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IMPROVING THE ENHANCED COMPANY OPERATIONS FIRE SUPPORT TEAM

by

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June 2011

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The researcher uses an agent-based model to develop data on the frequency and duration of contacts with enemy forces. Subsequently, he uses a deterministic fatigue model to gain insight into the effects of various rest policies over a set of noise factors. Finally, the research uses the data gathered from the agent-based and fatigue models to populate a discrete-event model. This model represents the fire-support process. State-of-the-art design of experiments is used to explore the discrete-event model.

Analysis of the results of the discrete-event model suggests that authority to clear fires needs to be pushed down to the FiST from higher levels. Further analysis demonstrates that technological aids to the FiST are not as important as suspected. Task saturation does not appear to be a significant cause of mission failure. Finally, FiSTs, as currently constructed, fail in an ECO environment in the first fifteen days.

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IMPROVING THE ENHANCED COMPANY OPERATIONS FIRE SUPPORT TEAM

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THESIS DISCLAIMER

The reader is cautioned that the computer models presented in the research have not been exercised for all cases of interest. While every effort has been made within the time available to ensure that the programs are free of computation and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACE	Air Combat Element
AI	Area of Influence
AO	Area of Operations
ARG	Amphibious Ready Group
BDA	Battle Damage Assessment
C2	Command and Control
CAS	Close Air Support
CASEVAC	Casualty evacuation
CFF	Call for Fire
CE	Command Element
CLT	Company Landing Team
CW-IED	Command Wire Improvised Explosive Device
DO	Distributed Operations
DOE	Design of Experiments
DOTMLPF	Doctrine, Organization, Training, Material, Leadership, Personnel, and Facilities
ECO	Enhanced Company Operations
EFSS	Expeditionary Fire Support System
EMAGTF	Expeditionary Marine Air Ground Task Force
EMO	Enhanced MAGTF Operations
EO	Enhanced Operations
EOS	End of Service
EWTG-PAC	Expeditionary Warfare Training Group Pacific
FAC	Forward Air Controller
FARP	Forward Arming and Refuelling Point
FAST	Fatigue Avoidance Scheduling Tool
FiST	Fire Support Team
FO	Forward Observer
FSC	Fire Support Coordinator

FSCC	Fire Support Coordination Center
FSO	Fire Support Officer
F/W	Fixed-Wing
GCE	Ground Combat Element
IDF	Indirect Fire
IED	Improvised Explosive Device
IMPRINT	Improved Performance Research Integration Tool
ISR	Intelligence, Surveillance, or Reconnaissance
JFO	Joint Fire Observer
JTAC	Joint Terminal Attack Controller
LCE	Logistics Combat Element
LCMR	Lightweight Counter Mortar Radar
LOE	Limited Objective Experiment
MAGTF	Marine Air Ground Task Force
MANA	Map-Aware Non-Uniform Automata
MANPADS	Man-Portable Air-Defense Systems
MAWTS-1	Marine Air Weapons and Tactics Squadron One
MCAGCC	Marine Corps Air Ground Combat Center 29 Palms
MCWL	Marine Corps Warfighting Lab
MEU	Marine Expeditionary Unit
MOE	Measures of Effectiveness
MOS	Military Occupational Specialties
NBNOLH	Nearly Balanced Nearly Orthogonal Latin Hypercube
NGF	Naval Gun Fire
nm	Nautical Miles
NPS	Naval Postgraduate School
OLH	Orthogonal Latin Hypercube
QRF	Quick Reaction Force

Recon	Reconnaissance
RO	Radio Operator
SACC	Supporting Arms Coordination Center
SAFTE	Sleep, Activity, Fatigue, and Task Effectiveness
SAM	Surface-to-Air Missile
SATCOM	Satellite Communications
SEAD	Suppression of Enemy Air Defenses
SEED	Simulation Experiments and Efficient Design
SME	Subject Matter Expert
SOP	Standard Operating Procedure
TTECG	Training and Tactical Exercise Control Group
UAS	Unmanned Aerial System
UHF	Ultra-High Frequency
USMC	United States Marine Corps
VHF	Very High Frequency
VIED	Victim-Activated Improvised Explosive Device
XO	Executive Officer

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EXECUTIVE SUMMARY

Marine units commonly take responsibility for larger battle spaces in counterinsurgency warfare and stability operations than a larger unit would take in conventional operations. This expansion of responsibility at the lower levels of the Marine Corps requires a rethinking of how command and control is practiced throughout the Marine Corps. The Marine Corps' response to this challenge is to develop practices that will enable Marines to perform what it has dubbed Enhanced Operations (EO). The Commandant of the Marine Corps identified Fire Support as a key area in which significant change and experimentation must occur.

This research utilizes an agent-based simulation tool, a deterministic fatigue model, and a discrete-event model to evaluate the effects of Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMPLPF) policies on the effectiveness of the Fire Support process for a Company Landing Team (CLT) participating in Enhanced Company Operations (ECO). In an ECO environment, the CLT has only a limited communications connection with the higher commander that doctrinally coordinates fire support activities between subordinate units and with supporting agencies. Further, the CLT may be responsible for a very large amount of area, and have different types of enemy units and terrain to contend with over an extended period of time. The CLT's Fire Support Team (FiST) has to operate under these conditions, and possibly with expanded authority to redress the communications shortfall.

This research examines the ability of the proposed ECO FiST to sustain performance in a mid-intensity environment. Additionally, this research identifies the factors that contribute most to FiST effectiveness. The results of this research provide DOTMLPF recommendations for the Marine Corps Warfighting Lab (MCWL) to use as it continues to develop its ECO and Enhanced Marine Air Ground Task Force (MAGTF) Operations (EMO) experiments.

MCWL generated the scenario studied in this research. The scenario depicts low- to mid-intensity combat in the area of Marine Corps Air Ground Combat Center 29 Palms. The enemy force has the ability to conduct indirect fire, plant improvised explosive devices, and move about the battle space with a limited motorized capability. The CLT is limited to foot patrols within an Area of Operations (AO), though it possesses countermortar radar and various unmanned aerial systems. Additionally, there are two reconnaissance teams operating beyond the bounds of the CLT’s AO. The distillation of this scenario, incorporated into the Map Aware Non-Uniform Automata (MANA) simulation environment, models where, how frequently, and for how long the CLT is able to gain and maintain contact with enemy units.

State-of-the-art, Design of Experiment (DOE) principles guide the execution of this research through the three models. This enables the researcher to efficiently determine which policies are most effective under a wide variety of conditions. The design factors in this experiment are the size and scope of the FiST’s responsibility, the capacity of the FiST, the activity policy of the FiST, and the fire-support structure of the

FiST. The noise factors are the difficulty of traversing the terrain, the concealment offered by the terrain, the effect of atmospheric conditions on sensors, and the ability of the enemy to conceal their activities. The final design matrix consists of 680 design points.

The design matrix guided 68,000 simulated ECO missions. The researcher's analysis of the output data provided valuable insight into the issues explored. The analytical results of this exploration will help planners at MCWL as they develop future EO experiments and doctrine. Specific findings, based on the scenario examined, include:

- As currently constituted, a FiST will fail to meet performance expectations within the first fifteen days of employment.
- Task saturation is not a significant cause of mission failure.
- The most important policy decision that can be implemented is to delegate weapons clearance authority to the FiST.
- The addition of Command and Control (C2) equipment does not appear to be a significant factor in overall performance.
- FiST rest and responsibility policies do not appear to have a significant effect on performance.

Follow-on work can both improve and expand on this research:

- Using the most up-to-date information from training commands, the models can be made more accurate.
- More efficient software packages could improve the modeling of fatigue.
- The model can be expanded to analyze EMO.

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I. INTRODUCTION

A. OVERVIEW

The Marine Corps Warfighting Lab (MCWL) is conducting experiments to test and refine concepts that will allow future small units to take on a variety of missions and tasks that are currently assigned to larger units. This concept started life under the rubric of Distributed Operations (DO), as it envisioned small units, scattered over a very large area, undertaking missions below the threshold of major combat operations. As this concept matured, its name changed as well, and it is now referred to as Enhanced Operations (EO) (United States Marine Corps [USMC], 2008). No matter the name, the goal is for the Marine Corps to do more with less.

MCWL is currently experimenting with Enhanced Company Operations (ECO), wherein an infantry company is designated as a Company Landing Team (CLT) (USMC, 2008). This CLT is assigned a mission where it operates over 100 miles from its higher headquarters, which reduces the level of communications between them. This separation forces the CLT to take on more responsibility for the coordination of assets that traditionally resided in the battalion or higher levels of command. The goal of MCWL's experiments is to identify the changes to Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) that are necessary to enable a CLT to succeed (USMC, 2008).

One of the key coordinating tasks that a CLT will have to take on is the control of fire support assets that are the doctrinal responsibility of the battalion Fire Support Coordination Center (FSCC). According to Commandant Conway,

> Of all the applications of *Marine Corps Operations in Complex and Distributed Environments* [sic], fires might be that which requires the most immediate attention of our doctrine writers. With battalions, even companies, operating over hundreds of miles and beyond the limits of mutual support, a fresh look at control measures and procedures is required. (USMC, 2008, p. 4)

This research attempts to find robust solutions to this challenge of maximizing the effectiveness of the CLT's use of fire support assets over a wide variety of conditions.

B. BACKGROUND

The Marine Corps doctrinally deploys its forces as Marine Air Ground Task Forces (MAGTFs). A MAGTF consists of four separate elements:

1. The Ground Combat Element (GCE), which is typically built around an infantry battalion and is given additions of artillery, armor, and other specialized ground units.
2. The Air Combat Element (ACE), which is typically built around a tilt rotor squadron and receives additional aircraft types such as heavy lift, helicopter gunships, and jet aircraft, as well as unmanned aerial systems (UASs) and additional command and control (C2) capabilities.
3. The Logistics Combat Element (LCE) provides the logistical support for the MAGTF.
4. Finally, the Command Element (CE) provides the overall command, control, and coordination of the MAGTF.

MAGTFs are created to support a wide variety of operations ranging from disaster relief through major combat operations. The MAGTF just described is a Marine Expeditionary Unit (MEU), which is embarked on shipping and is often the first American military presence on the scene for anything short of major combat operations. The MAGTF can be scaled up or down from a MEU by replacing the components with larger or smaller echelons. Additionally, specialized attachments can be added to custom tailor a MAGTF for specific operations.

Despite the wide range of missions that a MEU typically executes, subordinate units rely heavily on higher echelons for most of the coordination necessary to accomplish their individual tasks. This process works well in situations where communications are easy and units are in close proximity, which allows them to mutually support each other. However, in cases where communications are more difficult, or units are dispersed, coordination and mutual support suffers (USMC, 2008).

1. The Fire Support Team (FiST)

The Company Commander is responsible for coordination of his fires and organizes his personnel accordingly. The FiST is the agency that assists the Company Commander in coordinating and controlling fires.

a. The Current Fire Support Team (FiST)

The present-day FiST employs supporting arms (mortars, artillery, and aviation ordnance) to support the company's scheme of maneuver. These arms are controlled by artillery and mortar Forward Observers (FOs), a Forward Air Controller (FAC), and a Naval Gunfire (NGF) spotter. "The Company Commander may assign an officer as the company Fire

Support Coordinator (FSC) to coordinate supporting arms with the company's scheme of maneuver" (USMC, 2001, p. 1-6). This organization of personnel, while not explicitly doctrinal, has nonetheless evolved into the FiST. Typically, the officer assigned to be the company FSC, or FiST leader, is either the Company Executive Officer (XO) or the Weapons Platoon Commander. In addition to the principals named above, several Radio Operators (ROs) augment the FiST. These ROs bring sufficient types and numbers of radios to monitor all of the necessary fire support and coordination nets. While FiSTs have experimented with various technical aids to enhance coordination and weapons accuracy, the baseline for training still relies on the Marines utilizing paper maps and compasses to execute fire support tasks.

The FiST's employment of supporting arms, either individually or in combination, is subject to the approval of the Battalion FSCC. Thus, when the FiST begins the process of engaging a target, the actual employment of fires is still subject to the FSCC's final approval. The FiST also conducts fire support planning in conjunction with the Battalion FSCC for future operations.

b. The Fire Support Team (FiST) in Enhanced Company Operations (ECO)

The role of the FiST expands significantly in ECO. MCWL envisions the FiST being responsible not only for selecting targets, but also for coordinating all aspects of the engagement. Thus, the FiST is the final approval authority for weapon's release. Additionally, the FiST will take on the FSCC's planning and coordinating responsibilities, not only for their CLT, but also for any friendly forces operating in the CLT's Area of Influence (AI). For the purpose of this research, MCWL has selected a different composition for the FiST to reflect the nature of ECO. An artillery Fire Support Officer (FSO), a mortar FO, three Joint Fires Observers (JFOs), and a Joint Terminal Attack Controller (JTAC) comprise the FiST, in addition to the company FSC. The JFOs are capable of calling in and directing mortars and artillery, as well as spotting targets for aircraft. The JTAC does the same job as a FAC, but is typically an enlisted Marine. Additionally, the battalion may choose to augment this FiST with one of its FACs. Several ROs support the FiST with the necessary array of radios. Despite these changes, the baseline for the CLT FiST is still going to rely on the same map and compass skills.

2. The Fire Support Coordination Center (FSCC)

> The Battalion FSCC performs fire support coordination in terms of closely integrating multiple supporting arms with maneuver. It monitors and receives all fire support requests originating within the battalion. The battalion FSCC ensures that supporting arms are integrated with the scheme of maneuver and that friendly forces are not endangered. It may also coordinate missions for observers to attack targets outside the battalion's zone of action. (USMC, 2001, p. 1-5)

a. The Current Fire Support Coordination Center (FSCC)

The FSCC is the final approval authority within the battalion for the use of supporting arms. It also coordinates with other friendly units to integrate the effects of fires. Additionally, the FSCC has the ability to engage targets on its own initiative. As part of its responsibilities, it monitors both the radio nets used for requesting fires as well as the radio nets on which the battalion's units report their positions. This monitoring enables the FSCC to deconflict fires on the battlefield throughout the battalion's battle space, and to protect friendly units from the inadvertent effects of friendly fires.

b. The Fire Support Coordination Center (FSCC) in Enhanced Company Operations (ECO)

In ECO, MCWL envisions that the FSCC likely will not perform its traditional mission due to the difficulties in communication over large distances. Distance and terrain would degrade the FiST's ability to monitor the Very High Frequency (VHF) and Ultra High Frequency (UHF) radio nets, while satellite communications (SATCOM) is likely to remain limited in the foreseeable future. If the FiST cannot monitor the VHF and UHF nets, it cannot maintain the necessary situational awareness to perform its doctrinal tasks. A possible result of this is that the FSCC will remain aboard the amphibious shipping, where it would work with the ship's personnel in the Supporting Arms Coordination Center (SACC).

C. OBJECTIVE STATEMENT

The CLT FiST is expected to carry far greater responsibilities than its present-day counterpart does, and to do so without significant support from a higher echelon. This research examines the ability of the proposed ECO FiST to sustain performance across a prolonged period of time in a mid-intensity environment. Additionally, this research identifies the factors that contribute most to FiST effectiveness. The results of this research will provide DOTMLPF recommendations for MCWL to use as it continues to develop its ECO and Enhanced MAGTF Operations (EMO) experiments.

D. RESEARCH QUESTIONS

The following questions guide this research:

- How long can the CLT FiST, as currently constituted, function in an enhanced environment?
- How often will the CLT FiST fail to execute tasks due to task saturation?
- What affects do various FSCC/SACC and FiST policies have on the FiST's ability to successfully accomplish its assigned tasks?
- What additions to the CLT FiST's equipment have a positive effect on its ability to successfully accomplish its assigned tasks?
- What FiST Standard Operating Procedures (SOPs) have a positive effect on its ability to successfully accomplish its assigned tasks?

E. BENEFITS OF THE STUDY

This research immediately benefits MCWL. The results enable MCWL to more narrowly define the fires component of its upcoming Limited Objective Experiment (LOE), so that they can build on the conclusions presented here. Consequently, MCWL can extract maximum value from its research as it continues to define ECO and EMO.

F. METHODOLOGY

The researcher has broken this research into three phases (see Figure 1). In the first phase, MCWL develops an ECO scenario that resembles an upcoming LOE in its choice of location. The scenario is a mid-intensity combat operation with an enemy force operating over a large area, while a CLT attempts to control a portion of the area. Concurrently, the researcher gathers data from training commands throughout the Navy and Marine Corps. The commands have been asked to provide data on student performance and to make subject matter experts available for interviews. The information developed in this research determines how long fires support agencies take to complete tasks, and also how many tasks they can coordinate simultaneously.

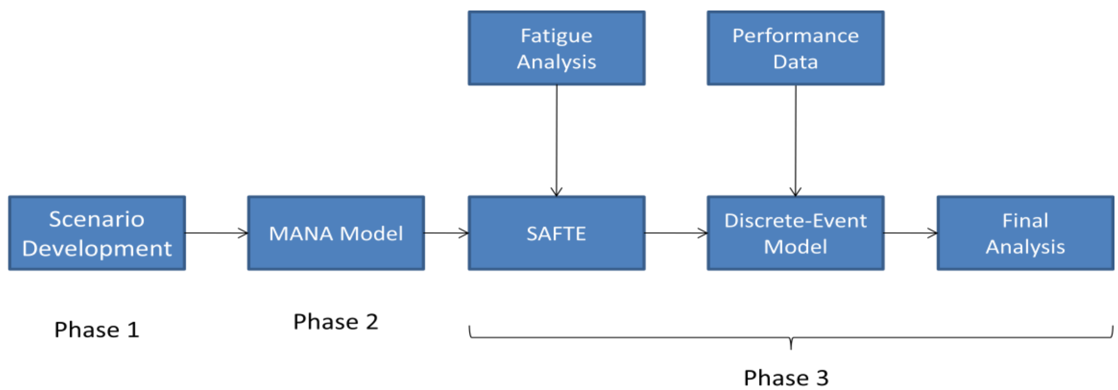

Figure 1. Research progresses from scenario development through final analysis. The data from MANA is used to feed the SAFTE model and, subsequently, both support the discrete-event model. Additionally, data from training commands is also used. The results of the discrete-event model are analyzed to provide the basis for the researcher's conclusions.

Design of Experiments (DOE) principles guides the execution of this experiment, starting with the second phase. This ensures that the problem space is adequately explored, while at the same time efficiently using limited resources. The scenario is modeled and run in an agent-based simulation tool called Map-Aware Non-uniform Automata (MANA). In simplest terms, the MANA scenario stochastically generates interactions between CLT and enemy forces in an intuitively plausible fashion. The output from MANA is used to generate an arrival distribution of specific events that the CLT FiST might have to deal with. Additionally, the analyzed output provides a distribution representing how long the CLT can maintain contact with an enemy unit once it has detected it. This information provides the final phase of the research.

In phase three, the researcher evaluates the endurance and performance of the FiST over time for each design point, based on the factors present and the output from phase two. The research uses the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model (Hursh, et al., 2003) to perform this analysis. The researcher takes these results and uses them to construct a discrete-event model that is supported by the information gathered in all the previous phases. The discrete-event model is used to analyze the overall effects of the variables on the CLT FiST. The analysis of the data from this phase concludes the research.

G. LITERATURE REVIEW

Multiple Marine Corps publications describe the tasks that both the FSCC and FiST are to perform in combat. However, the performance metrics of these tasks are written in ambiguous terms. FSCC and FiST are to "Execute fires to achieve effective combined arms employment in support of [the] company commander's scheme of maneuver/concept of operations during both daylight and limited visibility" (Department of the Navy, 2005, pp. 4-49).

MCWL did conduct an experiment to determine how to construct a CLT FiST, but its focus was on internal procedures and relationships between FiST members (Sullivan et al., 2010). However, the data provided by this MCWL study are not useful for the purposes of this research as it is not statistically significant, owing to the limited number of trials and the fact that all of the members of the experimental FiST were infantry officers and not the usual mix of Military Occupational Specialties (MOSs) and ranks found in a FiST. A further MCWL experiment in Hawaii evaluated a CLT in action, and raised concerns about the ability of the FiST to coordinate and deconflict fires with a distant SACC (Donnely et al., 2010). Both MCWL reports emphasize the need for further study of the CLT FiST.

Recently, researchers at the Naval Postgraduate School (NPS) used the SAFTE model in conjunction with the Fatigue Avoidance Scheduling Tool (FAST) to determine optimum manning for a task. They did this by constructing an optimization problem that specified a minimum level of performance from the workers (Tvaryanas and Miller, 2010). The nature of optimization solutions limits the applicability of this arrangement, however, as it assumes the external conditions are known and remain static throughout the duration of the mission.

A more robust solution to a manning and workload problem was presented by using a discrete-event model to represent the workload of computer specialists for the Turkish Air Force (Camur, 2009). The researcher provided a by using simulation over a range of conditions. However, the nature of their simulation and the tasks that they were modeling did not require them to study fatigue effects on performance. Additionally, the arrival rates for events in the discrete-event model were arbitrarily chosen.

This research builds on both of these previous works, while answering the questions MCWL has posed. Fatigue modeling is incorporated into a discrete-event model to evaluate performance under a range of circumstances. Additionally, the arrival process of events in the discrete-event model is based on data-farming principles from an agent-based simulation. This enables the researcher to find solutions that are effective over a wide range of conditions.

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II. MODEL DEVELOPMENT

This chapter describes the scenario and models used in this research. Additionally, the researcher describes in detail the assumptions and abstractions made for each of the models.

A. SCENARIO DESCRIPTION

1. Overview

The researcher and representatives of the Experiments Division at MCWL developed a scenario that takes place in a mid-intensity combat environment at the Marine Corps Air Ground Combat Center (MCAGCC) in Twentynine Palms, California.

2. General Situation

An insurgent force known as the Reds has been detected operating in the area of Twentynine Palms, also known as 29 Palms (see Figures 2 and 3). They have driven off any local authority that might have challenged them and are now terrorizing the populace. The nearest MEU has been tasked to stabilize the situation. This MEU only has one CLT that can respond to the crisis, as the other two are tasked with similar challenges. The CLT’s mission is to secure an area of 29 Palms until follow-on forces can arrive at an undetermined time in the future to relieve them and restore order to the region.

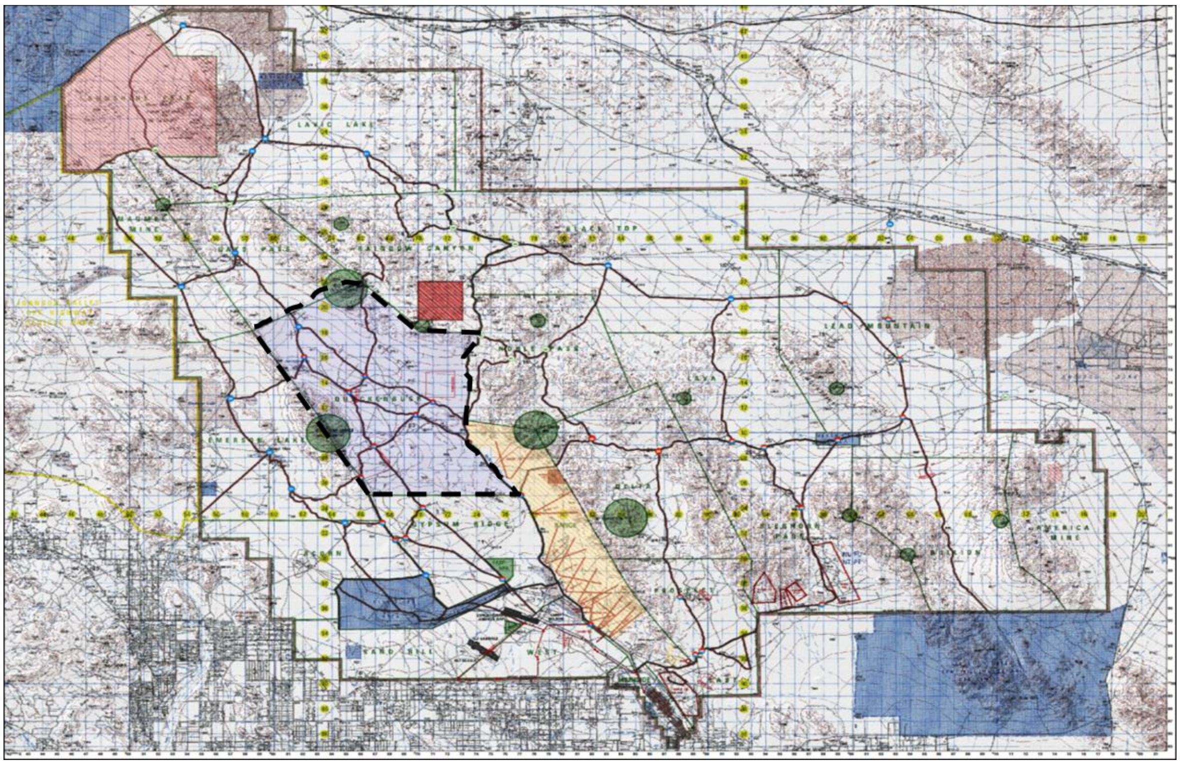

Figure 2. The above is a standard 1:50,000 map of MCAGCC 29 Palms and the surrounding area. The area marked by the dashed lines and shaded is the Quackenbush Range complex.

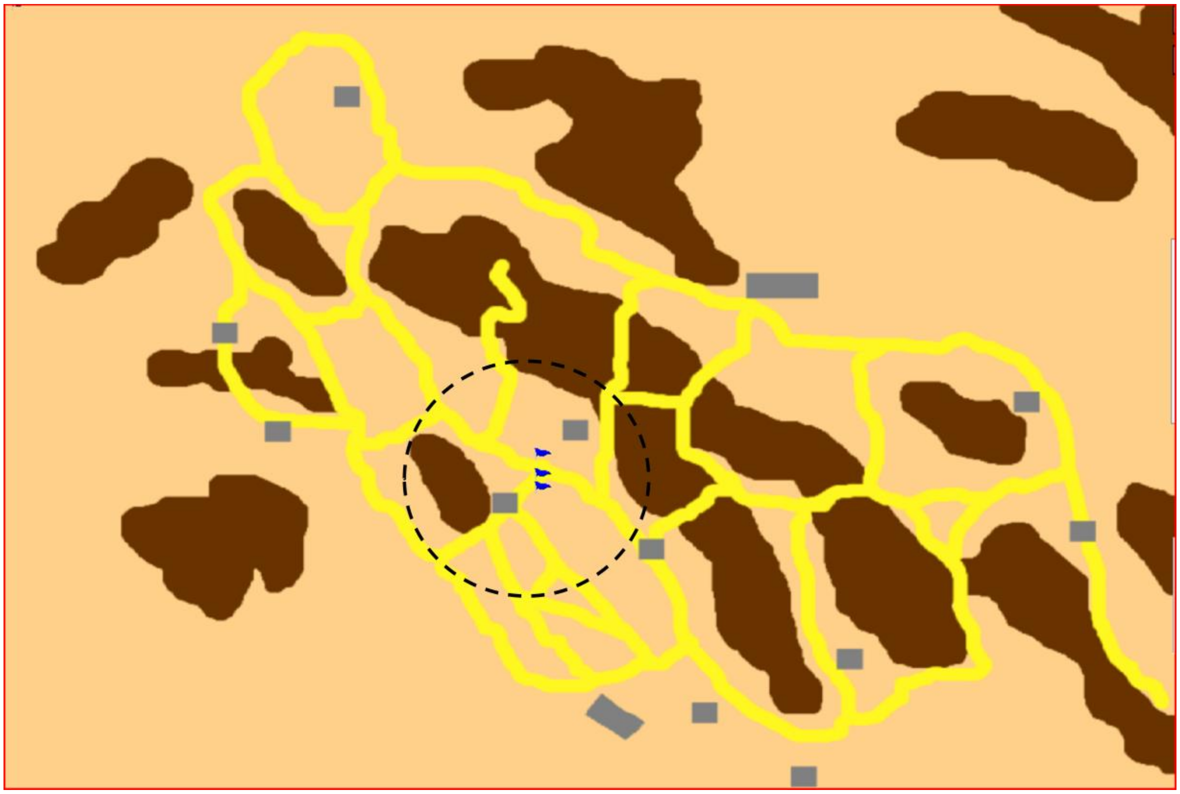

Figure 3. This is the MANA rendering of the same area as shown in Figure 2. The dark brown areas are elevations, the grey rectangles are urban terrain, and the yellow bands are the road network. Since MANA does not handle irregular boundaries well, a circle has been utilized to represent the Quackenbush Range. The blue flags are a MANA artifact and should be ignored.

3. Special Situation

a. Enemy

The Reds are a mixed force of infantry and motorized assets. They can put together a force of four motorized squads, four infantry squads, two improvised explosive device (IED) teams, three surface-to-air-missile (SAM) teams, and two mortar teams. There are additional supporters of the Reds who will emplace victim-activated IEDs (VIEDs). Their infantry and motorized units have access to modern small arms, medium machineguns, and rocket-propelled grenades. Additionally, their motorized units have technical vehicles that mount heavy machineguns. Their IED teams are armed similarly to their infantry squads, but have the ability to use command-detonated IEDs to initiate ambushes. Red mortar teams are armed with low-caliber mortars and are mounted in vehicles. SAM teams are armed with SA-7, -14, or -16 man-portable air-defense systems (MANPADS). Red forces have cell phones and the ability to contact each other for support. Additionally, Red forces have access to commercially acquired night vision devices and binoculars.

Red infantry units focus on defending the area around their supply caches and the local area. Red motorized units patrol the outlying villages, usually stopping in them for variable lengths of time to extract money and supplies from the locals. IED teams and emplacers typically target known routes of CLT forces. Red mortar teams focus on harassing CLT forces and supporting their infantry and motorized units. SAM teams protect the area around the supply caches and also accompany motorized patrols.

Red force tactics emphasize harassment of the CLT forces and the local population. Red forces are cognizant of the CLT's ability to use combined arms effectively in combat, and thus they do not fight CLT forces for longer than fifteen minutes before attempting to break contact and escape. Mortar teams and VIED emplacers always immediately seek to get away from CLT forces, while infantry, IED teams, and motorized squads may fight longer. Red forces typically retreat to their supply caches and rest areas near the Quackenbush Range on MCAGCC, 29 Palms, before venturing forth again.

b. Friendly

The CLT is responsible for an area of operations (AO) that consists of the Quackenbush Range aboard 29 Palms (see Figure 4). A helicopter and tilt-rotor insertion positions the CLT in the Quackenbush Range complex. A CLT is composed of nine rifle squads and three weapons squads. In this scenario, the CLT's commander has attached the weapons squads to the rifle squads. The CLT is equipped with rifles, light and medium machineguns, rocket-launchers, and 60mm mortars. The EMAGTF has given the CLT as attachments a section of four M252 81mm mortars, an Expeditionary Fire Support System (EFSS) 120mm mortar, and a FAC to supplement their JTAC. Besides the vehicle designed to transport the EFSS, there are no other vehicles with the CLT. In addition to weapons, the CLT has two MQ-9b Raven UAS suites with three Ravens each, and an AN/TPQ-48 Lightweight Counter Mortar Radar (LCMR). The CLT has sufficient communications to contact the MAGTF and any unit within the 29 Palms area.

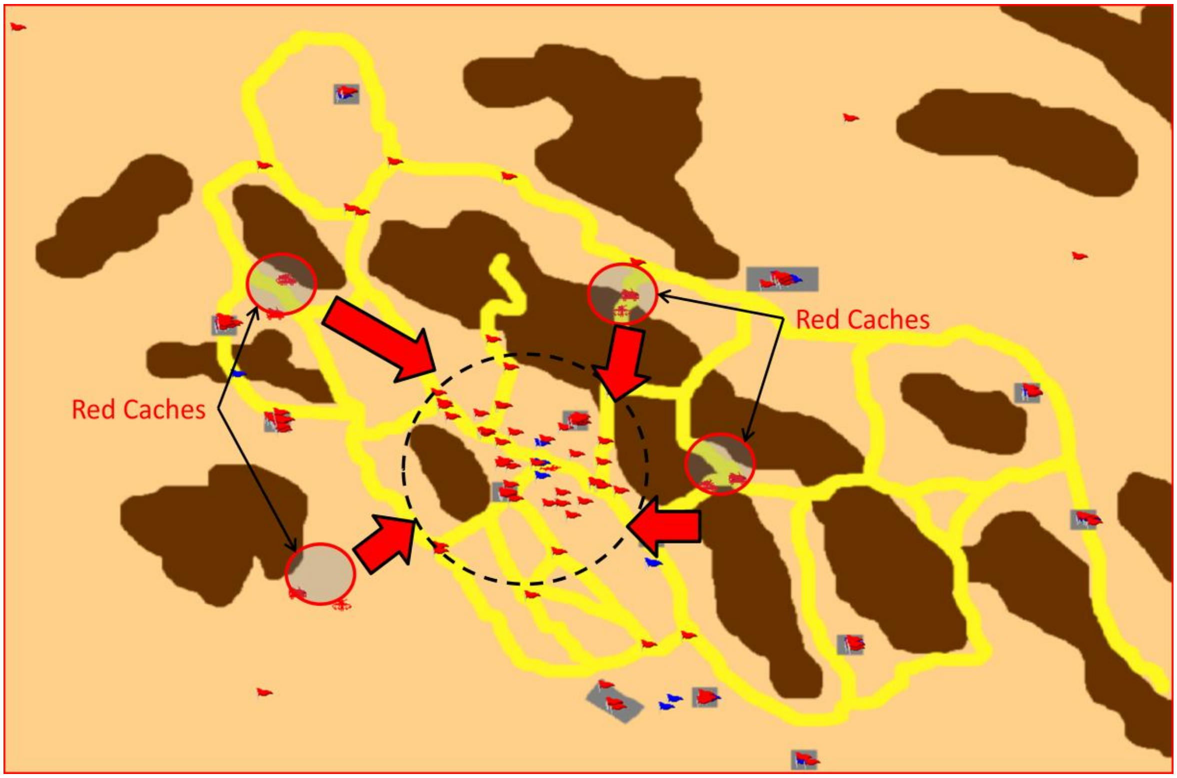

Figure 4. This image of the MANA battlefield displays the position of the Red forces at the start of scenario. They are gathered around their cache sites from which they will begin to penetrate the Quackenbush Range on the axis corresponding to the red arrows. The exceptions to this are the technical vehicles, which will take clockwise or counterclockwise paths between the urban areas (shaded in gray).

The MAGTF remains located aboard the amphibious ready group (ARG) 150 nautical miles (nm) west of the 29 Palms area. The MAGTF has allocated two reconnaissance teams to operate in the 29 Palms AI. These teams are armed and equipped identically to the infantry squads and possess sufficient communications to contact either the CLT or the MAGTF. The MAGTF operates a UAS of its own that can support the CLT, as well as AV-8b Harrier Jets and AH-1Z attack helicopters to provide close air support (CAS).

Additionally, the MAGTF provides casualty evacuation (CASEVAC) and resupply with its MV-22 Ospreys and CH-53E helicopters, respectively.

CLT units patrol the Quackenbush Range and attempt to gain and maintain contact with any Red forces they detect. The CLT maintains a quick reaction force (QRF) to either reinforce patrols that are in contact or to investigate sightings by other sensors. The CLT conducts an average of four squad-sized patrols per day, but at most only two patrols are available at any one time. Patrols last approximately six hours. The QRF is always available. The reconnaissance (recon) teams patrol the areas outside of the Quackenbush Range. They are inserted into a patrol area by air assets for a period of six days, at the end of which they return to the ARG to rest and refit for two days before being inserted into a new patrol area.

4. Mission

The CLT's mission is to prevent the Red forces from consolidating their hold over the 29 Palms region.

5. Execution

CLT and recon team tactics focus on gaining and maintaining contact with Red units so as to utilize supporting arms to defeat them.

6. Administration and Logistics

The MAGTF will resupply the CLT by air on a daily basis shortly after sunset. Recon teams will be resupplied every two days.

7. Command and Signal

The MAGTF headquarters is located aboard ARG shipping. The other CLTs assigned to the MAGTF are pursuing separate missions, but this CLT is the main effort and has priority of support and fires. All requests for aviation fires, resupply, and CASEVAC will go to the MAGTF. The MAGTF will issue directives to the CLT and recon teams on how to coordinate their operations. The FSCC will remain in the SACC. The CLT will maintain a common operational picture of all activities in the AO and AI at their headquarters. The CLT FiST will be located in the CLT headquarters with access to all information.

B. CHARACTERISTICS OF THE MANA MODEL

A full description of MANA and its capabilities is available from the *MANA version 4 User's Manual* and *MANA-V Supplementary Manual*. Both manuals are available from the New Zealand Defense Technology Agency and also on the Simulation Experiments and Efficient Designs (SEED) Center website at NPS (http://harvest.nps.edu/).

The researcher chose MANA to support this research because it provides an accessible environment in which to model agents that change their behavior based on changing conditions, which they either detect or receive input on from their allies. Additionally, a user can set the output controls on MANA to receive the data that is necessary for his or her research. Finally, common spreadsheet programs are able to easily work with the output data from MANA, enabling a researcher to refine the data that he or she may need, even if MANA does not return it in the desired format.

MANA is a time-step, stochastic model in which agents base their actions in each time step on what they see, what their allies see, and their preprogrammed behaviors. In addition, based on external or internal stimuli, these behaviors themselves can change, giving the agent a different "personality" under different conditions. An example in this model is the Red command wire-IED (CW-IED) team. While this agent approaches its destination, it is wary of Blue forces and attempts to avoid any that it sees. However, once the CW-IED team arrives at its target, its behavior changes. It now sets up an ambush and lays in wait for a Blue agent to come close enough to detonate its IED (McIntosh, et al., 2007).

1. Goal

The goal of the MANA simulation is to determine the frequency with which the CLT and EMAGTF detect enemy forces and how long they are able to maintain contact with those forces. This depends on the temporal and spatial relationship between the Red and the Blue forces. The MANA simulation models the CLT in their AO and AI after they have been inserted and set up their base in the Quackenbush Range region of 29 Palms. The response variables we are interested in are where and at what times Red units are detected, and how long the CLT is able to maintain contact with those units. The variables that will be varied in the MANA model are the traficability of the terrain, the amount of concealment it provides, the ability of the Red force to camouflage its infantry forces, and sensor effectiveness.

2. Conceptual Model

The MANA model is essentially a large-scale game of freeze tag. The CLT and EMAGTF forces are "it" while the Red forces attempt to accomplish tasks without being detected and "tagged." Based on their missions, some Red forces, if "tagged," will "freeze" in place for a period of time before running away, while others will immediately seek to escape from the CLT forces upon sighting them.

3. Terrain and Scale

The model takes place in the area occupied by MCAGCC 29 Palms and adjacent land (refer to Figures 2 and 3). The battlefield chosen is 80 kilometers (km) along the east-west axis and 60 km from north to south, centered on the Quackenbush training area. The terrain throughout the area is high desert, with large flat areas cut by dry stream beds and light scrub. There are few hills, but several sharp ridges that can rise over a thousand feet above the surrounding terrain. These ridges are extremely difficult to traverse. A network of all weather roads connects most regions of MCAGCC 29 Palms. The numerous urban combat ranges, the two airfields, and the CLT base itself represent villages on the scenario map. The urban combat ranges and one of the airfields are relocated, so as to ensure a larger spread of habitation and to spur behaviors in the model. These additional villages are connected to the road network. The urban areas are not modeled in any detail except for the fact that they provide concealment and slow movement. Elevations on the battlefield range from 1,000 to 5,000 feet above sea level.

The time scale of events is set such that every model time step equals one minute. This is an important selection, as the output that is being sought would be in minutes and, more importantly, the time step limit of MANA is 100,000 steps. Eighty-six thousand four hundred steps provide two months' worth of simulation time, with the proper amount of detail needed in the discrete-event model. However, the number of time steps means that a single run of the MANA scenario takes about an hour to complete on a modern processor.

4. Red Force

Each Red agent represents a different capability. These capabilities are foot patrols, motorized patrols, indirect fire IDF teams, VIED emplacement teams, and CW-IED teams. All of these units start off at one of the four Red force supply caches surrounding, but outside, the Quackenbush Range (see Figure 4). The foot patrols attempt to occupy areas in and around the immediate vicinity of the Quackenbush Range for one day before moving to a new location. The motorized patrols follow a similar pattern, but they patrol through the outlying villages, staying in them for up to two days. The IDF teams initially begin operations by shelling the CLT base, though they will support Red units that request assistance. The VIED teams proceed through a series of waypoints and emplace an IED at each one for approximately a week, before digging it up and moving it to a better position. The CW-IED teams behave much as the VIED teams, except they move after a shorter period of time if they have not engaged a target.

5. Blue Force (CLT and Recon)

The Blue forces start patrolling at the start of the scenario (see Figure 5). The CLT patrols remain within the boundary of the Quackenbush Range and last approximately six hours if contact is not made with the enemy. The MQ-9s patrol out to a radius of 10 km from the base for an hour each. The Shadow UAS is unlimited by any range restriction, but is limited to approximately two hours of fuel. The recon teams operate beyond the border of the Quackenbush Range for a period of six days before returning to the base to rest and refit for two days. They are then inserted into another section of the area outside the Quackenbush Range to resume patrolling.

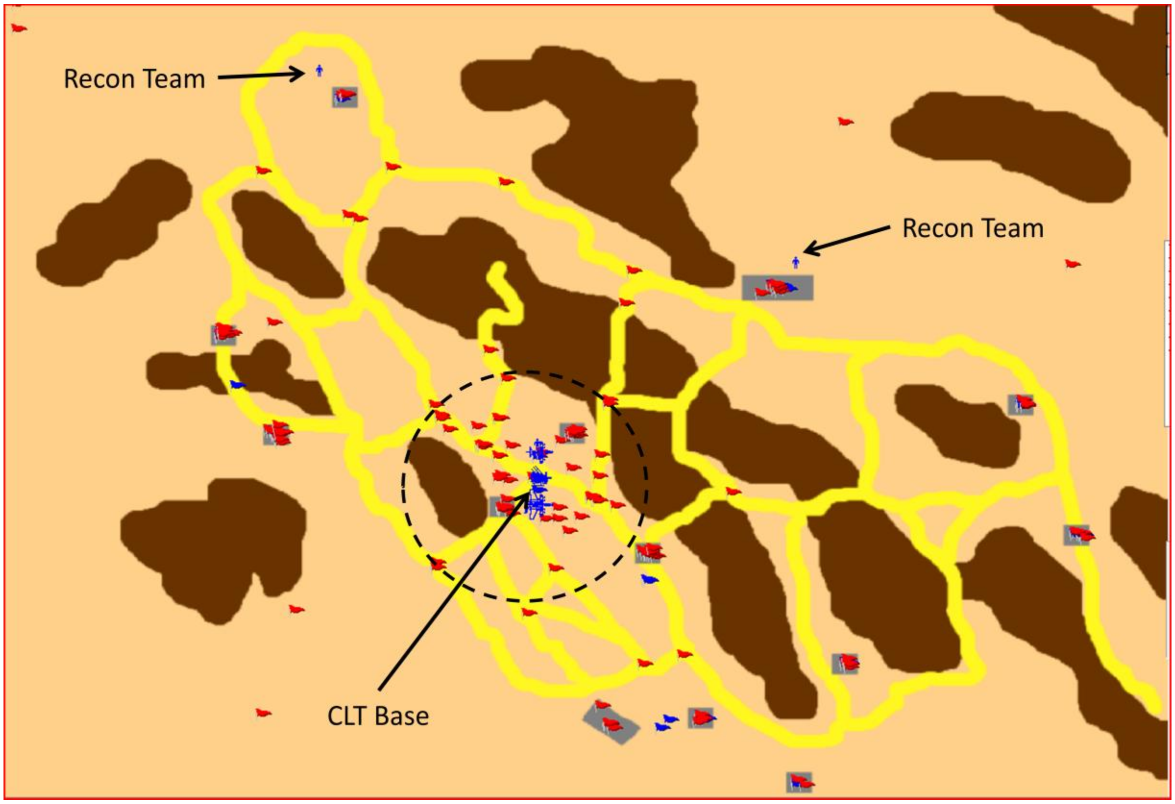

Figure 5. This version of the MANA map displays the starting positions of the CLT and recon teams. The dashed black circle represents the limits of the CLT's AO. All of the CLT units start near the center of the circle and execute random patrol patterns until their patrols expire. At that time, they return to the center to rest or refuel. The recon teams spend six days roaming the general area they are inserted into before being extracted by helicopter to rest.

6. Logistical Support

The Red force resupplies and rests its forces at one of the four supply caches surrounding the Quackenbush Range complex. Red forces spend between one and three days resting before venturing back out on their missions. Blue forces are all resupplied from their base in the Quackenbush Range. The amount of time required to rest and resupply varies depending on the unit type.

7. Data Sources, Abstractions, Assumptions, and Validations

Data for this scenario was primarily developed from the researcher's own experiences in the Marine Corps, specifically at 29 Palms and in Afghanistan. The data inputs were discussed with MCWL to ensure that they considered them valid. Since weapons accuracy and effects are not being modeled except as far as their use would spur behavior by the agents, only the essential details are incorporated into the model. The researcher and MCWL also discussed the details of the various units' behaviors and responses to ensure that they conformed to real-world experience.

In order to start work on this model, numerous assumptions had to be made. Each of these was discussed with MCWL at length to ensure that they were realistic and would not adversely affect the data that was being gathered. These assumptions are:

1. Both the insurgents and Marines can replace their losses seamlessly and without any loss of capability.
2. The civilian population will avoid interactions with both Red and Blue agents.
3. No manned air assets will conduct intelligence, surveillance, or reconnaissance (ISR), as the Enhanced Marine Air Ground Task Force (EMAGTF) needs them for CAS.
4. The Marines have a base chance of 70% to detect an IED and avoid detonation (modified by terrain).
5. Communications between all units are perfect.
6. Any CW-IED will be part of a complex ambush.
7. Red forces will only maintain contact up to fifteen minutes, and then seek to retreat in order to avoid supporting arms.

8. The Red forces always know where the CLT base is.
9. Red supply caches cannot be detected.
10. Red forces that are resupplying are assumed to be hiding in caves and are undetectable.
11. The Red force has access to night vision devices.
12. The LCMR can detect all IDF fire within eight km of the CLT base.
13. A UAS will move towards already located targets in preference to searching for targets.
14. After being engaged and breaking contact, Red units spend time refitting before their next attack.

Since the goal of this model is target detection, a vast array of details that would normally have gone into modeling a large number of units were done away with. Additionally, many of these abstractions support the assumptions made above:

1. All squads have only one agent.
2. All agents are invulnerable.
3. UASs are invisible.
4. While the CLT has nine squads, work details, rest periods, and guard shifts result in only two being capable of patrolling at a time, with a third as the quick reaction force. Thus, only three squads are modeled.
5. While each MQ-9 suite has three Raven-Bs, there is only one control unit per suite, so only two MQ-9s are modeled.
6. The base serves as the refuel and rest point for all USMC units, including the recon teams and Shadow UASs. Once units are refueled, they become inert and invisible until their rest time has elapsed.
7. Since the Red forces are expected to always know the location of the CLT base, an invisible observer is placed next to it. This agent ensures that Red IDF teams can always target the base.

8. Red SAM teams are not modeled, but their presence is felt in the discrete-event model.
9. The CLT and recon teams' weapons are only used to fire on IEDs that have been discovered in order to trigger the proper data output.
10. Only the VIED, CW-IED, and IDF teams have functioning weapons. The IDF teams' weapons serve to track the amount of IDF that patrols and the Blue base would receive. For both types of IED teams, their weapons are only activated when emplaced. Their weapons being discharged represent an IED detonating successfully against a USMC target.

C. CHARACTERISTICS OF THE SAFTE MODEL

The SAFTE model was developed by Dr. Hursh for the Department of Defense. It is designed to examine the effect of fatigue on cognitive task performance. The model enables the researcher to specify a sleep schedule and conditions. Figure 6 depicts the SAFTE model that Dr. Hursh describes thusly:

> The conceptual architecture of the SAFTE model is shown in Figure 1 [6]. The core of this model is schematized as a sleep reservoir which represents sleep-dependant processes that govern the capacity to perform cognitive work. Under fully rested, optimal conditions, a person has a finite, maximal capacity to perform, annotated as the Reservoir Capacity, Rc [sic]. While one is awake, the actual 'contents' of this reservoir are depleted and while asleep they are replenished. Replenishment (Sleep Accumulation) is determined by Sleep Intensity and Sleep Quality. Sleep Intensity is in turn governed by both the Time-of-Day (Circadian Process) and the current level of the reservoir (Sleep Debt). Sleep Quality is modeled as its continuity, or conversely, Fragmentation, in part determined by external, real-world demands, or requirements to perform. Performance Effectiveness is the output of the modeled system. The level of

> Effectiveness is simultaneously modulated by Time-of-Day (Circadian) effects and the level of the Sleep Reservoir. Transient post-sleep decay of performance is modeled by the term Inertia. (Hursh et al., 2003, p. 8)

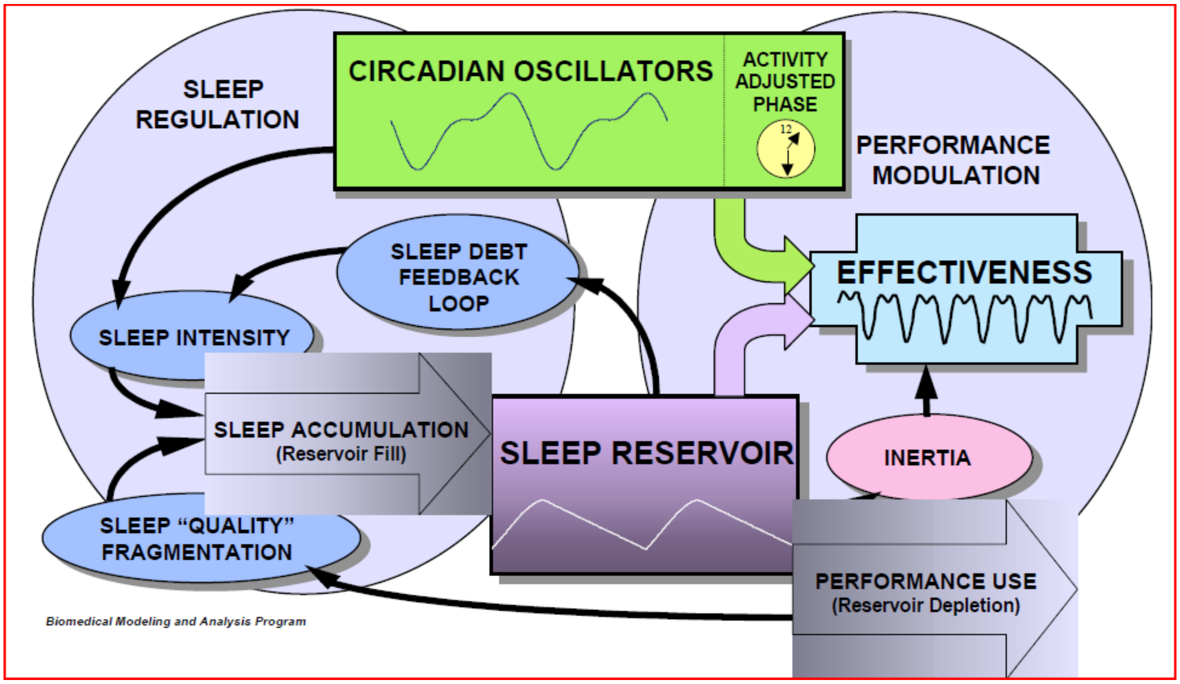

Figure 6. The SAFTE model. Effectiveness is a combination of the individual's circadian rhythm and the amount of sleep that has been stored in the sleep reservoir (From United States Air Force Research Laboratory, 2003, p. 1).

SAFTE's metric for cognitive performance is based on sleep study participants' ability to complete cognitive tasks after certain amounts of sleep deprivation.

> While all of the tasks that the FiST executes would not necessarily fall neatly into the tasks performed by the laboratory participants, it is reasonable to assume that changes in military task performance would correlate with changes in the underlying cognitive task capacity. (Hursh et al., 2003, p. 20)

Therefore, the researcher is using the predicted cognitive effectiveness from SAFTE as a proxy for the FiST's cognitive effectiveness in performing fire support tasks.

1. Goal

The SAFTE model is used in this research to predict the expected performance of the FiST while it is deployed in the 29 Palms area. This information is used to affect the performance of tasks within the discrete-event model. Additionally, fatigue effects are analyzed on their own. The particular effects are:

1. The minimum effectiveness reached by a policy within the first 15 days.
2. The minimum effectiveness reached within the first 30 days.
3. The minimum effectiveness reached over the whole 60 days.
4. The mean effectiveness achieved in the first 15 days.
5. The mean effectiveness achieved in the first 30 days.
6. The mean effectiveness achieved over the whole 60 days.

2. Conceptual Model

This model is based on the concept that the FiST's effectiveness can be calculated by comparing the effectiveness of the FiST leader with that of the rest of the FiST. The FiST leader is separated out from the rest of the FiST because he initiates each FiST mission and he gives final approval. The researcher has aggregated the rest of the FiST together as not all members contribute equally to all missions. The overall effectiveness is calculated by taking the lesser of the FiST leader or the FiST’s effectiveness.

3. Data Sources, Abstractions, Assumptions, and Validations

The data that is input into the SAFTE model originates mostly from analyzing the results of the MANA model. This information is analyzed to provide an arrival distribution for specific events that stimulate FiST activity. Since SAFTE is a deterministic model, the expected values of the arrival distributions are used to create the arrivals; given more time, the actual distributions would be used. If the FiST is awake when an event arrives, there is no effect on their sleep schedule, except to possibly keep them up longer. If the FiST is asleep, however, their sleep schedule will show them as having been woken up for the time necessary to deal with the event and immediately return to sleep. The assumptions for the model are:

1. Each event lasts one hour.
2. The FiST attains asymptotic performance prior to going into action.
3. The FiST receives eight hours of sleep each night for the previous three nights before employment.
4. The FiST is able to sleep for eight hours unless woken for a FiST task.
5. The FiST members have median sensitivity to sleep deprivation.

Assumption 1 assigns an hour to each FiST task. Most tasks themselves would take significantly less time, but the hour reflects the FiST not only dealing with the task at hand, but also looking for follow-up missions, collecting Battle Damage Assessments (BDA), debriefing themselves and any outside agencies, and the myriad other small tasks that occur after an engagement.

Assumption 2 posits that the FiST has trained extensively together for some time and has reached its peak performance level. In one fatigue experiment, the researchers note that some aspects of performance continue to increase despite sleep deprivation (Elliot et al., 2002). One explanation offered for this is that the fatigue portion of most of these experiments typically lasts about 36 hours, and the teams are usually still learning and developing more efficient techniques to meet their performance goals before the experiment ends, which offsets the effects of fatigue (Chaiken et al., 2008). Learning and team task adaption are beyond the scope of this research, and Assumption 3 enables the researcher to keep the models focused on measuring the effect of fatigue on cognitive effectiveness.

Assumption 4 is the most problematic, as it assumes that members of the FiST will not nap during their "awake" time. In reality, a fatigued member of the FiST would likely be sent to rest and recuperate until he recovered sufficiently to fully contribute to the team. However, a more dynamic model was beyond the capability of the researcher to develop in the time available for this research.

Assumption 5 assumes that the CLT members have median sensitivity to sleep deprivation. While individuals differ in their susceptibility to sleep deprivation,[1] median susceptibility provides an excellent baseline against which future comparisons can be made.

The complexity of studying the effects of fatigue on a population, particularly a simulated population, requires a couple of abstractions to be made. The first one is that no provision is made in the model for the FiST or a member of it to take a nap during their shift if they have not had sufficient sleep. The second abstraction is that the only events that are tracked are fire-support events. The rest of the FiST's activity and responsibilities are not modeled, including the time they would spend planning for missions with the SACC or adjacent units. Both of these abstractions reduce the complexity of the fatigue model, which the researcher deems necessary due to the limited time to affect the full research project.

There are two limitations in the utilization of the fatigue model that deserve to be addressed. SAFTE allows the researcher to set the degree to which the environment is conducive to sleep in addition to the quantity. These settings are Excellent, Good, Fair, and Poor, and reflect an increasing number of interruptions that occur during each hour of sleep as the sleep environment degrades. These interruptions do not necessarily result in the individual awaking, but will adversely affect sleep quality.[2] The researcher had initially planned to set the environment to Good or Fair before starting the research in

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[1] See built-in help file in FAST. The key phrase is "percentile line."

[2] See built-in help file in FAST. The key phrase is "sleep environment."

order to reflect the austere conditions that a CLT would endure. However, FAST defaults to Excellent sleep with all new schedules. There is no apparent way to change the sleep environment for a schedule as a whole, but rather each individual sleep segment has to have its sleep changed. Since the nature of the experiment (see Chapter III) requires hundreds of inputs to FAST, the researcher decided that in the interest of completing this research in time, the default setting would remain in use. This means that sleep deprivation will not have as drastic an effect as it might have had; that is the model is biased against fatigue being important.

In a sleep study with live participants, the participants would wear wrist-worn activity monitors or actiwatches. These watches would record the intensity of activity that participants are engaged in throughout the day, as well as the quality of sleep they are receiving. Since that is not possible with a simulation model, the FiST is only coded as awake or asleep during each model run, with no measure of intensity for either state. This also reduces the accuracy of this fatigue model, and the experiment as a whole.

D. CHARACTERISTICS OF THE DISCRETE-EVENT MODEL

A discrete event simulation only models events and actions that are of interest to the researcher. Typically, this type of simulation is used to model processes where an event requires a process or processes to be performed on it. The researcher chose to use a discrete-event model due to these characteristics.

1. Goal

The goal of the discrete-event model is to evaluate the CLT FiST's overall effectiveness. The Measure of Effectiveness (MOE) measured is the percentage of enemy targets that are successfully engaged by the FiST.

2. Conceptual Model

The basic conceptual design of the discrete-event model is centered on the arrival of targets and other events that would trigger FiST activity. These events' arrival process is based on the data derived from the appropriate MANA scenario. Events consist of IDF fire on the CLT's base, IED detonations, contact with Red units, and the arrival of the resupply and CASEVAC aircraft.

Once an event arrives, the model immediately determines where it occurs (see Figure 7). If the event occurs in a zone for which the CLT is responsible, the event then proceeds to have additional information developed. IDF fire on the CLT base occurs only in Zone 1. The arrival of resupply aircraft is scripted to occur at the CLT base after sunset each day, and it supports the individual recon teams on alternate days. If the CLT FiST is not responsible for the recon team's resupply, the helicopter is not scripted to arrive for them.

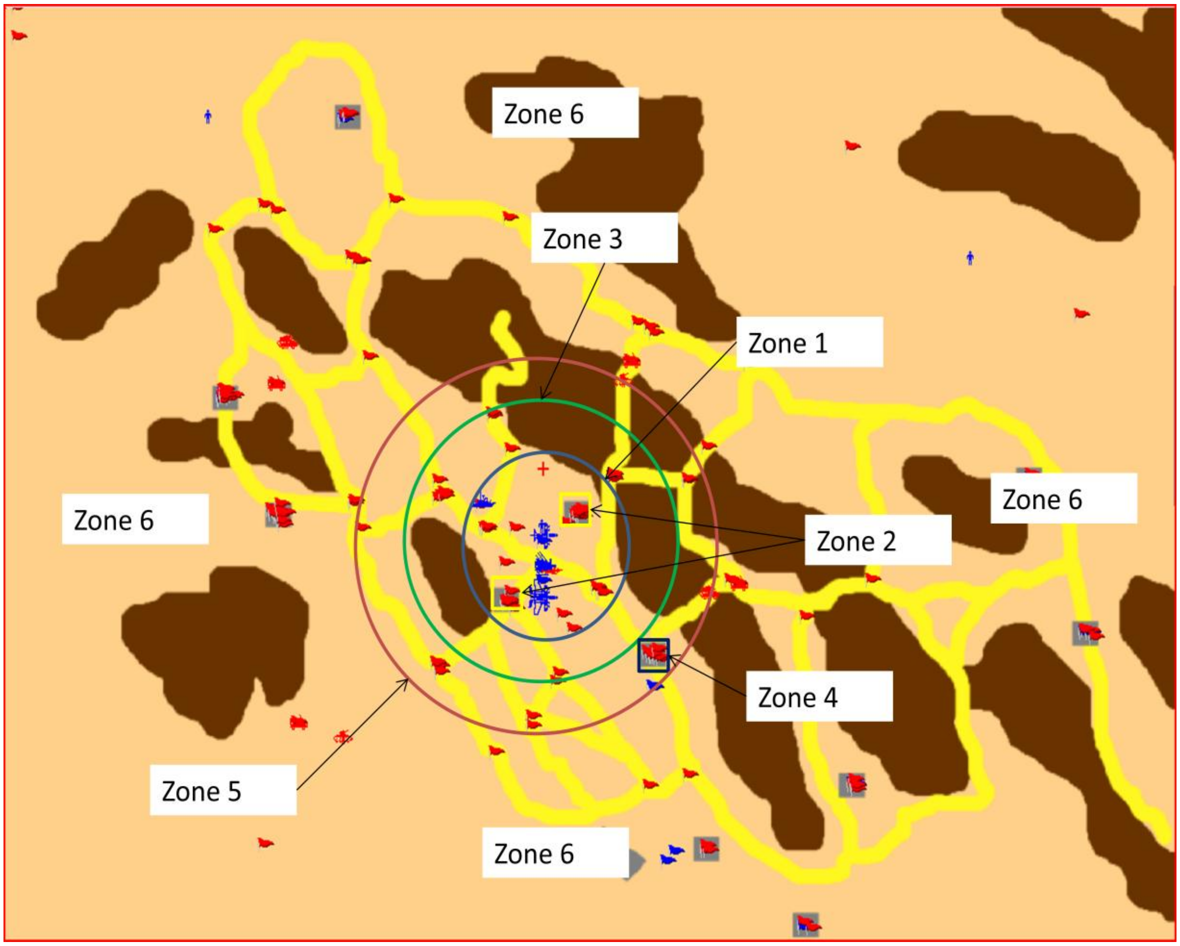

Figure 7. This map displays the overlays of the various engagement zones on the MANA map. Each of the concentric circles is measured from the location of the CLT's base. Zone 1 corresponds to the outer range of their 81mm mortars, and Zone 2 consists of the urban areas within Zone 1. Zone 3 is the abstract boundary of the Quackenbush Range used for this model. Zone 5 is the outer range of the EFSS, while Zone 4 is an urban area within Zone 5. Zone 6 consists of all of the areas outside of the EFSS range ring.

For an IED event, the model determines whether the device is discovered and deactivated by the Marines or it detonates. In the latter case, a CASEVAC is triggered that the CLT FiST has to coordinate in addition to their other tasks. Additionally, the model determines if the IED was command detonated as part of an ambush or if it is a VIED. In the former case, this results in an immediate follow-on engagement with the ambush force. A further check is made, based on the location of the encounter, to determine whether an enemy IDF team supports the ambush. If the event is an encounter with Red technical vehicles or infiltrators, the only check made is whether RED IDF teams fire in support of them.

Once the details about each event are determined, any contact with an enemy force has its duration determined based on a combination of the zone in which it occurs and the enemy unit type (technical vehicle, IDF team, etc.). At this point, the event is put in the queue for service by the FiST. As it moves to be serviced, the model checks the FiST's predicted cognitive effectiveness based on the time in the model. The FiST's time to service the event is multiplied by the inverse of the cognitive effectiveness in order to reflect the affects of fatigue (Hursh et al., 2003). Based on the target's location and composition, the FiST will engage it with a certain mix of weaponry. As the FiST services the event, it may find a need for CASEVAC or CAS aircraft. These assets take time to arrive in the AI/AO, and also have a limited time that they can remain on station before they have to return to the ARG (see Chapter II.D.3). One of the underlying assumptions of the scenario is that the Red forces have MANPADs. Thus, in all cases that the CLT FiST utilizes CAS, it will also make use of Suppression of Enemy Air Defenses (SEAD) fires from the 81mm mortar or EFSS, depending on the location of the target.

If an enemy target's contact duration expires before the FiST finishes engaging it, the target will be considered to have reneged. In this case, the target is considered to have successfully escaped engagement by the FiST, and will be recorded as such. If the target has not reneged by the time the FiST finishes, the target will be considered to have been successfully engaged, and will be tallied as a successful mission. The MOE of this experiment is the percentage of total targets successfully engaged by the FiST. Figure 8 is an event graph of this conceptual model (Law & Kelton, 1982).

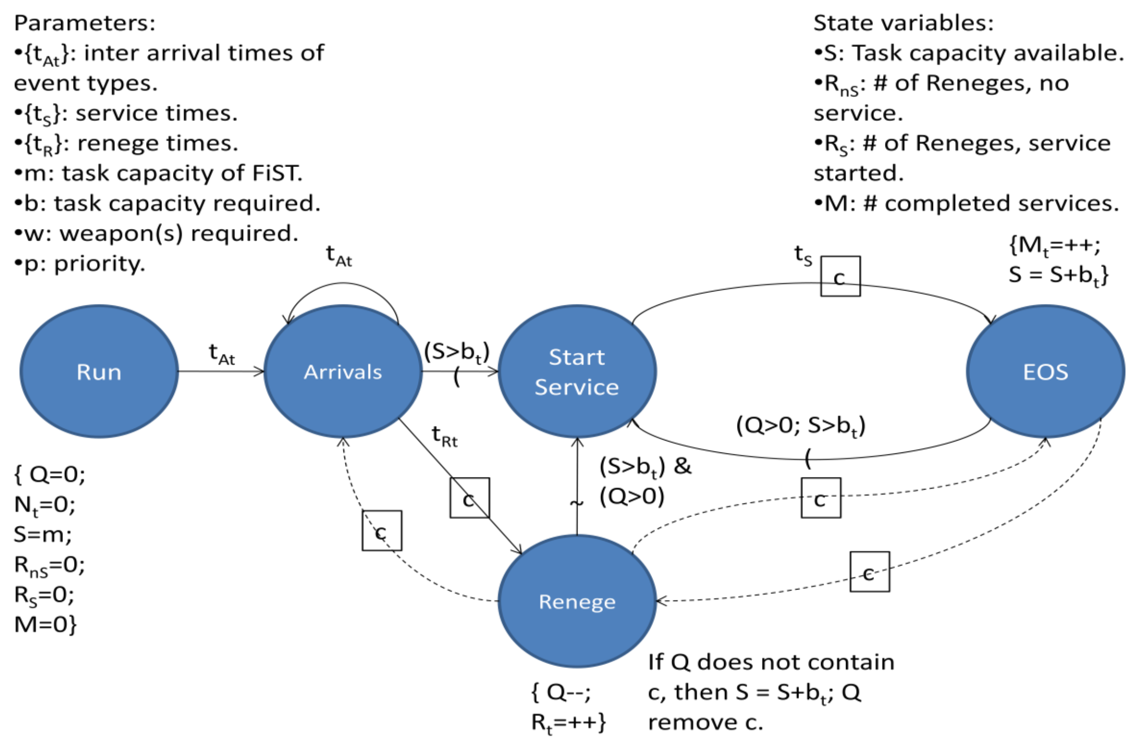

Figure 8. The event graph diagram of the discrete-event model. The model assigns attributes to each event, including the renege time of the event. The event then moves to Start Service, where it may renege if it waits too long for service. From Start Service, it is acted on by the FiST and fire support agencies. Once the event arrives at End of Service (EOS), it is determined if the event was successfully serviced before it reneged.

The finished model in ExtendSim7 (see Figure 9) is broken into four primary parts (Imagine That!, 2007). The images from ExtendSim7 are hard to read due to the scope and complexity of the model, but the researcher has included them because of the insight they can provide into the structure of the discrete-event model. In the first part (see Figure 10), events arrive and have their attributes assigned to them. Further, each event is assigned a serial number for use in tracking and, if necessary, CAS aircraft are requested to engage the appropriate targets. The second part of the ExtendSim7 model is the fire-support process. The structure of this part of the model varies with the selection of the fire-support process (see Chapter III). Due the four different choices of the fire-support process, this section of the model is distinct for each one (Figure 11 shows the model for centralized fire support, Fire-Support Process One). Additionally, coding of attribute assignments in the arrival section of the model also varies due to the exact fire-support process in use. Events that enter this part of the model enter a queue until the FiST can address them. Once the event leaves the queue, it is checked to see if it reneges. If it does not, it takes resources such as the FiST's capacity and weapon systems while the event is being serviced. The third part of the model (see Figure 12) is the postprocess after the fire support section. In this part, events are regrouped together, and resources are released. At the end of it, an equation determines if service is completed before the event would have reneged, in order to determine how the event is counted in the fourth and final part of the model. The fourth part of the model (see Figure 12) is the output. Here data is organized to be output into an Excel spreadsheet for analysis.

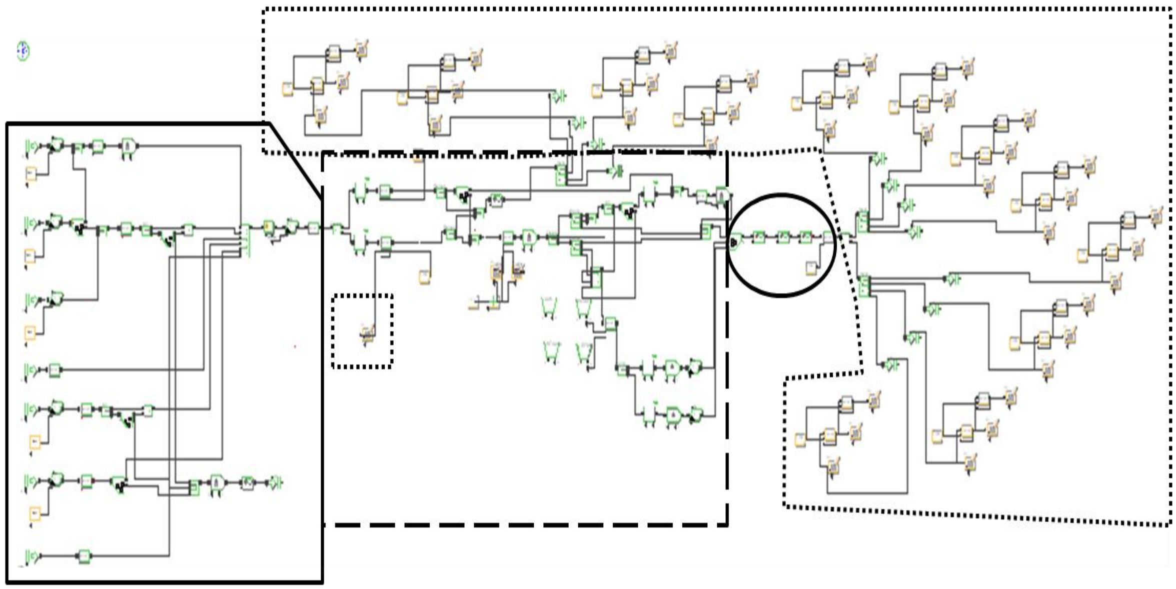

Figure 9. ExtendSim7 Fire-Support Model. The solid polygon encloses the arrival process, the dashed rectangle the fire-support process, the solid oval the post process, and the dotted polygon the output. Note the output module within the fire-support process.

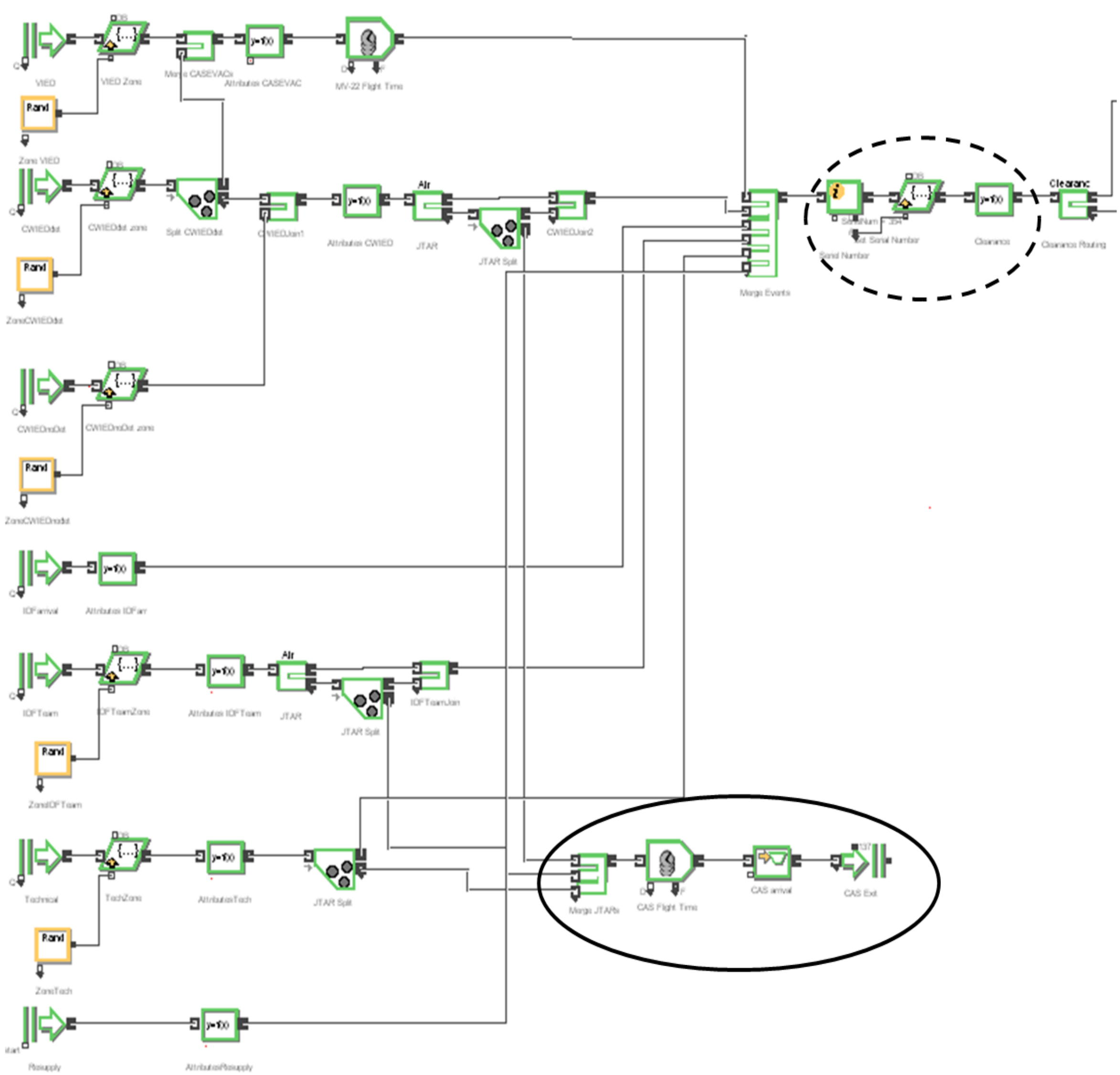

Figure 10. The fire-support model arrival process. The solid oval encloses the area where events requiring a CAS aircraft request air support. The dashed oval indicates where events receive their serial number for tracking and matching purposes. As events arrive at each entry, a determination of their zone is made, followed by the assignment of attributes.

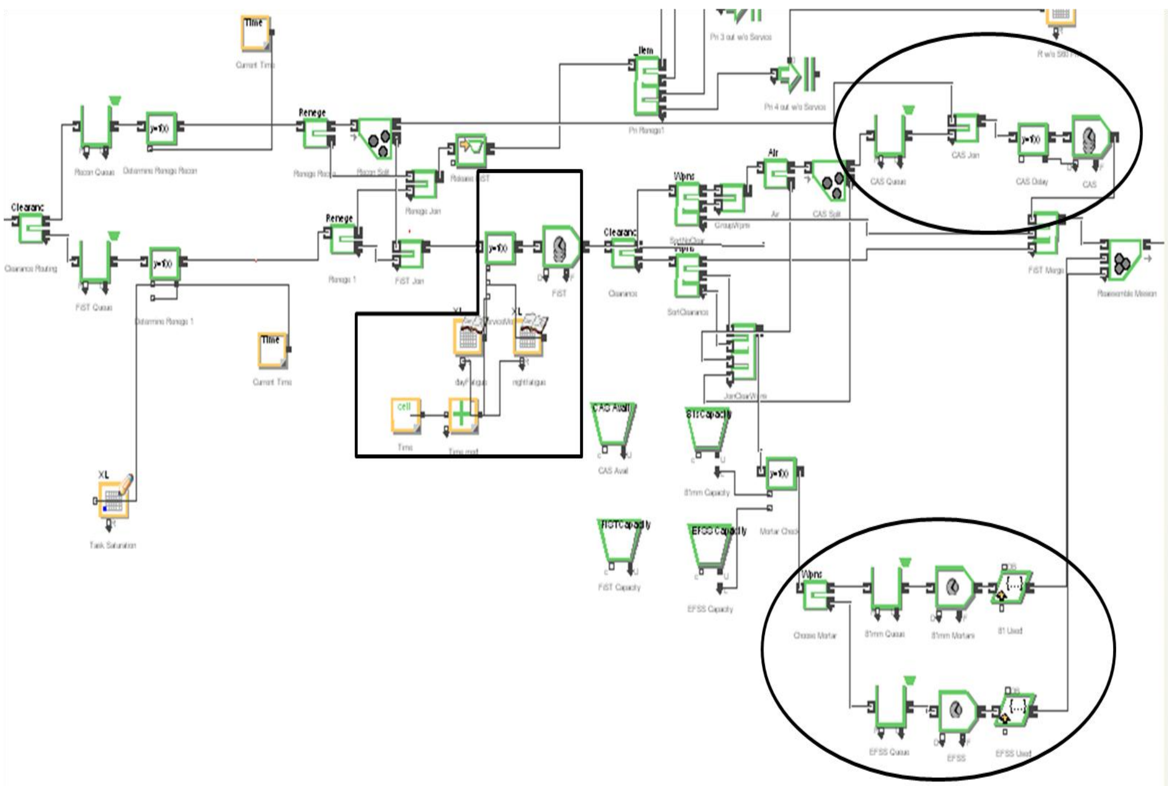

Figure 11. Fire-Support Process One (see Chapter III). The solid L-shape encloses the FiST and the blocks that modify its performance based on its fatigue. The upper solid oval is the CAS process, while the lower is the EFSS and 81mm process.

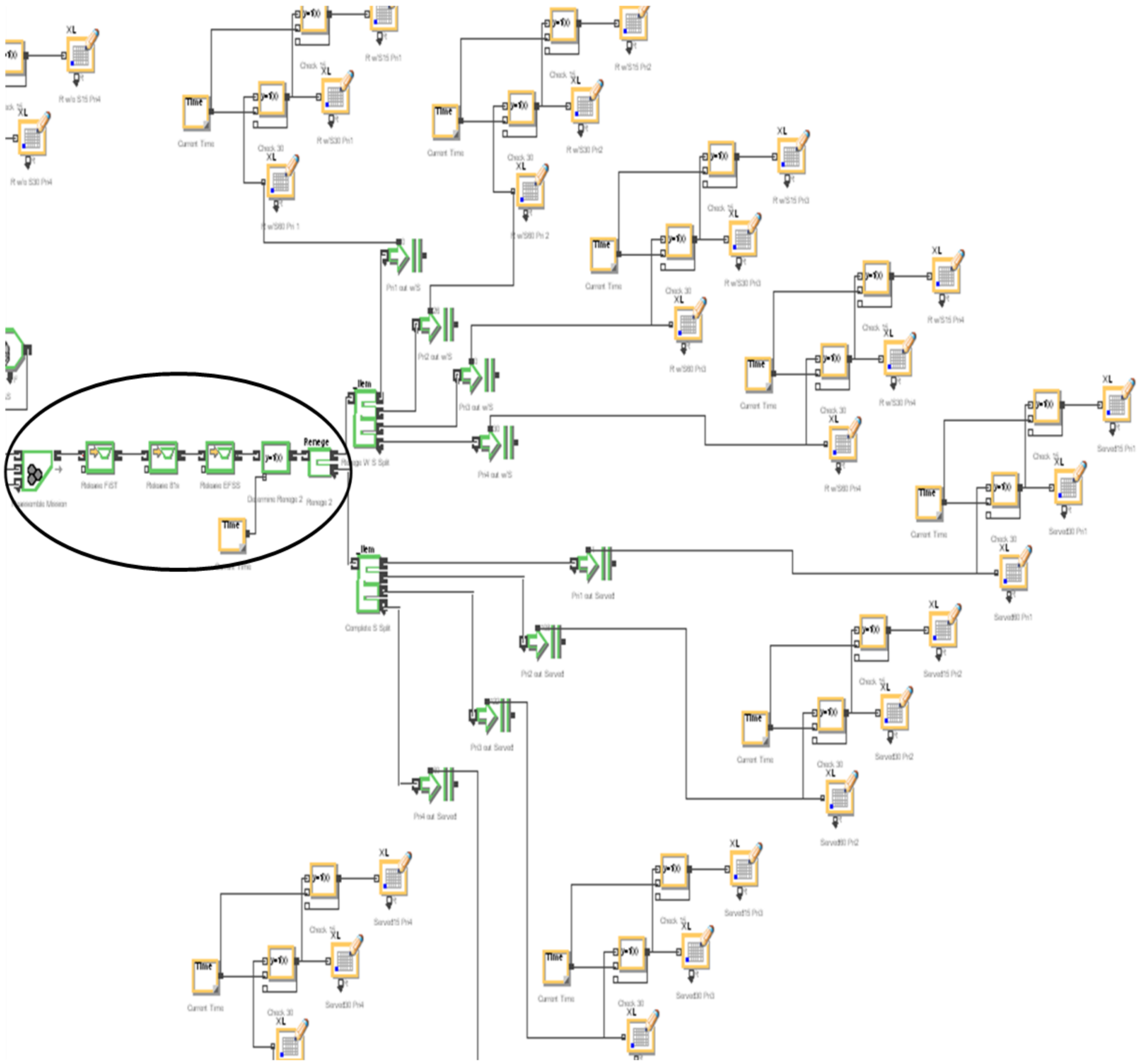

Figure 12. The postprocess and the output sections. The solid oval encloses the the postprocess, where events are batched, resources are released, and successful completion is checked. Events then proceed to the appropriate output and are then broken down by event type, and the time in the model (first 15 days, first 30 days, and first 60 days).

3. Data Sources, Abstractions, Assumptions, and Validations

The input data for the discrete-event simulation comes from many sources. The researcher provides the data on targets from the output analysis of the MANA model. The researcher also uses the output analysis of the SAFTE model to provide the fatigue inputs. Data on task performance is contributed by the units supporting this research (see Chapter IV.A). Some of the necessary information has to be assumed as the researcher could not locate it, particularly information on SACC and mortar performance. In this case, the researcher relied on his own experience in training and combat.

- SACC
  - Time to approve CAS mission is a Uniform (U) distribution with range 5-10 minutes.
  - Time to approve 81mm or EFSS mission U(2-3) minutes.
  - Time to approve SEAD U(6-15) minutes.
- FiST
  - Develop and approve a mortar Call for Fire CFF U(2-5) minutes.
  - Develop a CAS 9-line U(2-10) minutes.
  - Pass a CAS 9-line to an aircraft and receive acknowledgement U(5-15).
- 81mm Mortars execute CFF U(2-5) minutes.
- EFSS execute CFF U(3-6) minutes.
- Fixed-Wing (F/W) CAS execute CAS 9-line after acknowledgement is Normal distribution(8.3, 3.9).

Assumptions:

1. Firing agencies (CAS and mortars) can only prosecute one target at a time.
2. If a target reneges while being processed, the FiST, SACC, and firing agencies still spend that amount of time attempting to prosecute the target.
3. Observers can provide targeting information to the FiST in negligible amount of time.
4. The FiST does not start a mission until it can devote sufficient resources to complete it.

5. Only fixed-wing aircraft are available for CAS due to the distance from the ARG.
6. CAS aircraft have only twenty minutes of on-station time.
7. CAS aircraft return to the EMAGTF once the target is engaged or it reneges.
8. CAS aircraft can only engage one target before they must return to the EMAGTF to rearm.
9. CAS aircraft are only delivering bombs, not forward firing ordnance such as rockets or cannon.
10. Aircraft are employed sequentially.
11. Once Mortars are allocated to a target for SEAD, they cannot support other events.
12. There is no target location error.
13. The FiST has twenty minutes to respond to IDF.
14. Resupply occurs at 1900 daily for the CLT. This event lasts 30 minutes and includes the time the helicopter is being routed and manually offloaded.
15. Resupply occurs at 2000 on alternate days for the recon teams. The whole event lasts an hour as the aircraft enters the AI, lands, is unloaded by the team, takes off, and proceeds to the other team, and then repeats the process before departing the AO/AI.

Assumption 1 is based on the fact that split section operations with 81mm mortars are seldom practiced, and the EFSS is a single tube. It is assumed that the CAS aircraft will employ all of their ordnance in the attack on their target. Assumption 2 assumes that if a target escapes while being prosecuted, the FiST and CLT will expend sufficient time trying to reacquire it that it would equal the time it would have taken to prosecute it. Assumption 3 posits that the time for a JFO to call in a target to be serviced is negligible. Assumption 4 assumes that the FiST will not start part of a mission if it cannot see it to completion. Thus, a very complex mission requiring all of the FiST's attention will not be started even if some of their attention is made available.

Assumption 5 is based on the distance to the ARG as stated by the scenario. At 150 nm, any helicopter would take over an hour to reach the AO/AI, while fixed-wing aircraft could arrive much sooner (Marine Air Weapons and Tactics Squadron One [MAWTS-1], 2010). Assumption 6 is based on a likely ordnance load for an AV-8B Harrier (MAWTS-1, 2010). Assumption 8 is based on the limited duration and ordnance carried by CAS aircraft (MAWTS-1, 2010). Assumption 9 is based on the researcher's own experience and the MANPAD threat in the scenario. Assumption 10 is based on a discussion with a CAS instructor at MAWTS-1 (Major J. F. Foley, personal communication, 4/1/2011).

Assumption 11 reflects that aiming mortar tubes is a manual process, and there is no way to quickly revert to a previous aim point. Assumption 12 assumes that the FiST is able to find the actual location of a target in a negligible amount of time. Assumption 13 reflects the nature of responding to an IDF attack. It reflects not so much the time it takes to hit an IDF team, but rather the amount of time the FiST is likely to spend attempting to hit such an elusive target. Assumptions 14 and 15 are based on the researcher's own experience and the nature of the scenario as described by MCWL.

Abstractions

1. A CAS aircraft is requested when an appropriate target is detected, even if the FiST does not have the capacity to act on it at that time.
2. There is no limit on the number of CAS aircraft that can support the CLT.
3. The FiST does not dynamically retask; once committed to a mission, they stay with it until complete.
4. Aircraft cannot be dynamically retasked. If the target it was requested for leaves, the aircraft returns to the ARG.
5. The appearance of a target requires only one employment of supporting arms.
6. If the SACC handles clearance for an event beyond the AO, it is not modeled.

Abstraction one enables the FiST to request a CAS aircraft, even though they do not have the capacity to necessarily utilize it at the requested time. This enables the FiST to manage its time in a more realistic manner. Abstraction two does not take into account the limited number of aircraft aboard an ARG. Since the model is focusing on FiST performance and not resource availability, the researcher has chosen to make aircraft always available. Abstraction three prevents the mission from being dropped in the discrete-event model and never resumed. Abstraction four has the same results for aircraft.

Abstraction five limits the FiST's participation in any engagement to a single utilization of supporting arms. While anactual engagement may last for hours and require numerous applications of supporting arms, this abstraction eliminates the need to determine damage or lethality of weapons and keeps the model focused on FiST task performance. Abstraction six likewise serves to keep the model focused on FiST performance.

III. EXPERIMENTAL DESIGN

This chapter describes both the noise and decision variables being modeled in this research. Further, the chapter describes the DOE utilized to make the most efficient use of the limited resources of time and computing power available to the researcher.

A. INTRODUCTION

An efficient DOE enables simulation-based research to explore variables under consideration in a manner that makes the best use of limited resources. In this experiment, the limited resource is the time available to the researcher to conduct the experiments due to the amount of labor involved with each design point. With an efficient design of this experiment, the researcher is able to maximize the amount of information he seeks to gather from the experiment, while making the best use of limited resources.

B. VARIABLES OF INTEREST

Two sets of factors were investigated for this experiment. The decision factors are those which decision makers can reasonably be expected to control. Decision factors would include equipment decisions and policies promulgated by the commander of the CLT or MAGTF. The other factors, known as noise factors, are those that are beyond the control of decision makers. Some factors do not fit neatly into either category, but for the purposes of this research, each factor is assigned to one category or the other. Tables 1 and 2 summarize the decision and noise factors, respectively.

Decision Factors			
Factor	**Model**	**Range**	**Description**
FiST Activity Cycle	SAFTE	Categorical: 5 levels	The work and rest cycle of the FiST.
SACC Policies	SAFTE	Categorical: 5 levels	The manner in which the SACC has organized the AO and AI.
Fire Support Process	Discrete-Event	Categorical: 4 levels	The combination of fire-support processes utilized by the FiST.
FiST Task Capacity	Discrete-Event	Categorical: 3 levels	The task capacity of the FiST.

Table 1. Decision factors

Noise Factors			
Factor	**Model**	**Range**	**Description**
Terrain Concealment	MANA	Continous: 0.00 to 1.0	This measures how much concealment the terrain offers. A lower number indicates less concealment.
Terrain Going	MANA	Continous: 0.5 to 0.8	This measures how difficult it is to move across the terrain. A higher value indicates terrain that is easier to move across.
Red Concealment	MANA	Continous: 0.00 to 0.75	The ability of Red foot-mobile forces (IED teams and infiltrators) to conceal themselves from Marine forces.
Sensor Effectiveness	MANA	Continous: 0.2 to 1.00	This number represents how well sensors function in the environment.

Table 2. Noise factors

1. Decision Factors

a. FiST Activity Cycle

This factor represents the choices the CLT can make to arrange the FiST's activity and rest cycle. The levels are:

1. The FiST works a 12-hour day from 0800 to 2000. They sleep from 2200 to 0600. The two hours before and after their work shift are used to take care of other tasks.
2. The FiST works a "port-and-starboard" schedule. Half of the FiST is always manning the radios, while the other half is resting or taking care of other tasks. The first shift works from 0800 to 2000 and the second shift works from 2000 to 0800. Turnover times are negligible. The FiST leader is on the first shift, but he must be present for all events to give his approval. The artillery FO is present on the second shift. The mortar FO is on the first shift. The FAC and JTAC are on opposite shifts.
3. The FiST executes a "port-and-starboard" schedule as in 2. The FiST leader is only needed when there is a task that originates within the AO or fires must be cleared by the FiST. The FiST leader would not need to be present to conduct a CASEVAC mission or a resupply in the AI. It is assumed that the artillery FO is delegated the authority to coordinate nonfire-related tasks in the AI.
4. The FiST executes a "port-and-starboard" schedule as in 2. The FiST leader is only needed when there are targets to be engaged in the AO. Thus, for example, he would not need to be present to clear fires on a target spotted in the AI nor to conduct a CASEVAC or resupply in the AO. It is assumed that the artillery FO is delegated the authority to clear fires in the AI and coordinate tasks in the AO that do not involve firing.
5. The FiST executes a "port-and-starboard" schedule as in 2. Whichever section is on duty is authorized to perform or approve all tasks

without the presence of the FiST leader. It is assumed that the artillery FO has the same authority that the FiST leader has during the second shift.

b. SACC Policies

This factor represents the amount of authority that the SACC has assumed in regard to the clearance of fires and how it has defined the responsibility of the FiST. The five SACC policies are:

1. All approval of fires is done by CLT FiST. The SACC is not involved in clearing any fires and the FiST is responsible for all fires and events in the AO and AI.
2. SACC approves all fires in the AI, while FiST approves all fires in the AO. The SACC has full responsibility for all events in the AI, while the FiST has full responsibility for all events in the AO.
3. The SACC approves all missions in the AI requiring CAS, while the FiST approves those that do not. However, the FiST still must coordinate all other events in the AI, including CASEVACs and resupply missions.
4. The FiST clears all events within the range of the EFSS (12 km with rocket-assisted projectiles). The SACC handles all events beyond the range of the EFSS.
5. In both the AI and AO, SACC approval is necessary to engage a target. The CLT FiST only coordinates missions within the AO.

c. Fire-Support Process

This factor represents the different fire-support processes for controlling 81mm mortars and the EFSS. In a decentralized process, the firing agency prepares to engage the target, while the approving authority reviews the mission. Preparations consist of preparing ammunition and aiming the weapon system at the target. In a centralized process, the firing agency does not begin preparations to engage the target until the mission is approved. A decentralized model is usually used for aircraft, due to their short on-station time if a JTAC or FAC is controlling them. If there is no JTAC or FAC present, then a centralized model is used, with the FiST's FAC or JTAC handling the details of CAS coordination. The four fire-support processes are:

1. 81mm mortars and EFSS are always centralized (see Figure 13).
2. Mortars are centralized in the AO, but decentralized in the AI (see Figure 14).
3. 81mm mortars and EFSS are always decentralized (see Figure 15).
4. 81mm mortars are centralized, but EFSS is decentralized (see Figure 16).

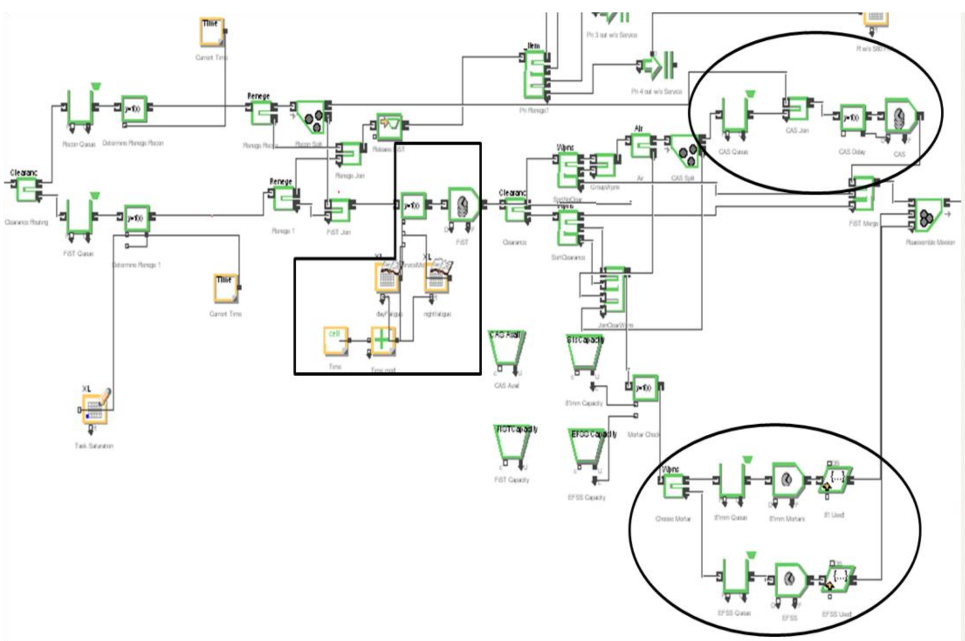

Figure 13. Fire-Support Process One. The solid L-shape encloses the FiST and the blocks that modify its performance, based on its fatigue. The upper solid oval is the CAS process, while the lower is the EFSS and 81mm process.

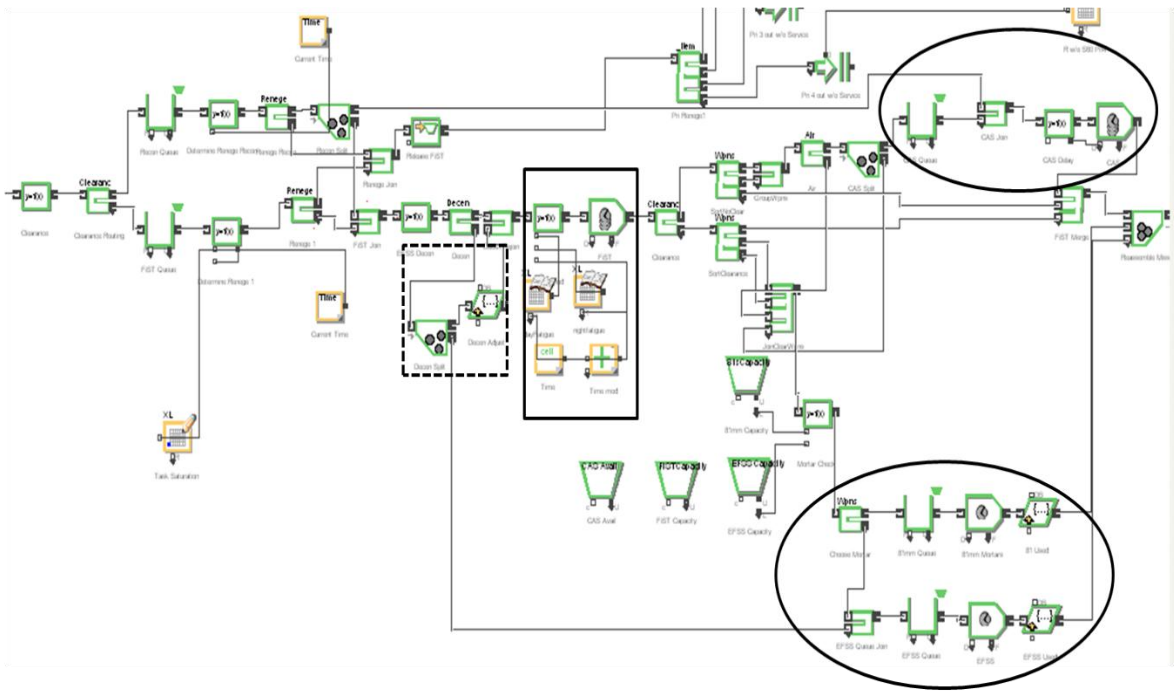

Figure 14. Fire-Support Process Two. The solid rectangle encloses the FiST and the blocks that modify its performance, based on fatigue. The dashed square encloses the blocks that enable the EFFS to be utilized in a decentralized mode beyond the AO. The upper solid oval is the CAS process, while the lower is the EFSS and 81mm process.

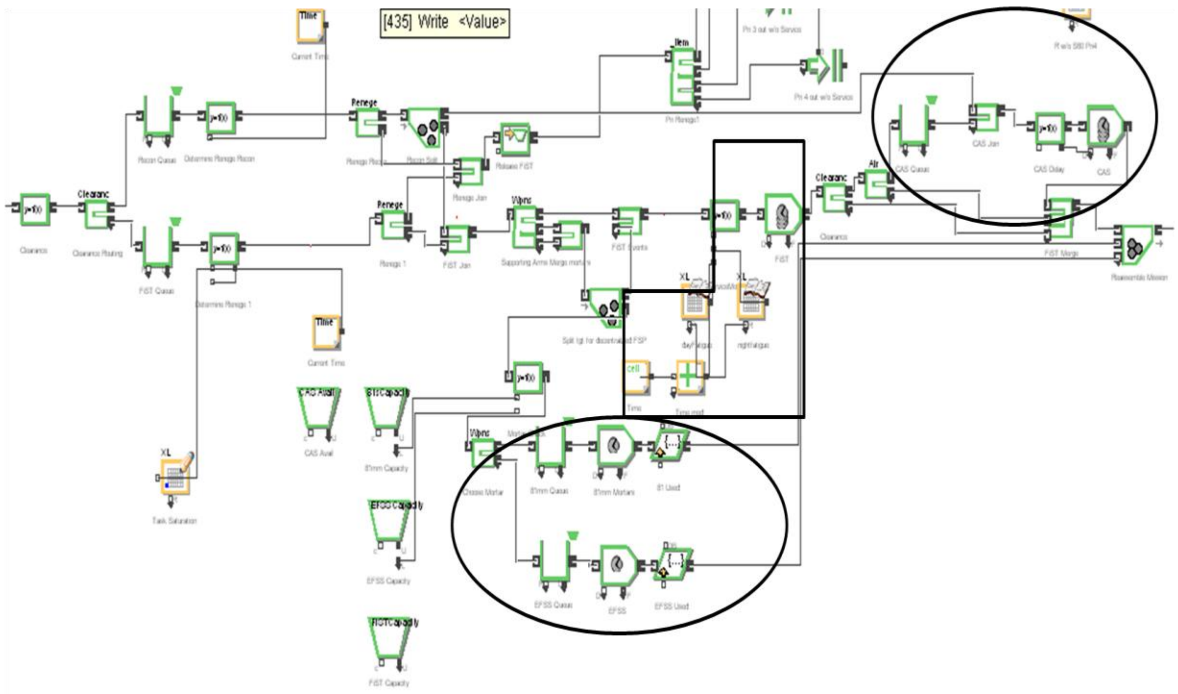

Figure 15. Fire-Support Process Three. The solid L-shape encloses the FiST and the blocks that modify its performance, based on its fatigue. The upper solid oval is the CAS process, while the lower is the EFSS and 81mm process.

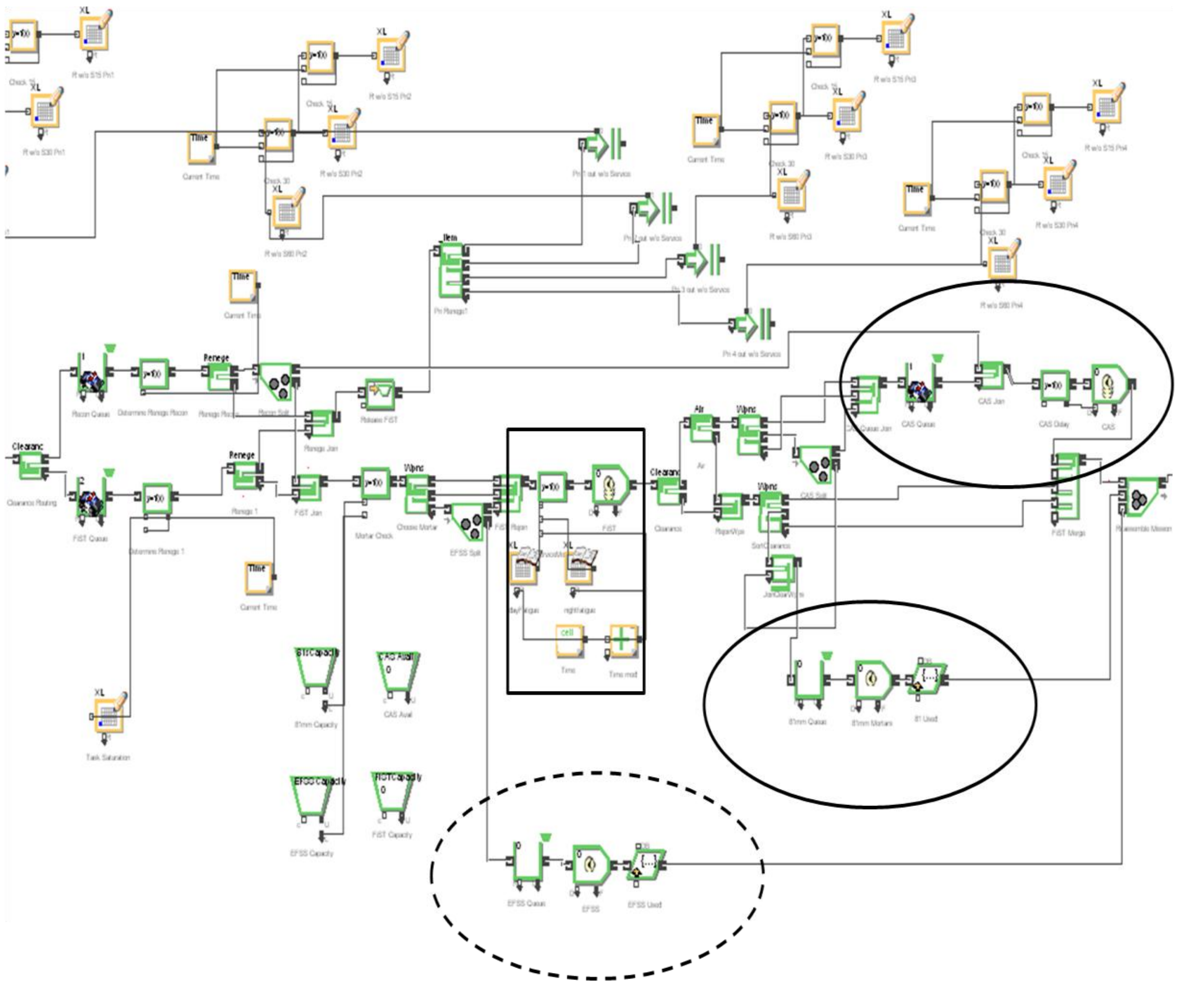

Figure 16. The fire-support process for Fire-Support Process Four. The solid rectangle encloses the FiST and the blocks that modify its performance, based on its fatigue. The upper solid oval is the CAS process, while the lower is the 81mm process. The dashed oval encloses the EFSS process. In this process, the EFSS operates decentralized, while the 81s are centralized.

d. FiST Task Capacity

This factor represents the CLT FiST's ability to perform multiple simultaneous or near-simultaneous tasks. The baseline capacity was determined by soliciting subject matter experts (see Chapter IV.A.1). The baseline reflects a FiST with current training and equipped only with maps and radios for communication and coordination. The incrementing of the FiST's capacity could reflect a variety of methods of increasing the FiST's task capacity, but for the purposes of this research, it represents an increase in task capacity through technological means. The three task capacity levels are:

1. FiST baseline capacity.
2. Increment FiST capacity by 1.
3. Increment FiST capacity by 2.

2. Noise Factors

These factors consist of those conditions that the EMAGTF cannot control. They enable the researcher to see how the decision factors perform under a variety of conditions in order to find the most robust solution (Sanchez, 2000).

a. Terrain Concealment

This factor represents the amount of concealment provided by the dominant terrain in the MANA scenario. A higher value indicates a greater amount of concealment, while a lower value indicates less concealment. A high value may indicate thick vegetation or a great deal of microterrain that enables people to hide. A low value may indicate flatter and more featureless terrain.

b. Terrain Going

This factor represents the difficulty of traversing the terrain in the MANA scenario. It is only applied to the dominant terrain in the simulation. A higher value indicates more easily traversable terrain, while a lower value represents more challenging terrain. A high value may indicate a road or other paved and flattened surface, while a low value may indicate broken ground with numerous gullies.

c. Red Concealment

This factor represents the ability of the Red force to hide their actions from the CLT and EMAGTF. This reflects physical concealment that is created by camouflaged clothing, taking advantage of natural cover, and concealing identifying features such as weapons. A higher value indicates that the Red forces are more effective at concealing their presence.

d. Sensor Effectiveness

This factor reflects the effects that weather and atmospheric conditions have on the effectiveness of the two forces' sensors. The weather or atmospheric effects in questions could range from precipitation, haze, or dust to anything else that would limit sensor effectiveness for a prolonged period.

C. DESIGN OF EXPERIMENTS (DOE)

This research uses an iterative approach to design, evaluate, and refine each step of the experiment. For each phase, reviews were conducted of the input and the output. If the output was determined to have diverged significantly from reality, the model and the input data were revisited and revised as necessary to conform to the goals of the experiment.

1. Overall Design

Traditionally, experiments involving categorical decision factors utilize a full-factorial DOE. This obviously results in very large design matrices. In the case of this research's decision variables, this would have resulted in 300 design points representing every input combination. When noise factors are added in, the full DOE would reach 5,100 design points. In some environments this would not be considered onerous, given sufficient time and computing resources. However, due to the time limitations of this research and because three different models are being incorporated, the researcher decided that such an approach was intractable.

Helcio Veiera developed a technique called the Nearly-Balanced Nearly-Orthogonal Latin Hypercube (NBNOLH) that allows more efficient designs when using categorical decision variables. This technique makes use of mixed-integer programming to create more efficient orthogonal designs (Vieira, Sanchez, Kienitz, & Beldarrain, 2011). When Veiera's technique is applied to the decision factors, the result is a design matrix with only 40 design points. This DOE has a maximum correlation of 0.0627. Interestingly, the NBNOLH repeats design point 27 as design point 35. This is necessary in order to keep the correlation coefficient within tolerance (H. Veiera, personal communication, 4/26/2011).

In order to create a more robust design, the researcher utilizes an Orthogonal Latin Hypercube (OLH) to create a design matrix for the noise factors (Cioppa & Lucas, 2007). This process creates a design matrix with 17 design points. The OLH should create a perfectly orthogonal design matrix, but in this case, the correlations were not quite as expected due to rounding (see Figure 17). This is because the design matrix is only carried to two places in the OLH spreadsheet, because the four noise factors can only be input with two-digit precision in MANA. Despite this, the resultant correlations are still quite small, indicating that the OLH very closely approximates orthogonality.

Multivariate

Correlations

	Going	Concealment	Red Camouflage	Sensors
Going	1.0000	-0.0107	-0.0072	0.0079
Concealment	-0.0107	1.0000	-0.0017	-0.0035
Red Camouflage	-0.0072	-0.0017	1.0000	-0.0084
Sensors	0.0079	-0.0035	-0.0084	1.0000

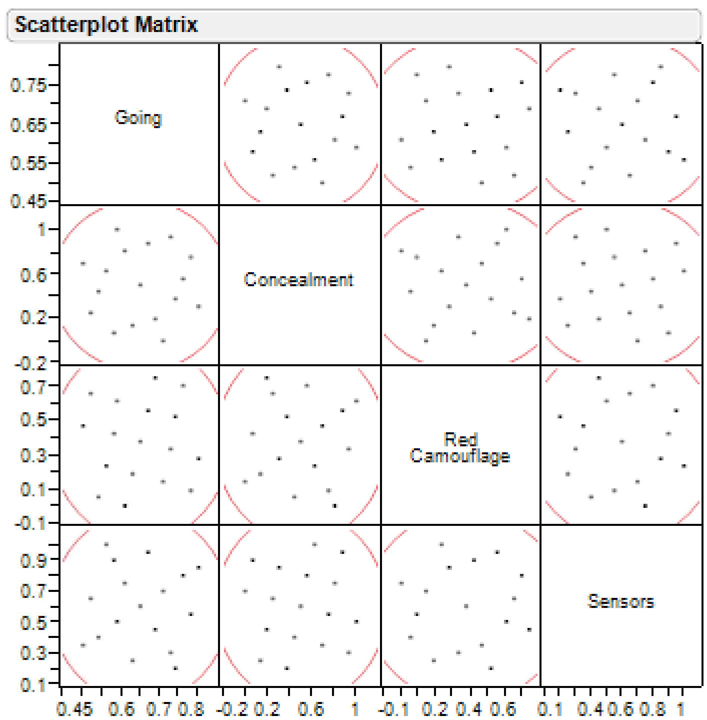

Figure 17. The correlation matrix and scatterplot of the Noise Factor DOE. The scatterplot shows all of the pairwise input combinations of noise factors.

This noise factor design matrix is then crossed with the NBNOLH design matrix to create the final design matrix (Kleijnen, Sanchez, Lucas, & Cioppa, 2005). The result is a design matrix with 680 design points. The highest correlation, between the FiST Capacity and the SACC Policy, is below 0.05, bringing the design quite close to being completely orthogonal (see Figure 18). The crossing of the two matrices allows the researcher to examine each design point from the NBNOLH over a range of conditions. This, in turn, enables the researcher to make policy recommendations that are valid over a wide range of conditions (Kleijnen et al., 2005).

Multivariate

Correlations

	FiST.Act	SACC.Pol	FSP	FiST.cap	Going	Concealment	Red Camouflage	Sensors
FiST.Act	1.0000	-0.0112	0.0032	0.0410	0.0000	0.0000	0.0000	-0.0000
SACC.Pol	-0.0112	1.0000	-0.0244	0.0433	0.0000	0.0000	-0.0000	0.0000
FSP	0.0032	-0.0244	1.0000	-0.0395	0.0000	0.0000	0.0000	-0.0000
FiST.cap	0.0410	0.0433	-0.0395	1.0000	-0.0000	-0.0000	-0.0000	-0.0000
Going	0.0000	0.0000	0.0000	-0.0000	1.0000	-0.0107	-0.0072	0.0079
Concealment	0.0000	0.0000	0.0000	-0.0000	-0.0107	1.0000	-0.0017	-0.0035
Red Camouflage	0.0000	-0.0000	0.0000	-0.0000	-0.0072	-0.0017	1.0000	-0.0084
Sensors	-0.0000	0.0000	-0.0000	-0.0000	0.0079	-0.0035	-0.0084	1.0000

Scatterplot Matrix

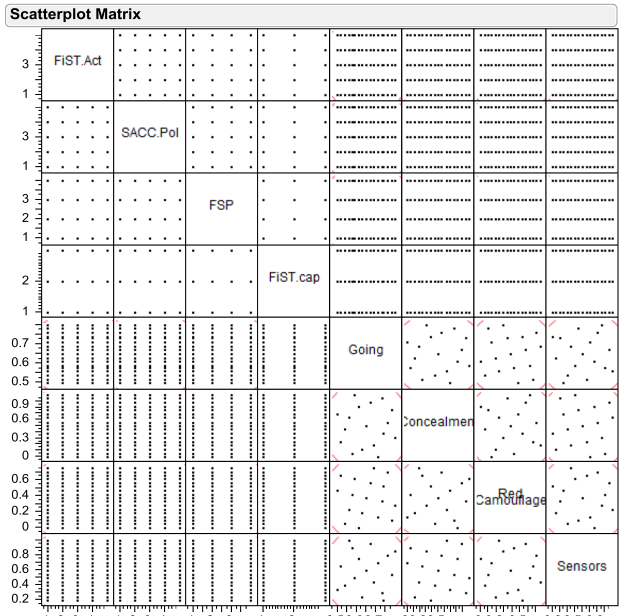

Figure 18. The correlation matrix and scatterplot of the final DOE.

2. Full Factorial for Fatigue

While the overall design matrix makes use of the latest advances in the field of DOE, the design for the fatigue experiment uses perhaps the oldest DOE technique. Based on the assumptions for the SAFTE model (see Chapter II.C.3), the FiST Activity Cycle and SACC Policy factors are the only two decision factors that affect the fatigue analysis conducted with the SAFTE model. Additionally, an inspection of the final experiment's DOE reveals that the two factors are combined in a full factorial, with several repetitions. In order to reduce the workload, the researcher uses a full-factorial design matrix. The resulting matrix, when crossed with the noise factors, yields a design matrix with 425 design points. Since this reflects a significant reduction in work from the 680 design points in the overall DOE, and still provides all of the information that the researcher needs, this option is used for the fatigue experiment. Since this DOE is the result of a cross between an OLH and a full factorial, it should be completely orthogonal. However, when the correlation matrix is inspected, it is obvious that this is not quite so (see Figure 19). As with the final DOE, this is because of the rounding done in the OLH; however, the highest correlation is only 0.0079, which is still nearly orthogonal. Thus, there should be no adverse multicollinearity effects (Devore, 2008).

Multivariate

Correlations

	FiST.Act	SACC.Pol	Going	Concealment	Red Camouflage	Sensors
FiST.Act	1.0000	0.0000	-0.0000	-0.0000	-0.0000	0.0000
SACC.Pol	0.0000	1.0000	-0.0000	-0.0000	-0.0000	0.0000
Going	-0.0000	-0.0000	1.0000	-0.0107	-0.0072	0.0079
Concealment	-0.0000	-0.0000	-0.0107	1.0000	-0.0017	-0.0035
Red Camouflage	-0.0000	-0.0000	-0.0072	-0.0017	1.0000	-0.0084
Sensors	0.0000	0.0000	0.0079	-0.0035	-0.0084	1.0000

Scatterplot Matrix

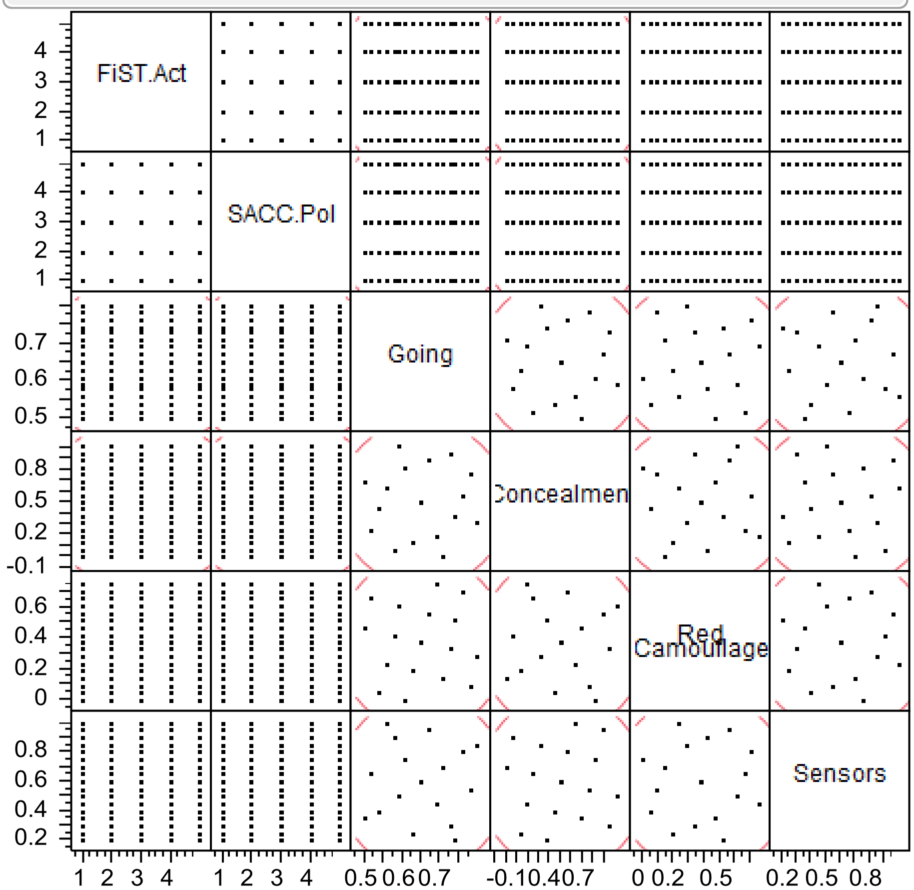

Figure 19. The correlation matrix and scatterplot of the Fatigue DOE.

D. RUNNING THE EXPERIMENTS

Each repetition of the MANA scenario takes approximately an hour to run on a modern desktop processor, during which it develops two months' worth of performance data. Since this is a significant use of the SEED Center's resources, the researcher decided to limit the model to 30 replications at each design point. Only noise factors are varied in MANA, so only the OLH DOE is run through that model. This results in 510 individual MANA repetitions, which takes up to a day to complete on the SEED Center's computing cluster. Steve Upton, who works for the SEED Center, created a postprocessor that then organizes the data into a useable format for analysis by the researcher. This postprocessor likewise can take about a day to finish running. Thus, every run of the MANA simulation takes at least two days to generate useful data.

At this point, the researcher utilizes a data organizing and reconciling script in R that organizes the data for ease of analysis and follow-on computations. The output of the seventeen design points of the MANA experiment is evaluated and analyzed for each SACC Policy, as this factor is the one that most directly affects the arrival processes. If an event occurred in a location that the FiST was not responsible for, it is ignored. This, in turn, allowed the researcher to organize the data in a format that would be immediately useful for the discrete-event model. The data is then studied by the researcher to ensure that enough events are occurring in the AO to generate a statistically useful amount of events in the discrete-event model. The researcher then alters the noise factors and obtains a new Latin Hypercube before running the MANA simulation again. Once the simulation provided useful and reliable results, the data were analyzed before use in the fatigue model.

A challenge that appears frequently throughout this research is the need for manual transfers, or “air gaps,” between models (see Figure 20), output, and analysis. These gaps are where the workload increased significantly, as the researcher is unable to find a way to automate the interface between models and some of the data analysis tools. The first manual transfer occurs after the MANA model is run and the data are prepared for analysis. JMP offers the most accessible tool for fitting the arrival of events to a distribution for use in the fatigue and discrete-event models. However, while JMP enables a limited amount of scripting, the analysis being done does not readily lend itself to this, and so it is done by hand. The next manual transfer appears where the sleep schedules are created. Once the arrival processes are analyzed, R is used to create sleep schedules for use in the SAFTE model through the FAST interface. R is very good at creating the necessary data strings, but it does not format the output file in such a way that it can be read in by FAST. Thus, the researcher has to save the file in a different format and then manually alter each file. While the alterations are trivial, and take less than a minute, there are 425 files. Fortunately, FAST has the ability to receive files in a very limited batch mode, and the output data is readable by R without further formatting. From analysis of this data, the researcher can make recommendations on policies that maximize cognitive effectiveness.

Additionally, the fatigue model's output is used to create effectiveness data in the discrete-event model.

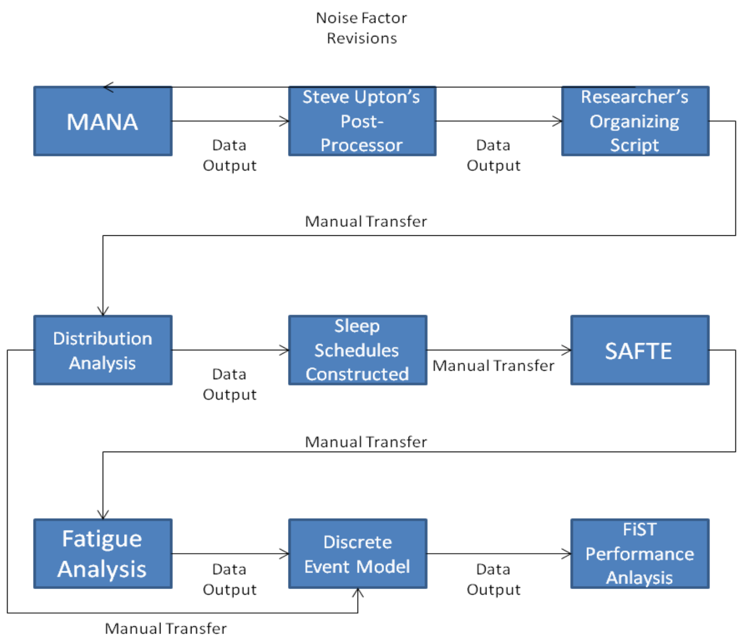

Figure 20. Experimental flow with the manual transfers noted. These are the greatest impediment to the research as they consume large amounts of time, and after passing them, going back becomes problematic at best.

The last model to be created and run is the discrete-event model. Before it can be run, however, the researcher gathers data from the supporting training commands in the form of performance data and Subject Matter Expert (SME) inputs. The data and insight from the SMEs are focused on how quickly the FiST, SACC, and firing agencies can perform the tasks necessary to engage targets under the conditions presented in the model, and how many tasks the FiST can complete simultaneously.

The discrete-event model is constructed in ExtendSim7, at the request of MCWL. One of the challenges with utilizing ExtendSim7 at NPS is that it is not located on a cluster, but only on individual workstations. Furthermore, the workstations tended to fail after a few hundred runs of the model. The researcher thus limits each design point to only 100 runs in order to ensure coverage of the final DOE. Running the discrete-event model proved to be an extremely labor-intensive task, and took approximately two weeks to complete due to the size of the matrix and the limitations of ExtendSim7 in the NPS environment. However, upon completion, the researcher is able to quickly organize the output data with an R-script and commence analysis.

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IV. DATA ANALYSIS

This chapter summarizes how the data is analyzed,and interpreted by the researcher.

A. GATHERED DATA

The researcher attempted to gather a significant amount of data from the Training and Tactical Exercise Control Group (TTECG), Expeditionary Warfare Training Group Pacific (EWTG-PAC), Marine Air Weapons and Tactics Squadron One (MAWTS-1), and the mortar course at 1st Marine Division Schools. The data sought were a mixture of training performance data and SME inputs. The list of questions that were asked of the SMEs is located in the Appendix: SME Questions. All of the data were gathered under the auspices of the NPS Institutional Review Board. Regrettably, only MAWTS-1 responded and provided data and SME insight.

1. Data

Dr. Fredlake, an analyst assigned to MAWTS-1, provided the researcher with analysis that he produced for MAWTS-1 on the topic of how long it took for aircraft to deliver ordnance once they had received the appropriate 9-line brief[3] from a FAC or JTAC. Dr Fredlake’s research covers both fixed- and rotary-wing aircraft, employing a variety of ordnance. However, the researcher is only focusing on the time it takes for fixed-wing aircraft to deliver bombs; based on model assumptions and the scenario (see

[3] A 9-line brief is the mission information that a JTAC passes to a CAS aircraft in order to initiate a mission.

Chapter II). Dr. Fredlake asserts that there is no statistical difference between fixed-wing aircraft delivering guided or unguided ordnance, so the researcher is using the aggregated data for both types of weapons (Fredlake, 2010). The result is an approximately normal distribution, with a mean of 8.3 minutes and a standard deviation of 3.9 minutes. However, Dr. Fredlake notes that the values must be positive, so the normal distribution is only an approximation (Dr. C. Fredlake, personal communication, 3/31/2011). According to Dr. Fredlake's research, the shortest time from receipt of a 9-line brief to ordnance delivery is one minute. For the purpose of the model, the time to deliver ordnance is determined from a truncated normal distribution, with the parameters given above, and a lower limit of one minute.

2. Subject Matter Expert (SME)

Major James Foley, USMC, an instructor in MAWTS-1's Air Officer Department, provides significant insights into the capacity of a FAC or JTAC operating alone or in a FiST. He states that FACs and JTACs can manage three aircraft or sections, but can only employ two of them while the third holds. Additionally, he asserts that attacks against multiple targets or using multiple aircraft sections are almost always sequential. He states that it can take from 2 minutes to more than 10 minutes for a FAC or JTAC to develop his plan and 9-line brief for arriving aircraft while working with a FiST. Additionally, Major Foley states that a FAC or JTAC may take from 5 minutes to over 15 minutes to pass the 9-line brief to an arriving aircraft. He also states that the presence of unsuppressed

MANPADs in the vicinity of a target for fixed-wing CAS would not have a significant effect on the time to prosecute the target, as the fixed-wing aircraft could either remain above the MANPAD threat throughout the engagement or only expose itself briefly during the final attack phase (Major J. F. Foley, personal communication, 4/1/2011).

Based on Major Foley's insight, for purposes of this model, an aircraft or section in holding is considered to still be in the queue, so it does not affect the FiST's capacity. Furthermore, all aircraft employment is handled sequentially. Finally, employing an aircraft utilizes one unit of task capacity for the FiST. If another aircraft is being utilized, but not holding, such as a UAS, another unit of capacity is used. Finally, employing mortars in conjunction with the aircraft uses another unit of task capacity. Thus, in a scenario where a target has to be engaged with aircraft and mortars and a UAS is present, three units of task capacity are needed to execute the mission. The time ranges that Major Foley provided are used in the model as uniform distributions with ranges [2,10] and [5,15] for developing a CAS mission and passing the 9-line to an aircraft, respectively.

B. FARMED DATA

Data farming permits the researcher to explore a problem by varying factors of a model that may provide insights. The researcher then utilizes the results to further explore particular areas of the model to gain better insight into the model. In this research, the process was only conducted once, but further research and exploration of the results could result in several "growing seasons" of data being developed (Horne, 2001).

1. MANA Output Data

Steve Upton's postprocessor takes the data from numerous MANA output files and organizes them in a manner convenient for analysis. This postprocessor returned three files in comma separated variable format:

1. allContacts: This file recorded the time, location, duration, and name of each enemy detection.
2. allShotEvents: This file recorded the time, location, and name of each IED event, whether it detonated or not. Additionally, it recorded all instances and locations of Red force Indirect Fire (IDF).
3. allUAVContacts: This file recorded the time, location, duration, and name of each enemy detection made by a UAS.

The researcher then runs his own R script to analyze the data. The researcher first eliminates any encounters with Red forces that lasted five or fewer minutes from allContacts. These encounters are a MANA artifact, as they represent CLT forces gaining and then losing contact repeatedly over short time periods with the same enemy unit. By removing these contacts, the number of enemy contacts is decreased by as much as 50%. The researcher chose a threshold of five minutes as, in his experience, it would be very difficult for an observing unit to identify, locate, and then coordinate any sort of supporting arms engagement in that period. This same culling was used on allUAVContacts.

The researcher next reconciles the CW-IED team events in allContacts and allShotEvents. The goal, in this case, is to avoid duplicate counting of encounters. The file allContacts included CW-IED teams that were encountered while moving, but also after they had attempted to detonate an IED. The file allShotEvents only included those CW-IED contacts that had attempted or succeeded in detonating an IED. The researcher reconciled the data by removing all of the ambushes instigated by CW-IED teams from allContacts.

a. Arrival Rates

The first analytical task the researcher undertakes with this data is to determine the arrival process for specific events. The researcher first segregates the data by event, and then calculates interarrival times between the same types of events. The Decision Factor that has the most bearing on the arrival rate of events is the SACC Policy, as the researcher is only interested in events the FiST has to respond to. Thus, the researcher analyzes each of the MANA runs based on the OLH over the five different SACC policies. This analysis, based on SACC Policy, allows the construction of arrival distributions specific to the SACC Policy and design point of the Noise OLH.

The specific events that are being analyzed are:

1. CW-IED teams detonating an IED: This indicates an ambush concurrent with a CASEVAC.
2. CW-IED teams failing to detonate an IED: This indicates an ambush without a concurrent CASEVAC.
3. CW-IED teams: This indicates the detection of a moving CW-IED team.
4. IDF teams: This indicates the detection of an IDF team. It does not mean that IDF has been received.

5. Infiltrators: This indicates the detection of Red Infiltrators.
6. Technicals: This indicates the detection of Red Technical Vehicles.
7. VIED: This indicates a VIED detonating, resulting in a CASEVAC.
8. VIED teams: This indicates the detection of moving VIED emplacers.
9. IDF fire on the base: This indicates Red IDF teams firing on the CLT base.

The researcher then fits distributions using Corrected Akaike's Information Criterion to each of the arrival data sets (SAS Institute Inc., 2010). Often, the distribution that best fit the data was of a type not supported in ExtendSim7. For arrivals, the Weibull, Normal, and Exponential distributions work best in ExtendSim7, while the Lognormal and Logistic did not, due to how the arrival process is structured in ExtendSim7. Thus, the researcher finds the best-fitting distribution that worked in ExtendSim7. The median value of each distribution enables the researcher to create the expected arrival times for the fatigue model, and also serves as a gauge of the frequency of events. Additionally, the median was less likely to be influenced by extreme values. A look at the median values indicates that the arrival rates for CW-IED teams, Infiltrators, and VIED teams are very high. In fact, they occur at such a frequency that they often overlapped. A test run of the fatigue model with these events resulted in virtually no sleep for the FiST under every SACC Policy and Activity Cycle. Based on the researcher's own experience, and the stated goal that this model is to simulate low to mid-intensity combat, the researcher removed this data from consideration. The researcher believes that further culling, based on event duration, would be arbitrary, and would also bias the results of the discrete-event model phase of this research. The remaining event arrivals provide a reasonable approximation to mid-intensity combat. All further analysis ignored the CW-IED teams, Infiltrators, and VIED teams.

b. Arrival Locations

The researcher next determines the probability that given an event occurs, which zone it occurs in (see Figure 7). This was done for each combination of SACC Policy and design point in the Noise OLH. This is done for all of the events listed above, except for IDF fire on the CLT base, which always occurs in Zone 1.

c. Contact Durations

The researcher fits the contact duration data to a distribution, based on the noise with Corrected Akaike's Information Criterion (SAS Institute Inc., 2010). In every case, the researcher aggregates the raw data in Zones IIa and IIb because the discrete-event model treats both zones as a single zone. Further, there is often a paucity of data points for contact durations in some zones. In these cases, the data is aggregated with the nearest zone, and the zones share the same distribution. As with the analysis of arrival data, the best-fitting duration distirbution was not always in a form compatible with ExtendSim7. In these cases, the researcher would find the best-fitting distribution that worked easily with ExtendSim7. LogNormal, Exponential, and Weibull distributions best met this criteria.

d. Dependant Events

The researcher analyzes how often contact with the Red forces involved a UAS or possible indirect fire from an enemy IDF team. This information adds realism to the discrete-event model by adding additional stressors to the FiST.

The researcher totals the number of Red contacts in the zone and divides by the number of UAS contacts in the zone to determine the empirical probability of a UAS being involved in an encounter. Due to the difficulties in reconciling some of the data, the probabilities sometimes exceed 1.0. This occurs because UASs often "double-up" on contacts, or hand off contacts to each other. In these cases, the probability is simply set to 1.0. In every area, except for Zones 2 and 4, there is a very high probability of a UAS being present when a target is detected or tracking a target detected by other means. Zones 2 and 4 are significantly less likely to see a contact with a Red unit involve a UAS. This is likely due to the very small size of their area, and because they provide a great deal of concealment to the Red forces, since they are urban areas.

The researcher sums the number of IDF attacks on CLT units and recon teams in each zone for each OLH design point, and then divides by the sum of CLT and recon team encounters in that zone. The result is the probability that a Marine unit would receive IDF after encountering a

Red unit. The frequencies are so low (see Table 3) that the researcher has decided to ignore this data and not to incorporate it into the discrete-event model as originally planned. The researcher believes the inclusion of this would add a significant amount of complication to the discrete-event model and yield little benefit.

DP	Zone1	Zone2	Zone3	Zone4	Zone5	Zone6
1	0.000593	0	0	0	0	0
2	0.000396	0	0	0	0	0
3	0	0	0	0	0	0
4	0.000196	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0.004608	0	0	0	0
8	0	0.002392	0	0	0	0
9	0	0	0	0	0	0
10	0.000238	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0.015152	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0.002703	0	0	0	0
17	0	0	0	0	0	0

Table 3. Probability of a CLT unit receiving IDF fire while in contact with a Red unit. The probability of this is extremely low across the spectrum of design points in MANA.

2. SAFTE Output Data

The MOEs from SAFTE are the average cognitive effectiveness and the minimum cognitive effectiveness of the FiST. The researcher calculates these for the first 15 days, the first 30 days, and the whole 60 days. For FiST Activity Policy 1, this requires entering the activity schedule into SAFTE and reporting the results. FiST Activities 2 through 4 require some reconciliation. A simple schedule is calculated for the night shift without any interruptions. This schedule is then compared to the dayshift schedule of the FiST leader with interruptions. During the day shift, the FiST leader’s effectiveness is used. During the night shift, the FiST leader’s effectiveness is compared with the night shift’s, and the lowest effectiveness is used. FiST Activity 5 is the combination of two rest plans, for the opposite shifts of the FiST. The resulting output is then collapsed across the noise factors. Note that the standard deviation of FiST Activity 5 is zero, as the nature of the policy essentially removed the effect of the noise factors since the two shifts are only functioning at their assigned times.

a. Mean Cognitive Effectiveness

The researcher evaluates the mean cognitive effectiveness by using expected loss. This method enables the researcher to account for the mean value, as well as variation, in order to find the course of action that results in the most robust solution that minimizes the loss of effectiveness. This function is represented by:

$$E(L) = (\mu-\tau)^{2}+\sigma^{2}.$$

The researcher set τ to 100, which represents the goal of 100% cognitive effectiveness. μ is the mean cognitive effectiveness for the time period under consideration. σ is the standard deviation of the mean cognitive effectiveness.

The researcher chooses to use a partition tree to display the results of the expected loss analysis. This format is easily understood by readers both with and without a technical background. The algorithm seeks to group the effective loss into two groups of low variability. The algorithm then determines which decision factor to split into branches in order to attain this outcome (Hand, Mannila, & Smyth, 2001). The process is repeated on each branch of the tree. This results in an easy to understand graphical display of results.

The result of this analysis shows that the minimum effective loss occurs when FiST Activity Policy 5 was selected for all three time. However, this may not always be an option, depending on command policies and the level of confidence the FiST leader has in the other members of his team. In this case, the duration of the team's employment drives the selection of the secondary policy (see Figures 21-23). If the FiST will be employed for fifteen days or less, the FiST leader should seek to delegate authority for all fires outside of the AO and nonfire events in the AO to the night shift. Failing this, the FiST leader should seek to limit the scope of the CLT FiST's responsibility. For longer deployments, the FiST leader should seek to reduce the scope of the FiST's responsibility as the secondary policy. If the FiST leader is unable to do that, then he should seek to delegate authority to the night shift for fires outside of the AO and nonfiring events in the AO.

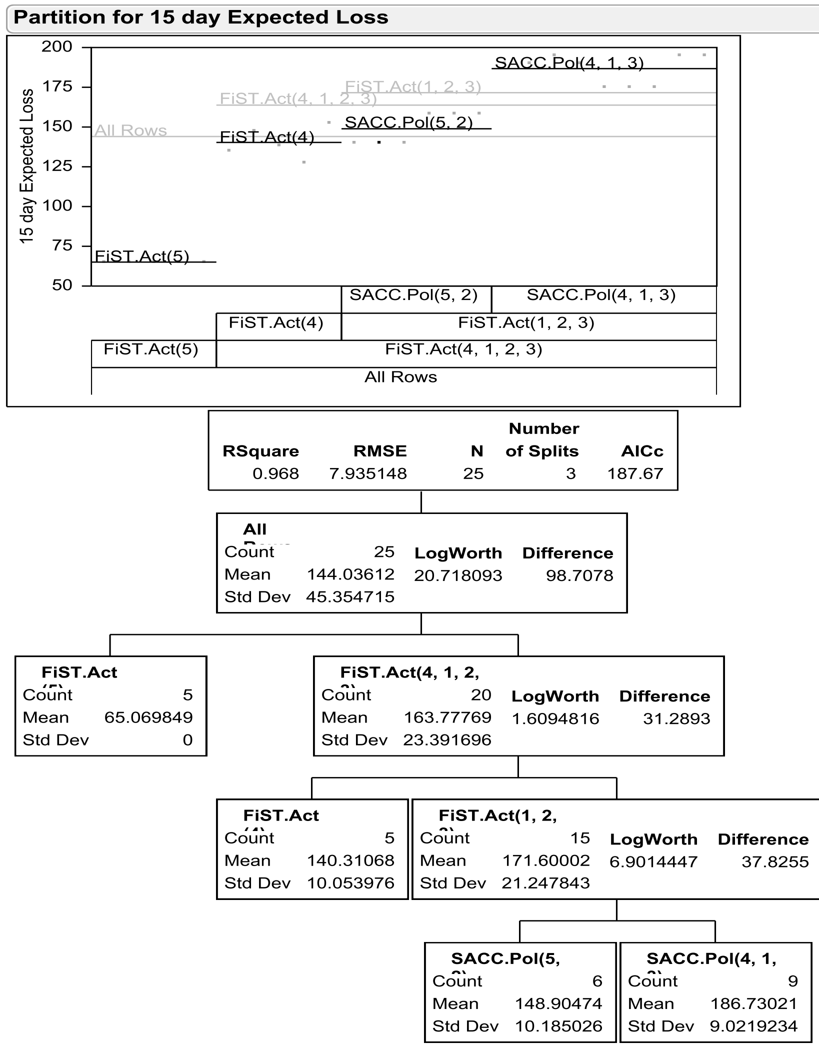


Figure 21. Partition tree for minimum effective loss of cognitive effectiveness for 15-day FiST employment. As can be seen, the best policy in this case is to utilize FiST Activity Policy 5. Failing that, FiST Activity Policy 4 is the next best option.

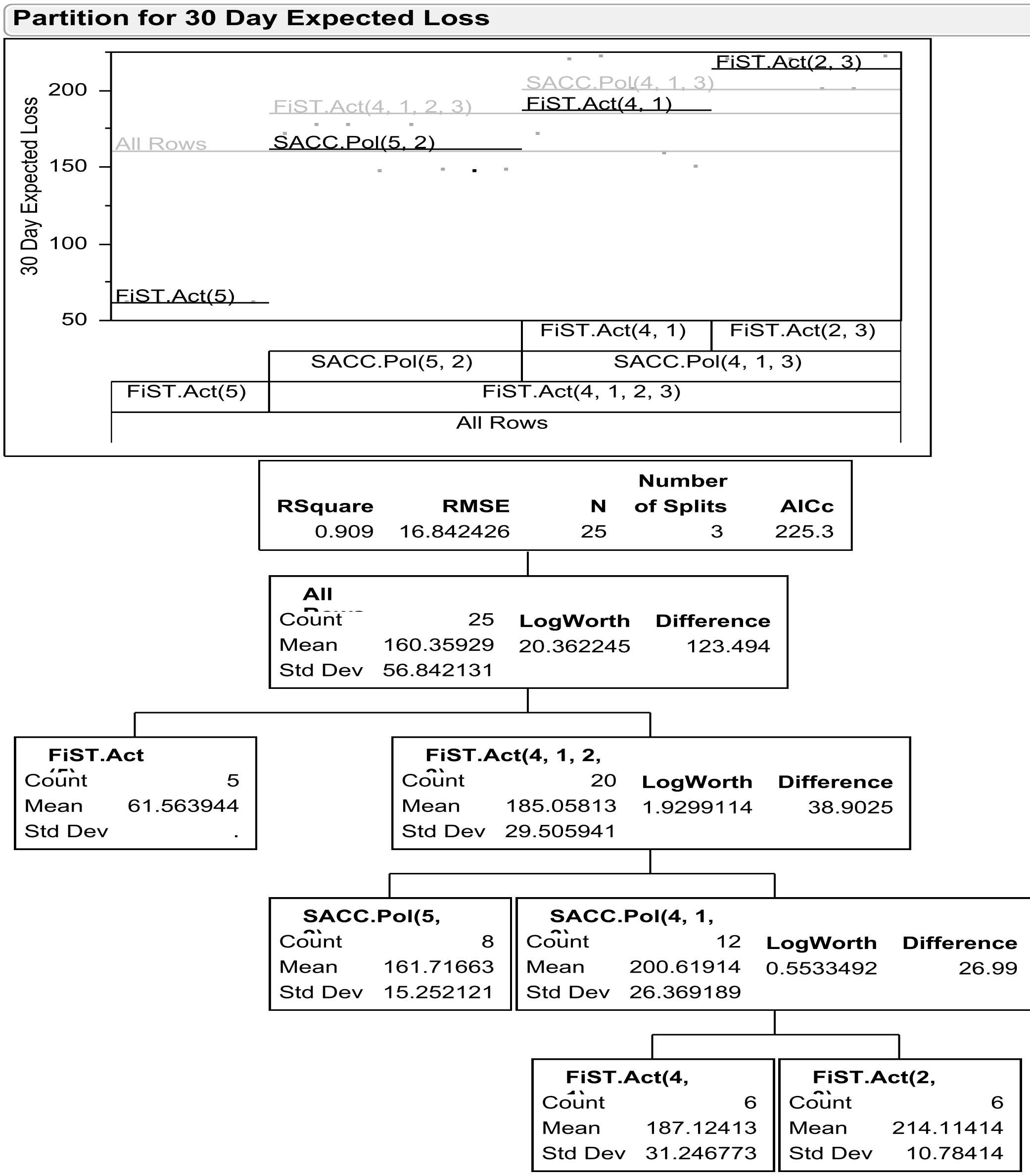


Figure 22. Partition tree for minimum effective loss of cognitive effectiveness for 30-day FiST employment. As can be seen, the best policy in this case is to utilize FiST Activity Policy 5. Failing that, SACC Policies 5 or 2 are the next best option.

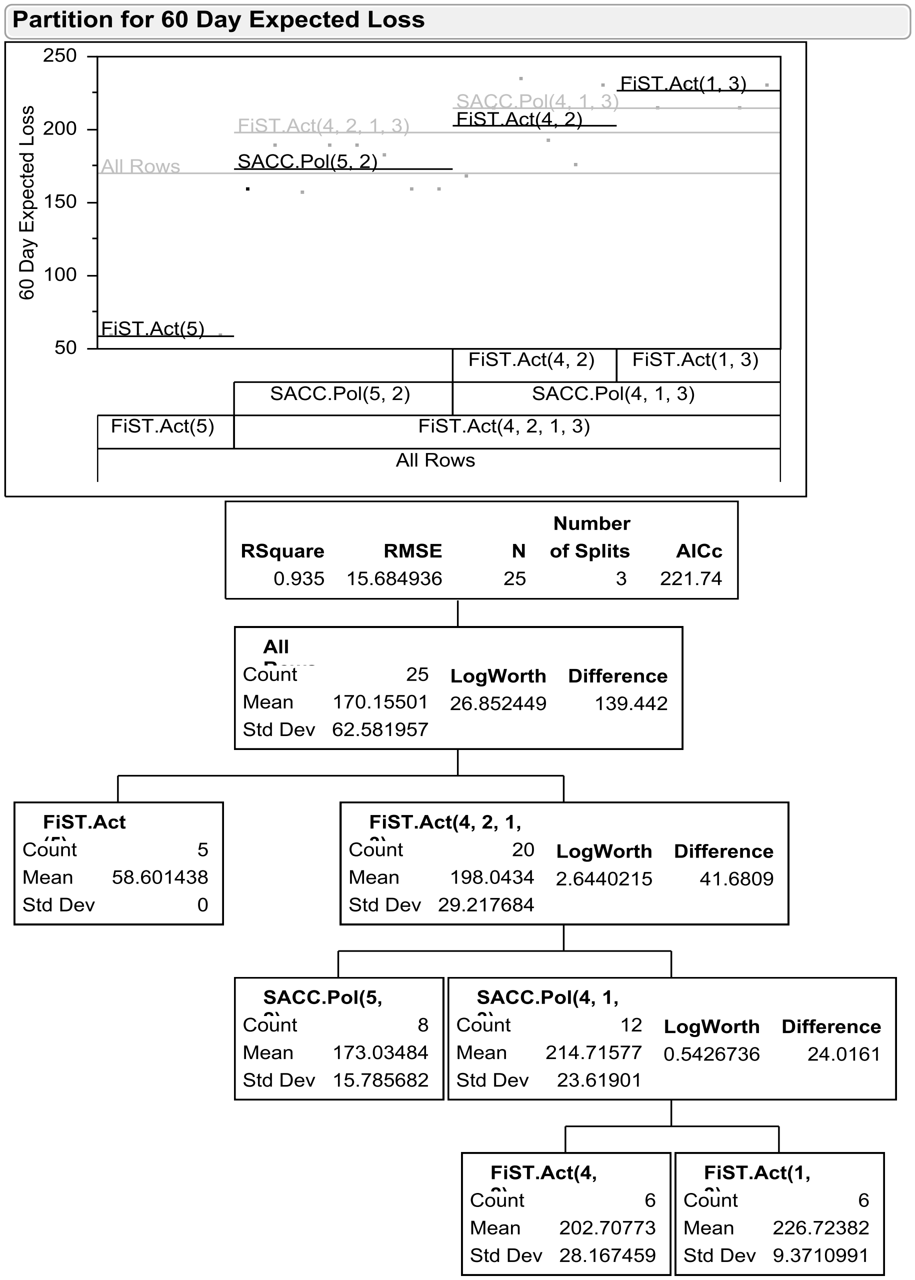


Figure 23. Partition tree for minimum effective loss of cognitive effectiveness for 60-day FiST emplotment. In this case is to utilize FiST Activity Policy 5. Failing that, SACC Policy 4 is the next best option.

b. Worst Case Cognitive Effectiveness

The minimum cognitive effectiveness is also included in the data. This data informs decision makers about the possible shortcoming of a policy combination. FiST Activity Policy 5 has the highest minimum effectiveness, and reaches this point within the first fifteen days. All of the other policy combinations have significantly lower minimum cognitive effectiveness within the first fifteen days, and continue to decline at least into the first 30 days, and, in some cases, over the entire 60-day period. This supports the use of FiST Activity Policy 5 as the best overall choice for an activity policy.

3. Discrete-Event Model Output Data

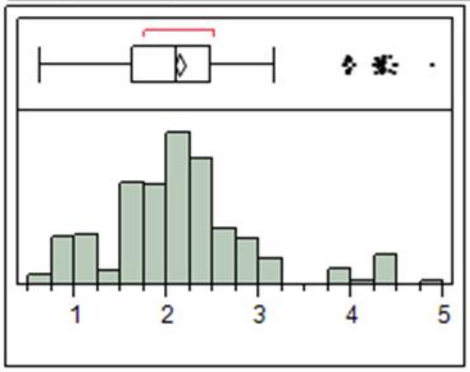
The MOE for the discrete-event model is FiST task performance. This is defined as the ratio of the number of fire-support tasks successfully completed to the number of fire-support tasks attempted. This excludes any tasks that were still waiting to start in the queue, as well as all CASEVAC and resupply missions.

a. Arrival Frequency

The researcher analyzes the data output from ExtendSim7 to ensure that the simulation reflects a low to mid-intensity combat scenario.

The researcher determines the average arrival rate of fire-support events for each design point and plots a histogram (see Figure 24). The arrival process has both a mean and a median of approximately two events per day, with the lowest frequency being about one event every two days, and the highest almost five events per day. This appears to capture the range of low- to mid-intensity combat operations.

DailyActivty



Quantiles

100.0%	maximum	4.86
99.5%		4.44901
97.5%		4.32085
90.0%		2.9393
75.0%	quartile	2.47558
50.0%	median	2.0995
25.0%	quartile	1.62592
10.0%		1.15257
2.5%		0.94334
0.5%		0.64421
0.0%	minimum	0.62867

Moments

Mean	2.1378931
Std Dev	0.766065
Std Err Mean	0.0293773
Upper 95% Mean	2.1955743
Lower 95% Mean	2.080212
N	680

Figure 24. Arrival Frequencies of Fire-Support Events. The median and mean have approximately two events arriving per day, and only at the 90^{th} percentile does this increase to three events. This appears to capture the range of combat from low- to mid-intensity.

b. Fist Endurance

Another question of particular concern to MCWL is how long a FiST, as currently organized, can function with a CLT. In order to answer this and subsequent questions, the researcher collapses the data across the noise factors. The researcher looks at the worst performance of each policy combination over the three time intervals. In conjunction with MCWL, the researcher set 0.8 as the threshold for failure. The worst mean performance for each combination of decision factors is utilized to compare performance. The combination that most closely resembles a current FiST is the one with FiST Activity Policy 1, SACC Policy 5, Fire Support Policy 2, and FiST Capacity 2. This combination’s worst performance was consistently under 80%

in all three time intervals (0.79, 0.78, and 0.78 for 15, 30, and 60 days, respectively). However, it was not the worst combination. The worst performer was a design point with FiST Activity Policy 5, SACC Policy 5, Fire Support Policy 3, and FiST Capacity 1. This FiST reflects several changes made to the FiST structure, most notably the delegation of full authority to the second shift, which maximizes the cognitive effectiveness of the FiST. Despite this, this combination resulted in sustained performance of just over 0.7 for the entire experiment.

c. Effectiveness

The researcher initially looks at FiST performance by finding the mean and minimum performance for each combination of design factors for the entire 60-day period. A casual examination reveals that the ten most effective combinations utilize either SACC Policy 3 or 4, while including the whole range of the other factors. Similarly, the researcher found that of the ten lowest-performing design points, seven of them utilized SACC Policy 5, and the other three utilized SACC Policy 1. In fact, the six lowest-performing design points utilized only SACC Policy 5. As with the high performers, the other decision factors displayed the full range of options among the weakest performers. This inspection of the data suggests that SACC Policy 5 reduces performance significantly, while SACC Policies 3 and 4 tend to enhance it.

The researcher also examined the worst performance of each of the combinations of decision factors. Those ten highest combinations with the best minimum performance were more varied than the ten highest mean performances, though they notably did not include SACC Policy 5. The ten lowest minimum performance combinations, however, strongly resembled the ten lowest mean performance events. Six of them utilized SACC Policy 5, while the remaining four were split between SACC Policies 1 and 4. This simple inspection of the data again suggests that SACC Policy 5 diminishes performance.

In order to gain more insight into the problem, the researcher compares FiST effectiveness by using expected loss. This method enables the researcher to account for the mean value, as well as variation, in order to find the course of action that results in the most robust solution that minimizes the loss of effectiveness. This function is represented by:

$$E(L)= \mu-\tau\ ^{2}+\sigma^{2} .$$

The researcher set τ to 1.0, which represents the goal of servicing 100% of the targets. μ is the mean FiST performance for the time period under consideration. σ is the standard deviation of the FiST performance with the same decision factors. The partition trees show the results of this analysis (see Figures 25, 26, and 27 for fifteen days, 30 days, and 60 days of FiST employment, respectively). In all three of these trees, the first split removes SACC Policy 5 in order to improve performance. In the 15- and 30-day trees, the first split also removes SACC Policy 1 as well, while the second split for the 60-day employment removes SACC Policy 1. Following the splits based on SACC Policies 1 and 5, the next split is based on the fire-support process, and all subsequent splits are based on further refinement of the SACC Policy choice. However, the variance and expected loss have the most significant decreases in the initial SACC Policy splits. The researcher concludes from this that the FiST should have the authority to clear their own fires, in contrast to SACC Policy 5. Further, the geographic scope of the FiST's responsibility should be reduced from the entire AO and AI (SACC Policy 1). The remaining three SACC Policies all authorize the FiST to clear its own fires and restrict its responsibility to either the AO or the AO and part of the AI. FiST Activity Policy and FiST Task Capacity are both ubiquitous by their absence in all three of these trees. The researcher believes that the limitations of the fatigue research (see Chapter II.B.7) may account for the apparent lack of importance placed on the FiST Activity Policy.

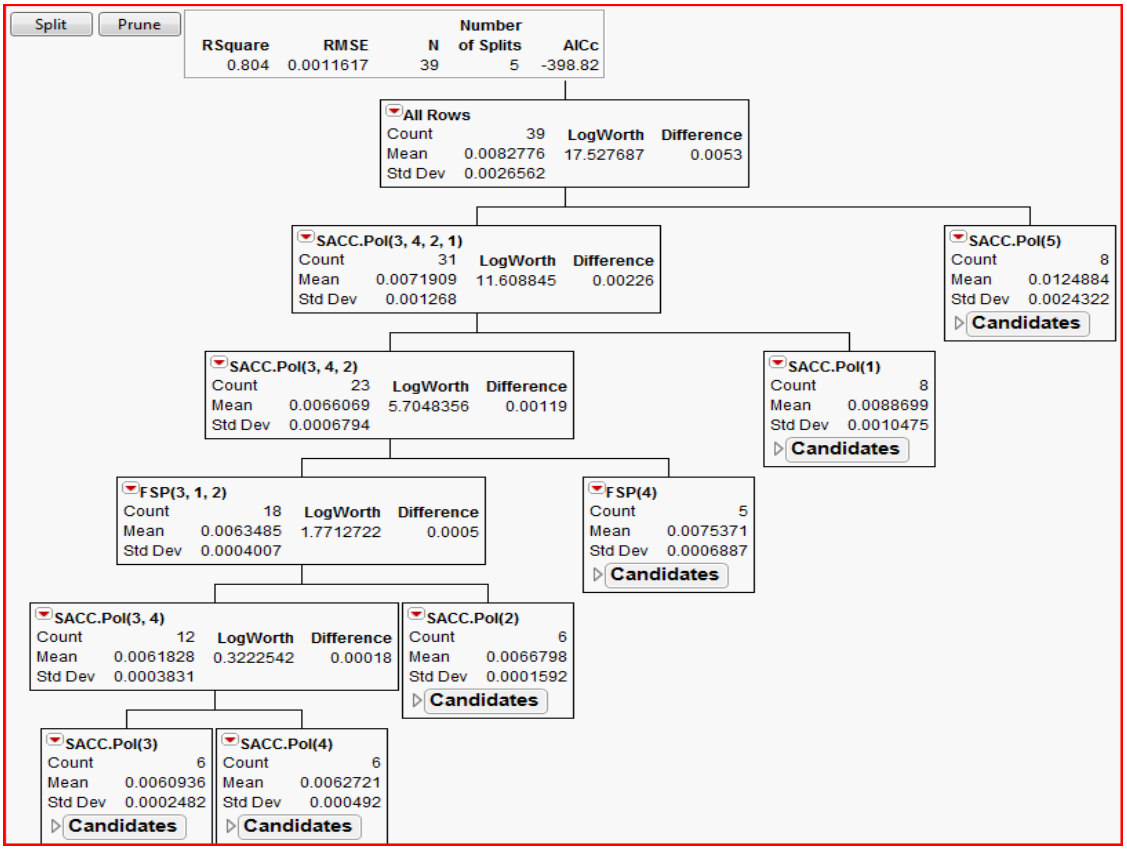


Figure 25. The partition tree for FiST effectiveness over a period of 60 days. As can be seen, the largest reduction in effective loss comes in the first two splits.

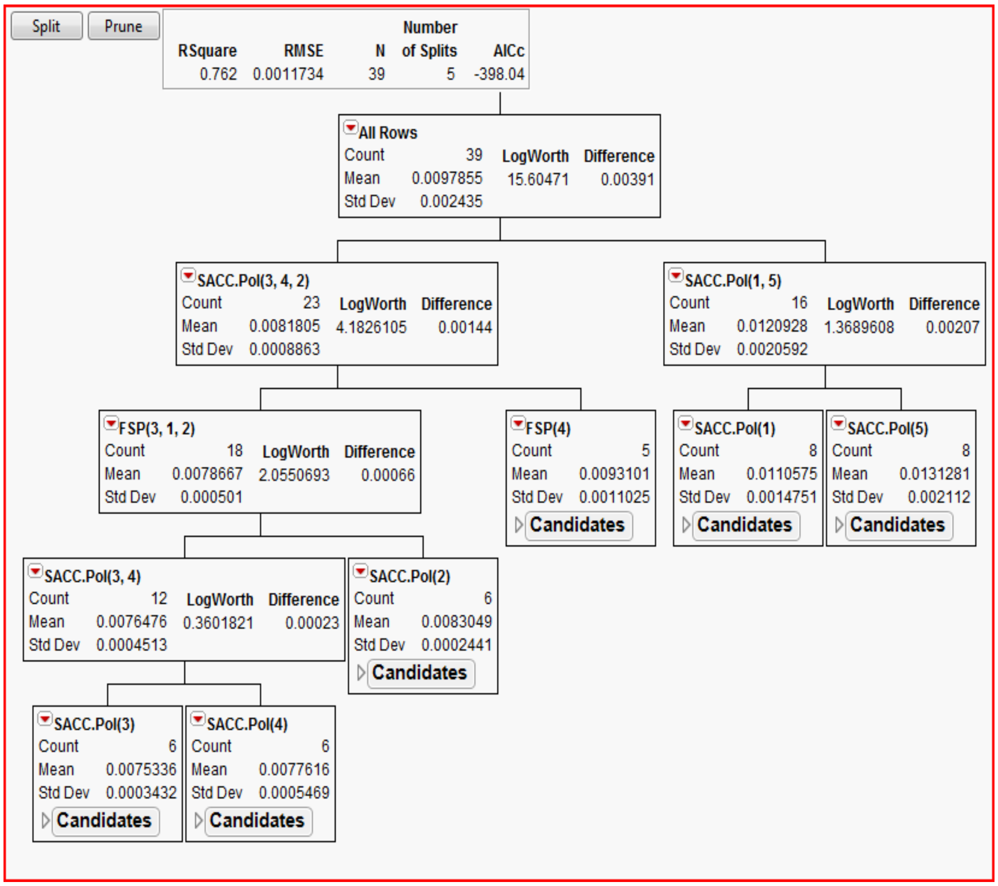


Figure 26. Thirty-day effectiveness. Here too, the largest decrease in expected loss is found by using SACC Policies 2, 3, or 4.

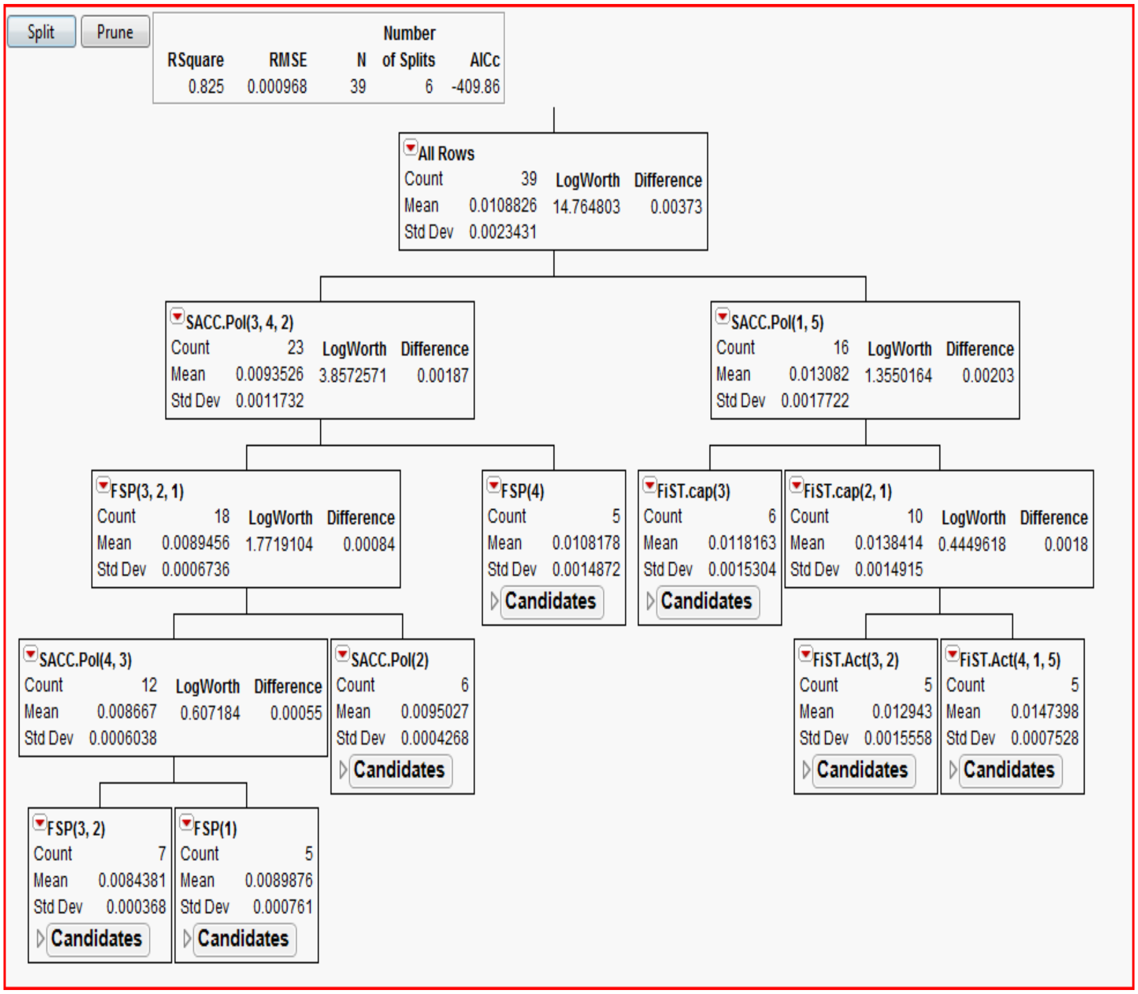


Figure 27. Fifteen-day effectiveness. Here too, the largest decrease in expected loss is found by using SACC Policies 2, 3, or 4.

In order to gain further insight into these models, and some understanding of the role of FiST Activity Policy and Task Capacity, the researcher constructs a multiple regression model using stepwise regression on a 60-day employment. The researcher chooses to consider all first order effects and interactions (see Figure 28). The first two terms confirm the essential correctness of the partition trees' initial splits. FiST Activity Policy appears in an interaction with the SACC Policy as the third most important factor, but the SACC Policy includes SACC Policy 1, which is removed in the first or second split of the partition tree. This would account for the absence of the FiST Activity policy in the partition tree. FiST Task Capacity appears as only the ninth most important factor.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
SACC.Pol{3&4&2&1-5}	-0.002555	9.798e-8	-26081	<.0001*
SACC.Pol{3&4&2-1}	-0.001058	8.87e-8	-11926	<.0001*
(FiST.Act{3&4&1-2&5}-0.17949)*(SACC.Pol{3&4&2&1-5}-0.58974)	0.0011747	1.026e-7	11453	<.0001*
(SACC.Pol{3&4&2&1-5}-0.58974)*FSP{2-4}	-0.001447	1.293e-7	-11190	<.0001*
FiST.Act{3&4&1-2&5}	-0.000573	5.8e-8	-9872	<.0001*
(FiST.Act{3-4&1}+0.17949)*(SACC.Pol{3&4&2&1-5}-0.58974)	0.0010057	1.358e-7	7403.2	<.0001*
FiST.Act{4-1}	0.0005965	8.574e-8	6957.0	<.0001*
FSP{1&3-2&4}	-0.000528	7.773e-8	-6794	<.0001*
FiST.cap{3&2-1}	-0.000399	5.994e-8	-6658	<.0001*
FiST.Act{3-4&1}	-0.000525	7.949e-8	-6603	<.0001*
FSP{1-3}	0.0005135	8.899e-8	5770.3	<.0001*
(SACC.Pol{3&4&2&1-5}-0.58974)*(FSP{1&3-2&4}-0.07692)	0.0006928	1.382e-7	5012.6	<.0001*
(FiST.Act{2-5}+0.05128)*(FiST.cap{3&2-1}-0.33333)	0.0005421	1.305e-7	4154.7	<.0001*
FSP{2-4}	0.0003214	8.592e-8	3740.5	<.0001*
(FiST.Act{3&4&1-2&5}-0.17949)*(FiST.cap{3&2-1}-0.33333)	-0.000389	1.174e-7	-3319	<.0001*
(FiST.Act{3-4&1}+0.17949)*(FiST.cap{3&2-1}-0.33333)	0.000336	1.045e-7	3214.8	<.0001*
(FiST.Act{4-1}-0.02564)*FSP{2-4}	0.0005342	1.722e-7	3102.7	<.0001*
(FiST.Act{3-4&1}+0.17949)*FiST.cap{3-2}	-0.000408	1.32e-7	-3092	<.0001*
(FiST.Act{3&4&1-2&5}-0.17949)*(SACC.Pol{3-4&2}+0.23077)	0.0002566	8.952e-8	2866.5	<.0001*
SACC.Pol{3-4&2}	-0.000244	9.115e-8	-2680	<.0001*
(SACC.Pol{3&4&2&1-5}-0.58974)*(FiST.cap{3&2-1}-0.33333)	0.0003812	1.446e-7	2636.3	<.0001*
(FiST.Act{2-5}+0.05128)*(FSP{1-3}-0.02564)	0.0003259	1.251e-7	2604.9	<.0001*
FSP{2-4}*FiST.cap{3-2}	0.0003207	1.595e-7	2010.3	<.0001*
(FiST.Act{2-5}+0.05128)*(SACC.Pol{3&4&2-1}-0.38462)	0.000467	2.386e-7	1957.2	<.0001*
FiST.cap{3-2}	-0.000127	6.578e-8	-1932	<.0001*
FiST.Act{2-5}	-0.00015	9.874e-8	-1515	<.0001*
(FiST.Act{3&4&1-2&5}-0.17949)*FSP{2-4}	0.0001141	9.408e-8	1212.5	<.0001*
(SACC.Pol{3&4&2-1}-0.38462)*FSP{2-4}	-0.000127	1.075e-7	-1182	<.0001*
(SACC.Pol{3-4&2}+0.23077)*(FSP{1&3-2&4}-0.07692)	7.0477e-5	1.867e-7	377.48	<.0001*
(FSP{1-3}-0.02564)*FiST.cap{3-2}	-4.26e-5	1.177e-7	-361.8	<.0001*
(FiST.Act{2-5}+0.05128)*FSP{2-4}	-0.000037	1.645e-7	-224.7	<.0001*
(FiST.Act{3-4&1}+0.17949)*(SACC.Pol{3-4&2}+0.23077)	-1.743e-5	1.029e-7	-169.5	<.0001*
(FiST.Act{3&4&1-2&5}-0.17949)*FiST.cap{3-2}	-7.104e-6	8.305e-8	-85.53	0.0001*
(FiST.Act{4-1}-0.02564)*(FSP{1-3}-0.02564)	6.3284e-6	1.005e-7	62.98	0.0003*
(FSP{1-3}-0.02564)*(FiST.cap{3&2-1}-0.33333)	-3.965e-6	1.129e-7	-35.12	0.0008*
(SACC.Pol{3-4&2}+0.23077)*(FiST.cap{3&2-1}-0.33333)	1.2352e-6	1.55e-7	7.97	0.0154*

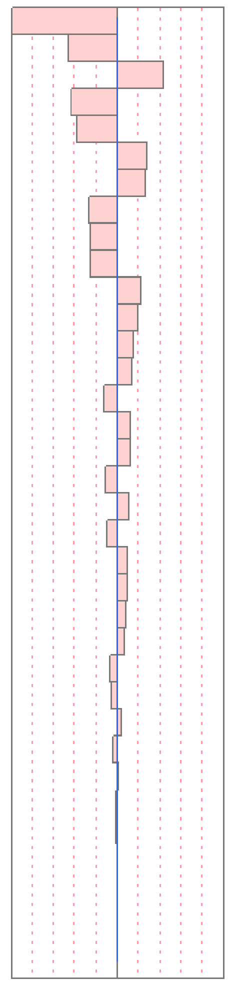


Figure 28. The multiple regression model for 60-day FiST effectiveness. Note the high level of importance given to the removal of SACC Policies 1 and 5. FiST Activity appears in combination as the third most important factor, and on its own as the seventh most important. The FiST's task capacity only appears as the ninth most important factor.

The regression model for 30-day FiST employment is quite similar. However, the regression model for fifteen-day employment (see Figure 29) shows that FiST Task Capacity is a close second to SACC Policy in importance, and yet it is not considered on the partition tree (see Figure 27). The researcher disaggregates FiST performance into performance of missions requiring close air support, possibly supported by mortars, and missions utilizing only mortars in order to further explore this.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
SACC.Pol{3&4&2-1&5}	-0.001778	1.47e-10	-1e+7	<.0001*
FiST.cap{3&2-1}	-0.00099	8.61e-11	-1e+7	<.0001*
FiST.Act{1&3-4&2}*FSP{2-4}	0.001391	1.64e-10	8.5e+6	<.0001*
FiST.Act{1&3-4&2}	-0.000538	8.6e-11	-6e+6	<.0001*
(FiST.Act{1&3&4&2-5}-0.53846)*(SACC.Pol{3&4&2-1&5}-0.17949)	0.0004728	8.24e-11	5.7e+6	<.0001*
(FiST.Act{1&3&4&2-5}-0.53846)*(SACC.Pol{3-4}+0.02564)	0.0011459	2.05e-10	5.6e+6	<.0001*
FiST.Act{1&3&4&2-5}	-0.000826	1.5e-10	-6e+6	<.0001*
(SACC.Pol{3&4&2-1&5}-0.17949)*FiST.cap{3-2}	0.0005279	1.61e-10	3.3e+6	<.0001*
(FiST.Act{1-3}+0.02564)*(SACC.Pol{3-4}+0.02564)	-0.001068	3.31e-10	-3e+6	<.0001*
(FiST.Act{1-3}+0.02564)*(FSP{3-1}+0.02564)	-0.000679	2.11e-10	-3e+6	<.0001*
FSP{3-1}	-0.000431	1.4e-10	-3e+6	<.0001*
SACC.Pol{3&4-2}	-0.000641	2.12e-10	-3e+6	<.0001*
(FSP{3&1-2&4}-0.07692)*FiST.cap{3-2}	0.0004624	1.53e-10	3e+6	<.0001*
FiST.Act{4-2}	0.0003355	1.23e-10	2.7e+6	<.0001*
FSP{2-4}*(FiST.cap{3&2-1}-0.33333)	0.0009669	4.12e-10	2.3e+6	<.0001*
FSP{3&1-2&4}	-0.000286	1.32e-10	-2e+6	<.0001*
FiST.Act{1&3-4&2}*(SACC.Pol{3&4&2-1&5}-0.17949)	0.0001688	8.28e-11	2e+6	<.0001*
(FiST.Act{1&3&4&2-5}-0.53846)*(FSP{3&1-2&4}-0.07692)	-0.00031	1.57e-10	-2e+6	<.0001*
FiST.cap{3-2}	-0.000289	1.81e-10	-2e+6	<.0001*
FSP{2-4}	-0.000151	9.74e-11	-2e+6	<.0001*
FiST.Act{1-3}	0.0001601	1.25e-10	1.3e+6	<.0001*
(SACC.Pol{3-4}+0.02564)*FiST.cap{3-2}	-0.000408	3.27e-10	-1e+6	<.0001*
SACC.Pol{3-4}	0.000154	1.33e-10	1.2e+6	<.0001*
SACC.Pol{1-5}*(FSP{3&1-2&4}-0.07692)	0.0001878	1.74e-10	1.1e+6	<.0001*
(FiST.Act{1&3&4&2-5}-0.53846)*(FSP{3-1}+0.02564)	-0.000169	1.78e-10	-9e+5	<.0001*
(FiST.Act{1-3}+0.02564)*FSP{2-4}	-0.00032	3.42e-10	-9e+5	<.0001*
(FiST.Act{1-3}+0.02564)*(FSP{3&1-2&4}-0.07692)	9.6048e-5	1.69e-10	568664	<.0001*
(FiST.Act{4-2}-0.02564)*FSP{2-4}	0.0001961	3.96e-10	494698	<.0001*
(SACC.Pol{3-4}+0.02564)*(FSP{3-1}+0.02564)	0.0001104	3.24e-10	340716	<.0001*
(FiST.Act{4-2}-0.02564)*SACC.Pol{1-5}	-7.217e-5	2.46e-10	-3e+5	<.0001*
SACC.Pol{1-5}	0.0001133	3.95e-10	286902	<.0001*
(SACC.Pol{3&4&2-1&5}-0.17949)*(FSP{3&1-2&4}-0.07692)	0.0000289	1.18e-10	245588	<.0001*
(FiST.Act{4-2}-0.02564)*(FSP{3-1}+0.02564)	4.9423e-5	3.28e-10	150736	<.0001*
FiST.Act{1&3-4&2}*(FSP{3&1-2&4}-0.07692)	-1.88e-5	1.54e-10	-1e+5	<.0001*
(FiST.Act{1-3}+0.02564)*(SACC.Pol{3&4&2-1&5}-0.17949)	3.6746e-5	3.22e-10	113979	<.0001*
(SACC.Pol{3&4-2}-0.17949)*(FSP{3-1}+0.02564)	-1.075e-5	2.5e-10	-42966	<.0001*
(FSP{3-1}+0.02564)*FiST.cap{3-2}	-8.33e-7	1.16e-10	-7184	<.0001*

Figure 29. While the utilization of SACC Policies 2, 3, or 4 remains the most important factor, increased FiST capacity is a very close second, even though it does not show up on the partition tree.

The partition tree for fifteen-day employment of CAS does not show particularly unexpected results (see Figure 30), though both Task Capacity and Activity Policy appear in the lower branches. Mortar missions (see Figure 31), however, show significantly different results. In this case, FiST capacity is the most important effect on minimizing effective loss, while SACC policies are distinctly secondary. The researcher believes that this is because the SACC policies do not have as significant an impact on mortar employment as they do on aircraft. The 81mm mortars do not see any reduction in the number of targets based on any SACC policies, while the EFSS only sees the last three km of its twelve km range ring reduced by SACC Policies 1, 2, and 5. By comparison, those same policies remove large amounts of the battle space from consideration by CAS aircraft, at least as far as the FiST is concerned. A multiple regression performed under the same conditions as those for overall performance confirms the validity of the mortar effectiveness partition tree (see Figure 32). A perusal of the disaggregated performance for both the 30-day and 60-day CAS and mortar performance revealed similar results.

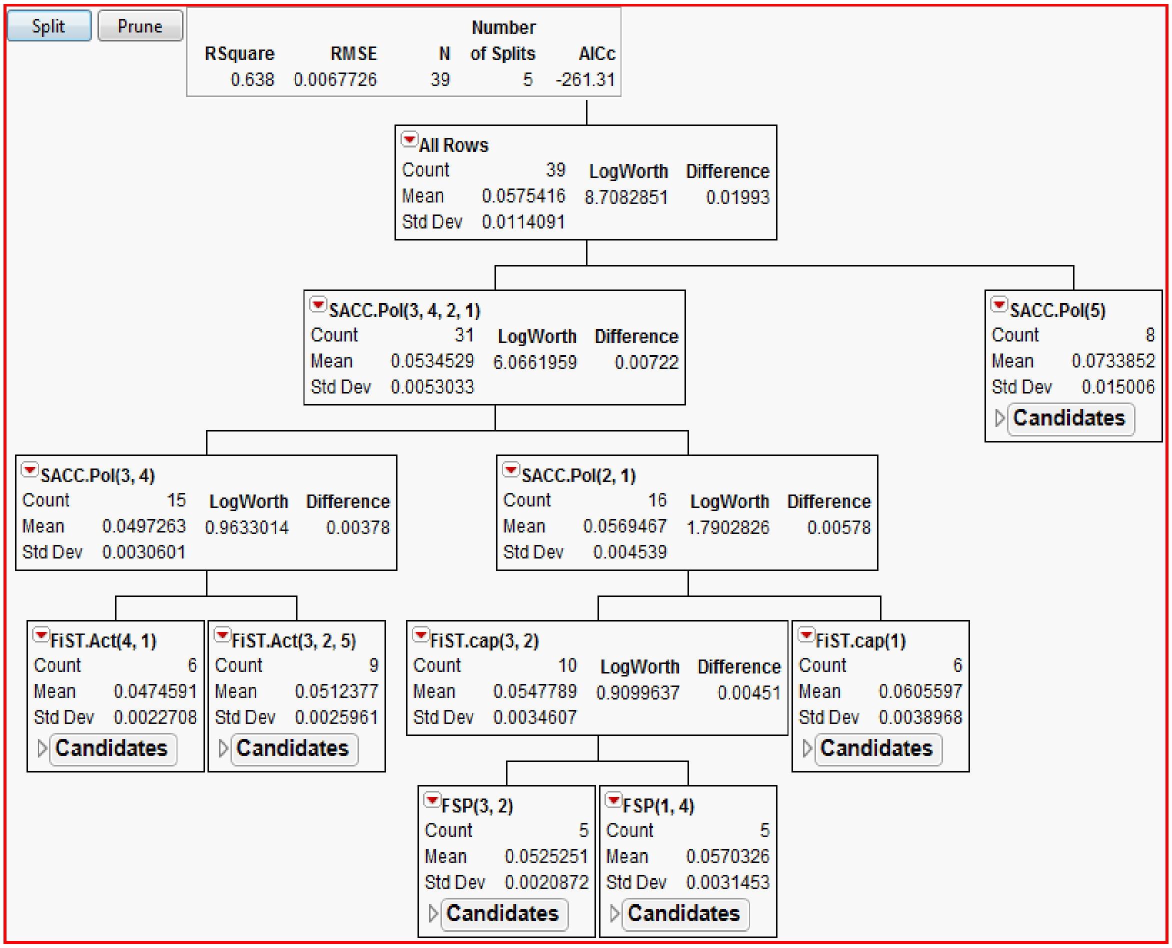


Figure 30. Expected loss for CAS mission performance over 15 days. As expected, SACC Policies are the most important factors in minimizing expected loss. However, FiST Activity Policy and Task Capacity do appear.

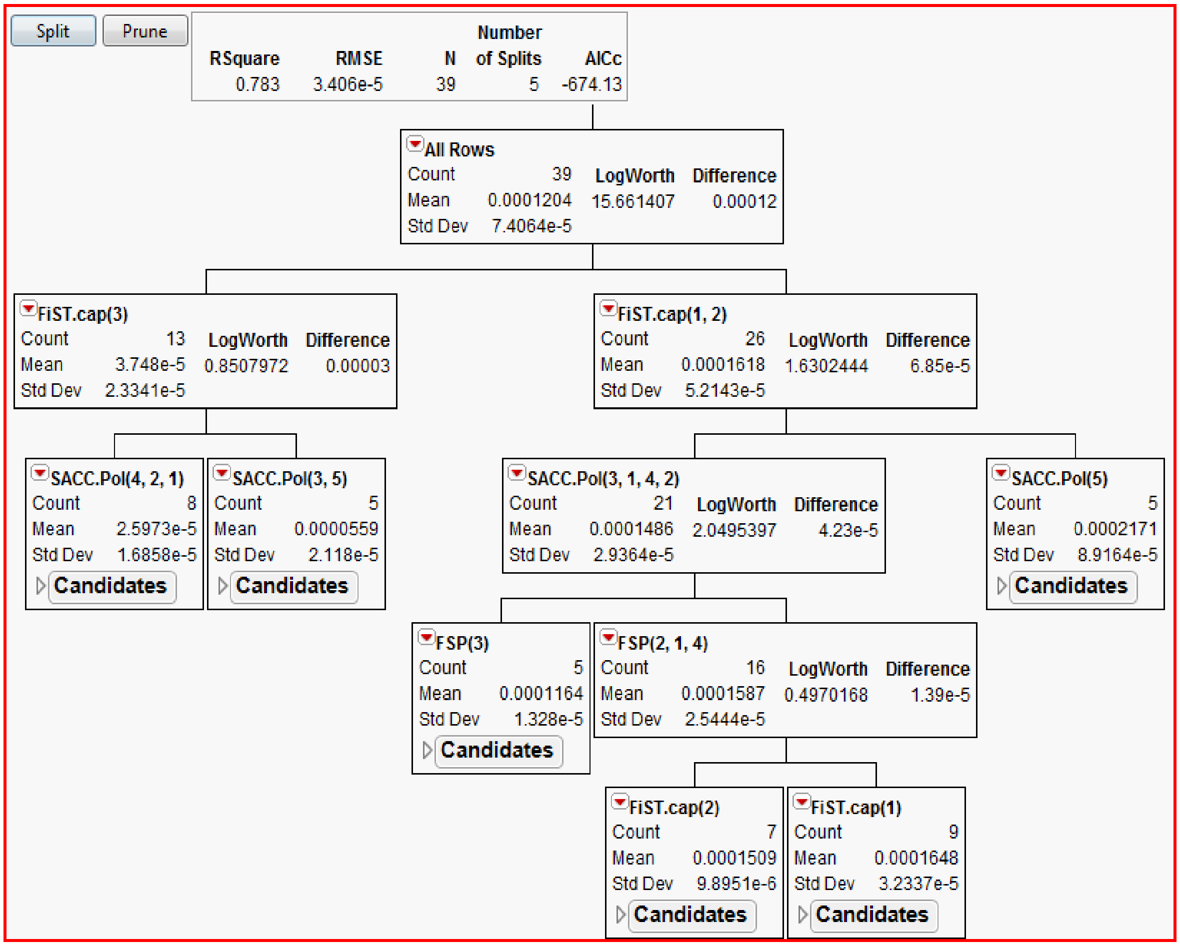


Figure 31. Expected loss for mortar mission performance over 15 days. Maximizing FiST capacity appears to be the most effective means of reducing effective loss, followed by adjusting the SACC Policy.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
FiST.cap{2&1-3}	-0.003761	3.107e-7	-12104	<.0001 *
SACC.Pol{5-2&3&1&4}	-0.001222	3.072e-7	-3977	<.0001 *
FSP{1-3}	-0.000753	2.069e-7	-3642	<.0001 *
FSP{2&4-1&3}	-0.000427	1.216e-7	-3508	<.0001 *
FiST.Act{4-3}*(FSP{2&4-1&3}+0.07692)	-0.000459	2.767e-7	-1660	<.0001 *
FiST.Act{2&1-5&4&3}	-0.000196	1.453e-7	-1351	<.0001 *
(FiST.Act{2&1-5&4&3}+0.28205)*FSP{2-4}	0.0003904	3.106e-7	1256.8	<.0001 *
FiST.Act{2-1}*(SACC.Pol{5-2&3&1&4}+0.58974)	0.0009441	7.554e-7	1249.7	<.0001 *
FiST.Act{4-3}*FSP{2-4}	0.0007077	6.524e-7	1084.8	<.0001 *
FiST.Act{5-4&3}	0.0002132	2.14e-7	996.45	<.0001 *
FiST.Act{4-3}	-0.00029	2.937e-7	-988.7	<.0001 *
(FiST.Act{2&1-5&4&3}+0.28205)*(SACC.Pol{5-2&3&1&4}+0.58974)	-0.00041	5.122e-7	-799.6	<.0001 *
FiST.Act{4-3}*(SACC.Pol{5-2&3&1&4}+0.58974)	-0.00035	4.742e-7	-738.7	<.0001 *
(FiST.Act{5-4&3}+0.17949)*(FSP{2&4-1&3}+0.07692)	-0.000226	3.14e-7	-718.5	<.0001 *
FiST.Act{4-3}*(SACC.Pol{2-3}-0.02564)	0.0002763	4.721e-7	585.22	<.0001 *
(FSP{2&4-1&3}+0.07692)*FiST.cap{2-1}	-0.000179	3.106e-7	-576.4	<.0001 *
(FiST.Act{2&1-5&4&3}+0.28205)*FiST.cap{2-1}	9.7566e-5	2.062e-7	473.23	<.0001 *
(SACC.Pol{2&3-1&4}+0.02564)*(FSP{1-3}-0.02564)	0.0001738	3.825e-7	454.27	<.0001 *
FiST.cap{2-1}	0.0001168	2.8e-7	416.97	<.0001 *
(SACC.Pol{5-2&3&1&4}+0.58974)*FSP{2-4}	-0.000358	8.857e-7	-403.7	<.0001 *
(FiST.Act{5-4&3}+0.17949)*(FiST.cap{2&1-3}-0.33333)	0.000139	4.254e-7	326.66	<.0001 *
(SACC.Pol{5-2&3&1&4}+0.58974)*(FiST.cap{2&1-3}-0.33333)	-0.000187	5.725e-7	-325.8	<.0001 *
(FiST.Act{5-4&3}+0.17949)*(FSP{1-3}-0.02564)	0.0001999	6.276e-7	318.57	<.0001 *
FSP{2-4}	0.0001239	3.944e-7	314.08	<.0001 *
(SACC.Pol{2-3}-0.02564)*(FSP{1-3}-0.02564)	-0.00016	6.582e-7	-242.8	<.0001 *
FiST.Act{2-1}	9.2531e-5	3.996e-7	231.54	<.0001 *
SACC.Pol{1-4}	-0.000056	2.449e-7	-229.0	<.0001 *
SACC.Pol{2-3}	8.7748e-5	3.913e-7	224.23	<.0001 *
(SACC.Pol{2&3-1&4}+0.02564)*(FiST.cap{2&1-3}-0.33333)	-7.452e-5	3.428e-7	-217.4	<.0001 *
(FiST.Act{2&1-5&4&3}+0.28205)*(SACC.Pol{2-3}-0.02564)	6.8621e-5	3.553e-7	193.11	<.0001 *
FiST.Act{2-1}*FiST.cap{2-1}	-6.447e-5	6.014e-7	-107.2	<.0001 *
(FSP{1-3}-0.02564)*FiST.cap{2-1}	-5.924e-5	7.938e-7	-74.63	0.0002 *
FiST.Act{4-3}*(FiST.cap{2&1-3}-0.33333)	1.5085e-5	2.635e-7	57.25	0.0003 *
SACC.Pol{2&3-1&4}	1.3576e-5	4.178e-7	32.49	0.0009 *
SACC.Pol{1-4}*FSP{2-4}	-2.121e-5	7.472e-7	-28.39	0.0012 *
SACC.Pol{1-4}*FiST.cap{2-1}	5.9576e-6	4.92e-7	12.11	0.0068 *

Figure 32. A multiple regression of 15-day mortar effectiveness expected loss. Note the importance of the FiST's capacity.

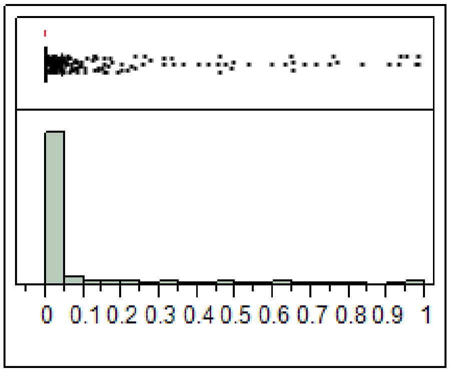
d. Task Saturation

Task saturation is a particular concern for MCWL, as the SACC will not necessarily be able to take the load off of an overwhelmed FiST. In this model, task saturation is defined to occur whenever a task is delayed in the queue because the FiST is unable to service it. This does not necessarily mean that the FiST has no capacity left, but it does not have enough capacity left to deal with the task in question. For every event that waits in the queue, the total count of task saturation is incremented by one for that model run. This count is then divided by the total number of events that pass through the model to create the saturation ratio:

$$\frac{\text{Total Events Delayed in Queue}}{\text{Total Events in Model}} = R_{TS} \quad .$$

This ratio is compared to the ratio of fire support events that renege before service to all fire support events that pass through the system. The researcher used only the events that renege before service, as their reneging is wholly attributable to task saturation. An event that reneged after service and was delayed in the queue may have reneged due to task saturation itself, or due to a combination of task saturation and other causes, and the model does not support analysis of this. The failure due to task saturation ratio is then tested for correlation with the saturation ratio for every design point (see Figure 31). The distribution of p-values indicates that all but a few of these tests established dependence between the two ratios with an α of 0.05. The distribution or correlations further shows that the correlation is overwhelmingly positive.

p.value



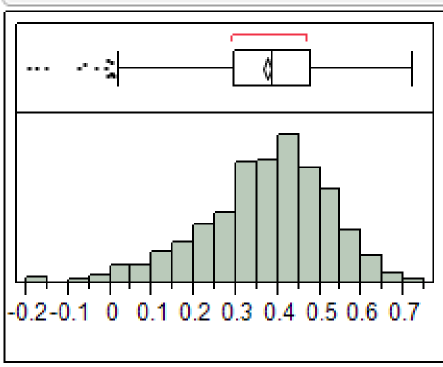
Quantiles

100.0%	maximum	0.98131
99.5%		0.96578
97.5%		0.63186
90.0%		0.07929
75.0%	quartile	0.00282
50.0%	median	6.5e-5
25.0%	quartile	4.48e-7
10.0%		3.69e-9
2.5%		1.1e-11
0.5%		1e-14
0.0%	minimum	0

Moments

Mean	0.042255
Std Dev	0.1455623
Std Err Mean	0.0056069
Upper 95% Mean	0.053264
Lower 95% Mean	0.0312459
N	674

totalcor



Quantiles

100.0%	maximum	0.72143
99.5%		0.67841
97.5%		0.61371
90.0%		0.5477
75.0%	quartile	0.47951
50.0%	median	0.38848
25.0%	quartile	0.29565
10.0%		0.17553
2.5%		0.03672
0.5%		-0.1249
0.0%	minimum	-0.1965

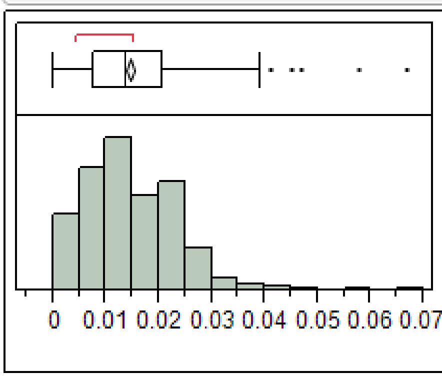
Moments

Mean	0.3736196
Std Dev	0.1476712
Std Err Mean	0.0056881
Upper 95% Mean	0.3847881
Lower 95% Mean	0.362451
N	674

Figure 33. The correlation test of the task saturation ratios and the failure without service ratios. As can be seen, the p-value distribution (top) establishes that in over 75% of cases there is linear dependence, and the correlation distribution (bottom) establishes that this correlation is positive.

However, the existence of correlation does not necessarily imply significance to the effects of task saturation. The distribution of the failure ratio (see Figure 32) shows that the proportion of events at each design point that fail solely to saturation is low. While the maximum failure rate is just shy of 7%, the overwhelming majority of failure rates are below 3%. This implies that failures due to task saturation are not significant. Using the expected loss technique, with $\tau = 0$, the most effective means to reduce failed missions due solely to task saturation is to significantly increase the task capacity of the FiST (see Figure 35). However, when overall FiST performance is considered, the task capacity of the FiST was not one of the more significant factors (see Figure 28) except in the mortar employment analysis.

NoServe Rate



Quantiles

100.0%	maximum	0.06686
99.5%		0.04616
97.5%		0.03173
90.0%		0.02479
75.0%	quartile	0.02057
50.0%	median	0.01371
25.0%	quartile	0.00766
10.0%		0.00449
2.5%		0.00094
0.5%		0
0.0%	minimum	0

Moments

Mean	0.0145005
Std Dev	0.008543
Std Err Mean	0.0003276
Upper 95% Mean	0.0151438
Lower 95% Mean	0.0138573
N	680

Figure 34. The rate at which events renege before the FiST can serve them. Both the mean and median barely exceed 1%.

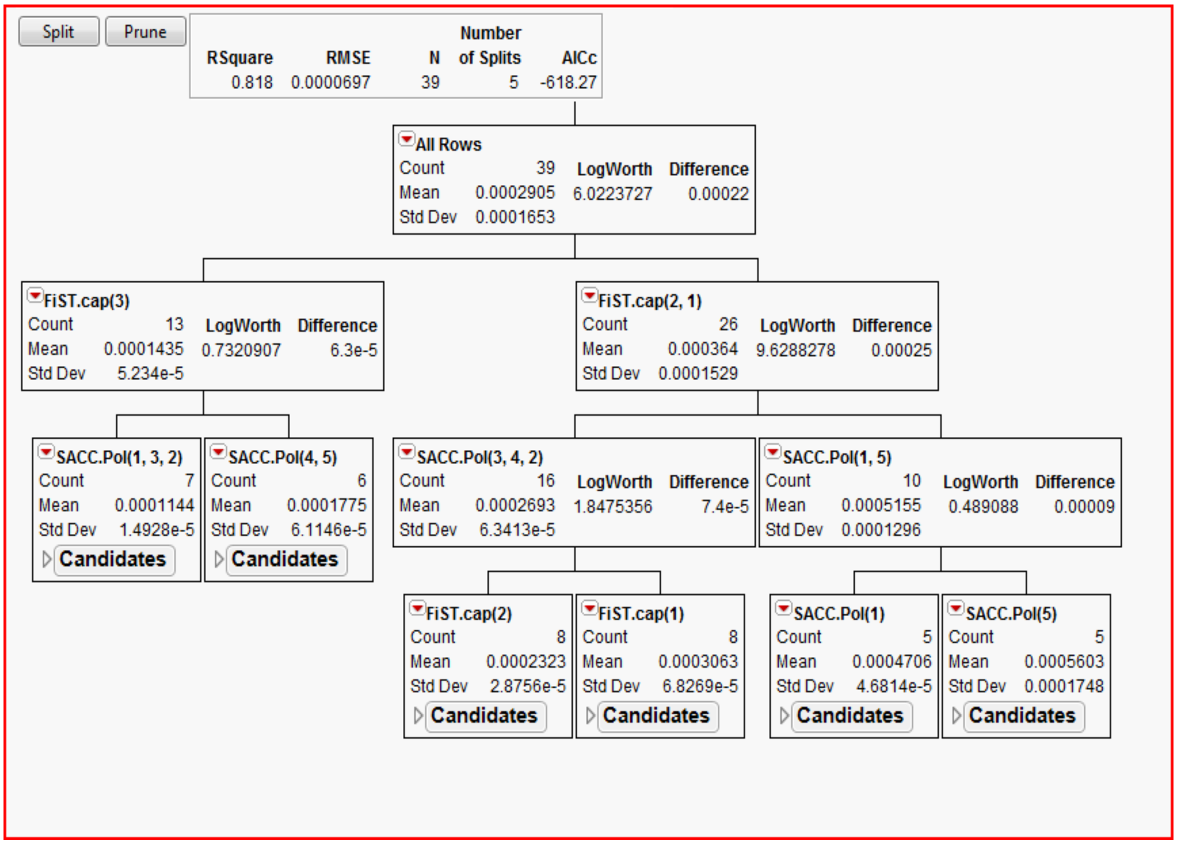


Figure 35. Partition tree to minimize effective loss due to task saturation.

V. CONCLUSIONS

A. INSIGHTS INTO RESEARCH QUESTIONS

The researcher's analysis of the model results provides interesting insight into the research questions posited in Chapter I. These insights remain contingent on the scenario and assumptions from Chapter II.

1. How Long Can the Current FiST Sustain ECO?

The fatigue and final models both suggest that a FiST operating as currently constituted would reach failure within the first fifteen days of employment. The data from the former model showed the current organization schema of the FiST resulting in the worst possible cognitive task effectiveness in each employment length across all of the noise points. In this model, the culprit is the FiST's restrictive rest policy, coupled with the scope of its responsibility. The discrete-event model, while not labeling the current configuration as the worst performer, clearly showed it to be lacking compared with most other policy combinations. In this model, the analysis showed that failure was primarily due to the necessity of getting SACC approval for each mission.

The fatigue model prevented the FiST from adapting its sleep schedule to events. Essentially, if their sleep is interrupted, they were unable to take a subsequent nap to try to restore it. While this suggests a bias in favor of the day and night shift schedules, none of the other FiST activity policies allow flexible sleeping patterns either.

2. How Often Will the FiST Fail to Execute Tasks Due to Task Saturation?

The analysis demonstrates that task saturation is a very infrequent event. While it correlates to events reneging before they are serviced, it is questionable if, in a mid-intensity environment, it warrants further study. While the model abstracted each engagement to require only one supporting arms engagement, it could be argued that a real engagement, even against a small unit, could see numerous supporting arms assets flood the battlefield and possibly overwhelm the FiST. However, this would be a case of the FiST succumbing to its own friction instead of the pace of events.

3. What Affects Do Various SACC and Fire Support Policies Have on Performance?

The most important policy that the SACC can implement to improve FiST performance is to delegate weapons' clearance authority to the FiST. Additionally, the size and scope of the FiST's responsibility needs to be properly scaled to afford them the best ability to quickly engage targets.

4. Does Improving C2 Equipment Increase the FiST's Performance?

An increase in FiST task capacity, which functions as a proxy for improved C2 equipment, does not have a significant positive effect on FiST performance. The researcher believes this is because task saturation is not a significant cause of mission failure.

5. What FiST SOPs Have a Positive Effect on Performance?

While FiST SOPs significantly affect the units' cognitive effectiveness, they are not a significant factor in assessing overall FiST performance with the discrete-event model. This implies that in low- to mid-intensity combat, the FiST can get enough sleep to function effectively, and that the FiST's cognitive effectiveness, as presented in this model, was not as important as the scope of responsibility assigned and the authority delegated to them. However, cognitive effectiveness was abstracted in this model as a time penalty. No attempt was made to measure the effect of cognitive effectiveness on accurately completing a task. In addition, the researcher believes that the limits noted with the fatigue model (see Chapter II.B.7) may have reduced the apparent importance of the FiST's work and rest plan.

B. DOTMLPF RECOMMENDATIONS

1. Doctrine

The SACC should delegate weapons employment authority to the FiST in an ECO environment. The model clearly demonstrates that the added time required getting SACC approval for weapons employment can mean the difference between a successful engagement and a target escaping before fires can be brought to bear. Further, the scope of the FiST's responsibility needs to be carefully shaped, based on the nature of the battle space.

2. Organization

The researcher suggests that the Company Commander should designate another member of the FiST to function as the FiST leader in the absence of the designated FiST leader. This designation would allow the FiST leader and other members of the Fist to maintain a regular sleep schedule and maximize their cognitive effectiveness.

3. Training

The SACC should train for ECO by acting as a facilitator and force supplier to the FiSTs. FiSTs should train for ECO by taking on the full responsibility to clear and coordinate fires in their AO. The FiST should also train to enable it to conduct 24-hour operations without disturbing the resting shift.

4. Materiel

This research does not suggest any change to the FiST's Table of Equipment.

5. Leadership

This research does not suggest any change to leadership of the FiST or supported and supporting entities.

6. Personnel

This research does not suggest any change to the FiST's Table of Organization.

7. Facilities

No changes to facilities are suggested by this research.

C. FOLLOW-ON WORK

There are numerous areas of this research in which further work can be done. The first area would be to improve the input data. While much of the data in this model was supplied from various Marine Corps agencies, the researcher found that he still had to use his experience to fill in some of the gaps. If agencies such as TTECG, EWTG-PAC, and division schools contributed their data and experience, the model could only be improved.

The MANA model, which provides the event frequencies and durations, deserves further refinement in order to better capture the nature of events. The utilization of the SAFTE model, while providing needed insight on cognitive task effectiveness, does not allow for the FiST to adjust their behavior and has significant limitations (see Chapter II.B.7). Further work that addresses these limitations, or uses the Improved Performance Research Integration Tool (IMPRINT) instead of FAST to interface with SAFTE, would create a more realistic model.

The discrete-event model could be expanded to cover all of the EMAGTF's units, which will provide a more all-encompassing measure of how well the EMAGTF's fire support agencies perform. Furthermore, some changes to the model would allow a researcher to explore how the number and types of available CAS and CASEVAC aircraft contribute to success. Moreover, the positioning of the ARG and Forward Arming and Refuelling Points (FARPs) could be modeled as well, granting insight into their effects. The model could better capture behaviors with more dynamic decision-making rules that would allow agencies to retask when higher priority missions arrive. Additionally, using another software package, such as IMPRINT, would enable the model to better capture the effects of fatigue on the entire process.

Finally, this research demonstrates that simulation can be a valuable asset for MCWL. The insights gained from this research will enable MCWL to fine-tune its live exercises in order to get the most benefit out of them and avoid exploring unprofitable alternatives. Further use of simulation to assist MCWL is strongly recommended within the scope of this research, and beyond it.

APPENDIX. SME QUESTIONS

For all questions, please only rely on your experience at (organization) unless otherwise noted. If you have additional insight into any questions, please feel free to expand upon it. If you wish to be quoted individually, please identify any individual quotes as opposed to group opinions, and to whom they come from.

FiST

Aggregate

Capacity

- What is the modal capacity of a FiST to conduct multiple simultaneous or near simultaneous fire support and coordination tasks? Examples of tasks include coordinating different firing agencies to strike a single target, engaging multiple targets with different agencies, conducting coordination with neighboring units, routing aircraft for CASEVAC/holding/resupply, etc.

Times

- Assuming a FiST has only been provided with the relevant target location and description:
  - Indirect Fire
    - What is the minimum period of time it would take the FiST to develop, coordinate, and communicate its mission to the firing agency?
    - What would be the maximum time?
    - What would be the modal (most common) time?
  - Aviation Fires
    - What is the minimum period of time it would take the FiST to develop and coordinate the mission? Brief the mission to the aircraft?
    - What would be the maximum time?
    - What would be the modal (most common) time?
  - Combined Arms

        - What is the minimum period of time it would take the FiST to develop and coordinate a mission involving both aviation and indirect fire agencies? Brief to mission to the agencies?
        - What would be the maximum time?
        - What would be the modal (most common) time?

Leader

Capacity

- What is the modal (most common) capacity of a FiST leader to conduct multiple simultaneous or near simultaneous fire support and coordination tasks? Examples of tasks include coordinating different firing agencies to strike a single target, engaging multiple targets with different agencies, conducting coordination with neighboring units, routing aircraft for CASEVAC/holding/resupply, etc.

Time

- After the other FiST members have completed planning a mission:
    - What is the minimum amount of time it takes the FiST leader to QA and approve a mission?
    - What is the maximum?
    - What is the modal (most common) amount of time?
- ***<u>This question only based on operating forces experience:</u>***
    - When a FiST is deployed to a Phase 2/Phase 3 environment (hold-build), what is the average amount of time each day that a FiST leader spent conducting official duties not related to fire support (do not include eating, exercise, hygiene, recreation, etc.)
        - If he was a company XO
        - If he was a weapon's platoon commander
        - If held another billet (specify).

FAC/JTAC

Capacity

- What is the modal (most common) capacity of a FAC/JTAC conducting multiple simultaneous or near simultaneous aviation control tasks? Examples of tasks include coordinating different aircraft to strike a single target, engaging multiple targets with different aircraft, conducting coordination with neighboring units, routing aircraft for CASEVAC/holding/resupply, conducting ISR, etc.

Time

- From the time a target is detected and located:
  - What is the minimum time it takes the FAC to develop his game plan and 9-line while working with FiST (before the FiST leader approves it)?
  - What is the maximum time?
  - What is the modal (most common) amount of time?
- From when a section checks in:
  - What is the minimum amount of time it takes the FAC to pass the 9-line to a section and receive the read back?
  - What is the maximum time?
  - What is the modal (most common) amount of time?

Mortar FO

Capacity

- What is the modal (most common) capacity of a mortar FO conducting multiple simultaneous or near simultaneous aviation control tasks? Examples of tasks include coordinating different agencies to strike a single target, engaging multiple targets with different assets, conducting coordination with neighboring units, deconflicting with aircraft?

Time

- From the time a target is detected and located:
  - What is the minimum time it takes the FO to develop his game plan and CFF while working with FiST (before the FiST leader approves it)?
  - What is the maximum time?
  - What is the modal (most common) amount of time?
- From when the FiST leader approves the mission:
  - What is the minimum amount of time it takes the FO to pass the CFF to a firing agency and receive the read back?
  - What is the maximum time?
  - What is the modal (most common) amount of time?

Arty FO

Capacity

- What is the modal (most common) capacity of an artillery FO conducting multiple simultaneous or near simultaneous aviation control tasks? Examples of tasks include coordinating different agencies to strike a single target, engaging multiple targets with different assets, conducting coordination with neighboring units, deconflicting with aircraft?

Time

- From the time a target is detected and located:
  - What is the minimum time it takes the FO to develop his game plan and CFF while working with FiST (before the FiST leader approves it)?
  - What is the maximum time?
  - What is the modal (most common) amount of time?
- From when the FiST leader approves the mission:
  - What is the minimum amount of time it takes the FO to pass the CFF to a firing agency and receive the read back?
  - What is the maximum time?
  - What is the modal (most common) amount of time?

FSCC

Capacity

- What is the modal (most common) capacity of an FSCC to conducting multiple simultaneous or near simultaneous fire support tasks? Examples of tasks evaluating and approving/disapproving fire support requests using only one agency, fire support requests using multiple agencies, originating and prosecuting FSCC fires missions, keeping track of fire support assets, tracking friendly maneuver units, managing ISR, etc.

Time

- From receipt of a fire support request from a subordinate unit using just one agency:
  - The minimum time to approve/deny the mission
  - The maximum time
  - The modal (most common) time.
- From receipt of a fire support request from a subordinate unit using multiple firing agencies:
  - The minimum time to approve/deny the mission
  - The maximum time
  - The modal (most common) time.

Fire Support Agencies

Artillery

How long from receipt of a CFF does it take to:

- Process the fire support request to the point that the tubes are laid on the target.
  - Minimum
  - Maximum
  - Modal (most common)
- From firing the initial salvo to FFE impacting.
  - Minimum
  - Maximum
  - Modal (most common)

Mortars

How long from receipt of a CFF does it take to:

- Process the fire support request to the point that the tubes are laid on the target.
  - Minimum
  - Maximum
  - Modal (most common)
- From firing the initial salvo to FFE impacting.
  - Minimum
  - Maximum
  - Modal (most common)

Aviation

How long from receipt of a 9-line to attack a single target with just the aircraft:

- Release ordnance on the target
  - Minimum
  - Maximum
  - Modal (most common)

How long from receipt of a 9-line to attack a single target marked by another firing agency:

- Release ordnance on the target
  - Minimum
  - Maximum
  - Modal (most common)

Observers (0861s)

While operating alone or attached to a maneuver unit (not the FiST)

How long to report the identification and location of a target:

- Minimum
- Maximum
- Modal (most common)

How long to create and transmit a CFF after detecting a target:

- Minimum
- Maximum
- Modal (most common)

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