremendous implications in the simulation's outcomes. These parameters include the units' stances, rules of engagement level, and force protection level. Furthermore, assumptions about the population and the scenario have tremendous implications on the responses. Additional factors, which are analogous to the simulation's setup and execution, were identified.

a. *Player Controlled Factors*

Arguably, the most fundamental decision a player representing a faction must make is which stance to take. Therefore, it is critical that this decision have an effect on the game. We found that the faction stance selection has significant effects on the population's consent to that faction, the consent of that faction's allies, and the security of the country. In addition, the interaction of stances amongst different factions proves to be important as well. This also proves true if a faction is acting on behalf of another faction. For example, the coalition stances in this scenario often acted on behalf of the Iraqi government, resulting in consent for both factions being correlated.

In regards to stance selection, the behavior of the security MOE seems intuitive. When the Sunni Nationalists were in an aggressive stance, the highest average security was obtained when the coalition forces took an aggressive stance. However, if the Sunni Nationalists are withdrawn, security was at its highest when the coalition was either withdrawn or providing humanitarian aid. Because security is a measure of perceived violent death, this seems logical. However, it is surprising to learn that regardless of Sunni stance, the security values are higher when the coalition took an attacking stance as opposed to a securing stance. Nonetheless, because PSOM is very malleable, the stances' parameters can be changed, and we feel this is a simple fix and should be looked into further by the developers or users of PSOM.

With regard to overall Sunni consent toward the coalition and the Iraqi government, the stance of the coalition also proved significant. On average, when the coalition provides humanitarian aid the consent MOE is higher. The amount of the consent values change is also dependent on the Sunni Nationalists' stance, but the trend stays true. By focusing in on Baghdad we found that if the Sunni Nationalists are

aggressively attacking the country's infrastructure, merely providing humanitarian aid will do very little for consent. However, with a withdrawn enemy, the coalition's aid is uninterrupted and consent increases. We also found that consent is at its lowest when the coalition takes on an attacking stance versus humanitarian aid, securing, or withdrawn. It is here that we see the first complicated dynamic in contemporary war; the way to increase consent alone seems intuitive—provide aid. This applies to security as well: to increase security, provide security. Yet to increase both security and consent takes substantial planning on the coalition's part. The second dynamic is shown when the scenario lasts two years as opposed to one year. We found that the positive benefit of providing aid when the Sunni Nationalists are in an aggressive stance drops off tremendously when the scenario is extended to a second year. It is in this protracted war that higher levels of consent can be earned by the coalition by providing increased security through offensive stances.

The rules of engagement level and force protection level the factions choose prove very significant toward security, but have minimal effect on consent. The results for security were intuitive; the more restrictive the competing factions' ROE the higher security. The inverse proves true for force protection; the greater the risk the factions are willing to take, the lower the security level. We also found significant interactions between ROE and stance. For example, a faction using an offensive stance with a loose ROE will result in lower security.

b. Assumptions about the Population

PSOM is a population centric model. Therefore, it should come as no surprise that the initial assumptions made about the population have a tremendous impact on the measures of effectiveness. The initial consent level an ethnic group has toward a faction will continue to impact the values for consent. Although this is logical, it is a powerful initial assumption. Also, the marginal gains of an ethnic group can strongly drive the level of consent and security in the simulation. These values represent the importance a population agent places on particular goods to include security. They have extreme implications on the description of an ethnic group. If these values are entered at

too high a level it is almost impossible to increase consent and security will decrease significantly. These values must be considered with the utmost care or both security and consent will be adversely affected. What is of interest is that the Sunni marginal gains for security have the greatest effect on consent where the Sunni marginal gains for goods have the greatest effect on security.

If the simulation is intended for use in any sort of analysis it would be imperative to execute the model under multiple initial conditions (Gilbert, 2005). Unless of course, the user can find a subject matter expert, for example, that knows the importance of sanitation to a Sunni.

c. Model Settings

The settings file focuses primarily on those parameters that are not scenario specific, such as the number of personnel in an infantry company or modifiers which affect the mathematical models within the simulation. For the most part, these settings did not prove overly sensitive to change; however, a few key insights were gained.

The Average ROE is a modifier used primarily in the civilian casualty determination algorithm. The developers at DSTL state this value is “normally 3” (Jon Parkman, 2008). By varying this value we see tremendous changes in both consent and security. This parameter is significant enough to completely change the outcomes of the game and should not be adjusted unless completely understood by the user. The other settings values which were found significant are a few basic modifiers, primarily the population’s memory coefficient and the ROE modifier (see Chapter IV). For the most part their manipulation is of minimal effect or easily understood.

However, there seems to be a lack of effect pertaining to the changing of unit capabilities. We found that changing a unit’s (company level) attributes by 20% has minimal effect on both security and consent. We then changed these values by over 50% from the initial values and saw that large changes in attributes can affect the model. These attributes include unit firepower, sensors, ability to change populace attitude, and

unit size. The ability to show that these factors matter should assure the user that unit capability is important; however, the lack of sensitivity says move cautiously if considering the use of PSOM as a force analysis tool.

The exception to this is the unit's firepower setting and protection level. The protection level acts in an understandable way by having positive changes on security and consent; however, firepower has the opposite effect on security and consent. When using the preset units in PSOM, it is important to remember that a unit with tremendous firepower, such as an armored battalion, might use different equipment based on the combat situation.

d. Time Step and Time of Simulation

There are two ways to look at time step and both were analyzed in this thesis. First, it is clear that the length of the time step is significant. As would be expected, the results of twelve 7-day time steps provided significantly different results than twelve 30-day time steps. However, we found that fifty-two 7-day time steps provided substantially different results than twelve 30-day time steps when looking at the consent metric. Therefore, it is best to stay with the developer recommended 30-day time step.

Intuitively, the results of twelve months of game play differ from those of twenty-four months of game play with regard to both security and consent. Using the standard Iraq scenario, which portrays an aggressive Sunni Nationalist Faction, we see that on average security increased from 12 to 24 months. However, when the coalition chooses a stance of humanitarian aid, there is a decrease in consent from 12 to 24 months. Consent increases on average between 12 and 24 months provided the coalition chooses a securing stance against the active insurgency. This implies that PSOM is much more than a simple model portraying linear relationships amongst user inputs. The implications of non-linear (the curve looks quadratic) changes in consent over time is most likely the result of an initial consent for a coalition that provides life improving services upfront; however, as the promise of a better country is not met due to a lack of

security the consent decreases. Where-as a coalition that initially provides marginal goods and services, but provides and then increases security can gradually continue to gain consent from the population.

2. Accuracy of the Peace Support Operation Model

Because social modeling is far more complex than physics-based modeling there is no binary answer as to the accuracy of the model's outputs. However, through the comparison of our quantitative results with doctrine, personal experience, and the help of subject matter experts, subjective analysis can be obtained. First and foremost, the model uses a multitude of player and subject matter expert inputs to create a simulated environment which describes irregular warfare. In the process of conducting this research we have explored a vast amount of the PSOM parameter space and found many doctrinally analogous results. It is assuring that the model is more than an empty black box that provides output regardless of input. Also of note, the model is very flexible. There are modifiers that can influence the importance of the majority of the algorithms within the simulation. This allows the user to define the space in which the wargame is played and therefore influence its accuracy.

Looking at the consent MOE we have learned that it is very dependent on the initial assumptions about the population. We have also learned that it is very difficult to increase this factor. Arguably this is logical, as it is very difficult to change the initial perceptions of a population. However, what the game does show, which proves a level of accuracy, is that a faction cannot just "build" consent. Using the base case Iraq scenario with an active insurgency, we manipulated the coalition combat units to all be able to provide humanitarian aid in a manner equivalent to humanitarian aid organizations. Over a two-year simulation with all coalition units in Sunni populated areas (37 battalions) focused on providing an exaggerated amount of aid, there is a clear increase in production. However, even under this design, consent either stayed at the initial conditions or eventually decreased. However, with the same units now providing security, and only non-maneuver units providing aid, we see some excursions where consent increased and a slightly higher value in consent than the aforementioned

scenario. These results are encouraging in that you cannot just buy a population's consent. This falls into line with the importance of Unity of Effort in Counterinsurgency Operations as discussed in FM 3-24 (U.S. Army, 2006).

Military efforts are necessary and important to counterinsurgency (COIN) efforts, but they are only effective when integrated into a comprehensive strategy employing all instruments of national power. A successful COIN operation meets the contested population's needs to the extent needed to win popular support while protecting the population from the insurgents.

This goes back to the complexity of the definition of consent. However, along the same lines a large part of consent is production and an important part of production is determined by the ability to hire human capital. The ability to hire is determined on price for labor and consent toward the hiring faction. This price for labor is set, and no faction can change this price. This places a great restriction on wealthy factions, such as the coalition in Iraq, who can raise the price paid for labor to ensure human capital is obtained where needed.

Another capability PSOM provides is the ability to share the credit for production of goods or the provision of security. Throughout this research the coalition shared its production credit with the Iraqi government. This did in fact influence the population's consent toward the government which is a key factor in the development of legitimacy toward the host nation (U.S. Army, 2006).

In looking at security we found some effects that should be explored further. Security is greatly influenced by the unit's rules of engagement and risk tolerance, which makes sense. However, the stances, although statistically significant, are arguably not significant enough. Once again, looking at two years of combat in the base case Iraq scenario where there is an active insurgency, we found there to be only a slight difference between all coalition maneuver battalions providing aid and all coalition maneuver battalions securing through patrols. The mean difference between the two is 0.1, and when looking at the extremes in the final DOE where the coalition did its best for security while patrolling and the coalition did its worst for security while providing aid, the difference is only 0.5. Since security falls within a range of 0 to 10, a difference of 0.5, while "statistically significant," may not appear exceptionally significant for the purpose

of analysis. The abilities of stances to affect MOEs can be adjusted within the settings; however, this is not a task to be taken on by an individual who does not completely understand the model's algorithms.

Finally, as discussed earlier, there are questionable implications about the absolute changes in unit characteristics. Initially this seems illogical; if you make every company in Iraq 20% better you would expect different results in security and consent. This can be argued with the recent surge of forces in Iraq. However, the recent success in Iraq is much more than a result of increased manpower and capability; it is the result of the well-planned use of these increased attributes. It is beyond the scope of this study and our current abilities to develop multiple courses of action to test this capability within the model. This should be studied prior to using PSOM as a tool for capability analysis.

3. Potential Uses for the Peace Support Operations Model

PSOM is a campaign level wargame and therein lies its greatest potential. Combat is stochastic in nature (Lucas, 2000), and the addition of a complex populace, IGOs, and political players only add to the uncertainty of war. The limited stochastic nature of PSOM places a tremendous limit on using a batch mode to analyze scenarios. In 2006 the Al-Askari Mosque in Samarra, Iraq was destroyed by Sunni insurgents resulting in violence across Iraq. This level of resolution would have to be deliberately built into the scenario file in PSOM and would thus be limited to the scenario developer's creativity. However, such realistic actions which can change the state of a campaign can be expected to occur with the human-in-the-loop. Without the human players such extreme actions would more than likely not happen. As Clausewitz stated:

They aim at fixed values; but everything in war is uncertain, and calculations have to be made with variable quantities

—Carl Von Clausewitz, On War

The Peace Support Operations Model provides an opportunity for a large number of players to interact and to learn from a simulated population. This population is dynamic, consisting of the emersion of many diverse social groups which have the ability to change over time. The results of the algorithms, which are constantly being updated

and are easily modified, have proven feasible within this study. There is no doubt valuable lessons can be learned for use in staff development and training.

In the same argument, wargaming is of tremendous importance in course of action development. If the manpower is available to provide a human-in-the-loop wargame, PSOM can provide insight into stability operations where traditional lethality focused models cannot. Once a scenario is developed and a plan implemented, it takes minimal effort to change the underlying assumptions about the population. For example, a plan can be implemented against a multitude of modified populations and results will vary accordingly. As long as the decision makers understand that the complexity of social modeling ensures no model is a crystal ball, this implementation shows potential.

As a wargame PSOM provides an environment that brigade and higher staffs can easily work within. At the same time PSOM provides a large list of outputs which can easily be transformed into strategic level MOEs to parallel current doctrine. These attributes strengthen the argument for its use as a wargame.

The limited sensitivity we found in the model toward unit attributes causes some initial concern about the model's use in force development. Based on our results alone the model does not appear sensitive enough to attribute changes. However, as stated earlier, these forces were not used in any intelligent manner, so the results are questionable. Further analysis on this aspect of the model is recommended prior to its use in force capability analysis.

Also, PSOM proves sensitive to time length and therefore time step. Although it is a Peace Support simulation, its use for short-term operations such as disaster relief or hasty interventions could be limited. If the needed response resolution from an operation is to be measured in days or weeks, PSOM could provide skewed results. The same assumption can be made for tactical level operations. The creators of PSOM recommend it for task force level use and higher. The simulation's unit interaction algorithms are conducted at a company level resolution. Therefore, further analysis is needed to determine if PSOM could be an effective tool for company and below level training and course of action development.

4. Risk Analysis

As with all tools in the military, PSOM has inherent risk if misused. PSOM will not provide the right answer. It will only provide insights as to what happens in its simulated space. And, because it is minimally stochastic, it does not provide a wide range of possible outcomes. This is why the human-in-the-loop aspect is essential. Also, there are a tremendous number of parameters which can affect the game. This aspect makes PSOM very flexible; however, if these parameters are not placed by an expert the resulting MOEs are questionable at best. It is absolutely crucial that a scenario builder not only know how to change the parameters, but understand the algorithms he or she is changing. Currently there are draft manuals for PSOM available which need to be completed prior to its mass use (or the scenario builder needs to have the developers on speed dial).

Finally, prior to the use of PSOM as a learning tool or for course of action development, the scenario and its settings should be data farmed using a similar, but less extensive, methodology to that discussed in this thesis. This will verify the scenario and help prevent questionable outcomes from the realm of possibilities creative players bring to the wargame. As a participant in wargaming, both as a planner and as a student, nothing will shut down the opinion of a military officer faster than infeasible results. The data farming process will act as a large-scale rehearsal to ensure the model and its scenario are acceptable prior to gathering the expensive amount of manpower required for such a wargame.

5. Methodology

Many of the readers of this document are curious about the potential of PSOM. However, the analysis of PSOM was partially used to verify the data farming methodology as a suitable technique to quantifiably assess military simulation models which account for societal phenomenon. Since data farming's introduction during Project Albert in 1999 it has been used repeatedly on a host of agent-based simulation packages to gain insight into both the application and the outcomes. Dr. Horne suggests its implementation in the verification and validation process (Horne, 2004) and we have

implemented it in this thesis with success. By indentifying key factors, developing efficient experimental designs, using high performance computing power to conduct the experiments, and analyzing simulation output with data mining techniques a wealth of information can be gained from a simulation that was designed to be played one step at a time over the course of days. To explore even a fraction of the simulated space covered over the past six months would be inconceivable if it were to be done via a human-in-the-loop game play. Additionally, this was all accomplished with minimal manpower. This methodology is scientific in its background and can provide substantial insights into the rapidly growing field of PMESII models.

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APPENDIX A. SCENARIO EXPERIMENTAL DESIGN

The scenario design of experiment consists of twenty-one factors. The following table shows the first five design points for the DOE and all dependent settings used. For example, although stance is an experimental factor, the substances must be changed to align with the actual stances within PSOM. Factors changed throughout the experiment are highlighted.

	DP 1	DP 2	DP 3	DP 4	DP 5
NGO Stance	8	8	8	8	8
NGO SubStance	4	4	4	4	4
Sunni AIF Stance	1	1	1	1	1
Sunni AIF Sub Stance	1	1	1	1	1
Sunni AIF ATK US	0	0	0	0	0
Sunni AIF ATK Iraqi Gov't	1	1	1	1	1
Coalition Stance	8	8	8	8	8
Coalition Sub Stance	4	4	4	4	4
Coalition intel RelationShip with Sunni AIF	0	0	0	0	0
Coalition ROE	4	5	5	4	5
Coalition Force Protection	1	4	2	5	3
Sunni ROE	2	1	5	4	2
Sunni Force Protection	2	3	2	3	1
Sunni Political Ideology	13	34	30	6	9
Sunni MG Security	0.53	0.375	0.558	0.427	0.347
Initial Threat	1.2	0.2	-1.4	-0.9	-1
Initial Consent	-0.1	1	-0.2	-0.9	0.4
Normalized Initial Consent	4.750208	7.310586	4.50166	2.890505	5.986877
Sunni Marginal Gains	0.591	0.516	0.422	0.338	0.483
Coalition Leadership	72	92	58	98	48
Coalition Experience	55	77	80	91	6
Coalition Reputation	94	48	88	63	84
Coalition Cas Tolerance	19	23	47	8	64
Coalition Turns at location	8	4	6	2	7
HumanAidFactionTargetsandGoodDelivered	0	0	0	0	0

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APPENDIX B. SETTINGS EXPERIMENTAL DESIGN

The settings design of experiment consists of sixty-six factors. The DOE shown below is the first five design points with the inclusive factor values.

	DP 1	DP 2	DP 3	DP 4	DP 5
UnitFirePower	93.504	72.352	68.864	77.6	86.304
UnitProtection	99.92	107.56	94.52	96.12	90.48
UnitSensor	59.76	58.98	40.4	53.38	55.9
UNitIntel	22.328	20.272	22.68	17.448	19.632
UnitPhysicalCamo	1.1608	1.1068	0.9076	0.948	1.186
UnitSocialCamo	0.8228	0.928	1.0468	0.8708	0.9668
UnitMobilityPerMan	35.352	28.236	29.868	25.788	26.88
UnitChangeAttitudePerMan	3.2628	3.2544	2.7096	3.4896	3.3936
UnitCrime	1.7784	2.3424	1.6608	2.3856	2.1088
UnitPolicing	2.9292	3.0072	2.9364	2.7132	2.6496
UNitCollateralDamage	7.7588	7.63	6.916	7.6272	7.1932
UNitSize	81	102	98	84	77
UnitPalitive	0.2729	0.3341	0.3144	0.2506	0.3366
StanceAttacksUnit	0.2963	0.3251	0.2668	0.3011	0.3182
StanceProtectPopulation	0.4459	0.3736	0.4258	0.3982	0.3394
StanceProvideAid	0.1688	0.1663	0.173	0.191	0.189
StanceModifyPerception	0.4624	0.3634	0.4694	0.468	0.4302
StanceExtort	0.2715	0.0747	0.2289	0.1206	0.1293
StanceCounterCrime	0.2555	0.2863	0.3086	0.3084	0.2899
StanceIntelGather	0.5796	0.446	0.5658	0.5134	0.4982
StanceQRF	0.3246	0.3494	0.3755	0.3341	0.4696
StanceAVGSize	30.828	32.232	33.204	26.04	27.084
StanceProtectionModifier	0.9491	0.9264	0.7558	0.8832	0.7763
StanceMobilityModifier	0.9764	1.0988	0.8124	1.1416	0.9984
StanceDetectabilityModifier	1.415	1.4141	1.128	1.1208	0.9826
StanceDetectionModifier	1.4952	1.4526	1.6902	1.4214	1.7004
StanceRecognitionModifier	1.1948	0.9812	0.8716	0.8448	1.09
PopulationDecisionRadius	56.28	48.18	48.52	54.84	49.92
PopulationMemoryCoef	3.546	2.556	2.9712	3.4176	3.504
PopulationConsentPoliticalMScaler	-0.6954	-0.9434	-0.9565	-0.865	-0.6634
PopulationConsentPoliticalCScaler	0.0855	0.0807	0.0933	0.0979	0.1185
PopulationAverageTermInPrison	2.802	2.538	2.76	2.8464	2.5884
PopulationSelfPresenters	0.5826	0.5448	0.4596	0.5152	0.4714

PopulationPoliceClearRate	0.2518	0.2385	0.2919	0.2268	0.2923
PopulationInfectionMargGains	0.2295	0.2017	0.2108	0.1946	0.2072
CombatModQueDecayRate	0.0143	0.0136	0.0147	0.0139	0.0156
PercentForceonDuty	0.2712	0.3176	0.2711	0.3196	0.3354
PlanningDelay	6.5352	5.9184	6.132	4.9296	5.8296
OperationTime	4.6368	4.1648	4.3952	3.8208	4.3856
RecupTlme	10.716	8.98	11	8.62	11.052
AvgDistanceTraveled	7.3024	8.3008	8.4256	7.1136	6.432
MaxFatigue	0.7462	0.6826	0.8029	0.7197	0.9357
FatigueDropOff Factor	3.6544	4.3552	3.712	4.512	3.4192
ForceProtectionMean	2.6016	2.6292	3.0324	3.1896	2.4348
ForceProtectionKValue	0.3547	0.2478	0.3568	0.3288	0.2521
ForceProtectionMod	0.33	0.2456	0.3475	0.3516	0.3449
MeanROE	2.8176	2.9484	3.5784	2.5032	3.2736
ROEKValue	0.2874	0.3589	0.261	0.2636	0.2696
ROEMod	0.2778	0.2612	0.2896	0.3532	0.3272
MaxLeadershipMod	2.1992	1.972	1.612	1.632	1.6984
MinLeadershipMod	0.1615	0.1602	0.2021	0.1613	0.2214
LeadershipDropOffFactor	0.0186	0.0175	0.0192	0.0207	0.018
FamiliarizationStranger	0.5306	0.56	0.5136	0.4022	0.5668
FamiliarizationNative	1.8528	2.1352	2.1632	2.1408	1.9304
FamiliarizationLearninig	0.0982	0.0904	0.1146	0.105	0.101
ExperienceConscript	0.2037	0.2291	0.1912	0.2024	0.1704
ExperienceVEt	2.244	1.8736	1.9704	1.988	2.2392
ExperienceLearningFactor	0.0842	0.0965	0.1047	0.0879	0.0752
InterUnitBaseCasATT	0.0872	0.1044	0.0875	0.1007	0.1036
InterUnitBaseCasualtiesDEF	0.1082	0.1086	0.0905	0.1044	0.0852
InterUNitBaseContactSize	29.292	26.076	26.52	29.844	24.348
GoodExpected	0.4174	0.4004	0.593	0.5432	0.5496
GoodProtectionValuePower	10880	8636	10856	11092	11624
GoodProtectionValueWater	64.344	77.812	56.364	83.58	74.732
GoodProtectionValueEducation	63.364	76.02	71.54	65.184	83.664
GoodProtectionValueHealthCare	132.84	144.54	166.08	124.56	172.62

APPENDIX C. CUMULATIVE EXPERIMENTAL DESIGN

The first five design points of the cumulative experimental design are shown below.

	DP 1	DP 2	DP 3	DP 4	DP 5
Coalition Stance	0	0	0	0	0
Simulation Time	60	60	60	60	60
Unit Fire Power	81	56	63	69	125
Unit Protection	150	75	94	113	144
Unit Sensors	131	138	56	81	94
Unit Change Attitude	4	6	3	10	2
Unit Manpower	75	50	113	106	81
Unit Intelligence	48	29	44	24	20

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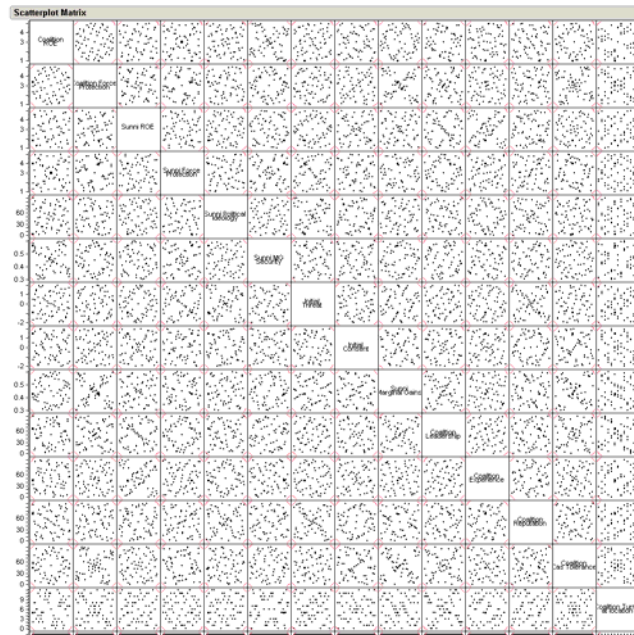
APPENDIX D. CORRELATION AND SPACE FILLING QUALITY OF FACTORS

This appendix shows the pair-wise correlations and space filling qualities for the quantitative variables for each DOE. The use of NOLHs results in low pair-wise correlations while maintaining good space filling properties.

A. SCENARIO EXPERIMENTAL DESIGN

Correlations													
	Coalition RCE	Coalition Force Protection	Summi RCE	Summi Force Protection	Summi Political Ideology	Summi MS Security	Initial Threat	Initial Consent	Summi Marginal Gains	Coalition Leadership	Coalition Experience	Coalition Reputation	Coalition Cas Tolerance
Coalition RCE	1.0000	-0.0000	-0.0000	0.0001	-0.0091	0.0012	-0.0006	0.0074	0.0054	-0.0056	0.0065	0.0076	-0.0003
Coalition Force Protection	-0.0000	1.0000	-0.0000	-0.0000	-0.0032	0.0069	-0.0047	0.0036	-0.0148	-0.0129	-0.0064	0.0057	-0.0038
Summi RCE	-0.0000	-0.0000	1.0000	-0.0000	0.0028	0.0193	-0.0051	0.0025	-0.0024	0.0037	-0.0012	-0.0118	-0.0032
Summi Force Protection	0.0001	-0.0000	-0.0000	1.0000	-0.0019	-0.0033	0.0069	0.0039	0.0068	0.0064	-0.0014	-0.0062	-0.0042
Summi Political Ideology	-0.0091	-0.0032	0.0028	-0.0019	1.0000	-0.0017	-0.0045	-0.0037	-0.0008	-0.0042	-0.0044	-0.0066	-0.0000
Summi MS Security	0.0012	0.0069	0.0193	-0.0033	-0.0017	1.0000	-0.0095	0.0017	-0.0010	-0.0019	0.0091	-0.0122	0.0070
Initial Threat	-0.0006	-0.0047	-0.0051	0.0069	-0.0045	-0.0095	1.0000	-0.0033	-0.0201	-0.0064	-0.0069	0.0049	0.0039
Initial Consent	0.0074	0.0036	0.0025	0.0039	-0.0037	0.0017	-0.0033	1.0000	-0.0086	0.0147	-0.0005	-0.0151	0.0083
Summi Marginal Gains	0.0054	-0.0148	-0.0024	0.0068	-0.0008	-0.0010	-0.0201	-0.0086	1.0000	0.0163	-0.0037	-0.0075	-0.0182
Coalition Leadership	-0.0056	-0.0129	0.0037	0.0064	-0.0042	-0.0019	-0.0064	0.0147	0.0163	1.0000	0.0067	0.0038	0.0039
Coalition Experience	0.0065	-0.0064	-0.0012	-0.0014	-0.0044	0.0091	-0.0069	-0.0005	-0.0037	0.0067	1.0000	-0.0080	-0.0020
Coalition Reputation	0.0076	0.0057	-0.0118	-0.0062	-0.0066	-0.0122	0.0049	-0.0151	-0.0075	0.0038	-0.0080	1.0000	0.0014
Coalition Cas Tolerance	-0.0003	-0.0038	-0.0032	-0.0042	-0.0000	0.0070	0.0039	0.0083	-0.0182	0.0039	-0.0020	0.0014	1.0000
Coalition Turns at location	-0.0015	-0.0179	-0.0130	-0.0008	0.0107	-0.0177	0.0048	0.0026	-0.0035	-0.0244	0.0009	-0.0211	0.0099
HumanAndFactionTargetsandGoodDelivered	0.0000	-0.0000	-0.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

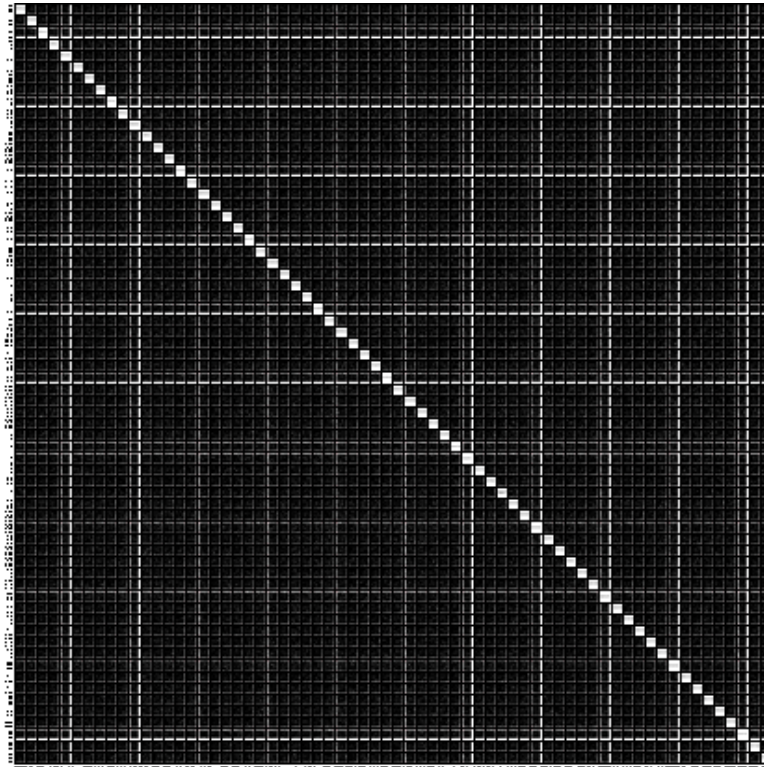
Pair wise correlations for the quantitative factors in the scenario DOE. The largest absolute value is .02.



Scatter plot with factor names on the diagonal of the Scenario DOE. This scatter plot displays the space filling quality of the NOLH for this experiment.

B. SETTINGS DOE

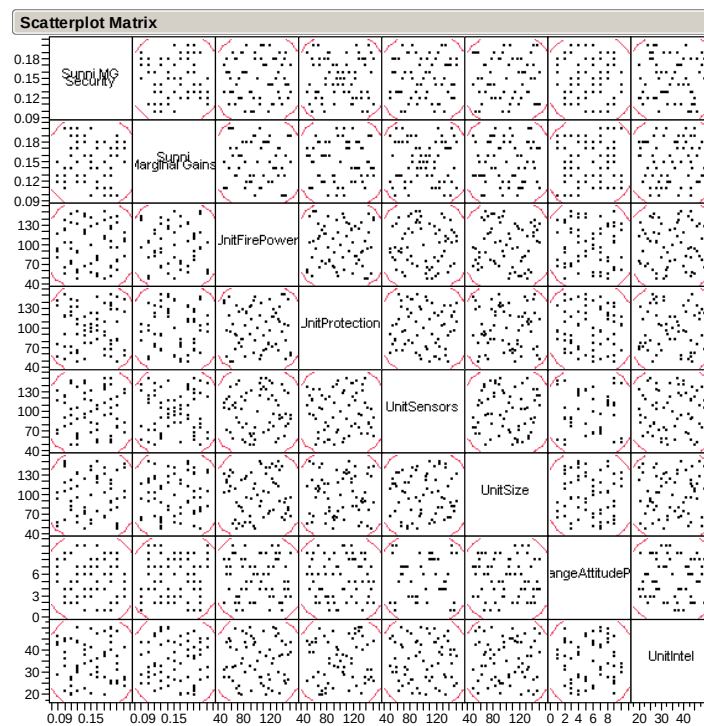
Because of the number of factors and the number of design points, the correlation matrix for the setting DOE cannot be displayed in this appendix. However the greatest correlation was .0025, so clearly our results qualify as “nearly orthogonal”. Below is the scatterplot matrix. This figure is clearly illegible. Its purpose is to display the space filling power of COL Hernandez’s (2008) expansion of the NOLH.



C. CUMULATIVE DOE

Correlations								
	Sunni MG Security	Sunni Marginal Gains	UnitFirePower	UnitProtection	UnitSensors	UnitSize	UnitChangeAttitudePerMan	UnitIntel
Sunni MG Security	1.0000	-0.0001	0.0095	-0.0024	0.0085	0.0177	-0.0172	-0.0006
Sunni Marginal Gains	-0.0001	1.0000	-0.0060	-0.0065	0.0002	0.0037	0.0532	0.0017
UnitFirePower	0.0095	-0.0060	1.0000	-0.0000	-0.0000	0.0061	-0.0331	0.0048
UnitProtection	-0.0024	-0.0065	-0.0000	1.0000	0.0000	-0.0112	-0.0167	0.0072
UnitSensors	0.0085	0.0002	-0.0000	0.0000	1.0000	-0.0010	-0.0029	-0.0106
UnitSize	0.0177	0.0037	0.0061	-0.0112	-0.0010	1.0000	-0.0127	-0.0073
UnitChangeAttitudePerMan	-0.0172	0.0532	-0.0331	-0.0167	-0.0029	-0.0127	1.0000	0.0102
UnitIntel	-0.0006	0.0017	0.0048	0.0072	-0.0106	-0.0073	0.0102	1.0000

Above are the pair wise correlations for the quantitative factors in the scenario DOE. The largest absolute value is .05.



This scatter plot with factor names on the diagonal of the Cumulative DOE shows the space filling quality of this design of experiment.

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APPENDIX E. HUMANITARIAN AID SETTINGS

In order to explore the consent metric, we gave all maneuver battalions humanitarian aid providing capabilities. The below screen shot shows the attributes we gave these units.

The screenshot shows the 'Data and Settings Editor' window with the 'Unit Abilities' tab selected. The unit type is 'Armd Sqn (CR2)'. The 'Military Values' section contains various attributes for the unit, and the 'Reconstruction Values' table shows the unit's capabilities in different sectors. A red circle highlights the 'Reconstruction Values' table.

Military Values

Name: Armd Sqn (CR2)

Domain: Land (dropdown) Mobility: 30

Firepower: 80 Change Attitude: 3

Protection: 100 Crime: 2

Sensors: 50 Policing: 3

Intelligence: 20 Collateral Damage: 7

Social Camouflage: 1

Physical Camouflage: 1

Manpower: 90

Max Footprint Size: 0

Logistics Cost: 0

Logistics Provision: 0

Domain Modifiers

Land: 1

Air: 0.2

Maritime: 0

Reconstruction Values

Economic Sector	Infrastructure	Human Capital	Palliative
Income	0.0005	0.025	1
Power	0.0005	0.025	1
Sanitation	0.0005	0.025	1
Potable Water	0	0	1
Education	0	0	1
Healthcare	0.0005	0.025	1
Shelter	0.0005	0.025	1
Information	0	0	1
Internal Order	0	0	1
Administration	0	0	1
Food	0	0	1
Transport	0	0	1
Military	0	0	1
Politics	0	0	1
Oil	0	0	1

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